Calculation Title Page

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☒ Safety Related	☐ Regulatory Related	☐ Non-Safety Related

Calculation Title:

Dresden LPCI/Core Spray NPSH Analysis
Post-DBA LOCA: Reduced Torus Temperature
Long-Term

Station/Unit: Dresden Units 2 and 3 System Abbreviation: LPCI/CS

Equipment No.: 2(3)-1502A/B/C/D Project No.:
2(3)-1401A/B

Rev: 0 Status: QA Serial # or CHRON # NA Date:

Prepared by: HARRY PALAS Date: 1/7/97

Revision Summary:

Electronic Calculation Data Files:

RING.PLL	4L252C45.PLU	2L502C45.PLU
RING.PLU	3L502C45.PLU	2L372C45.PLU
4L502C45.PLU	3L_50_25.PLU	1L502C45.PLU
4L372C45.PLU	3L_25_50.PLU	

Do any assumptions in this calculation require later verification? ☐ Yes ☒ No

Reviewed by: J.W. Drowley Date: 1/7/97

Review Method: DETAILED REVIEW Comments (C, NC or CI): NC

Approved by: Date: 1/8/97

Calculation Revision Page

Calculation No.: **DRE97-0003**	Page 2 of 10
Rev: **0** Status: QA Serial # or CHRON # **NA**	Date:__________
Prepared by:______________________________	Date:__________
Revision Summary:	
Electronic Calculation Data Files Revised:	
Do any assumptions in this calculation require later verification?	☐ Yes ☐ No
Reviewed by:______________________________	Date:__________
Review Method:	Comments (C, NC or CI): ______
Approved by:______________________________	Date:__________

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1.0 PURPOSE

The purpose of this calculation is to determine if sufficient Net Positive Suction Head (NPSH) is available to the Dresden LPCI and Core Spray (CS) pumps following a DBA-LOCA with atmospheric pressure in the torus. This calculation examines NPSH conditions at the bounding, long-term (> 600 seconds) condition following the accident, which occurs at the time of peak suppression pool temperature. The effects of throttled LPCI pumps and reduced peak suppression pool temperature will also be examined. The results of this calculation will be used to support a Dresden Exigent License Amendment.

2.0 METHODOLOGY AND ACCEPTANCE CRITERIA

The minimum suppression pool pressure required to ensure LPCI and CS pump protection will be determined under long-term post-LOCA conditions at the bounding NPSH condition. Since the suppression pool pressure remains constant after 600 seconds (14.7 psia), the bounding NPSH condition occurs at the time of peak suppression pool temperature. If the pressure required is less than 14.7 psia, then the pump NPSH requirements have been met. If the required pressure is greater than 14.7 psia, then the potential exists for the pumps to cavitate. In these situations, LPCI pump flows will be reduced to below-nominal values and new cases will be run to establish the ability of the operator to throttle the pumps to an acceptable condition. This acceptable condition is defined by the following criteria:

1) Adequate NPSH to the pumps - minimum pressure available is greater than minimum pressure required for the LPCI and CS pumps.

2) Adequate containment cooling - the minimum containment cooling flow analyzed is 5000 gpm (LPCI) through a single LPCI heat exchanger.

If an acceptable condition cannot be achieved by throttling, then cases involving reduced suppression pool temperatures will be explored.

Various pump combinations will be explored to determine the bounding NPSH case for the LPCI and Core Spray pumps. It will be shown that NPSH for the LPCI/CS pumps with 4 LPCI/2 CS pumps running is the bounding NPSH case. This calculation is bounding for NPSH due to use of the following conservative inputs:

- maximum long-term suppression pool temperature post-LOCA, thus maximizing the vapor pressure and minimizing NPSH margin
- torus pressure at time of peak temperature is atmospheric, thus minimizing NPSH margin
- Technical Specifications minimum suppression pool level including drawdown, minimizing elevation head and minimizing NPSH margin
- increased clean, commercial steel pipe friction losses by 15% to account for aging effects

3.0 ASSUMPTIONS

1. It is assumed that at 10 minutes into the accident, operator action will be taken to ensure that the LPCI/CS pumps have been throttled to their rated flows (5000 and 4500 gpm respectively). Therefore, the pumps are at their rated flows at the time of peak suppression pool temperature.

2. LPCI/CS pump suction piping friction losses (excluding strainer losses) were developed for a single flow case using a FLO-SERIES model of the Dresden ECCS ring header and pump suction piping (Ref. 3). This piping model was then run at the various LPCI/CS pump combinations and flows as required to support the cases evaluated in this calculation (Attachment A). The model that was developed uses clean, commercial steel pipe. In order to compensate for the increased loss due to the potential effects of aging, the resulting friction losses from the model were increased by 15%. This is consistent with discussions provided in References 13 and 14.

3. To account for strainer plugging, one of the four torus strainers is assumed 100% blocked, while the remaining three strainers are assumed clean. While the torus strainers are not included in the FLO-SERIES model discussed in Assumption 2, blocking a strainer translates to blocking a torus-to-ring header entrance leg. This is accomplished in the model by closing one of the torus legs (Torus 1-4). Based on previous sensitivity analyses, Torus-4 was chosen for maximum effect on both LPCI and Core Spray suction losses for all pump combinations.

4. The peak suppression pool temperature post-LOCA is not provided in the original Dresden FSAR for any LPCI/CCSW pump combinations. A value of 170°F is estimated for the Dresden 1 LPCI / 2 CCSW case based on the following:

   - Quad Cities has similar ECCS flows, heat exchanger capacities and heat loads to Dresden; therefore, Quad Cities post-LOCA results can be employed to provide a reasonable estimate of Dresden's peak pool temperature (Ref. 1). Table 5.2.5 of the Quad Cities FSAR provides a Case (d), which yields a suppression pool maximum temperature of 168°F for a 1 RHR/2 RHRSW pump scenario based on an initial pool temperature of 90°F. For a Dresden initial pool temperature of 95°F, an adder of 2°F is used, resulting in a Dresden peak suppression pool temperature estimate of 170°F. The 2°F adder is supported by subsequent GE calculations which show a sensitivity of 1°F for a 5°F change in initial pool temperature (Ref. 2).

   - Reference 15, page 2-5 states the following: "The maximum torus temperature for a design basis accident would reach about 170°F."

   - The Dresden FSAR, page 6.2-17 includes a discussion regarding LPCI/CCSW heat exchanger sizing. It states "that in the event of the loss of coolant accident the terminal suppression pool temperature would not exceed 170°F."

5. Suppression pool pressure is assumed atmospheric (14.7 psia). This is conservative since pressure above atmospheric is expected in the suppression pool as a result of the elevated temperatures and blowdown of the non-condensables post-LOCA.

4.0 DESIGN INPUTS

1. LPCI and CS pump suction piping friction losses (excluding strainer losses) from the torus strainers to the pumps were developed in Reference 3 using a FLO-SERIES model of the ECCS ring header and suction piping. This piping model was then utilized for the various LPCI/CS pump combinations and flows as required to support the cases evaluated in this calculation (Attachment A).

2. The minimum torus level elevation with a maximum drawdown of 2.1 ft. is 491'5", or 491.4 ft. (Ref. 4). At the time of peak suppression pool temperature, a recovery of 1.1 ft. occurs, resulting in a net drawdown of 1 ft (Ref. 5). This represents a torus level elevation of 492.5'.

3. The torus strainers have a head loss of 5.8 ft. @ 10,000 gpm clean (Ref. 6).

4. LPCI and Core Spray pump centerline elevation is 478.1 ft. (Refs. 7, 8).

5. NPSH Available (NPSHA) is calculated using the following equation:

$$NPSHA = 144 \times V \times (P_t - P_v) + Z - h_L - h_{strain} \quad \text{(based on Ref. 9, p. 2.216)}$$

where:
- P_t = suppression pool pressure in psia
- P_v = saturation pressure in psia
- V = specific volume in ft^3/lb
- h_L = suction friction losses in feet
- h_{strain} = head loss across strainer in feet
- Z = static head of water above pump inlet (feet)

6. Saturation pressure of water at 170°F is 5.99 psia, and at 160°F is 4.74 psia (Ref. 10)

7. Specific volume of water at 170°F is 0.016451 ft^3/lb, and at 160°F is 0.016395 (Ref. 10)

8. The NPSH Required (NPSHR) for the LPCI pump is 30 ft. at 5000 gpm, 25.5 ft. at 3750 gpm, and 25 ft. at 2500 gpm (Ref. 11).

9. The NPSHR for the Core Spray pump is 27 ft. at 4500 gpm (Ref. 12).

5.0 REFERENCES

1. "An Estimated Suppression Pool Temperature for Dresden NPSH Evaluation", Nuclear Fuel Services Memo from K. Ramsden dated August 22, 1996

2. General Electric report GENE-637-042-1193 dated February, 1994

3. "ECCS Suction Hydraulic Analysis without the Strainers", Duke Engineering & Services Calculation Number DRE96-0241 dated December 20, 1996

4. "Submergence of LPCI Discharge Line Post LOCA - Dresden Units 2 & 3", letter from S. Eldridge to C. Schroeder dated September 29, 1992, CHRON# 0115532

5. "Dresden LPCI/Containment Cooling System," GE Nuclear Energy letter from S. Mintz to T. L. Chapman dated January 25, 1993

6. "Supporting Calculations for the ECCS Suction Strainer Modification", Nutech File No. 64.313.3119 Rev. 1, dated June 22, 1983

7. Sargent & Lundy Drawing M-547, LPCI pump suction

8. Sargent & Lundy Drawing M-549, Core Spray pump suction

9. "Pump Handbook", 2nd Edition, Karassik, Igor et. al., 1986

10. ASME Steam Tables, 1967

11. Bingham Pump Curve Nos. 25355-7, 27367-8, 27383, 25384-5 for Model 12x14x14.5 CVDS, Dresden Station LPCI pumps

12. Bingham Pump Curve Nos. 25213 (2A), 25243 (2B), 25231 (3A) and 25242 (3B) for Model 12x16x14.5 CVDS, Dresden Station Core Spray pumps.

13. Hydraulic Institute Engineering Data Book, Second Edition, 1990

14. Cameron Hydraulic Data, 17th Edition, Ingersoll-Rand Company, 1988

15. Dresden FSAR, Amendment 22, May 7, 1970

6.0 CALCULATIONS

The NPSHA equation presented in Design Input 5 can be rewritten to solve for the minimum suppression pool pressure required for pump protection by setting the NPSHA equal to the NPSH Required (NPSHR) as follows:

$$P_{t,\,min} = \frac{(NPSHR - Z + h_{total})}{144 \times V} + P_v \qquad (1)$$

where P_v	=	5.99 psia @170°F	(Design Input 6)
V	=	0.016451 ft^3/lb @170°F	(Design Input 7)
h_{total}	=	friction (h_L) + strainer (h_{strain}) loss	(Attachment A)
h_{strain}	=	5.8 ft. @ 10,000 gpm clean	(Design Input 3)
Z	=	492.5 ft. - 478.1 ft. = 14.4 ft.	(Design Inputs 2, 4)
NPSHR	=	30 ft. @ 5000 gpm for LPCI	(Design Input 8)
		27 ft. @ 4500 gpm for CS	(Design Input 9)

Solving Equation 1, the minimum suppression pool pressure required to satisfy LPCI and Core Spray pump NPSH requirements under a spectrum of pump combinations is determined to be:

LPCI/CS Pumps	Total LPCI Suction Loss h_{total} (ft)	Total CS Suction Loss h_{total} (ft)	Minimum Required Torus Pressure for LPCI (psia)	Minimum Required Torus Pressure for CS (psia)	Minimum Available Torus Pressure (psia)	**LPCI Margin (ft)**	**CS Margin (ft)**
4/2	16.1	13.3	19.4	16.9	14.7	**-11.1**	**-5.3**
3/2	13.0	10.1	18.1	15.6	14.7	**-8.0**	**-2.1**
2/2	10.6	7.5	17.1	14.5	14.7	**-5.6**	**0.5**
1/2	7.5	5.8	15.7	13.7	14.7	**-2.5**	**2.3**

All the combinations evaluated above involve 2 CS pumps. These cases bound the respective 1 CS pump scenarios due to the higher ring header/strainer losses of the 2-pump cases combined with no pool temperature benefit (cooling) from the added Core Spray pump (second pump actually adds heat to the pool). As shown above, the potential exists for the LPCI and CS pumps to cavitate in most of the pump scenarios. For these cases, throttling of the LPCI pumps may be required to ensure NPSH requirements are met. The following cases are provided to establish the ability of the operator to throttle the pumps to an acceptable condition as defined in Section 2.0.

Pump	NPSHR (ft)	Suction Loss h_L (ft)	Strainer Loss h_{strain} (ft)	Static Head (ft)	Vapor Pressure (psia)	Req'd Torus Pressure (psia)	Available Torus Pressure (psia)	Margin (ft)	LPCI/CS Pumps Running	LPCI/CS Total System Flows (gpm)	Status of Pumps
LPCI	30.0	10.7	5.4	14.4	5.99	19.4	14.7	-11.1	4/2	20000/9000	4 LPCI pumps throttled to 5000 gpm per pump
LPCI	25.5	6.5	3.7	14.4	5.99	15.0	14.7	-0.7	4/2	15000/9000	4 LPCI pumps throttled to 3750 gpm per pump
LPCI	25.0	3.4	2.3	14.4	5.99	12.9	14.7	4.3	4/2	10000/9000	4 LPCI pumps throttled to 2500 gpm per pump
LPCI	30.0	9.3	3.7	14.4	5.99	18.1	14.7	-8.0	3/2	15000/9000	3 LPCI pumps throttled to 5000 gpm per pump
LPCI 1-pp loop	30.0	7.0	2.3	14.4	5.99	16.5	14.7	-4.3	3/2	10000/9000	2 LPCI pumps throttled to 2500 gpm per pump; single LPCI throttled to 5000 gpm
LPCI 2-pp loop	25.0	3.4	2.3	14.4	5.99	12.9	14.7	4.3	3/2	10000/9000	2 LPCI pumps throttled to 2500 gpm per pump; single LPCI throttled to 5000 gpm
LPCI	30.0	8.3	2.3	14.4	5.99	17.1	14.7	-5.6	2/2	10000/9000	2 LPCI pumps throttled to 5000 gpm per pump
LPCI	25.5	5.0	1.8	14.4	5.99	13.5	14.7	2.8	2/2	7500/9000	2 LPCI pumps throttled to 3750 gpm per pump
LPCI	30.0	6.2	1.3	14.4	5.99	15.7	14.7	-2.4	1/2	5000/9000	1 LPCI pump throttled to 5000 gpm
CS	27.0	7.9	5.4	14.4	5.99	16.9	14.7	-5.3	4/2	20000/9000	4 LPCI pumps throttled to 5000 gpm per pump
CS	27.0	6.5	3.7	14.4	5.99	15.6	14.7	-2.2	4/2	15000/9000	4 LPCI pumps throttled to 3750 gpm per pump
CS	27.0	5.4	2.3	14.4	5.99	14.6	14.7	0.3	4/2	10000/9000	4 LPCI pumps throttled to 2500 gpm per pump
CS	27.0	6.4	3.7	14.4	5.99	15.6	14.7	-2.1	3/2	15000/9000	3 LPCI pumps throttled to 5000 gpm per pump
CS	27.0	5.4	2.3	14.4	5.99	14.6	14.7	0.3	3/2	10000/9000	2 LPCI pumps throttled to 2500 gpm per pump; single LPCI throttled to 5000 gpm
CS	27.0	5.2	2.3	14.4	5.99	14.5	14.7	0.5	2/2	10000/9000	2 LPCI pumps throttled to 5000 gpm per pump
CS	27.0	4.5	1.3	14.4	5.99	13.7	14.7	2.3	1/2	5000/9000	1 LPCI pump throttled to 5000 gpm

As shown above, the LPCI and Core Spray pumps can be throttled to ensure NPSH requirements are met and that adequate containment cooling exists for all ECCS pump combinations except the 1/2 case. In this case, the LPCI NPSH deficit is approximately 1 psi. Reducing the pool temperature by 10°F would result in a reduction in vapor pressure of slightly more than 1 psi. Therefore, at a suppression pool temperature of 160°F, the 1/2 case is as follows:

Pump	NPSHR (ft)	Suction Loss h_L (ft)	Strainer Loss h_{strain} (ft)	Static Head (ft)	Vapor Pressure (psia)	Req'd Torus Pressure (psia)	Available Torus Pressure (psia)	Margin (ft)	LPCI/CS Pumps Running	LPCI/CS Total System Flows (gpm)	Status of Pumps
LPCI	30.0	6.2	1.3	14.4	4.74	14.5	14.7	0.4	1/2	5000/9000	1 LPCI pump throttled to 5000 gpm

7.0 SUMMARY AND CONCLUSIONS

An NPSH analysis was performed for the LPCI/CS pumps under bounding, long-term post-accident conditions with atmospheric pressure in the torus. Selecting inputs to minimize NPSH margin, it was determined that the potential exists for the LPCI and CS pumps to cavitate in most of the pump scenarios. For these cases, throttling of the LPCI pumps may be required to ensure NPSH requirements are met. Specific cases involving throttled LPCI pumps were evaluated to establish the ability of the operator to throttle the pumps to an acceptable condition. The results of these cases were as follows:

- In the 3/2 case, the single pump LPCI loop may need to be throttled to below 5000 gpm, and containment heat removed with the 2-pump loop. This will ensure the LPCI heat exchanger receives its rated LPCI flow. Alternatively, a LPCI pump can be dropped to gain the required NPSH margin.

- In the 1/2 case, an NPSH deficit still exists after maximum throttling of the LPCI pump to 5000 gpm. It was determined that a reduction in the peak suppression pool temperature to 160°F would result in positive NPSH margin.

Therefore, at a reduced suppression pool peak temperature of 160°F, it is concluded that under all post-LOCA pump combinations, positive NPSH margin for the LPCI and Core Spray pumps can be achieved by throttling the available LPCI pumps.

ATTACHMENT A

LPCI/Core Spray Suction Friction Losses FLO-SERIES Model

Dresden LPCI/Core Spray pump suction friction losses were developed using a FLO-SERIES model of the Dresden ECCS ring header and pump suction piping (Ref. 3). The nodal diagram of the piping model is included as Figure A1. This model was run at the various LPCI and Core Spray pump combinations and flows listed below as required to support the cases evaluated in this calculation. The FLO-SERIES runs are included in this Attachment.

LPCI Pumps	CS Pumps	LPCI/CS Flow per Pump (gpm)	Strainer Loss# h_{strain} (ft)	LPCI Friction Loss (ft)	LPCI Loss +15% h_L (ft)	**Total LPCI Loss* h_{total} (ft)**	CS Friction Loss (ft)	CS Loss +15% h_L (ft)	**Total CS Loss* h_{total} (ft)**	FLO-SERIES Line-up Filename
4	2	5000/4500	5.4	9.3	10.7	**16.1**	6.9	7.9	**13.3**	4L502C45.PLU
4	2	3750/4500	3.7	5.6	6.5	**10.2**	5.7	6.5	**10.2**	4L372C45.PLU
4	2	2500/4500	2.3	2.9	3.4	**5.7**	4.7	5.4	**7.7**	4L252C45.PLU
3	2	5000/4500	3.7	8.1	9.3	**13.0**	5.6	6.4	**10.1**	3L502C45.PLU
3	2	5000/4500	2.3	6.1	7.0	**9.3**	4.7	5.4	**7.7**	3L_50_25.PLU
3	2	2500/4500	2.3	2.9	3.4	**5.7**	4.7	5.4	**7.7**	3L_25_50.PLU
2	2	5000/4500	2.3	7.2	8.3	**10.6**	4.5	5.2	**7.6**	2L502C45.PLU
2	2	3750/4500	1.8	4.4	5.0	**6.8**	4.2	4.8	**6.6**	2L372C45.PLU
1	2	5000/4500	1.3	5.4	6.2	**7.4**	3.9	4.5	**5.7**	1L502C45.PLU

Strainer Loss = (Flow per strainer/10,000 gpm)^2 x 5.8 ft.

* Total Loss = (Loss +15%) + Strainer Loss

Table A-1

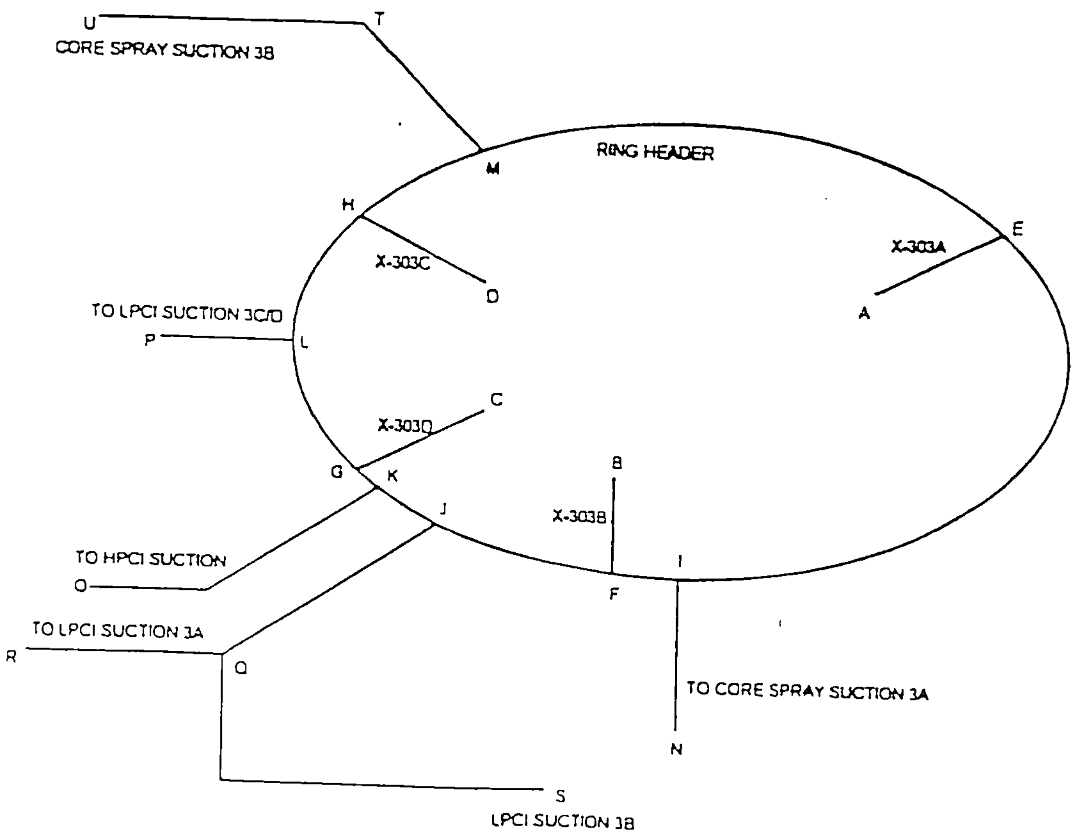

Figure A1: ECCS Suction Nodal Diagram including the Ring Header

Company: ComEd
Project:
by: Palas

4L502C45
12/21/96

LINEUP REPORT rev: 12/21/96

LINELIST: RING
dated: 12/18/96

DEVIATION: 0.0157 %
after: 5 iterations

4 LPCI @5000 and 2 CS @4500 Injecting. Nearest torus leg blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm
N	>>>	4500	O	>>>	0.0001
P	>>>	10000	R	>>>	5000
S	>>>	5000	U	>>>	4500

FLOWS IN: 0 gpm
FLOWS OUT: 29000 gpm

NET FLOWS OUT: 29000 gpm

PIPELINE		FLOW gpm		PRESSURE SOURCE	SET psig
Torus-1	<<<	9433	<<<	A	0
Torus-2	<<<	9552	<<<	B	0
Torus-3	<<<	10015	<<<	C	0

FLOWS IN: 29000 gpm
FLOWS OUT: 0 gpm

NET FLOWS IN: 29000 gpm

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LINEUP NODES

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NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0		p 0	0
B	0		p 0	0
C	0		p 0	0
E	0		* -1.403	-3.258
F	0		* -1.439	-3.341
G	0		* -1.582	-3.672
H	0		* -1.669	-3.874
I	0		* -1.444	-3.351
J	0		* -1.596	-3.705
K	0		* -1.591	-3.693
L	0		* -1.684	-3.909
M	0		* -1.662	-3.858
N	0	> 4500	* -1.694	-3.933
O	0	> 0.0001	* -1.591	-3.693
P	0	> 10000	* -1.948	-4.523
Q	0		* -2.208	-5.125
R	0	> 5000	* -2.75	-6.384
S	0	> 5000	* -3.996	-9.276
T	0		* -1.918	-4.451
U	0	> 4500	* -2.961	-6.874

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LINEUP PIPELINES

PIPELINE	FROM		TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
CS-3A	I		N	4500	6.274	0.251	0.582
CS3B-16	T		U	4500	7.911	1.044	2.423
CS3B-18	M		T	4500	6.274	0.255	0.593
HPCI	K		O	0	0	0	0
LPCI3A	Q		R	5000	11.64	0.543	1.259
LPCI3A/B	J		Q	10000	7.563	0.612	1.42
LPCI3B	Q		S	5000	11.64	1.789	4.152
LPCI3C/D	L		P	10000	7.563	0.264	0.614
Ring-1	E		I	2609	1.973	0.040	0.093
Ring-2	F		I	1891	1.43	0.004	0.010
Ring-3	F		J	7661	5.794	0.157	0.365
Ring-4	K		J	2339	1.769	0.005	0.012
Ring-5	G		K	2339	1.769	0.009	0.021
Ring-6	G		L	7676	5.805	0.102	0.237
Ring-7	H		L	2324	1.758	0.015	0.035
Ring-8	M	<->	H	2324	1.758	0.007	0.015
Ring-9	E		M	6824	5.161	0.259	0.601
Torus-1	A		E	9433	11.42	1.403	3.258
Torus-2	B		F	9552	11.57	1.439	3.341
Torus-3	C		G	10015	12.12	1.582	3.672
Torus-4	D		H	closed	0	0	0

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Company: ComEd
Project:
by: Palas

4L372C45
12/21/96

LINEUP REPORT rev: 12/21/96

LINELIST: RING
dated: 12/18/96

DEVIATION: 0.031 %
after: 5 iterations

4 LPCI @3750 and 2 CS @4500 Injecting. Nearest torus leg blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm
N	>>>	4500	O	>>>	0.0001
P	>>>	7500	R	>>>	3750
S	>>>	3750	U	>>>	4500

FLOWS IN: 0 gpm
FLOWS OUT: 24000 gpm

NET FLOWS OUT: 24000 gpm

PIPELINE		FLOW gpm		PRESSURE SOURCE	SET psig
Torus-1	<<<	7829	<<<	A	0
Torus-2	<<<	7929	<<<	B	0
Torus-3	<<<	8242	<<<	C	0

FLOWS IN: 24000 gpm
FLOWS OUT: 0 gpm

NET FLOWS IN: 24000 gpm

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NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0		p 0	0
B	0		p 0	0
C	0		p 0	0
E	0		* -0.967	-2.244
F	0		* -0.992	-2.302
G	0		* -1.072	-2.487
H	0		* -1.141	-2.648
I	0		* -0.998	-2.316
J	0		* -1.08	-2.507
K	0		* -1.077	-2.5
L	0		* -1.144	-2.656
M	0		* -1.14	-2.645
N	0	> 4500	* -1.249	-2.899
O	0	> 0.0001	* -1.077	-2.5
P	0	> 7500	* -1.293	-3.001
Q	0		* -1.425	-3.307
R	0	> 3750	* -1.73	-4.016
S	0	> 3750	* -2.432	-5.645
T	0		* -1.395	-3.238
U	0	> 4500	* -2.439	-5.661

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LINEUP PIPELINES

4L372C45
12/21/96

PIPELINE	FROM		TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
CS-3A	I		N	4500	6.274	0.251	0.582
CS3B-16	T		U	4500	7.911	1.044	2.423
CS3B-18	M		T	4500	6.274	0.255	0.593
HPCI	K		O	0	0	0	0
LPCI3A	Q		R	3750	8.732	0.305	0.709
LPCI3A/B	J		Q	7500	5.672	0.345	0.800
LPCI3B	Q		S	3750	8.732	1.007	2.338
LPCI3C/D	L		P	7500	5.672	0.149	0.345
Ring-1	E		I	2283	1.726	0.031	0.072
Ring-2	F		I	2217	1.677	0.006	0.014
Ring-3	F		J	5712	4.32	0.088	0.205
Ring-4	K		J	1788	1.352	0.003	0.007
Ring-5	G		K	1788	1.352	0.005	0.013
Ring-6	G		L	6454	4.881	0.073	0.169
Ring-7	H		L	1046	0.791	0.003	0.008
Ring-8	M	<->	H	1046	0.791	0.001	0.003
Ring-9	E		M	5546	4.194	0.173	0.401
Torus-1	A		E	7829	9.478	0.967	2.244
Torus-2	B		F	7929	9.6	0.992	2.302
Torus-3	C		G	8242	9.979	1.072	2.487
Torus-4	D		H	closed	0	0	0

CALCULATION NO. DRE97-0003
REV. 0 PAGE A8

Company: ComEd
Project:
by: Palas

4L252C45
12/21/96

LINEUP REPORT rev: 12/21/96

LINELIST: RING
dated: 12/18/96

DEVIATION: 0.0111 %
after: 6 iterations

4 LPCI @2500 and 2 CS @4500 Injecting. Nearest torus leg blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm
N	>>>	4500	O	>>>	0.0001
P	>>>	5000	R	>>>	2500
S	>>>	2500	U	>>>	4500

FLOWS IN: 0 gpm
FLOWS OUT: 19000 gpm
NET FLOWS OUT: 19000 gpm

PIPELINE		FLOW gpm		PRESSURE SOURCE	SET psig
Torus-1	<<<	6218	<<<	A	0
Torus-2	<<<	6302	<<<	B	0
Torus-3	<<<	6480	<<<	C	0

FLOWS IN: 19000 gpm
FLOWS OUT: 0 gpm
NET FLOWS IN: 19000 gpm

CALCULATION NO. DRE97-0003
REV. 0 PAGE A9

LINEUP NODES

4L252C45
12/21/96

NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0		p 0	0
B	0		p 0	0
C	0		p 0	0
E	0		* -0.610	-1.416
F	0		* -0.626	-1.454
G	0		* -0.662	-1.538
H	0		* -0.712	-1.652
I	0		* -0.634	-1.472
J	0		* -0.666	-1.547
K	0		* -0.665	-1.544
L	0		* -0.711	-1.651
M	0		* -0.712	-1.652
N	0	> 4500	* -0.885	-2.054
O	0	> 0.0001	* -0.665	-1.544
P	0	> 5000	* -0.778	-1.805
Q	0		* -0.820	-1.903
R	0	> 2500	* -0.956	-2.219
S	0	> 2500	* -1.269	-2.945
T	0		* -0.967	-2.245
U	0	> 4500	* -2.011	-4.668

CALCULATION NO. DRE97-0003

REV. 0 PAGE A10

LINEUP PIPELINES

4L252C45
12/21/96

PIPELINE	FROM		TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
CS-3A	I		N	4500	6.274	0.251	0.582
CS3B-16	T		U	4500	7.911	1.044	2.423
CS3B-18	M		T	4500	6.274	0.255	0.593
HPCI	K		O	0	0	0	0
LPCI3A	Q		R	2500	5.822	0.136	0.315
LPCI3A/B	J		Q	5000	3.781	0.154	0.357
LPCI3B	Q		S	2500	5.822	0.449	1.041
LPCI3C/D	L		P	5000	3.781	0.066	0.154
Ring-1	E		I	1999	1.512	0.024	0.056
Ring-2	F		I	2501	1.892	0.008	0.018
Ring-3	F		J	3800	2.874	0.040	0.093
Ring-4	K		J	1200	0.907	0.001	0.003
Ring-5	G		K	1200	0.907	0.002	0.006
Ring-6	G		L	5280	3.993	0.049	0.113
Ring-7	L	<->	H	280.3	0.212	0	0
Ring-8	H		M	280.3	0.212	0	0
Ring-9	E		M	4220	3.191	0.102	0.236
Torus-1	A		E	6218	7.529	0.610	1.416
Torus-2	B		F	6302	7.629	0.626	1.454
Torus-3	C		G	6480	7.845	0.662	1.538
Torus-4	D		H	closed	0	0	0

CALCULATION NO. DRE97-0003

REV. 0 PAGE A11

Company: ComEd
Project:
by: Palas

3L502C45
12/21/96

LINEUP REPORT rev: 12/21/96

LINELIST: RING
dated: 12/18/96

DEVIATION: 1.37 %
after: 3 iterations

3 LPCI @5000 and 2 CS @4500 Injecting. Nearest torus blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm
N	>>>	4500	P	>>>	5000
R	>>>	5000	S	>>>	5000
U	>>>	4500			

FLOWS IN: 0 gpm
FLOWS OUT: 24000 gpm
NET FLOWS OUT: 24000 gpm

PIPELINE		FLOW gpm		PRESSURE SOURCE	SET psig
Torus-1	<<<	7825	<<<	A	0
Torus-2	<<<	7891	<<<	B	0
Torus-3	<<<	8284	<<<	C	0

FLOWS IN: 24000 gpm
FLOWS OUT: 0 gpm
NET FLOWS IN: 24000 gpm

CALCULATION NO. DRE97-0003
REV. 0 PAGE A12

NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0		p 0	0
B	0		p 0	0
C	0		p 0	0
E	0		* -0.966	-2.242
F	0		* -0.982	-2.28
G	0		* -1.082	-2.513
H	0		* -1.109	-2.574
I	0		* -1.012	-2.349
J	0		* -1.086	-2.52
K	0		* -1.106	-2.568
L	0		* -1.118	-2.595
M	0		* -1.108	-2.573
N	0	> 4500	* -1.263	-2.931
P	0	> 5000	* -1.184	-2.748
Q	0		* -1.697	-3.939
R	0	> 5000	* -2.24	-5.199
S	0	> 5000	* -3.486	-8.091
T	0		* -1.364	-3.166
U	0	> 4500	* -2.408	-5.589

CALCULATION NO. DRE97-0003

REV. 0 PAGE A13

LINEUP PIPELINES

PIPELINE	FROM		TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
CS-3A	I		N	4500	6.274	0.251	0.582
CS3B-16	T		U	4500	7.911	1.044	2.423
CS3B-18	M		T	4500	6.274	0.255	0.593
HPCI	K		O	closed	0	0	0
LPCI3A	Q		R	5000	11.64	0.543	1.259
LPCI3A/B	J		Q	10000	7.563	0.612	1.42
LPCI3B	Q		S	5000	11.64	1.789	4.152
LPCI3C/D	L		P	5000	3.781	0.066	0.154
Ring-1	E		I	2801	2.119	0.046	0.107
Ring-2	F		I	1699	1.285	0.004	0.008
Ring-3	F		J	6192	4.683	0.103	0.240
Ring-4	K		J	3808	2.88	0.014	0.032
Ring-5	G		K	3808	2.88	0.024	0.056
Ring-6	G		L	4476	3.385	0.035	0.082
Ring-7	H		L	523.9	0.396	0	0.002
Ring-8	M	<->	H	523.9	0.396	0	0
Ring-9	E		M	5024	3.8	0.143	0.331
Torus-1	A		E	7825	9.474	0.966	2.242
Torus-2	B		F	7891	9.553	0.982	2.28
Torus-3	C		G	8284	10.03	1.082	2.513
Torus-4	D		H	closed	0	0	0

CALCULATION NO. DRE97-0003

REV. 0 PAGE A14

Company: ComEd
Project:
by: Palas

3L_50_25
12/21/96

LINEUP REPORT rev: 12/21/96

LINELIST: RING
dated: 12/18/96

DEVIATION: 0.0106 %
after: 6 iterations

2 LPCI @2500, 1 LPCI @5000 and 2 CS @4500 Injecting. Nearest torus blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm	
N	>>>	4500	P	>>>	5000	
S	>>>	5000	U	>>>	4500	
				FLOWS IN:	0 gpm	
				FLOWS OUT:	19000	gpm
				NET FLOWS OUT:	19000	gpm

PIPELINE		FLOW gpm		PRESSURE SOURCE	SET psig	
Torus-1	<<<	6218	<<<	A	0	
Torus-2	<<<	6302	<<<	B	0	
Torus-3	<<<	6480	<<<	C	0	
				FLOWS IN:	19000	gpm
				FLOWS OUT:	0 gpm	
				NET FLOWS IN:	19000	gpm

CALCULATION NO. DRE97-0003

REV. 0 PAGE A15

NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0		p 0	0
B	0		p 0	0
C	0		p 0	0
E	0		* -0.610	-1.416
F	0		* -0.626	-1.454
G	0		* -0.662	-1.538
H	0		* -0.712	-1.652
I	0		* -0.634	-1.472
J	0		* -0.666	-1.547
K	0		* -0.665	-1.544
L	0		* -0.711	-1.651
M	0		* -0.712	-1.652
N	0	> 4500	* -0.885	-2.054
P	0	> 5000	* -0.778	-1.805
Q	0		* -0.820	-1.903
R	0		* -0.820	-1.903
S	0	> 5000	* -2.609	-6.055
T	0		* -0.967	-2.245
U	0	> 4500	* -2.011	-4.668

CALCULATION NO. DRE97-0003
REV. 0 PAGE A16

LINEUP PIPELINES

PIPELINE	FROM		TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
CS-3A	I		N	4500	6.274	0.251	0.582
CS3B-16	T		U	4500	7.911	1.044	2.423
CS3B-18	M		T	4500	6.274	0.255	0.593
HPCI	K		O	closed	0	0	0
LPCI3A	Q		R	0	0	0	0
LPCI3A/B	J		Q	5000	3.781	0.154	0.357
LPCI3B	Q		S	5000	11.64	1.789	4.152
LPCI3C/D	L		P	5000	3.781	0.066	0.154
Ring-1	E		I	1999	1.512	0.024	0.056
Ring-2	F		I	2501	1.892	0.008	0.018
Ring-3	F		J	3800	2.874	0.040	0.093
Ring-4	K		J	1200	0.907	0.001	0.003
Ring-5	G		K	1200	0.907	0.002	0.006
Ring-6	G		L	5280	3.993	0.049	0.113
Ring-7	L	<->	H	280.3	0.212	0	0
Ring-8	H		M	280.3	0.212	0	0
Ring-9	E		M	4220	3.191	0.102	0.236
Torus-1	A		E	6218	7.529	0.610	1.416
Torus-2	B		F	6302	7.629	0.626	1.454
Torus-3	C		G	6480	7.845	0.662	1.538
Torus-4	D		H	closed	0	0	0

CALCULATION No. DRE97-0003
REV. 0 PAGE A17

Company: comed
Project:
by: palas

3L_25_50
01/03/97

LINEUP REPORT rev: 01/03/97

LINELIST: RING
dated: 12/18/96

DEVIATION: 0.0106 %
after: 6 iterations

2 LPCI @2500, 1 LPCI @5000 and 2 CS @4500 Injecting. Nearest torus blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm
N	>>>	4500	P	>>>	5000
R	>>>	2500	S	>>>	2500
U	>>>	4500			

FLOWS IN: 0 gpm
FLOWS OUT: 19000 gpm

NET FLOWS OUT: 19000 gpm

PIPELINE		FLOW gpm		PRESSURE SOURCE	SET psig
Torus-1	<<<	6218	<<<	A	0
Torus-2	<<<	6302	<<<	B	0
Torus-3	<<<	6480	<<<	C	0

FLOWS IN: 19000 gpm
FLOWS OUT: 0 gpm

NET FLOWS IN: 19000 gpm

CALCULATION No. DRE97-0003
REV. 0 PAGE A18

NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0		p 0	0
B	0		p 0	0
C	0		p 0	0
E	0		* -0.610	-1.416
F	0		* -0.626	-1.454
G	0		* -0.662	-1.538
H	0		* -0.712	-1.652
I	0		* -0.634	-1.472
J	0		* -0.666	-1.547
K	0		* -0.665	-1.544
L	0		* -0.711	-1.651
M	0		* -0.712	-1.652
N	0	> 4500	* -0.885	-2.054
P	0	> 5000	* -0.778	-1.805
Q	0		* -0.820	-1.903
R	0	> 2500	* -0.956	-2.219
S	0	> 2500	* -1.269	-2.945
T	0		* -0.967	-2.245
U	0	> 4500	* -2.011	-4.668

CALCULATION NO. DRE97-0003

REV. 0 PAGE A19

PIPELINE	FROM	TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
CS-3A	I	N	4500	6.274	0.251	0.582
CS3B-16	T	U	4500	7.911	1.044	2.423
CS3B-18	M	T	4500	6.274	0.255	0.593
HPCI	K	O	closed	0	0	0
LPCI3A	Q	R	2500	5.822	0.136	0.315
LPCI3A/B	J	Q	5000	3.781	0.154	0.357
LPCI3B	Q	S	2500	5.822	0.449	1.041
LPCI3C/D	L	P	5000	3.781	0.066	0.154
Ring-1	E	I	1999	1.512	0.024	0.056
Ring-2	F	I	2501	1.892	0.008	0.018
Ring-3	F	J	3800	2.874	0.040	0.093
Ring-4	K	J	1200	0.907	0.001	0.003
Ring-5	G	K	1200	0.907	0.002	0.006
Ring-6	G	L	5280	3.993	0.049	0.113
Ring-7	L	<-> H	280.3	0.212	0	0
Ring-8	H	M	280.3	0.212	0	0
Ring-9	E	M	4220	3.191	0.102	0.236
Torus-1	A	E	6218	7.529	0.610	1.416
Torus-2	B	F	6302	7.629	0.626	1.454
Torus-3	C	G	6480	7.845	0.662	1.538
Torus-4	D	H	closed	0	0	0

CALCULATION NO. DRE97-0003
REV. 0 PAGE A20

Company: ComEd
Project:
by: Palas

21502c45
12/21/96

LINEUP REPORT rev: 12/21/96

LINELIST: ring
dated: 12/18/96

DEVIATION: 1.47 %
after: 4 iterations

2 LPCI @5000 and 2 CS @4500 Injecting. Nearest torus leg blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first pipe specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm
N	>>>	4500	R	>>>	5000
S	>>>	5000	U	>>>	4500

NET FLOWS OUT: 19000 gpm

PRESSURE CONNECTIONS Node		Pipeline	FLOW gpm		PRESSURE psi g
A	>>>	Torus-1	6169	>>>	0
B	>>>	Torus-2	6419	>>>	0
C	>>>	Torus-3	6412	>>>	0

NET FLOWS IN: 19000 gpm

CALCULATION No. DRE97-0003
REV. 0 PAGE A21

LINEUP NODES

21502c45
12/21/96

NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0		p 0	0
B	0	-	p 0	0
C	0		p 0	0
E	0		* -0.600	-1.394
F	0		* -0.650	-1.509
G	0		* -0.649	-1.506
H	0		* -0.657	-1.525
I	0		* -0.653	-1.515
J	0		* -0.716	-1.662
K	0		* -0.691	-1.604
L	0		* -0.652	-1.513
M	0		* -0.659	-1.53
N	0	> 4500	* -0.904	-2.097
Q	0		* -1.327	-3.081
R	0	> 5000	* -1.87	-4.34
S	0	> 5000	* -3.116	-7.233
T	0		* -0.915	-2.123
U	0	> 4500	* -1.958	-4.546

CALCULATION No. DRE97-0003
REV. 0 PAGE A22

LINEUP PIPELINES

PIPELINE	FROM		TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
[illegible]-3A	I		N	4500	6.274	0.251	0.582
CS3B-16	T		U	4500	7.911	1.044	2.423
CS3B-18	M		T	4500	6.274	0.255	0.593
HPCI				closed	0	0	0
LPCI3A	Q		R	5000	11.64	0.543	1.259
LPCI3A/B	J		Q	10000	7.563	0.612	1.42
LPCI3B	Q		S	5000	11.64	1.789	4.152
LPCI3C/D	D		L	closed	0	0	0
Ring-1	E		I	2991	2.262	0.052	0.121
Ring-2	F		I	1509	1.141	0.003	0.007
Ring-3	F		J	4910	3.714	0.066	0.153
Ring-4	K		J	5090	3.849	0.025	0.057
Ring-5	G		K	5090	3.849	0.042	0.098
Ring-6	G		L	1322	1.000	0.003	0.008
Ring-7	L	<->	H	1322	1.000	0.005	0.012
Ring-8	H		M	1322	1.000	0.002	0.005
Ring-9	E		M	3178	2.403	0.059	0.136
Torus-1	A		E	6169	7.469	0.600	1.394
Torus-2	B		F	6419	7.772	0.650	1.509
Torus-3	C		G	6412	7.763	0.649	1.506
Torus-4	D		H	closed	0	0	0

CALCULATION NO. DRE97-0003
REV. 0 PAGE A23

Company: ComEd
Project:
by: Palas

2L372C45
12/21/96

LINEUP REPORT rev: 12/21/96

LINELIST: RING
dated: 12/18/96

DEVIATION: 0.29 %
after: 4 iterations

2 LPCI @3750 and 2 CS @4500 Injecting. Nearest torus leg blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm
N	>>>	4500	R	>>>	3750
S	>>>	3750	U	>>>	4500

FLOWS IN: 0 gpm
FLOWS OUT: 16500 gpm

NET FLOWS OUT: 16500 gpm

PIPELINE		FLOW gpm		PRESSURE SOURCE	SET psig
Torus-1	<<<	5376	<<<	A	0
Torus-2	<<<	5571	<<<	B	0
Torus-3	<<<	5553	<<<	C	0

FLOWS IN: 16500 gpm
FLOWS OUT: 0 gpm

NET FLOWS IN: 16500 gpm

CALCULATION No. DRE97-0003

REV. 0 PAGE A24

NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0		p 0	0
B	0		p 0	0
C	0		p 0	0
E	0		* -0.456	-1.059
F	0		* -0.490	-1.137
G	0		* -0.487	-1.129
H	0		* -0.500	-1.16
I	0		* -0.494	-1.148
J	0		* -0.526	-1.221
K	0		* -0.511	-1.187
L	0		* -0.492	-1.141
M	0		* -0.503	-1.168
N	0	> 4500	* -0.745	-1.73
Q	0		* -0.870	-2.021
R	0	> 3750	* -1.176	-2.729
S	0	> 3750	* -1.878	-4.359
T	0		* -0.759	-1.761
U	0	> 4500	* -1.802	-4.184

CALCULATION No. DRE97-0003
REV. 0 PAGE A25

LINEUP PIPELINES

PIPELINE	FROM		TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
CS-3A	I		N	4500	6.274	0.251	0.582
CS3B-16	T		U	4500	7.911	1.044	2.423
CS3B-18	M		T	4500	6.274	0.255	0.593
HPCI	K		O	closed	0	0	0
LPCI3A	Q		R	3750	8.732	0.305	0.709
LPCI3A/B	J		Q	7500	5.672	0.345	0.800
LPCI3B	Q		S	3750	8.732	1.007	2.338
LPCI3C/D	L		P	closed	0	0	0
Ring-1	E		I	2545	1.924	0.038	0.089
Ring-2	F		I	1955	1.479	0.005	0.011
Ring-3	F		J	3615	2.734	0.036	0.084
Ring-4	K		J	3885	2.938	0.014	0.033
Ring-5	G		K	3885	2.938	0.025	0.058
Ring-6	G		L	1668	1.262	0.005	0.012
Ring-7	L	<->	H	1668	1.262	0.008	0.019
Ring-8	H		M	1668	1.262	0.003	0.008
Ring-9	E		M	2832	2.142	0.047	0.109
Torus-1	A		E	5376	6.509	0.456	1.059
Torus-2	B		F	5571	6.744	0.490	1.137
Torus-3	C		G	5553	6.723	0.487	1.129
Torus-4	D		H	closed	0	0	0

CALCULATION No. DRE97-0003
REV. 0 PAGE A26

Company: ComEd
Project:
by: Palas

1L502C45
12/21/96

LINEUP REPORT rev: 12/21/96

LINELIST: RING
dated: 12/18/96

DEVIATION: 0.0179 %
after: 5 iterations

1 LPCI @5000 and 2 CS @4500 Injecting. Nearest torus leg blocked.

Volumetric flow rates require constant fluid properties in all pipelines.
Fluid properties in the first specification were used.

NODE		DEMAND gpm	NODE		DEMAND gpm
N	>>>	4500	S	>>>	5000
U	>>>	4500			

FLOWS IN: 0 gpm
FLOWS OUT: 14000 gpm

NET FLOWS OUT: 14000 gpm

PIPELINE		FLOW gpm		PRESSURE SOURCE	SET psig
Torus-1	<<<	4592	<<<	A	0
Torus-2	<<<	4719	<<<	B	0
Torus-3	<<<	4690	<<<	C	0

FLOWS IN: 14001 gpm
FLOWS OUT: 0 gpm

NET FLOWS IN: 14001 gpm

CALCULATION No. DRE97-0003
REV. 0 PAGE A27

LINEUP NODES

1L502C45
12/21/96

NODE	ELEVATION ft	DEMAND gpm	PRESSURE psi g	H GRADE ft
A	0	_	p 0	0
B	0		p 0	0
C	0		p 0	0
E	0		* -0.333	-0.772
F	0		* -0.351	-0.816
G	0		* -0.347	-0.806
H	0		* -0.365	-0.848
I	0		* -0.359	-0.833
J	0		* -0.366	-0.850
K	0		* -0.359	-0.834
L	0		* -0.354	-0.822
M	0		* -0.370	-0.860
N	0	> 4500	* -0.610	-1.415
Q	0		* -0.520	-1.207
S	0	> 5000	* -2.309	-5.359
T	0		* -0.626	-1.452
U	0	> 4500	* -1.669	-3.875

CALCULATION NO. DRE97-0003

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LINEUP PIPELINES

PIPELINE	FROM		TO	FLOW gpm	VEL ft/sec	dP psi g	Hl ft
CS-3A	I		N	4500	6.274	0.251	0.582
CS3B-16	T		U	4500	7.911	1.044	2.423
CS3B-18	M		T	4500	6.274	0.255	0.593
HPCI	K		O	closed	0	0	0
LPCI3A	Q		R	closed	0	0	0
LPCI3A/B	J		Q	5000	3.781	0.154	0.357
LPCI3B	Q		S	5000	11.64	1.789	4.152
LPCI3C/D	L		P	closed	0	0	0
Ring-1	E		I	2074	1.569	0.026	0.060
Ring-2	F		I	2426	1.835	0.007	0.017
Ring-3	F		J	2293	1.734	0.015	0.035
Ring-4	K		J	2707	2.047	0.007	0.016
Ring-5	G		K	2707	2.047	0.012	0.028
Ring-6	G		L	1983	1.499	0.007	0.017
Ring-7	L	<->	H	1983	1.499	0.011	0.026
Ring-8	H		M	1983	1.499	0.005	0.011
Ring-9	E		M	2517	1.904	0.038	0.087
Torus-1	A		E	4592	5.559	0.333	0.772
Torus-2	B		F	4719	5.713	0.351	0.816
Torus-3	C		G	4690	5.678	0.347	0.806
Torus-4	D		H	closed	0	0	0

CALCULATION No. DRE97-0003
REV. 0 PAGE A29

COMPARISON OF PROPOSED VS. 1976 NPSH CALCULATIONS

The primary inputs and assumptions utilized in the 1976 NPSH calculations and the proposed NPSH calculations are summarized in the table below:

Inputs/Assumptions	1976 Calculation	1997 Calculation
Initial torus temperature	95F	75F
Peak torus temperature	130F	132F
LPCI 4-pump runout flow	21,860 gpm	20,600 gpm
Core Spray pump runout flow	5400 gpm	5800 gpm
LPCI pump suction loss	7.5 ft. (clean pipe)	12.0 ft. (Includes aging)
Strainer loss	1 ft.	6.7 ft. (at runout flow rate)
Strainer plugging	nearest strainer plugged	nearest strainer plugged
Static Head above pumps	15.0 ft. (no drawdown)	13.3 ft. (Includes drawdown)
Reactor pressure	56 psid	0 psid
Containment Over pressure	0 psig	2 psig
Worst LPCI NPSH margin	-3 ft.	-3.3 ft.

In comparing the inputs and assumptions listed above, it can be seen that the proposed calculations are more conservative than the 1976 calculations. The NPSH margin is retained through the administrative control of the initial torus temperature and the use of 2 psig containment pressure.

The 1976 calculations manually developed ECCS ring header losses for a given flow case. Since the ring header flow distribution and losses with all ECCS pumps running is complex, a hydraulic piping model of the ring header was developed (DRE96-0241). A benchmark case was run to compare the model to the 1976 calculation, and the results provided below:

Flow Case: 4 LPCI pumps @5350 gpm per pump
2 Core Spray pumps @5400 gpm per pump

1976 Ring Header Loss: 2.5 ft.
1997 Ring Header Loss: 4.5 ft.

The piping model used in the new NPSH calculations is therefore shown to provide conservative ECCS ring header losses with respect to the 1976 NPSH calculations.

<u>Attachment 4</u>

The Use of Containment Over Pressure in NPSH Calculations for Dresden / Quad Cities Stations

and

An Evaluation of Dresden 2/3 Containment Performance Under Reduced Initial Suppression Pool and Service Water Temperature Assumptions.

The Use of Containment Overpressure in NPSH Calculations for Dresden/Quad Cities Stations

Introduction

Recent engineering efforts involved in the support of containment strainer replacement modifications, as well as inquiries received during the Dresden ISI have resulted in new information as well as new concerns regarding NPSH calculations for ECCS pumps during LOCA events. Specifically, the following items have become concerns:

1) Review of Mark I strainer modification documents for QC and Dresden have revealed that the differential pressure that would be expected at design flow rates is approximately 5.8 feet, vs the 1 foot value shown on the original containment drawings and used in support of ECCS pump NPSH predictions.

2) ISI questions raised concern regarding the NPSH performance of ECCS pumps during the initial phase of a LOCA, since the pumps would be expected to be operating at or near runout conditions following vessel depressurization, and would not be throttled by operator actions until 10 minutes into the event.

There are a number of issues specifically regarding Dresden LPCI/CCSW pump and heat exchanger performance that require reconstitution of the containment analysis to resolve. This effort has been in progress for several months, with a significant analytical basis nearing completion. Licensing amendments are in preparation to document the new analysis and benchmarks to allow replacement of the existing analysis.

The purpose of this submittal is to document the justification for the use of containment overpressure in current NPSH evaluations. 10CFR50.59 evaluations of the above concerns have determined that an unresolved safety question (USQ) exists specifically regarding the use of overpressure in these evaluations at Dresden. For Dresden, the question is whether any overpressure can be applied. Quad Cities is still performing a 10CFR50.59 evaluation and has not concluded whether or not an USQ exists at this time.

Description of Post-LOCA Plant Response

Both Dresden 2/3 and Quad Cities 1/2 are BWR 3/4 designs with Mark I containment systems. The limiting design basis accident with respect to containment thermal response is the DBA LOCA, which is a double ended break of a recirculation system suction pipe. This event yields a rapid vessel depressurization, fuel uncovery and places maximum demands on the ECCS systems. Following the blowdown, the vessel is reflooded to approximately two thirds core height due to injection by the Low pressure coolant injection (LPCI/RHR) and Core Spray (CS) pumps. At the 10 minute time frame, the operators are trained to initiate suppression pool cooling. For the limiting case of LOOP plus failure of a D/G, this would lead to one CS pump maintaining vessel level, one LPCI/RHR pump in the pool cooling mode, and 2 containment cooling service water pumps (CCSW) supplying the LPCI HX. For Quad Cities, only one service water pump would be started in this condition due to the higher horsepower requirements of their RHRSW pumps and limitations imposed by diesel loading capacity. The ECCS system performance, containment parameters, core power, and containment heat exchanger performance are essentially identical between the plants. Key parameters are shown in Table 1.

Containment Pressure Response

This event yields a rapid containment pressure rise initially due to the transport of non-condensibles from the drywell to the wetwell, and achieves a peak drywell pressure early in the event due to the differential pressure developed across the vent header system. The initial suppression pool heatup is approximately 50 F due to the effects of the blowdown and pool temperatures of approximately 150F are expected at 10 minutes into the event. The suppression pool temperature would continue to rise until the heat load of the containment cooling heat exchanger matched the heat input to the containment due to decay heat, latent heat from the vessel, feedwater addition, and pump heat. This occurs between 3 to 6 hours, depending on the availability of pumps for containment cooling. Maximum temperatures reached range from 163 F for a "complete" pool cooling complement (2 LPCI/2 CCSW) to 179 F for a "minimum" case of 1 LPCI/1 CCSW. Dresden's current design basis peak suppression pool temperature is 170 F for a 1 LPCI/2 CCSW pump configuration.

The pressure response of the drywell and wetwell are coupled over the long term, and are dependent on a number of factors. The key factors determining this response are:

1. Mixing fraction of fluid spilling from the break with drywell atmosphere. This affects the short term pressure response since the break fluid rapidly becomes subcooled following reflood, and would act to reduce pressure drywell pressure by condensing steam.

2. Manual Initiation of Containment Spray. This has a dominant effect on the pressure response of the coupled system. Initiation of containment spray in the 10 minute time frame would lead to rapid quench of steam in the drywell and return of non-condensibles to the drywell via the vacuum breakers. This reduces the system pressure and effectively sets the temperature of both the drywell and the wetwell airspace. In the long term, the spray temperature in the wetwell airspace effectively determines the containment pressure response.

3. Heat transfer to containment liner. This affects the short term pressure by condensing more steam in the drywell. It tends to have minor effect on the long term response, being overwhelmed by the action of containment spray. (Containment heat sinks have historically been ignored in BWR containment calculations).

4. Initial conditions in containment. The initial conditions of temperature and particularly relative humidity set the total non-condensible inventory. High initial temperatures and humidity lead to the lowest non-condensible inventory, and have a dramatic effect on the long term pressure response of the system.

5. Containment Cooling flow rates. The flow rates of LPCI/RHR and CCSW determine the effectiveness of the heat exchanger, which determines the peak pool temeperature achieved. In addition, the flow rates determine the spray temperature, which has a direct impact on the containment pressure.

Description of New Calculations

As indicated above, a series of new containment calculations has been performed for Dresden to address a number of design basis issues. These calculations were performed by General Electric, using the SHEX computer code. A number of cases were performed to identify the limiting scenario, relative to ECCS NPSH calculations, selected based on reaching the maximum pool temperature with lowest containment pressure. The new calculations are based on ANS 5.1-1979 decay heat standards and include all appropriate heat sources including FW mass energy and ECCS pump heat. In addition, the new analyses employed assumptions consistent with NRC Information Notice 96-55, specifically addressing the addition of heat sinks. The new containment calculations employ a methodology that is intended to provide the lowest pressure in the long term. These include:

1. Minimizing the non-condensibles present at initiation of event.

2. Initiating containment spray at 10 minutes and continuing for duration of event.

3. Including the effects of heat conduction to containment surfaces, based on Branch Technical position CSB 6-1.

4. Use of bounding values for drywell mixing ratio, to predict the lowest pressures both in the short term as well as the long term.

5. Calculation of variety of ECCS flow rates and pump combinations to ensure that the potential range of ECCS flows has been bounded.

Results of New Calculations

When combined with previous analyses performed for both Dresden and Quad Cities, a clear picture of the most limiting NPSH scenarios results. Some of the key results identified are:

1. The scenarios that employ a single LPCI in conjunction with two CCSW pumps yield the highest suppression pool temperatures with the lowest containment pressures. Previous studies were based on 2/2 or 1/1 combinations, and achieved higher pressures, even with lower suppression pool temperatures.

2. The coupled analyses demonstrate that at suppression pool temperatures of 171 F or greater, at least 2.9 psig overpressure is available.

3. The containment pressure during the short term, (eg. first 10 minutes) has been demonstrated to be at least 5.5 psig, even with worst case assumptions applied.

4. While different decay heat standards and heat exchanger performance predictions are applied in the new calculations, the peak containment temperatures being predicted are consistent with and fall near the original design basis temperature predictions. The pressure response is not a function of decay heat models, but is primarily only effected by the pool temperature and heat exchanger performance.

A comparison calculation of containment long term pressure based on ideal gas law models was also generated to confirm that the trend and overall results predicted by the new containment analyses is appropriate. This calculation supports the conclusions that the 1/2 cases will provide bounding pressure response as well as demonstrating that the GE calculations are yielding conservatively low values of containment pressure, relative to the suppression pool temperature predicted. This calculation is attached as an appendix to this document. These analyses were required to be performed in order to minimize pressure in the suppression pool. The data required to support the existing design basis of Dresden and Quad Cities is not available and therefore, the new data must be utilized. The existing containment responses for Dresden and Quad Cities will remain until they are further amended. Dresden is preparing a submittal that will change its Design Basis Containment Response. This submittal should be prepared by January 24, 1996.

Conclusions

Based on the results of new calculations, it is clear that significant containment overpressure conditions would exist, both in the short term (<10 minutes) as well as the long term post-LOCA period. The new calculations have been performed to minimize the extent of overpressure that would exist in both periods, and support the conclusion that overpressure would be available and can be employed to demonstrate adequate ECCS NPSH performance.

While the new containment calculations have not been reviewed and approved by NRC to date, they are more appropriate with respect to the prediction of minimum containment pressure both in the long and short term post-LOCA periods, than are the original design basis calculations. They result in peak pool temperatures near to but slightly above the original calculated values, and predict containment overpressures of several psi, even with the incorporation of currently recommended analysis assumptions to minimize overpressure. Therefore, the conceptual use of containment overpressures in the ranges indicated in the new analyses appears warranted in the performance of ECCS NPSH calculations.

Table 1. **Comparison of Key Containment Parameters for Dresden and Quad Cities**

Equipment/Parameter	Dresden 2/3	Quad Cities 1/2
Core Licensed Power	2527 MWT	2511 MWT
LPCI/RHR pump flow rate	4500 gpm rated	4500 gpm rated
CS pump flow rate	4500 gpm rated	4500 gpm rated
CCSW/RHRSW pump flow	3500 gpm/pump	3500 gpm/pump
LPCI/RHR HX original design condition	105 MBTU at 10700 gpm LPCI/ 7000 gpm CCSW 165F pool 95 F service water side	105 MBTU at 10700 gpm RHR/ 7000 gpm RHRSW 165F pool 95 F service water side
Drywell Free Volume	158236 cuft	158236 cuft
Wetwell Free Volume	120097 cuft	119963 cuft
Wetwell Water Volume	112000 cuft	111500 cuft

Memorandum

ComEd

Date: January 9, 1997
NFS:BSA:97-002

To: Mr. R. Freeman

Subject: An Evaluation of Dresden 2/3 Containment Performance Under Reduced Initial Suppression Pool and Service Water Temperature Assumptions

Enclosed please find a calculation summary entitled "An Evaluation of Dresden 2/3 Containment Performance Under Reduced CCSW Flow, HX Performance and Lowered Initial Suppression Pool Temperature". This calculation was performed at the request of your staff to provide technical support for proposed technical specification changes needed to accommodate ECCS pump NPSH calculations. This calculation incorporates the current penalties assigned to the LPCI HX performance due to reduced CCSW flow rates and new HX performance calculations, and extends these evaluations to consider the impacts of reductions in initial pool temperature and additional reductions in service water temperatures necessary to establish a maximum post-LOCA suppression pool temperature of 160F.

This work has been performed and reviewed in accordance with NFS procedures for controlled work. Please note that the limits established in this evaluation by comparison to Quad Cities UFSAR containment calculations are intended to be a temporary measure, until the Dresden plant specific containment analysis and supporting amendments are approved. The low values of suppression pool initial temperature and service water temperature being adopted will not support continued plant operation once seasonal heatup of the cooling water is experienced. It is our understanding that the new analyses are completed and once approved, will support the removal of these restrictions on initial pool temperature and service water temperature.

If you have any questions regarding this matter, please contact K. B. Ramsden at extension 3017 in Downers Grove.

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Enclosure

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An Evaluation of Dresden 2/3 Containment Performance Under Reduced CCSW Flow, HX Performance and Lowered Initial Suppression Pool Temperature

Introduction

The purpose of this evaluation is to provide an appropriate reduction in the service water temperature to compensate for a postulated reduction in available ECCS pump NPSH margin. The design basis heat transfer rate of the LPCI HX is 105 MBTU/hr at a suppression pool temperature (shell side) of 165F and service water temperature (tube side) of 95F, with LPCI flow at 10700 gpm and service water flow at 7000 gpm, per the heat exchanger data sheet. In a prior evaluation (Reference 1), HX performance reductions resulting from recalculation of HX performance as well as a reduction in CCSW flow to 6750 were performed. A subsequent evaluation (Reference 2) extended the first evaluation to include an allowance to cover CCSW flow rates as low as 5600 gpm. This reduction in CCSW flow accounts for anticipated operator actions to reduce CCSW flow as necessary to maintain a 20 psi differential pressure between the LPCI system operating at a nominal 5000 gpm LPCI flow rate and the CCSW system. The pressure differential is necessary to ensure that any potential leakage in a LCPI HX tube would be from the CCSW side (tube) to the LPCI side (shell). This evaluation extends the first two evaluations to include initial maximum suppression pool temperature reductions and additional service water maximum allowable temperature reductions required to ensure that the short term post-LOCA suppression pool temperature as well as the long term peak post-LOCA suppression pool temperature would remain low enough to allow demonstration of adequate NPSH with limited (2 psi short term, 0 psi long term) containment overpressure assumptions.

Short Term Post-LOCA Suppression Pool Temperature

The short term post-LOCA period is defined as the first six hundred seconds following the initiation of the event. This period includes the initial blowdown and peak overpressure period prior to the manual initiation of containment cooling and/or spray. This period is important with respect to the ECCS pump performance since performance above "rated" conditions is assumed in the Appendix K LOCA analysis. These high flow rates, combined with postulated failures of LPCI injection to the faulted loop can lead to significant ECCS pump suction losses as well as requiring the maximum NPSH margins.

While no Dresden specific suppression pool temperature vs time curves are available, and the original calculations have proven unrecoverable, the temperature profiles for Quad Cities are available and are considered representative for use at Dresden, based on plant similarities with respect to containment size, core power, and reactor operating parameters. The Quad Cities temperature profiles begin with an initial pool temperature of 90 F and rapidly increase to approximately 147 F at the 600 second end point of the short term period. A 15 degree reduction has been determined by M&S engineers (Reference 3) to result in acceptable NPSH performance throughout this interval with only an overpressure credit of 2 psi. This 15 degree reduction results in a new maximum allowable suppression pool temperature of 75 F during operation. Note that the current allowable suppression pool temperature is 95 F, and that this value will be restored following acceptance of new containment analysis and associated licensing amendments. This reduction in initial temperature will result in a corresponding linear reduction in the pool temperature throughout this interval, since pool cooling is not active. The end of interval temperature would be anticipated to be 132 F under these assumptions.

Long Term Containment Suppression Pool Temperature Analysis Requirements

In the long term containment response, the M&S engineers have determined that a reduction from the design maximum 170 F pool temperature to 160 F for the limiting 1 LPCI / 2 CCSW pumps operating is required in order to assure adequate ECCS NPSH margins exist under all postulated flow conditions. (Reference 4) The prior evaluations utilized linear reductions of service water temperature to ensure that the 170 F limiting value was not compromised, and resulted in a 84F maximum allowable service water temperature. The linear temperature reductions were then verified using a mathematical model of the post-LOCA suppression pool temperature response to ensure that the linear assumptions utilized were valid. In this evaluation, since the initial condition of the pool is being reduced substantially, in conjunction with further reductions in maximum allowable service water temperature, the simplified linear approach is not appropriate. Therefore the mathematical model must be employed to adequately account for boundary condition changes.

The mathematical model has been prepared and adjusted to ensure that a conservative representation of post-LOCA pool temperature response will be rendered. A model of the suppression pool, based on first principles and coupled to vendor analyses for the initial pool temperature subsequent to the blowdown and reflood period (approximately 600 seconds) was previously developed and documented in RSA-94-03. A section of that report covering the development of the numerical models is provided in the following section.

Analytical Basis

The post-LOCA behavior of the suppression pool can be characterized as consisting of two distinct periods, the initial vessel blowdown and core reflood phase, and a long term heatup of the suppression pool during extended recirculation of the suppression pool water through the vessel. The first period adds a large amount of energy and mass to the suppression pool due to the inventory of the vessel as well as the feedwater addition. The recirculation phase has three major contributors to the energy addition to the pool, namely the decay heat, the sensible heat stored in the vessel thick metal volumes, and the ECCS pump heat. The LPCI/CCSW containment cooling subsystem acts as a sink, with heat removal dependent on the flows assumed and the temperature difference between service water (CCSW) and the suppression pool. This situation can be readily characterized by the following equation:

$$mc_p \frac{dT}{dt} = \mathrm{Q}_{\mathrm{decay}}(t) + \mathrm{Q}_{\mathrm{pump}} + \mathrm{Q}_{\mathrm{sensheat}} - \mathrm{K}_{\mathrm{hx}} * [T(t) - \mathrm{T}_{\mathrm{sw}}]$$

where:

m = the pool mass (initial plus mass added during blowdown phase)

c_p= the specific heat of water (1.0 used)

Q_{decay}= decay energy (based on May-Witt or ANS 5.1 1979 curve used by GE)

Q_{pump}= pump motor horsepower converted to thermal energy (700 HP for LPCI, 800 HP for Core spray)

$Q_{sensheat}$= vessel metal mass sensible heat addition rate (approximately 70 MBTU added as an exponentially decreasing rate)

K_{HX}= LPCI heat exchanger performance based on flow rates of LPCI and CCSW (BTU/sec-F).

T_{SW}= CCSW temperature (typically constant at 95 F)

T(t)= Suppression pool temperature as a function of time

This equation readily lends itself to solution with fourth order Runge-Kutta numerical methods. A solution of this type was developed utilizing the MATHCAD software package.

Suppression Pool Temperature Model Input and Testing

The mathematical model described above was exercised to provide a conservative estimate of the effects of reduced initial suppression pool temperature as well as service water temperature reduction. This model, while in no way intended to replace the license basis containment model, does provide a reasonable method to verify that the temperature reductions will be conservative relative to the original design basis calculations. The model was previously developed and benchmarked against new GE containment analyses performed to support a LPCI/CCSW licensing amendment. The following changes were made to make the model reflect original licensing basis analysis:

1. The decay heat model was changed from ANS 5.1-1979 to the May-Witt decay heat curve. Based on review of the QC UFSAR, the nominal reactor power was applied as a multiplier to the May-Witt normalized curve.

2. The heat addition term due to pump heat was set to zero.

3. A temperature input of 147F was used for the pool temperature at 600 seconds, based on Quad Cities UFSAR analyses. (This compares with 152F for the new analyses, which include the effects of FW heat addition, 95F initial pool temperature, pump heat, and 1979 standard decay heat.) This temperature was reduced by 15 degrees to compensate for the lower initial suppression pool temperature.

The model was then tested to verify that it conservatively and accurately represents the long term post-LOCA suppression pool behavior. Two cases from the Quad Cities UFSAR were selected to validate the model. The first case was a 2 RHR/2 RHRSW pump combination. The second case was a 1 RHR/ 2 RHRSW pump combination. For comparison, the process flow diagram and the heat exchanger data sheet, both list a peak temperature of 165F for the 2/2 case. The Mathcad model was exercised using a 95 F and also a 90 F service water temperature, since this parameter was not explicitly identified in the QC UFSAR. The heat exchanger K value for case B/C is directly derivable from the HX data sheet (105 MBTU/hr @ 165F suppression pool/95F service water temperatures. The case D K-value is estimated based on 5350 RHR/7000 RHRSW flows using an effectiveness based HX performance model pattern on the QC HX geometry. The applicable pages of the QC UFSAR are attached in the Appendix. The results of the validation cases are presented in the following table.

Comparison of Mathcad Model to QC UFSAR Results

Case	LPCI flow	CCSW flow	Service Water Temp F	K-value (Btu/sec-F)	Time of Peak Pool Temp (sec)	Peak Pool Temp F
QC Case B/C	10700	7000	95 (?)	416.67	~11500	162
QC Case D	5350	7000	95 (?)	346.24	~16000	168
Mcad Model Case B/C	10700	7000	95	416.67	12628	164.87
Mcad Model Case B/C	10700	7000	90	416.67	11076	162.6
Mcad Model Case D	5350	7000	95	346.24	16896	171.25
Mcad Model Case D	5350	7000	90	346.24	15344	168.7

As can be readily seen, the Mathcad model provides a fairly good, but slightly conservative replication of the Quad Cities original cases. The close agreement both in magnitude of the peak temperature as well as the timing of the peak strongly suggests that the original Quad Cities cases were based on both 90F initial pool temperature as well as service water temperature.

Calculation of Dresden 1/2 Limiting Case

Since the Mathcad model was demonstrated to provide conservative representation of the Quad Cities cases, the next step was to modify the model to represent the Dresden 1/2 design case and then perform the iterations necessary to incorporate the currently applied reductions in heat exchanger performance, service water temperature, and initial suppression pool temperature. The only change necessary to the model is the rated power, for which 2578 MWT is used in place of 2561 MWT. A heat exchanger K-value of 341.57 BTU/sec-F was used for the design case based on effectiveness models representing the Dresden LPCI HX. Two cases were run in this configuration, representing a 95F service water as well as a 90 F service water condition. For the current limited CCSW flow (5600gpm) and reduced HX performance values, a K value of 296.96 BTU/sec-F was employed, based on the same Dresden HX models. Three cases were run, case D-1 which demonstrates the effect of the reduction in HX performance and service water temperature prior to this evaluation; Case D-2, which shows the effect of reduction in initial pool temperature to 75 F; and Case D-3 which calculates the combined effect of reduction in service water temperature to 75F as well as limiting the initial pool temperature to 75 F. The results are provided in the following table.

Dresden 1/2 Design Case Mathcad Model Results

Case	LPCI flow	CCSW flow	Service Water/ Initial pool Temp F	K-value (Btu/sec-F)	Time of Peak Pool Temp (sec)	Peak Pool Temp F
Base Case D	5000	7000	95 /90	341.57	17284	172
Base Case D sensitivity	5000	7000	90/90	341.57	15732	169.54
Mcad Model Case D-1	5000	5600	84/90	296.96	17588	172
Mcad Model Case D-2	5000	5600	84/75	296.96	22520	164.8
Mcad Model Case D-3	5000	5600	75/75	296.96	19232	160

The base case results indicate peak temperatures that compare very favorably with the 170 F value currently believed to be representative of the Dresden 1/2 design basis case. The base case run at a 90F assumed service water temperature demonstrates the sensitivity of the peak temperature to service water temperature. The results of Case D-1 illustrate the limiting conditions extant prior to this evaluation, and demonstrate that the reductions in service water temperature effected preserve the peak temperature relative to the base case. The results of Case D-2 illustrate the effect of reducing the suppression pool initial water temperature to 75 F. Case D-3 demonstrates that reducing the service water temperature limit to 75 F in conjunction with a reduced initial torus temperature limit of 75 F limits the peak pool temperature for the 1/2 case to 160 F which is the temperature necessary to ensure adequate NPSH with increased strainer losses and no overpressure credit as identified previously. As noted, this case incorporates all prior penalties and assessments related to reduced CCSW flow and LPCI HX performance issues. All Mathcad calc sheets are included in the Appendix to this evaluation.

Conclusions

A mathematical model of post-LOCA suppression pool thermal behavior has been developed and validated against the Quad Cities UFSAR. Based on this validation and on the nearly identical physical construction of the Dresden and Quad Cities containments, this model was then employed to evaluate the effects of reduced suppression pool initial temperature and reduced service water maximum temperature for Dresden Units 2 and 3. The design basis case was demonstrated to result in conservative temperature prediction. This case was then extended to reflect the currently applicable limitations on LPCI HX performance, CCSW flow rate, and service water temperature. Finally, the effect of proposed limits on initial pool temperature and service water temperature were assessed to demonstrate that they would effectively limit the maximum suppression pool temperature to 160 F.

It should be noted that while every effort has been made to ensure that a technically sound approach has been applied, this approach relies on extrapolation of Quad Cities analyses to Dresden. This is clearly intended as a short term strategy to support appropriate limits on Unit 3 to allow plant startup. The most technically defensible long term approach is to perform plant specific reanalysis of the Dresden containments. The new analysis will also be required to support continued plant operation subsequent to seasonal heatup of the cooling water supply.

References

1. NFS:BSA:96-111, "Evaluation of Reduced LPCI HX Performance", R. Tsai to R. Kundalkar, dated October 7, 1996.

2. NFS:BSA:96-140, "Evaluation of Reduced LPCI HX Performance due to Low CCSW Flow", R. Tsai to R. Kundalkar, dated November 4, 1996.

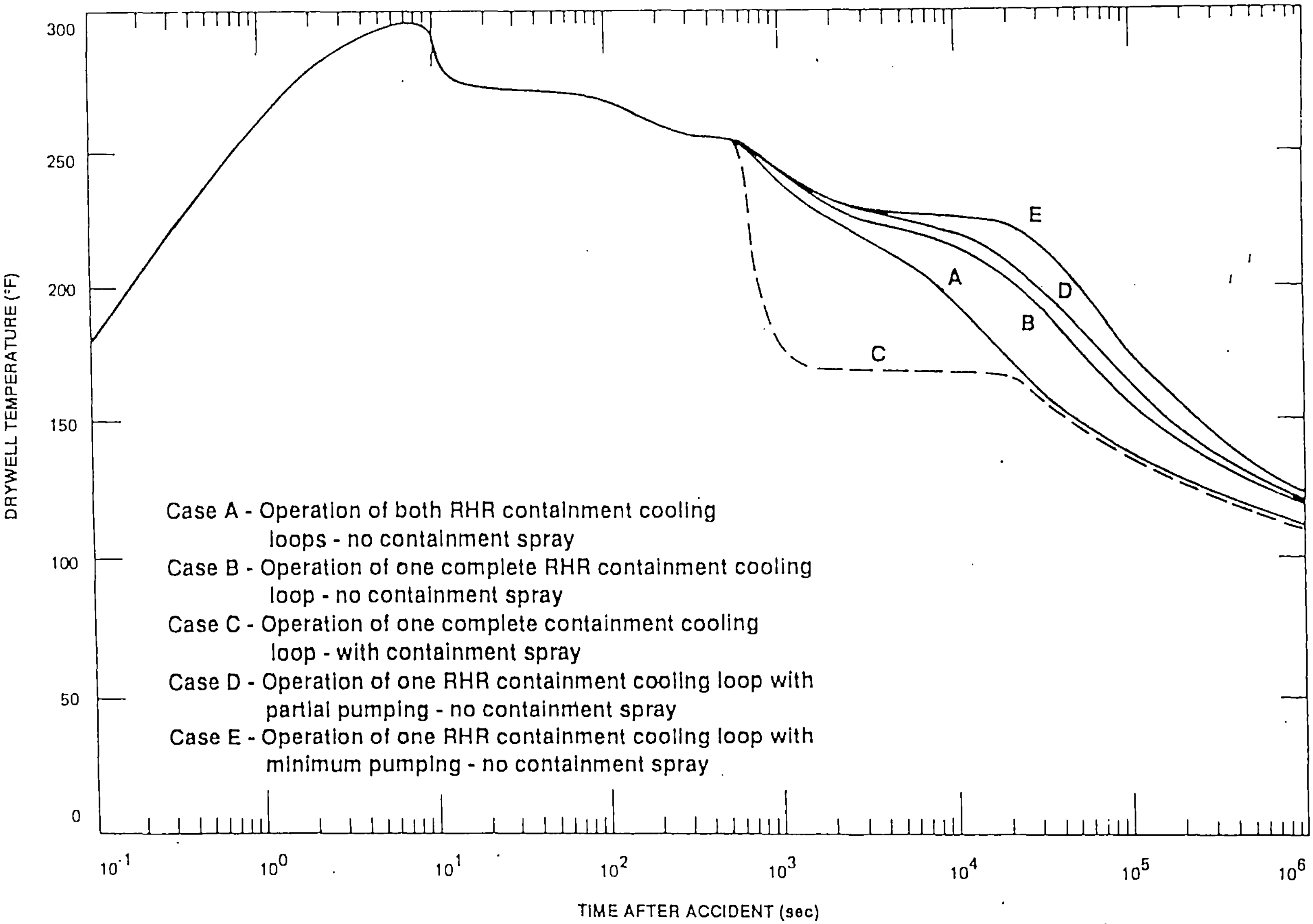
3. DRE97-0002, "Dresden LPCI/Core Spray NPSH Analysis Post-DBA LOCA:GE SIL 151 Case Short Term", H. Palas, dated 1/8/97.

4. DRE97-0003, "Dresden LPCI/Core Spray NPSH Analysis Post-DBA LOCA: Reduced Torus Temperature Long Term", H. Palas, dated 1/7/97.

Table 6.2-3

CONTAINMENT RESPONSE SUMMARY FOR A RECIRC LINE BREAK ACCIDENT

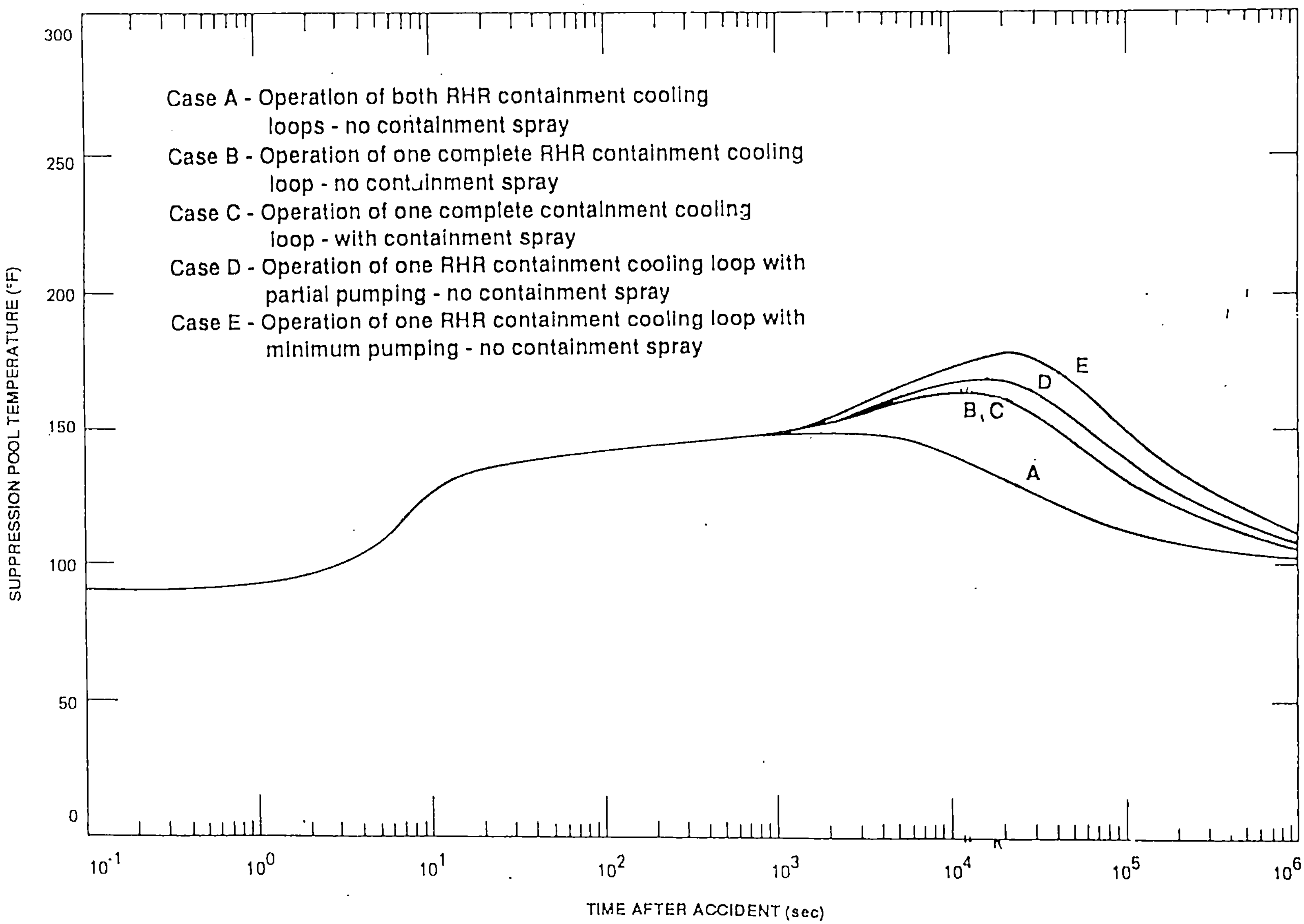
Case	RHR Loops	RHR Pumps	RHR Service Water Pumps	Containment Spray (gal/min)	Core Spray (gal/min)	Peak Pool Temperature (F°)	Secondary Peak Pressure (psig)
(a)	2	4	4	none	4500	149	no peak
(b)	1	2	2	none	4500	162	no peak
(c)	1	2	2	10,000	4500	162	8.0
(d)	1	1	2	none	4500	168	no peak
(e)	1	1	1	none	4500	177	17.2



QUAD CITIES STATION
UNITS 1 & 2

DRYWELL TEMPERATURE RESPONSE FOLLOWING DESIGN LOSS-OF-COOLANT ACCIDENT

FIGURE 6.2-17



QUAD CITIES STATION
UNITS 1 & 2

SUPPRESSION POOL TEMPERATURE RESPONSE FOLLOWING DESIGN LOSS-OF-COOLANT ACCIDENT

FIGURE 6.2-18

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*                         L     S   S   T    ::                            *
*                         LLLLL  SSS    T    ::                            *
*                                                                          *
*                                                                          *
*****************************************************************************
```

Quad Cities SUPPRESSION POOL HEATUP CALCULATIONS
2/2 Case with original K and 95F Service Water Temperature

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equat describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, poo temperature at 600 seconds, the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. purpose of this model is to provide a representation of the most likely initial licensing basis calculations, to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represen May-Witt curve values.

$i \equiv 1..9$

$t_i \equiv$	$p_i \equiv$
600	.02549
1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \text{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP, converted to B note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2\cdot 700 + 1\cdot 800)\cdot .70696\cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 416.67$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximatel MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^{8}\cdot .70}{7200}$$

Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes pr GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor ha added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 95.0$ service water temperature

$$f(x,y) \equiv \frac{Q(x)\cdot\frac{2561}{1.02}\cdot\frac{1000}{3600}\cdot 3413\cdot 1.0 + PHT + SENSHT\cdot e^{-\frac{x}{7200}} - (y - T_{sw})\cdot HXK}{(124194)\cdot 62.054}$$

Equations

The five equations below implement the fourth-order Runge-Kutta method for solving y'= f(x,y).

$k1(f,x,y,h) \equiv f(x,y)$

$k2(f,x,y,h) \equiv f(x+.5\cdot h, y+.5\cdot h\cdot k1(f,x,y,h))$

$k3(f,x,y,h) \equiv f(x+.5\cdot h, y+.5\cdot h\cdot k2(f,x,y,h))$

$k4(f,x,y,h) \equiv f(x+h, y+h\cdot k3(f,x,y,h))$

$$rk(f,x,y,h) \equiv \frac{h}{6}\cdot \left(k1(f,x,y,h) + 2\cdot k2(f,x,y,h) \ldots \atop + 2\cdot k3(f,x,y,h) + k4(f,x,y,h) \right)$$

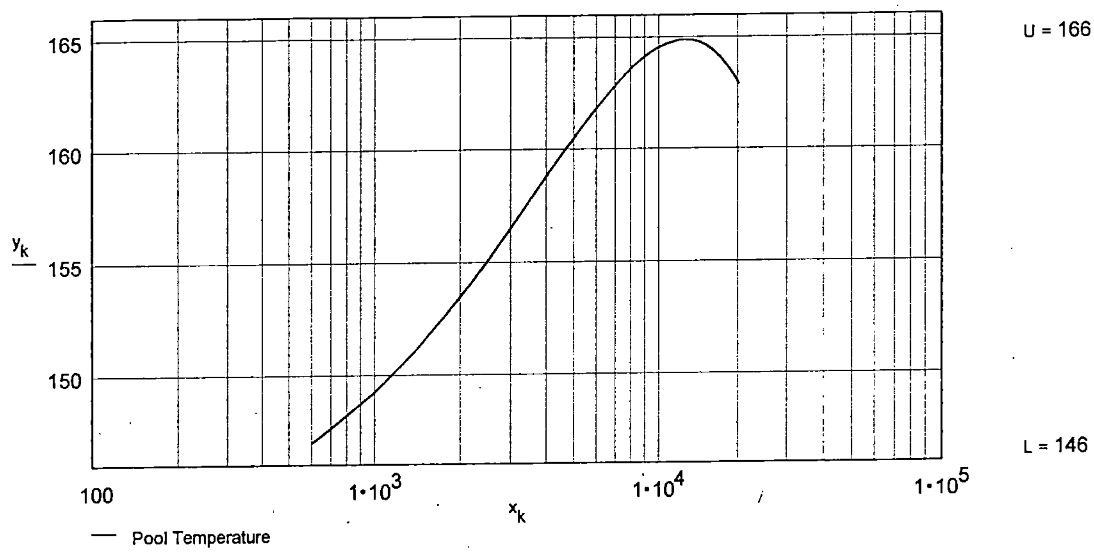
$j \equiv 1..n$ $\quad x_0 \equiv startx$ $\quad h \equiv \frac{endx - startx}{n}$ $\quad x_j \equiv startx + j\cdot h$

$y_0 \equiv inity$ $\quad y_j \equiv y_{j-1} + rk\left(f, x_{j-1}, y_{j-1}, h\right)$

$L \equiv floor(min(y) - .5)$ $\quad U \equiv ceil(max(y) + .5)$ $\quad k \equiv 0..n$

Enter starting and ending values of x, the number of intervals for the integration, and the initial value of y.

artx ≡ 600 endx ≡ 20000 n ≡ 50 intervals inity ≡ 147



max(y) = 164.878

Pressure Calculation

$R \equiv 53.34$ $\qquad LPCI \equiv \dfrac{5000}{7.4805\cdot.0164\cdot 60}$ $\qquad CS \equiv \dfrac{4500}{7.4805\cdot.0164\cdot 60}$

$Vdw \equiv 158236$ $\qquad Ma \equiv 19284$

$Vww \equiv 108000$ $\qquad Qpmp \equiv 2\cdot 700\cdot.70696\cdot 0.0$ $\qquad Qpmpc \equiv 800\cdot.70696\cdot 0.0$

note pump heat set to zero for initial basis type calc

$Pvb \equiv 0.5$

$$Tatm_k \equiv \frac{\left[y_k - \dfrac{HXK\cdot y_k - 95 - Qpmp}{LPCI}\right]\cdot LPCI + \left[Q\ x_k\cdot.2578\cdot 1000\cdot\dfrac{3413}{3600\cdot CS} + y_k + \dfrac{Qpmpc}{CS} + \dfrac{SENSHT\cdot e^{-\frac{x_k}{7200}}}{CS}\right]\cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK\cdot y_k - 95 - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from t ASME tables.

$$S := \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}$$

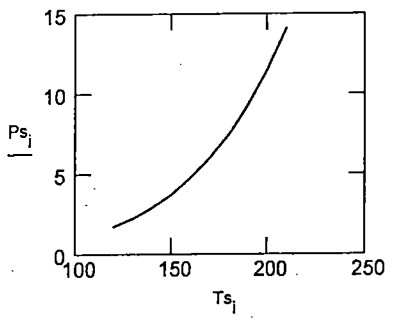
$Ts := S^{<0>}$

$Ps := S^{<1>}$

$i := 0..9$ $\qquad$ $vs := pspline(Ts, Ps)$

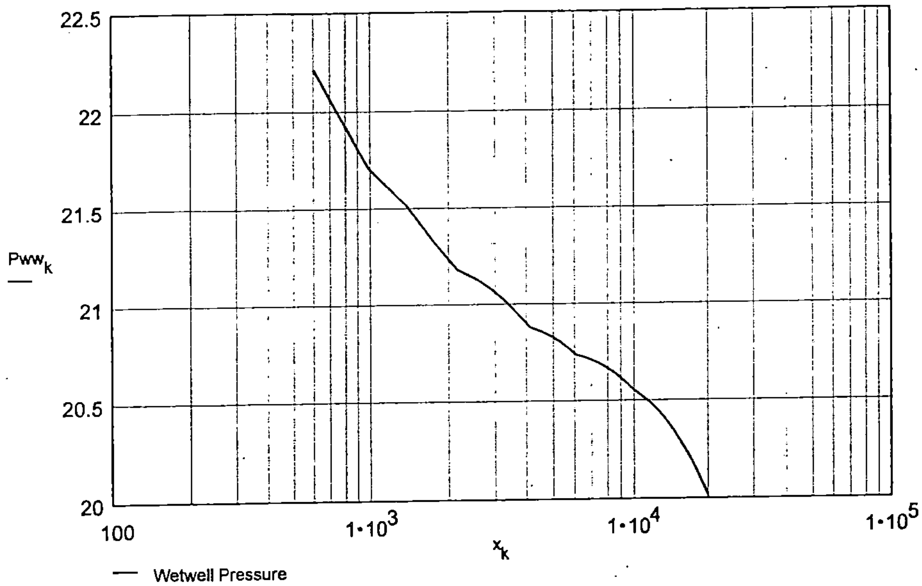
$Psat_k := interp\ vs, Ts, Ps, Tatm_k$

$Psatw_k := interp\ vs, Ts, Ps, Twatm_k$

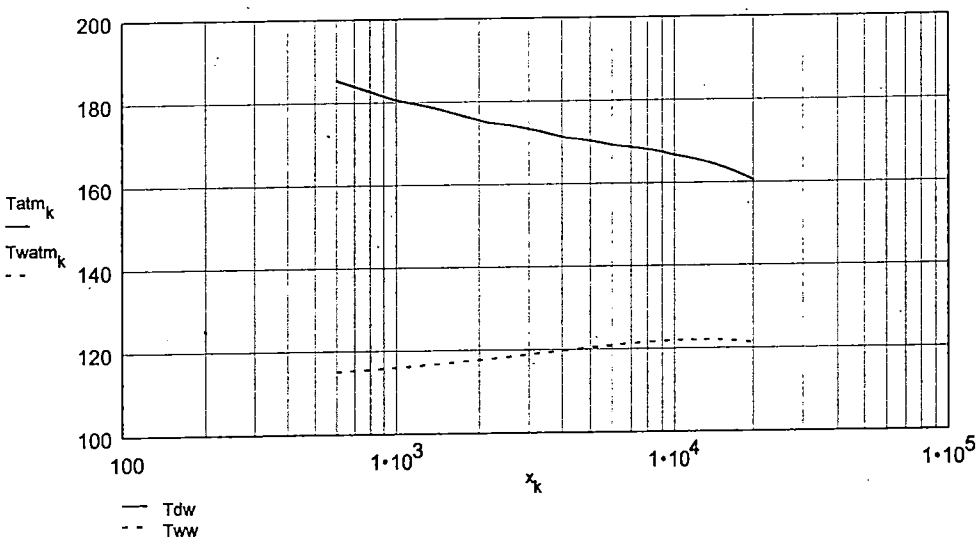


$$Maww_k := \frac{144\cdot\ Psat_k - Psatw_k + Pvb\ + Ma\cdot R\cdot\frac{Tatm_k + 460}{Vdw}}{R\cdot\frac{Tatm_k + 460}{Vdw} + R\cdot\frac{Twatm_k + 460}{Vww}}$$

$$Pww_k := Maww_k\cdot R\cdot\frac{Twatm_k + 460}{Vww\cdot 144} + Psatw_k$$



max(Pww) = 22.214



DATA

	Time sec	WW Press psia	WW air T deg F	DW Temp deg F	WW Pool T deg F
Variable	x_k	Pww_k	$Twatm_k$	$Tatm_k$	y_k
	600	22.214	115.103	185.414	147
	988	21.71	115.951	180.657	149.193
	1376	21.517	116.664	178.618	151.039
	1764	21.322	117.286	176.529	152.646
	2152	21.181	117.82	174.948	154.027
	2540	21.131	118.299	174.285	155.267
	2928	21.075	118.732	173.558	156.388
	3316	21.011	119.12	172.766	157.392
	3704	20.941	119.465	171.911	158.282
	4092	20.879	119.767	171.144	159.065
	4480	20.858	120.039	170.812	159.768
	4868	20.832	120.286	170.448	160.406
	5256	20.803	120.508	170.052	160.981
	5644	20.77	120.707	169.626	161.495
	6032	20.737	120.883	169.194	161.95
	6420	20.727	121.04	169.021	162.359
	6808	20.714	121.184	168.831	162.731
	7196	20.7	121.314	168.626	163.067
	7584	20.684	121.431	168.406	163.37
	7972	20.667	121.535	168.172	163.639
	8360	20.648	121.627	167.923	163.877
	8748	20.627	121.708	167.661	164.084
	9136	20.605	121.776	167.384	164.262
	9524	20.581	121.834	167.095	164.411
	9912	20.556	121.881	166.793	164.533
	10300	20.54	121.919	166.586	164.631
	10688	20.525	121.95	166.405	164.711
	11076	20.509	121.974	166.216	164.775
	11464	20.493	121.993	166.022	164.823
	11852	20.476	122.006	165.822	164.856
	12240	20.458	122.013	165.617	164.874
	12628	20.44	122.014	165.405	164.878
	13016	20.421	122.011	165.189	164.869
	13404	20.402	122.002	164.967	164.846
	13792	20.382	121.989	164.74	164.812
	14180	20.362	121.971	164.509	164.765
	14568	20.341	121.948	164.272	164.707
	14956	20.32	121.921	164.031	164.637
	15344	20.298	121.89	163.786	164.557
	15732	20.276	121.855	163.536	164.467
	16120	20.254	121.817	163.281	164.366
	16508	20.231	121.774	163.023	164.256
	16896	20.207	121.728	162.761	164.137
	17284	20.184	121.678	162.494	164.009
	17672	20.16	121.626	162.224	163.872
	18060	20.135	121.57	161.95	163.727
	18448	20.111	121.51	161.673	163.574
	18836	20.086	121.448	161.392	163.414
	19224	20.061	121.383	161.107	163.246
	19612	20.035	121.316	160.819	163.07

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Quad Cities SUPPRESSION POOL HEATUP CALCULATIONS
2/2 Case with original K and 90F Service Water Temperature

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equat describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, poo temperature at 600 seconds, the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. purpose of this model is to provide a representation of the most likely initial licensing basis calculations, to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represen May-Witt curve values.

$i \equiv 1..9$

$t_i =$	$p_i =$
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1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \mathrm{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP, converted to B note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2 \cdot 700 + 1 \cdot 800) \cdot .70696 \cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 416.67$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximatel MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^8 \cdot .70}{7200}$$

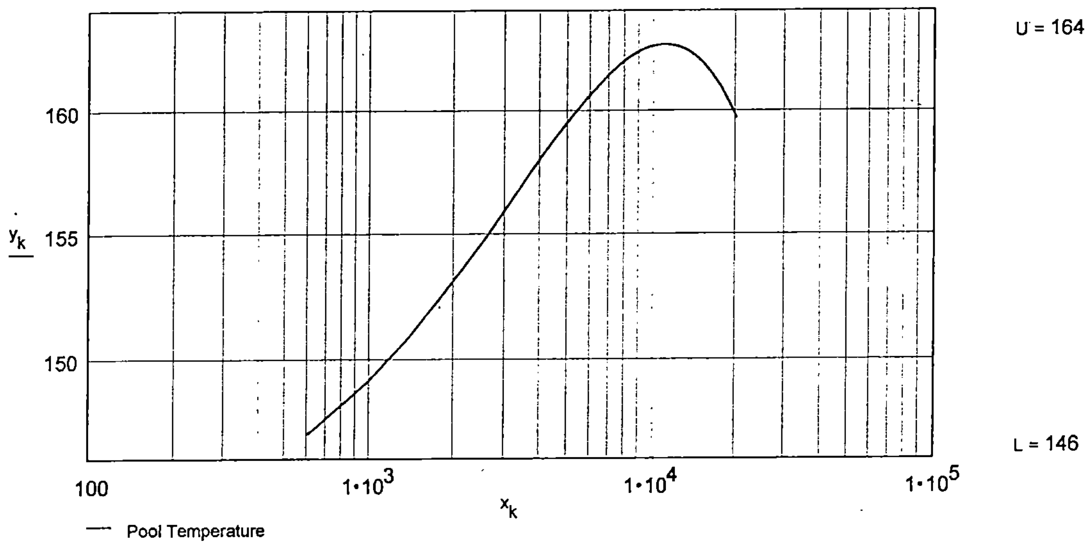
Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes pr GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor ha added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 90.0$ service water temperature

$$f(x,y) \equiv \frac{Q(x) \cdot \frac{2561}{1.02} \cdot \frac{1000}{3600} \cdot 3413 \cdot 1.0 + PHT + SENSHT \cdot e^{-\frac{x}{7200}} - (y - T_{sw}) \cdot HXK}{(124194) \cdot 62.054}$$

Enter starting and ending values of x, the number of intervals for the integration, and the initial value of y.

startx ≡ 600 endx ≡ 20000 n ≡ 50 intervals inity ≡ 147



max(y) = 162.613

Pressure Calculation

$R \equiv 53.34$ $\quad$ $LPCI \equiv \dfrac{5000}{7.4805 \cdot .0164 \cdot 60}$ $\quad$ $CS \equiv \dfrac{4500}{7.4805 \cdot .0164 \cdot 60}$

$Vdw \equiv 158236$ $\quad$ $Ma \equiv 19284$

$Vww \equiv 108000$ $\quad$ $Qpmp \equiv 2 \cdot 700 \cdot .70696 \cdot 0.0$ $\quad$ $Qpmpc \equiv 800 \cdot .70696 \cdot 0.0$

note pump heat set to zero for initial basis type calc

$Pvb \equiv 0.5$

$$Tatm_k \equiv \frac{\left[y_k - \dfrac{HXK \cdot y_k - 95 - Qpmp}{LPCI}\right] \cdot LPCI + \left[Q \cdot x_k \cdot 2578 \cdot 1000 \cdot \dfrac{3413}{3600 \cdot CS} + y_k + \dfrac{Qpmpc}{CS} + \dfrac{SENSHT \cdot e^{-\frac{x_k}{7200}}}{CS}\right] \cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK \cdot y_k - 95 - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from t ASME tables. .

$$S = \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}$$

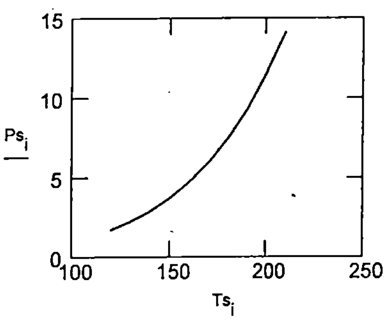
$Ts := S^{<0>}$

$Ps := S^{<1>}$

$i := 0..9$ $\quad$ $vs := \mathrm{pspline}(Ts, Ps)$

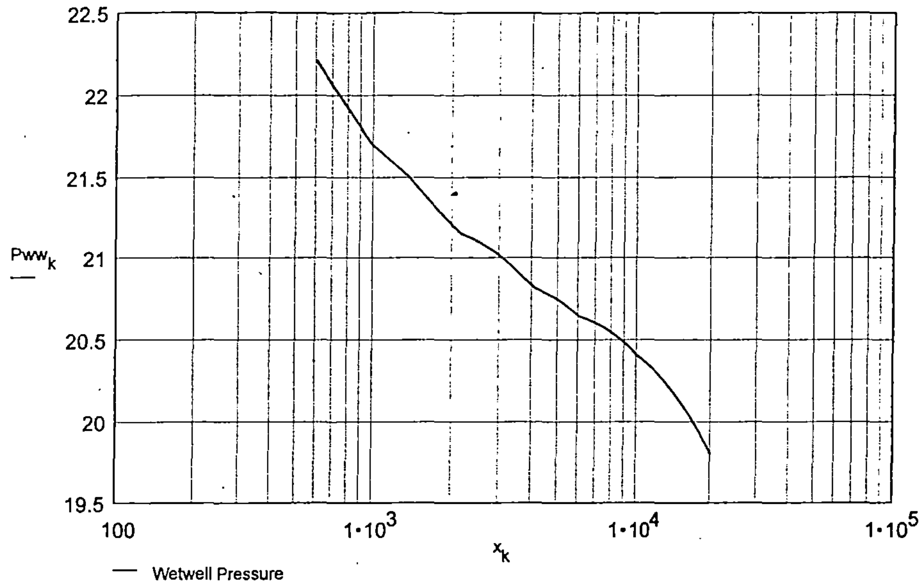
$Psat_k := \mathrm{interp}\ vs, Ts, Ps, Tatm_k$

$Psatw_k := \mathrm{interp}\ vs, Ts, Ps, Twatm_k$

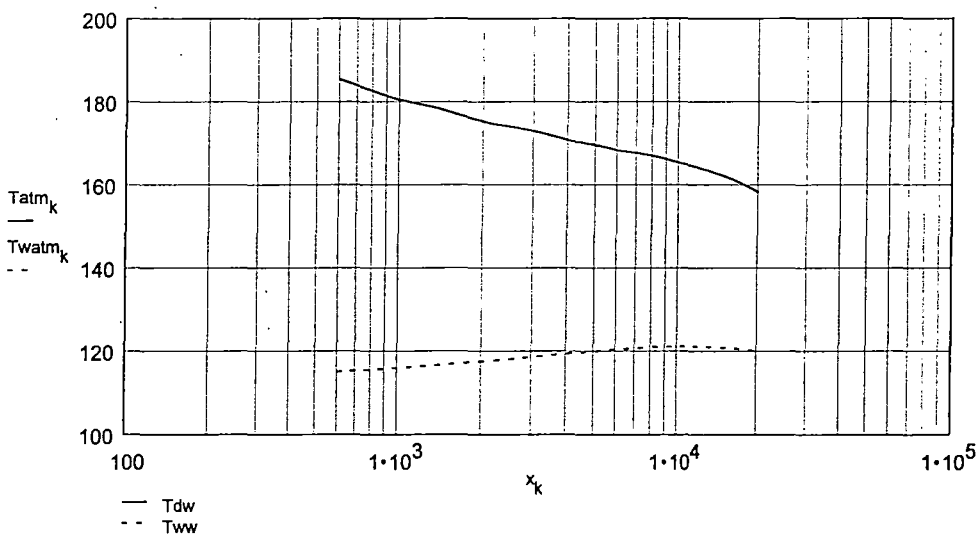


$$Maww_k := \frac{144 \cdot Psat_k - Psatw_k + Pvb + Ma \cdot R \cdot \dfrac{Tatm_k + 460}{Vdw}}{R \cdot \dfrac{Tatm_k + 460}{Vdw} + R \cdot \dfrac{Twatm_k + 460}{Vww}}$$

$$Pww_k := Maww_k \cdot R \cdot \frac{Twatm_k + 460}{Vww \cdot 144} + Psatw_k$$



max(Pww) = 22.214



DATA

	Time sec	WW Press psia	WW air T deg F	DW Temp deg F	WW Pool T deg F
Variable	x_k	Pww_k	$Twatm_k$	$Tatm_k$	y_k
	600	22.214	115.103	185.414	147
	988	21.701	115.91	180.587	149.089
	1376	21.499	116.585	178.479	150.834
	1764	21.297	117.168	176.323	152.341
	2152	21.149	117.664	174.675	153.625
	2540	21.092	118.107	173.948	154.77
	2928	21.028	118.504	173.157	155.796
	3316	20.958	118.856	172.303	156.709
	3704	20.882	119.166	171.388	157.51
	4092	20.814	119.435	170.561	158.205
	4480	20.786	119.673	170.171	158.822
	4868	20.754	119.887	169.75	159.376
	5256	20.719	120.078	169.299	159.869
	5644	20.681	120.245	168.817	160.302
	6032	20.642	120.391	168.332	160.678
	6420	20.626	120.519	168.107	161.009
	6808	20.609	120.633	167.866	161.305
	7196	20.589	120.735	167.611	161.567
	7584	20.569	120.823	167.342	161.797
	7972	20.546	120.9	167.059	161.995
	8360	20.522	120.965	166.763	162.164
	8748	20.497	121.019	166.454	162.303
	9136	20.471	121.062	166.133	162.414
	9524	20.443	121.094	165.799	162.497
	9912	20.414	121.116	165.454	162.555
	10300	20.393	121.13	165.205	162.59
	10688	20.374	121.137	164.981	162.609
	11076	20.354	121.139	164.752	162.613
	11464	20.334	121.134	164.518	162.602
	11852	20.314	121.125	164.279	162.577
	12240	20.293	121.11	164.035	162.539
	12628	20.271	121.09	163.787	162.487
	13016	20.249	121.066	163.533	162.424
	13404	20.227	121.037	163.276	162.349
	13792	20.204	121.003	163.014	162.262
	14180	20.18	120.965	162.748	162.164
	14568	20.157	120.924	162.478	162.056
	14956	20.133	120.878	162.204	161.938
	15344	20.108	120.828	161.926	161.81
	15732	20.084	120.775	161.644	161.673
	16120	20.059	120.719	161.359	161.527
	16508	20.034	120.659	161.07	161.372
	16896	20.008	120.596	160.778	161.209
	17284	19.982	120.53	160.482	161.038
	17672	19.956	120.461	160.184	160.859
	18060	19.93	120.389	159.882	160.673
	18448	19.903	120.314	159.577	160.479
	18836	19.877	120.237	159.269	160.279
	19224	19.85	120.157	158.958	160.072
	19612	19.823	120.074	158.645	159.859

```
*****************************************************************************
* User name:   NFSKR (73)                 Queue:  NFS1/4SI4E1              *
* File name:                              Server: NFS_HP4SI2               *
* Directory:                                                               *
* Description: PrntFile text                                               *
*              January 9, 1997                   9:33am                    *
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*                                                                          *
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*****************************************************************************
*                                                                          *
*                           L      SSS  TTTTT                              *
*                           L     S   S   T                                *
*                           L     S       T    ::                          *
*                           L      SSS    T    ::                          *
*                           L         S   T                                *
*                           L     S   S   T    ::                          *
*                           LLLLL  SSS    T    ::                          *
*                                                                          *
*                                                                          *
*****************************************************************************
```

Heat Exchanger Performance Calculations, RHR HEAT EXCHANGERS
2 RHR, 2 RHRSW performance at Original Data Sheet conditions
Two pass service water side

$N := 2278$ $\qquad N = 2.278 \cdot 10^{3}$ $\qquad \frac{2415 - 2278}{2415} = 0.057$

$l := \frac{288 - 2 \cdot 5.75}{12}$ $\qquad l = 23.042$ $\qquad t := \frac{.049}{12}$

$l := 24$

$OD := \frac{.75}{12}$ $\qquad ID := \frac{.652}{12}$

Tube outside area

$AO := \pi \cdot OD \cdot N \cdot l$ $\qquad AO = 1.073 \cdot 10^{4}$

Tube inside area

$AI := \pi \cdot ID \cdot N \cdot l$ $\qquad AI = 9.332 \cdot 10^{3}$

Flow Area

$FA := \frac{N}{2} \cdot \pi \cdot \frac{ID^{2}}{4}$ $\qquad FA = 2.641$

Tube side velocity

$SWFLOW := 7000$

$V := SWFLOW \cdot \frac{1}{7.4805} \cdot \frac{1}{60} \cdot \frac{1}{FA}$ $\qquad V = 5.906$

Apply Dittus Boelter Correlation to determine internal HTC
Assume service water temperature of 120F for properties determination

$\rho := 61.71$

$\mu := 1.35$

$k := 0.371$

$cp := .9985$

$Pr := 3.64$

$\nu := \frac{\mu}{\rho} \cdot \frac{1}{3600}$ $\qquad \nu = 6.077 \cdot 10^{-6}$

$$hi := \frac{k}{ID} \cdot \left[0.023 \cdot \left(ID \cdot \frac{V}{\nu} \right)^{0.8} \cdot \left(cp \cdot \frac{\mu}{k} \right)^{0.4} \right]$$

$hi = 1.579 \cdot 10^{3}$

$Re := ID \cdot \frac{V}{\nu}$ $\qquad Re = 5.28 \cdot 10^{4}$

$Q0 := 105 \cdot 10^{6}$

$DeltaT := 70$

$\rho h := 60.9$ $\rho c := 62.06$

$cph := 1.0017$ $cpc := .998$

$Mh := 10700 \cdot \frac{60}{7.4805}$ $Mc := 7000 \cdot \frac{60}{7.4805}$

$Ch := Mh \cdot \rho h \cdot cph$

$Cc := Mc \cdot \rho c \cdot cpc$

$Cstar := \frac{Cc}{Ch}$

$Cstar = 0.664$

$\varepsilon := \frac{Q0}{Cc \cdot DeltaT}$ $\varepsilon = 0.431$

$NTU := .7$ initial guess for NTU

$\Gamma := NTU \cdot \left(1 + Cstar^{2}\right)^{0.5}$

Given

$\varepsilon = 0.43135$

$$\varepsilon = \frac{2}{(1 + Cstar) + \left(1 + Cstar^{2}\right)^{.5} \cdot \frac{\left[1 + e^{-NTU \cdot \left(1 + Cstar^{2}\right)^{0.5}}\right]}{\left[1 - e^{-NTU \cdot \left(1 + Cstar^{2}\right)^{0.5}}\right]}}$$

$z := \text{find}(NTU)$

$z = 0.7135$

$NTU := z$

$NTU = 0.714$

$UA := NTU \cdot Cc$ $\quad UA = 2.481 \cdot 10^{6}$

$Rs := .0005$ $\quad kw := 8.08$ $\quad kw := 8.7$

Thermal conductivity from Marks hdbk for 304 ss.

$Rt := .002$

$$Aw := \frac{AO - AI}{2}$$

As a check, calculate U based on data sheet effective surface area, compare to data sheet value of 237 based on an effective HT area of 11000 ft2

$U := \frac{UA}{AO}$ $\quad U = 231.133$

$$UA = \frac{1}{\frac{1}{hs \cdot AO} + \frac{Rs}{AO} + \frac{t}{Aw \cdot kw} + \frac{Rt}{AI} + \frac{1}{hi \cdot AI}}$$

$$-UA \cdot Aw \cdot kw \cdot AI \cdot \frac{hi}{(UA \cdot Rs \cdot Aw \cdot kw \cdot AI \cdot hi - UA \cdot t \cdot AO \cdot AI \cdot hi + UA \cdot Rt \cdot AO \cdot Aw \cdot kw \cdot hi - UA \cdot AO \cdot Aw \cdot kw - AO \cdot Aw \cdot kw \cdot AI \cdot hi)}$$

$$hs := -UA \cdot Aw \cdot kw \cdot AI \cdot \frac{hi}{(UA \cdot Rs \cdot Aw \cdot kw \cdot AI \cdot hi + UA \cdot t \cdot AO \cdot AI \cdot hi + UA \cdot Rt \cdot AO \cdot Aw \cdot kw \cdot hi - UA \cdot AO \cdot Aw \cdot kw - AO \cdot Aw \cdot kw \cdot AI \cdot hi)}$$

$hi = 1.579 \cdot 10^{3}$ $\quad \frac{1}{hi \cdot AI} = 6.788 \cdot 10^{-8}$ $\quad \frac{Rt}{AI} = 2.143 \cdot 10^{-7}$

$hs = 3.389 \cdot 10^{3}$

$\frac{t}{Aw \cdot kw} = 4.678 \cdot 10^{-8}$ $\quad \frac{Rs}{AO} = 4.658 \cdot 10^{-8}$

Now we can calculate new data points at different flow rates

$$Chnew := Ch\cdot\frac{5350}{10700} \qquad Chnew = 2.618\cdot 10^{6}$$

$$Ccnew := Cc\cdot\frac{7000}{7000} \qquad Ccnew = 3.477\cdot 10^{6}$$

$$Cstarn := \frac{Ccnew}{Chnew} \qquad Cstarn = 1.328$$

$$Cstarn := \text{if}\left(Ccnew < Chnew, \frac{Ccnew}{Chnew}, \frac{Chnew}{Ccnew}\right) \qquad Cstarn = 0.753$$

$$Cmin := \text{if}(Ccnew < Chnew, Ccnew, Chnew) \qquad Cmin = 2.618\cdot 10^{6}$$

$$hin := hi\cdot\left(\frac{Ccnew}{Cc}\right)^{0.8} \qquad hin = 1.579\cdot 10^{3}$$

$$hsn := hs\cdot\left(\frac{Chnew}{Ch}\right)^{0.8} \qquad hsn = 1.946\cdot 10^{3}$$

$$UA := \frac{1}{\frac{1}{hsn\cdot AO}+\frac{Rs}{AO}+\frac{t}{Aw\cdot kw}+\frac{Rt}{AI}+\frac{1}{hin\cdot AI}}$$

$$UA = 2.362\cdot 10^{6}$$

$$NTU := \frac{UA}{Cmin}$$

$$NTU = 0.902$$

$$\varepsilon := \frac{2}{(1+Cstarn)+\left(1+Cstarn^{2}\right)^{.5}\cdot\left[\frac{1+e^{-NTU\cdot\left(1+Cstarn^{2}\right)^{0.5}}}{1-e^{-NTU\cdot\left(1+Cstarn^{2}\right)^{0.5}}}\right]}$$

$$\varepsilon = 0.476$$

$$DeltaT := 170 - 95$$

$$Qnew := \varepsilon\cdot Cmin\cdot DeltaT$$

$$Qnew = 9.34855\cdot 10^{7} \qquad U := \frac{UA}{AO} \qquad U = 220.012$$

$$KVAL := \frac{Qnew}{DeltaT\cdot 3600} \qquad KVAL = 346.243$$

```
*******************************************************************************
* User name:   NFSKR (73)                  Queue:  NFS1/4SI4E1                *
* File name:                               Server: NFS_HP4SI2                 *
* Directory:                                                                  *
* Description: PrntFile text                                                  *
*              January 9, 1997                     9:39am                     *
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*                       N  NN F         S K K   R R                           *
*                       N   N F     S   S K  K  R  R                          *
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*                                                                             *
*                                                                             *
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*******************************************************************************
*                                                                             *
*                          L      SSS  TTTTT                                  *
*                          L     S   S   T                                    *
*                          L     S       T    ::                              *
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*                          L     S   S   T    ::                              *
*                          LLLLL  SSS    T    ::                              *
*                                                                             *
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*******************************************************************************
```

Quad Cities SUPPRESSION POOL HEATUP CALCULATIONS
1/2 Case with nominal K and 90F Service Water Temperature, initial pool temperature at 90F

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equat describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, poo temperature at 600 seconds, the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. purpose of this model is to provide a representation of the most likely initial licensing basis calculations. to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represen May-Witt curve values.

$i \equiv 1..9$

$t_i \equiv$	$p_i \equiv$
600	.02549
1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \text{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP, converted to B note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2 \cdot 700 + 1 \cdot 800) \cdot .70696 \cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 346.24$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximatel MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^8 \cdot .70}{7200}$$

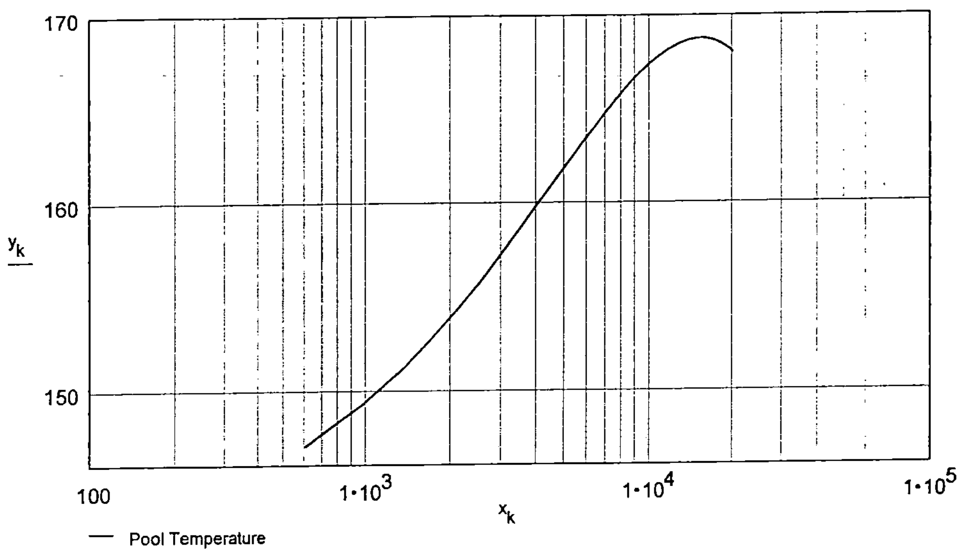
Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes pr GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor ha added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 90.0$ service water temperature

$$f(x,y) \equiv \frac{Q(x) \cdot \frac{2561}{1.02} \cdot \frac{1000}{3600} \cdot 3413 \cdot 1.0 - PHT + SENSHT \cdot e^{-\frac{x}{7200}} - (y - T_{sw}) \cdot HXK}{(124194) \cdot 62.054}$$

Enter starting and ending values of x, the number of intervals for the integration, and the initial value of y.

startx ≡ 600 endx ≡ 20000 n ≡ 50 intervals inity ≡ 147



U = 170

L = 146

max(y) = 168.746

Pressure Calculation

$R \equiv 53.34$ $\quad$ $LPCI \equiv \dfrac{5000}{7.4805 \cdot .0164 \cdot 60}$ $\quad$ $CS \equiv \dfrac{4500}{7.4805 \cdot .0164 \cdot 60}$

$Vdw \equiv 158236$ $\quad$ $Ma \equiv 19284$

$Vww \equiv 108000$ $\quad$ $Qpmp \equiv 2 \cdot 700 \cdot .70696 \cdot 0.0$ $\quad$ $Qpmpc \equiv 800 \cdot .70696 \cdot 0.0$

note pump heat set to zero for initial basis type calc

$Pvb \equiv 0.5$

$$Tatm_k \equiv \frac{\left[y_k - \dfrac{HXK \cdot \left(y_k - 95\right) - Qpmp}{LPCI}\right] \cdot LPCI + \left[Q\left(x_k\right) \cdot 2578 \cdot 1000 \cdot \dfrac{3413}{3600 \cdot CS} + y_k + \dfrac{Qpmpc}{CS} + \dfrac{SENSHT \cdot e^{-\frac{x_k}{7200}}}{CS}\right] \cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK \cdot \left(y_k - 95\right) - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from t ASME tables.

$$S := \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}$$

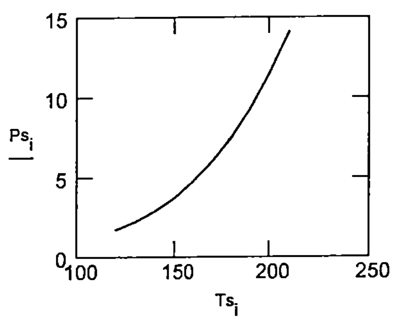
$Ts := S^{<0>}$

$Ps := S^{<1>}$

$i := 0..9$ $\qquad vs := \mathrm{pspline}(Ts, Ps)$

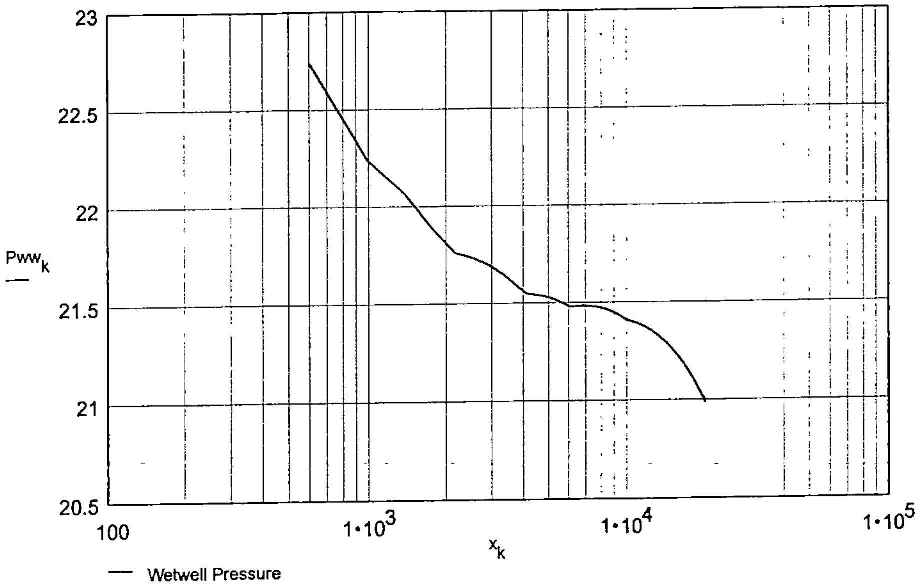
$Psat_k := \mathrm{interp}\ vs, Ts, Ps, Tatm_k$

$Psatw_k := \mathrm{interp}\ vs, Ts, Ps, Twatm_k$

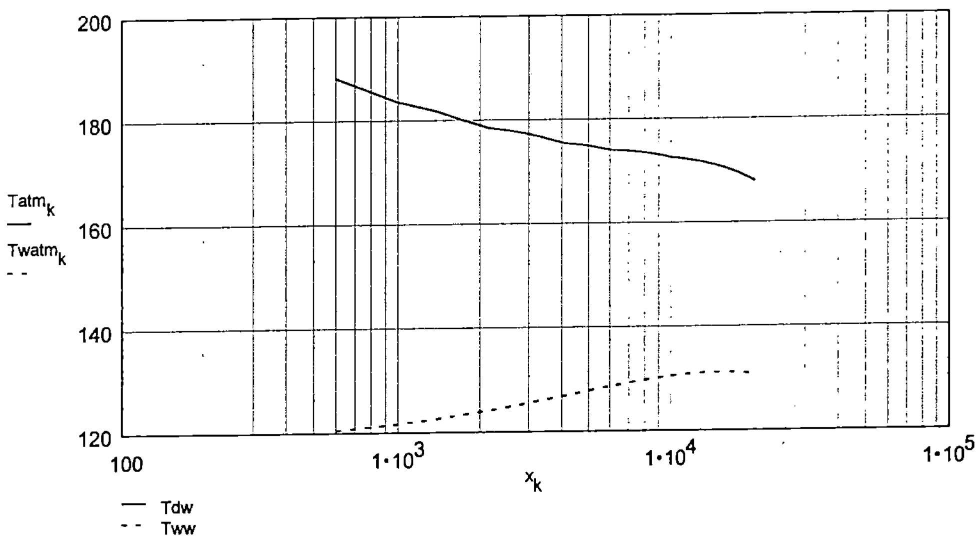


$$Maww_k := \frac{144 \cdot Psat_k - Psatw_k - Pvb + Ma \cdot R \cdot \dfrac{Tatm_k + 460}{Vdw}}{R \cdot \dfrac{Tatm_k + 460}{Vdw} + R \cdot \dfrac{Twatm_k + 460}{Vww}}$$

$$Pww_k := Maww_k \cdot R \cdot \frac{Twatm_k + 460}{Vww \cdot 144} - Psatw_k$$



max(Pww) = 22.737



DATA

	Time sec	WW Press psia	WW air T deg F	DW Temp deg F	WW Pool T deg F
Variable	x_k	Pww_k	$Twatm_k$	$Tatm_k$	y_k
	600	22.737	120.494	188.252	147
	988	22.241	121.619	183.688	149.293
	1376	22.067	122.576	181.827	151.245
	1764	21.888	123.418	179.906	152.962
	2152	21.764	124.15	178.483	154.457
	2540	21.735	124.815	177.973	155.813
	2928	21.697	125.422	177.393	157.051
	3316	21.65	125.973	176.743	158.174
	3704	21.595	126.469	176.026	159.186
	4092	21.548	126.913	175.391	160.091
	4480	21.543	127.317	175.187	160.916
	4868	21.533	127.69	174.947	161.677
	5256	21.518	128.032	174.672	162.375
	5644	21.499	128.344	174.363	163.011
	6032	21.479	128.627	174.046	163.588
	6420	21.483	128.887	173.983	164.118
	6808	21.484	129.128	173.903	164.61
	7196	21.483	129.352	173.804	165.066
	7584	21.479	129.559	173.687	165.488
	7972	21.474	129.749	173.554	165.875
	8360	21.466	129.922	173.403	166.23
	8748	21.455	130.081	173.236	166.552
	9136	21.443	130.224	173.054	166.844
	9524	21.429	130.352	172.855	167.106
	9912	21.412	130.466	172.641	167.339
	10300	21.405	130.568	172.52	167.546
	10688	21.399	130.66	172.421	167.735
	11076	21.392	130.744	172.315	167.905
	11464	21.384	130.819	172.2	168.058
	11852	21.374	130.885	172.077	168.194
	12240	21.364	130.944	171.947	168.314
	12628	21.353	130.995	171.809	168.418
	13016	21.341	131.039	171.664	168.506
	13404	21.328	131.075	171.511	168.581
	13792	21.313	131.104	171.352	168.64
	14180	21.299	131.127	171.185	168.686
	14568	21.283	131.143	171.012	168.719
	14956	21.266	131.153	170.833	168.739
	15344	21.249	131.156	170.647	168.746
	15732	21.231	131.154	170.454	168.741
	16120	21.212	131.146	170.256	168.724
	16508	21.192	131.132	170.051	168.696
	16896	21.172	131.113	169.841	168.657
	17284	21.151	131.088	169.625	168.608
	17672	21.129	131.059	169.403	168.547
	18060	21.107	131.024	169.176	168.477
	18448	21.084	130.985	168.943	168.397
	18836	21.06	130.941	168.706	168.307
	19224	21.036	130.892	168.463	168.208
	19612	21.012	130.84	168.214	168.1

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* User name:   NFSKR (73)                     Queue:  NFS1/4SI4E1          *
* File name:                                  Server: NFS_HP4SI2           *
* Directory:                                                               *
* Description: PrntFile text                                               *
*              January 9, 1997                        9:40am               *
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Quad Cities SUPPRESSION POOL HEATUP CALCULATIONS
1/2 Case with nominal K and 95F Service Water Temperature, initial pool temperature at 90F

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equat describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, poo temperature at 600 seconds. the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. purpose of this model is to provide a representation of the most likely initial licensing basis calculations, to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represen May-Witt curve values.

$i \equiv 1..9$

$t_i \equiv$	$p_i \equiv$
600	.02549
1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \mathrm{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP. converted to B note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2 \cdot 700 + 1 \cdot 800) \cdot .70696 \cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 346.24$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximatel MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^{8} \cdot .70}{7200}$$

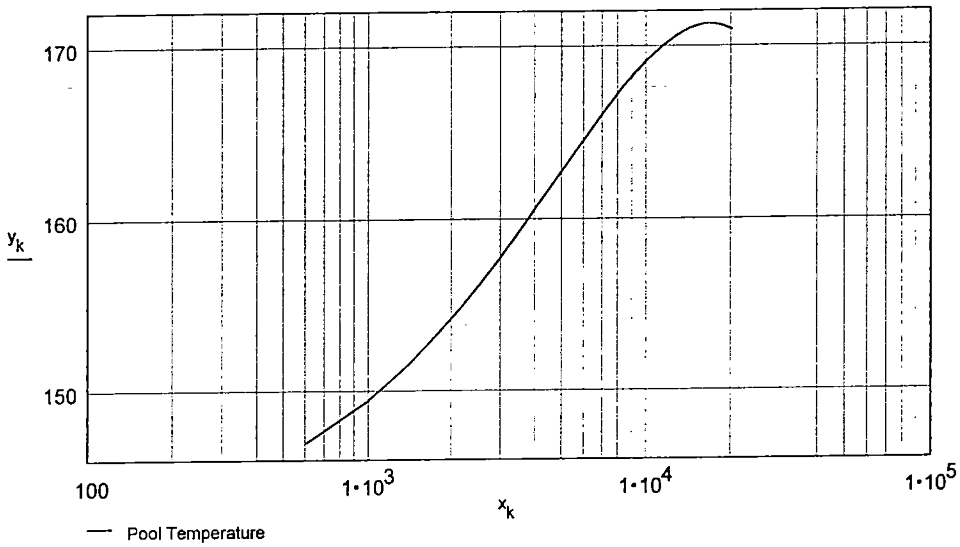
Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes pr GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor ha added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 95.0$ service water temperature

$$f(x,y) \equiv \frac{Q(x) \cdot \frac{2561}{1.02} \cdot \frac{1000}{3600} \cdot 3413 \cdot 1.0 + PHT + SENSHT \cdot e^{-\frac{x}{7200}} - (y - T_{sw}) \cdot HXK}{(124194) \cdot 62.054}$$

Enter starting and ending values of x, the number of intervals for the integration, and the initial value of y.

artx ≡ 600 endx ≡ 20000 n ≡ 50 intervals inity ≡ 147



U = 172

L = 146

max(y) = 171.253

Pressure Calculation

$R \equiv 53.34$ $\qquad$ $LPCI \equiv \dfrac{5000}{7.4805 \cdot .0164 \cdot 60}$ $\qquad$ $CS \equiv \dfrac{4500}{7.4805 \cdot .0164 \cdot 60}$

$Vdw \equiv 158236$ $\qquad$ $Ma \equiv 19284$

$Vww \equiv 108000$ $\qquad$ $Qpmp \equiv 2 \cdot 700 \cdot .70696 \cdot 0.0$ $\qquad$ $Qpmpc \equiv 800 \cdot .70696 \cdot 0.0$

note pump heat set to zero for initial basis type calc

$Pvb \equiv 0.5$

$$Tatm_k \equiv \frac{\left[y_k - \dfrac{HXK \cdot\ y_k - 95\ - Qpmp}{LPCI}\right] \cdot LPCI + \left[Q\ x_k \cdot 2578 \cdot 1000 \cdot \dfrac{3413}{3600 \cdot CS} + y_k + \dfrac{Qpmpc}{CS} + \dfrac{SENSHT \cdot e^{-\frac{x_k}{7200}}}{CS}\right] \cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK \cdot\ y_k - 95\ - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from t ASME tables.

$$S := \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}$$

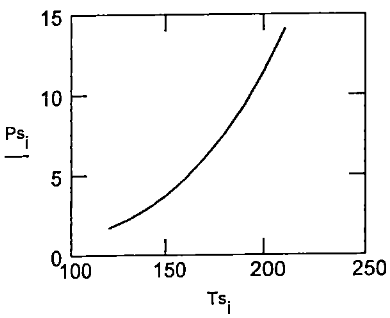
$Ts := S^{<0>}$

$Ps := S^{<1>}$

$i := 0..9$ $\quad$ $vs := pspline(Ts, Ps)$

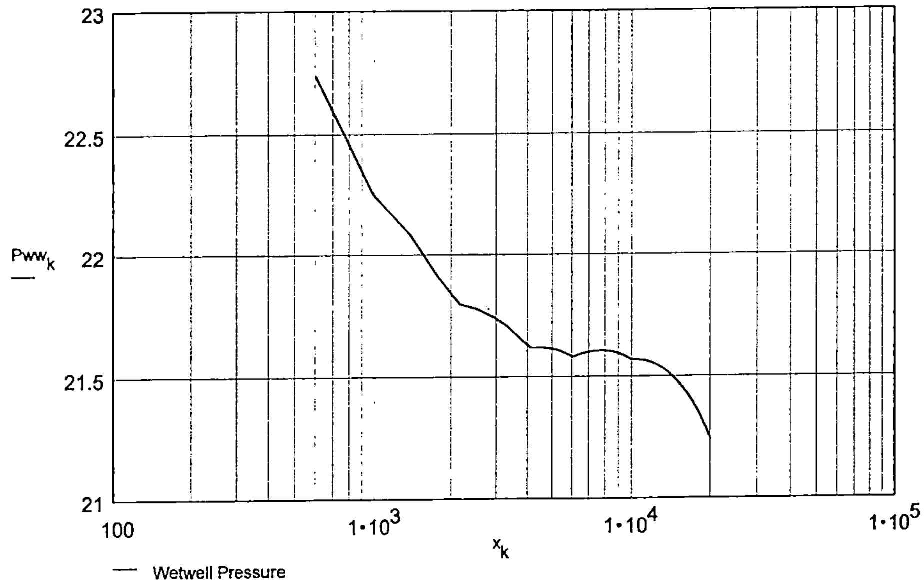
$Psat_k := interp\ vs, Ts, Ps, Tatm_k$

$Psatw_k := interp\ vs, Ts, Ps, Twatm_k$

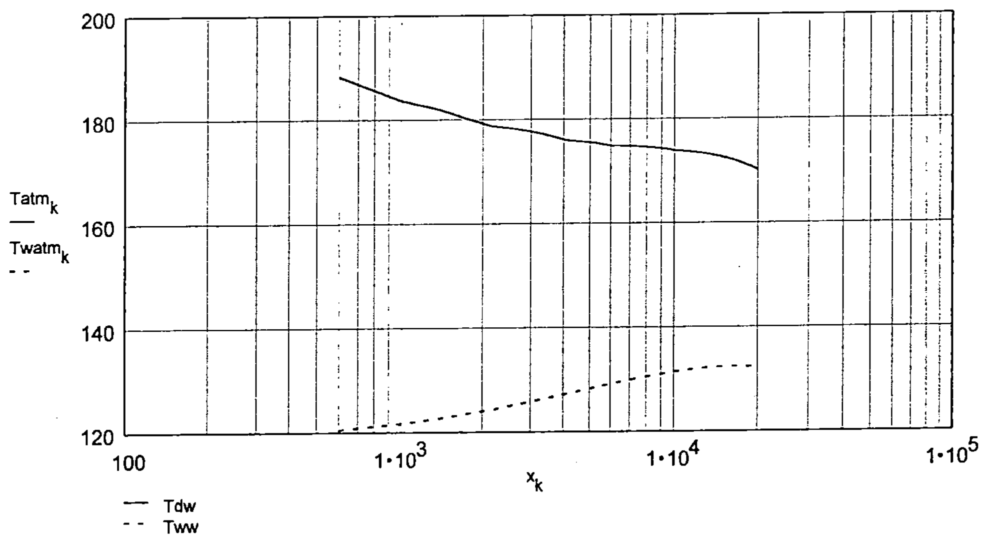


$$Maww_k := \frac{144 \cdot Psat_k - Psatw_k + Pvb + Ma \cdot R \cdot \frac{Tatm_k + 460}{Vdw}}{R \cdot \frac{Tatm_k + 460}{Vdw} + R \cdot \frac{Twatm_k + 460}{Vww}}$$

$$Pww_k := Maww_k \cdot R \cdot \frac{Twatm_k + 460}{Vww \cdot 144} + Psatw_k$$



max(Pww) = 22.737



DATA

	Time sec	WW Press psia	WW air T deg F	DW Temp deg F	WW Pool T deg F
Variable	x_k	Pww_k	$Twatm_k$	$Tatm_k$	y_k
	600	22.737	120.494	188.252	147
	988	22.25	121.661	183.751	149.379
	1376	22.084	122.66	181.952	151.416
	1764	21.913	123.542	180.092	153.217
	2152	21.796	124.315	178.729	154.793
	2540	21.774	125.02	178.279	156.23
	2928	21.744	125.666	177.756	157.547
	3316	21.704	126.255	177.163	158.749
	3704	21.656	126.788	176.502	159.837
	4092	21.615	127.269	175.922	160.817
	4480	21.617	127.71	175.772	161.716
	4868	21.613	128.118	175.585	162.549
	5256	21.605	128.495	175.363	163.318
	5644	21.593	128.841	175.105	164.025
	6032	21.578	129.158	174.838	164.67
	6420	21.588	129.451	174.825	165.268
	6808	21.596	129.725	174.793	165.827
	7196	21.6	129.981	174.742	166.349
	7584	21.603	130.219	174.673	166.834
	7972	21.603	130.44	174.585	167.285
	8360	21.6	130.644	174.48	167.701
	8748	21.596	130.832	174.358	168.085
	9136	21.589	131.004	174.219	168.437
	9524	21.579	131.162	174.063	168.758
	9912	21.568	131.304	173.892	169.048
	10300	21.565	131.434	173.812	169.313
	10688	21.564	131.554	173.755	169.557
	11076	21.562	131.664	173.688	169.782
	11464	21.559	131.766	173.613	169.989
	11852	21.554	131.858	173.529	170.178
	12240	21.548	131.942	173.437	170.35
	12628	21.542	132.019	173.336	170.505
	13016	21.534	132.087	173.228	170.644
	13404	21.525	132.147	173.111	170.768
	13792	21.515	132.2	172.988	170.876
	14180	21.504	132.246	172.856	170.97
	14568	21.492	132.285	172.717	171.049
	14956	21.479	132.318	172.572	171.115
	15344	21.465	132.344	172.419	171.168
	15732	21.45	132.363	172.259	171.208
	16120	21.435	132.376	172.093	171.235
	16508	21.419	132.384	171.92	171.25
	16896	21.401	132.385	171.74	171.253
	17284	21.383	132.381	171.555	171.245
	17672	21.365	132.372	171.363	171.225
	18060	21.345	132.357	171.165	171.195
	18448	21.325	132.337	170.961	171.154
	18836	21.304	132.312	170.752	171.103
	19224	21.283	132.282	170.536	171.043
	19612	21.261	132.248	170.316	170.972

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* User name:   NFSKR (74)                  Queue:  NFS1/4SI4E1                 *
* File name:                               Server: NFS_HP4SI2                  *
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*              January 8, 1997                     5:33pm                      *
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*                                                                              *
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********************************************************************************
```

Dresden SUPPRESSION POOL HEATUP CALCULATIONS
1/2 Case with original K and 90F Service Water Temperature

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equat describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, poo temperature at 600 seconds, the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. purpose of this model is to provide a representation of the most likely initial licensing basis calculations, to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represen May-Witt curve values.

$i \equiv 1..9$

$t_i \equiv$	$p_i \equiv$
600	.02549
1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \mathrm{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP, converted to B note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2 \cdot 700 + 1 \cdot 800) \cdot .70696 \cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 341.57$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximatel MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^8 \cdot .70}{7200}$$

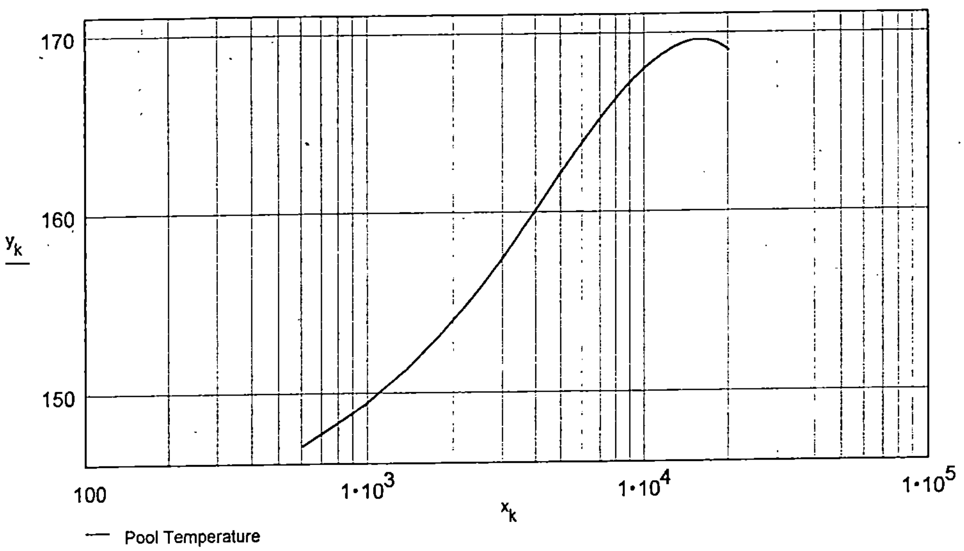
Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes pr GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor ha added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 90.0$ service water temperature

$$f(x, y) \equiv \frac{Q(x) \cdot \frac{2578}{1.02} \cdot \frac{1000}{3600} \cdot 3413 \cdot 1.0 + PHT + SENSHT \cdot e^{-\frac{x}{7200}} - (y - T_{sw}) \cdot HXK}{(124194) \cdot 62.054}$$

Enter starting and ending values of x, the number of intervals for the integration; and the initial value of y.

rtx ≡ 600 endx ≡ 20000 n ≡ 50 intervals inity ≡ 147



U = 171

L = 146

max(y) = 169.541

Pressure Calculation

$R \equiv 53.34$ $\qquad$ $LPCI \equiv \dfrac{5000}{7.4805 \cdot .0164 \cdot 60}$ $\qquad$ $CS \equiv \dfrac{4500}{7.4805 \cdot .0164 \cdot 60}$

$Vdw \equiv 158236$ $\qquad$ $Ma \equiv 19284$

$Vww \equiv 108000$ $\qquad$ $Qpmp \equiv 2 \cdot 700 \cdot .70696 \cdot 0.0$ $\qquad$ $Qpmpc \equiv 800 \cdot .70696 \cdot 0.0$

note pump heat set to zero for initial basis type calc

$Pvb \equiv 0.5$

$$Tatm_k \equiv \frac{\left[y_k - \dfrac{HXK \cdot y_k - 95 - Qpmp}{LPCI}\right] \cdot LPCI + \left[Q\ x_k \cdot 2578 \cdot 1000 \cdot \dfrac{3413}{3600 \cdot CS} + y_k + \dfrac{Qpmpc}{CS} + \dfrac{SENSHT \cdot e^{-\frac{x_k}{7200}}}{CS}\right] \cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK \cdot y_k - 95 - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from t ASME tables.

$$
S = \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}
$$

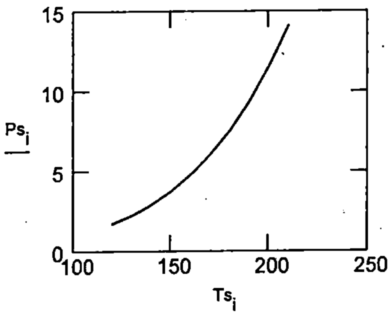
$Ts := S^{<0>}$

$Ps := S^{<1>}$

$i := 0..9$ $\qquad$ $vs := pspline(Ts, Ps)$

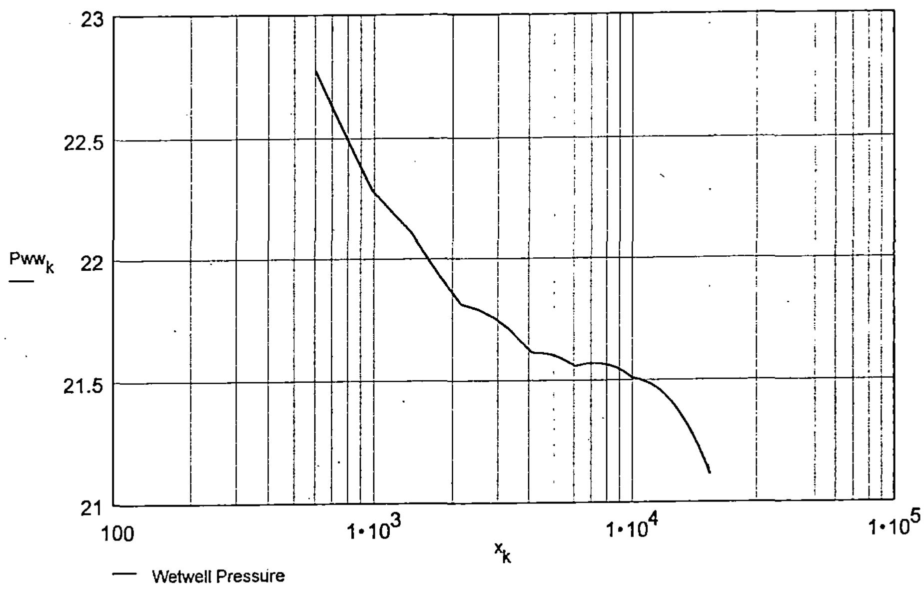
$Psat_k := interp\ vs, Ts, Ps, Tatm_k$

$Psatw_k := interp\ vs, Ts, Ps, Twatm_k$

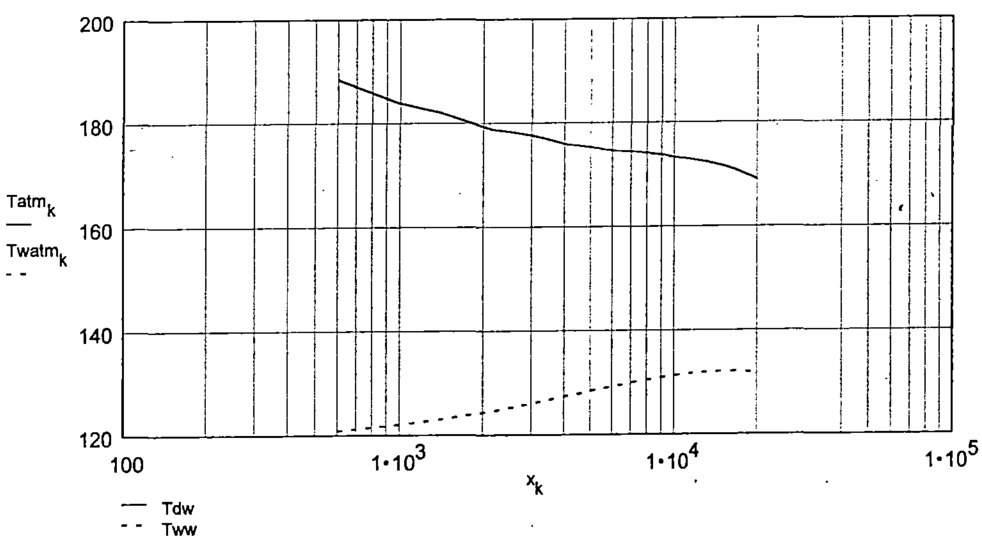


$$
Maww_k := \frac{144 \cdot Psat_k - Psatw_k + Pvb + Ma \cdot R \cdot \frac{Tatm_k + 460}{Vdw}}{R \cdot \frac{Tatm_k + 460}{Vdw} + R \cdot \frac{Twatm_k + 460}{Vww}}
$$

$$
Pww_k := Maww_k \cdot R \cdot \frac{Twatm_k + 460}{Vww \cdot 144} + Psatw_k
$$



max(Pww) = 22.773



DATA

	Time sec	WW Press psia	WW air T deg F		DW Temp deg F	WW Pool T deg F
Variable	x_k	Pww_k	$Twatm_k$	$Tatm_k$	y_k	
	600	22.773	120.852	188.44	147	
	988	22.28	122.008	183.908	149.325	
	1376	22.11	122.994	182.077	151.308	
	1764	21.934	123.862	180.184	153.054	
	2152	21.813	124.619	178.786	154.577	
	2540	21.787	125.306	178.302	155.96	
	2928	21.752	125.935	177.745	157.225	
	3316	21.709	126.507	177.119	158.374	
	3704	21.657	127.022	176.423	159.411	
	4092	21.612	127.484	175.809	160.34	
	4480	21.609	127.906	175.626	161.19	
	4868	21.602	128.296	175.406	161.974	
	5256	21.59	128.654	175.151	162.694	
	5644	21.574	128.982	174.861	163.353	
	6032	21.555	129.28	174.562	163.952	
	6420	21.561	129.554	174.517	164.504	
	6808	21.565	129.809	174.454	165.017	
	7196	21.566	130.047	174.372	165.495	
	7584	21.565	130.266	174.272	165.936	
	7972	21.561	130.469	174.155	166.344	
	8360	21.555	130.655	174.02	166.718	
	8748	21.547	130.825	173.869	167.06	
	9136	21.536	130.979	173.701	167.371	
	9524	21.524	131.119	173.517	167.652	
	9912	21.509	131.244	173.317	167.903	
	10300	21.503	131.356	173.21	168.128	
	10688	21.499	131.458	173.125	168.334	
	11076	21.493	131.552	173.032	168.522	
	11464	21.487	131.636	172.93	168.691	
	11852	21.479	131.712	172.82	168.844	
	12240	21.47	131.779	172.702	168.98	
	12628	21.46	131.839	172.576	169.1	
	13016	21.449	131.891	172.443	169.205	
	13404	21.438	131.936	172.302	169.294	
	13792	21.425	131.973	172.154	169.369	
	14180	21.411	132.003	171.999	169.43	
	14568	21.396	132.026	171.836	169.477	
	14956	21.381	132.043	171.667	169.511	
	15344	21.364	132.054	171.491	169.532	
	15732	21.347	132.058	171.309	169.541	
	16120	21.329	132.056	171.12	169.537	
	16508	21.31	132.049	170.925	169.522	
	16896	21.291	132.036	170.724	169.496	
	17284	21.271	132.017	170.517	169.458	
	17672	21.25	131.993	170.304	169.41	
	18060	21.228	131.964	170.085	169.352	
	18448	21.206	131.93	169.861	169.283	
	18836	21.183	131.891	169.631	169.205	
	19224	21.159	131.848	169.396	169.117	
	19612	21.135	131.799	169.155	169.02	

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* Description: PrntFile text                                                   *
*              January 8, 1997                     5:34pm                      *
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********************************************************************************
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Dresden SUPPRESSION POOL HEATUP CALCULATIONS

1/2 Case with original K and 95F Service Water Temperature

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equat describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, poo temperature at 600 seconds, the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. purpose of this model is to provide a representation of the most likely initial licensing basis calculations, to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represen May-Witt curve values.

$i \equiv 1..9$

$t_i \equiv$	$p_i \equiv$
600	.02549
1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \mathrm{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP, converted to B note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2 \cdot 700 + 1 \cdot 800) \cdot .70696 \cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 341.57$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximatel MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^8 \cdot .70}{7200}$$

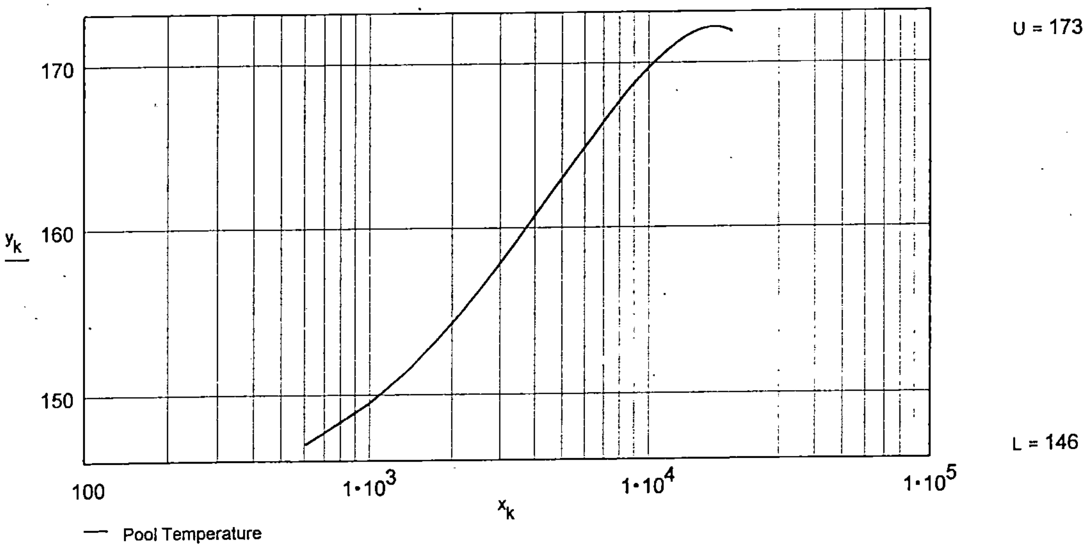
Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes pr GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor ha added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 95.0$ service water temperature

$$f(x,y) \equiv \frac{Q(x) \cdot \frac{2578}{1.02} \cdot \frac{1000}{3600} \cdot 3413 \cdot 1.0 + PHT + SENSHT \cdot e^{-\frac{x}{7200}} - (y - T_{sw}) \cdot HXK}{(124194) \cdot 62.054}$$

Enter starting and ending values of x, the number of intervals for the integration, and the initial value of y.

startx ≡ 600 endx ≡ 20000 n ≡ 50 intervals inity ≡ 147



max(y) = 172.072

Pressure Calculation

$R \equiv 53.34$ $\qquad LPCI \equiv \dfrac{5000}{7.4805 \cdot .0164 \cdot 60}$ $\qquad CS \equiv \dfrac{4500}{7.4805 \cdot .0164 \cdot 60}$

$Vdw \equiv 158236$ $\qquad Ma \equiv 19284$

$Vww \equiv 108000$ $\qquad Qpmp \equiv 2 \cdot 700 \cdot .70696 \cdot 0.0$ $\qquad Qpmpc \equiv 800 \cdot .70696 \cdot 0.0$

$Pvb \equiv 0.5$

note pump heat set to zero for initial basis type calc

$$Tatm_k \equiv \frac{\left[y_k - \dfrac{HXK \cdot \; y_k - 95 \; - Qpmp}{LPCI} \right] \cdot LPCI + \left[Q \;\; x_k \;\; \cdot 2578 \cdot 1000 \cdot \dfrac{3413}{3600 \cdot CS} + y_k + \dfrac{Qpmpc}{CS} + \dfrac{SENSHT \cdot e^{-\frac{x_k}{7200}}}{CS} \right] \cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK \cdot \; y_k - 95 \; - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from t ASME tables.

$$S := \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}$$

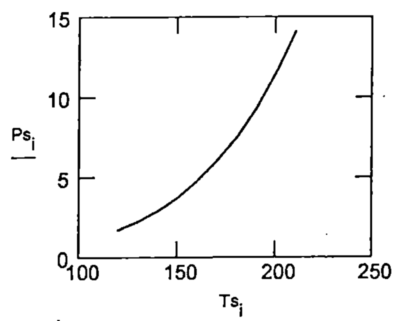
$Ts := S^{\langle 0 \rangle}$

$Ps := S^{\langle 1 \rangle}$

$i := 0..9$ $\qquad$ $vs := \mathrm{pspline}(Ts, Ps)$

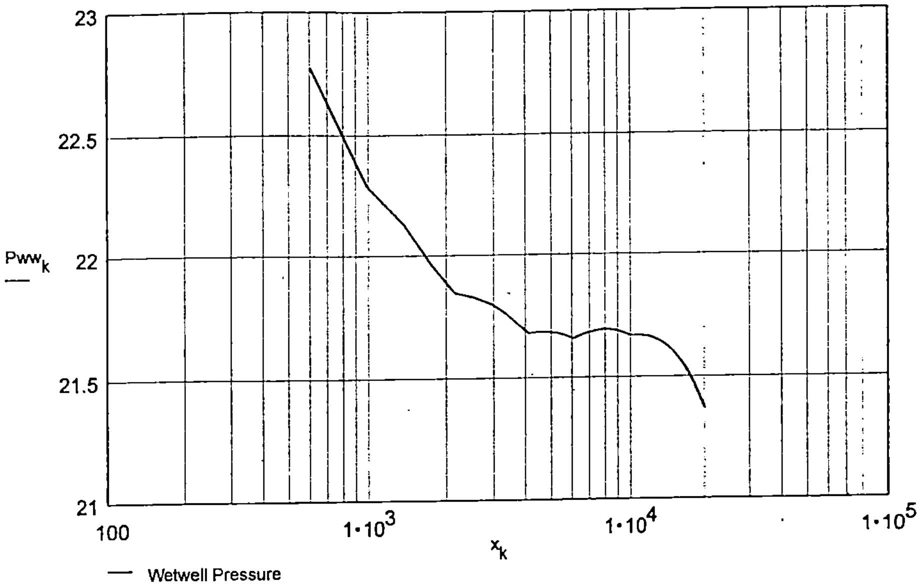
$Psat_k := \mathrm{interp}(vs, Ts, Ps, Tatm_k)$

$Psatw_k := \mathrm{interp}(vs, Ts, Ps, Twatm_k)$

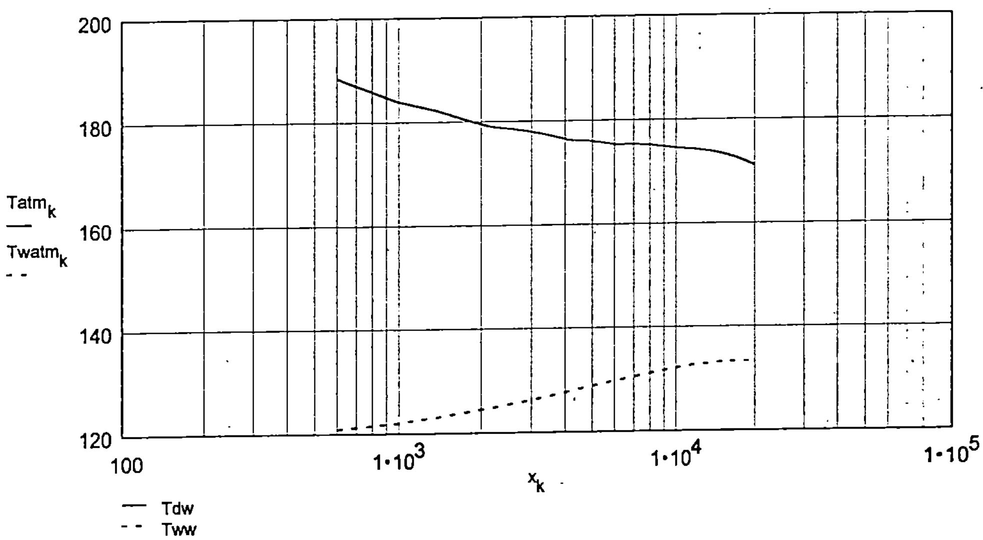


$$Maww_k := \frac{144 \cdot (Psat_k - Psatw_k + Pvb) + Ma \cdot R \cdot \dfrac{Tatm_k + 460}{Vdw}}{R \cdot \dfrac{Tatm_k + 460}{Vdw} + R \cdot \dfrac{Twatm_k + 460}{Vww}}$$

$$Pww_k := Maww_k \cdot R \cdot \frac{Twatm_k + 460}{Vww \cdot 144} + Psatw_k$$



max(Pww) = 22.773



DATA

	Time sec	WW Press psia	WW air T deg F	DW Temp deg F	WW Pool T deg F
Variable	x_k	Pww_k	$Twatm_k$	$Tatm_k$	y_k
	600	22.773	120.852	188.44	147
	988	22.289	122.05	183.971	149.411
	1376	22.127	123.078	182.201	151.477
	1764	21.959	123.987	180.368	153.306
	2152	21.845	124.784	179.031	154.909
	2540	21.827	125.511	178.605	156.372
	2928	21.799	126.179	178.106	157.715
	3316	21.763	126.789	177.536	158.941
	3704	21.717	127.342	176.896	160.054
	4092	21.679	127.841	176.337	161.057
	4480	21.683	128.299	176.207	161.98
	4868	21.683	128.725	176.04	162.836
	5256	21.677	129.118	175.837	163.627
	5644	21.667	129.48	175.598	164.355
	6032	21.655	129.812	175.349	165.022
	6420	21.667	130.119	175.353	165.64
	6808	21.677	130.407	175.338	166.22
	7196	21.684	130.677	175.304	166.762
	7584	21.689	130.928	175.251	167.267
	7972	21.691	131.162	175.18	167.737
	8360	21.691	131.378	175.09	168.173
	8748	21.688	131.578	174.983	168.576
	9136	21.683	131.762	174.859	168.946
	9524	21.675	131.931	174.718	169.285
	9912	21.666	132.084	174.56	169.593
	10300	21.665	132.224	174.495	169.875
	10688	21.665	132.354	174.451	170.137
	11076	21.665	132.475	174.397	170.379
	11464	21.663	132.586	174.335	170.602
	11852	21.66	132.688	174.264	170.808
	12240	21.656	132.781	174.184	170.995
	12628	21.651	132.866	174.096	171.166
	13016	21.644	132.943	173.999	171.321
	13404	21.637	133.012	173.894	171.459
	13792	21.628	133.073	173.782	171.582
	14180	21.618	133.127	173.661	171.691
	14568	21.607	133.174	173.533	171.785
	14956	21.596	133.213	173.398	171.864
	15344	21.583	133.246	173.255	171.931
	15732	21.569	133.273	173.106	171.984
	16120	21.555	133.293	172.949	172.024
	16508	21.54	133.307	172.785	172.052
	16896	21.523	133.314	172.615	172.068
	17284	21.506	133.316	172.439	172.072
	17672	21.488	133.313	172.256	172.064
	18060	21.47	133.304	172.066	172.046
	18448	21.45	133.289	171.871	172.017
	18836	21.43	133.269	171.669	171.977
	19224	21.409	133.244	171.462	171.927
	19612	21.388	133.215	171.249	171.867

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******************************************************************************
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  ectory:                                                                    *
  scription: PrntFile text                                                   *
*            January 8, 1997                        5:40pm                   *
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*                         N N N FFFF   SSS  KK    RRRR                       *
*                         N  NN F         S K K   R R                        *
*                         N   N F     S   S K  K  R  R                       *
*                         N   N F      SSS  K   K R   R                      *
*                                                                            *
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******************************************************************************
*                                                                            *
*                           L      SSS  TTTTT                                *
*                           L     S   S   T                                  *
*                           L     S       T     ::                           *
*                           L      SSS    T     ::                           *
*                           L         S   T                                  *
*                           L     S   S   T     ::                           *
*                           LLLLL  SSS    T     ::                           *
*                                                                            *
*                                                                            *
*                                                                            *
******************************************************************************
```

Dresden SUPPRESSION POOL HEATUP CALCULATIONS
1/2 Case with limiting K and 84F Service Water Temperature, initial pool temperature at 75F

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equat describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, poo temperature at 600 seconds, the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. purpose of this model is to provide a representation of the most likely initial licensing basis calculations, to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represen May-Witt curve values.

$i \equiv 1..9$

$t_i \equiv$	$p_i \equiv$
600	.02549
1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \mathrm{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP, converted to B note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2\cdot 700 + 1\cdot 800)\cdot .70696\cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 296.96$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximatel MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^{8}\cdot .70}{7200}$$

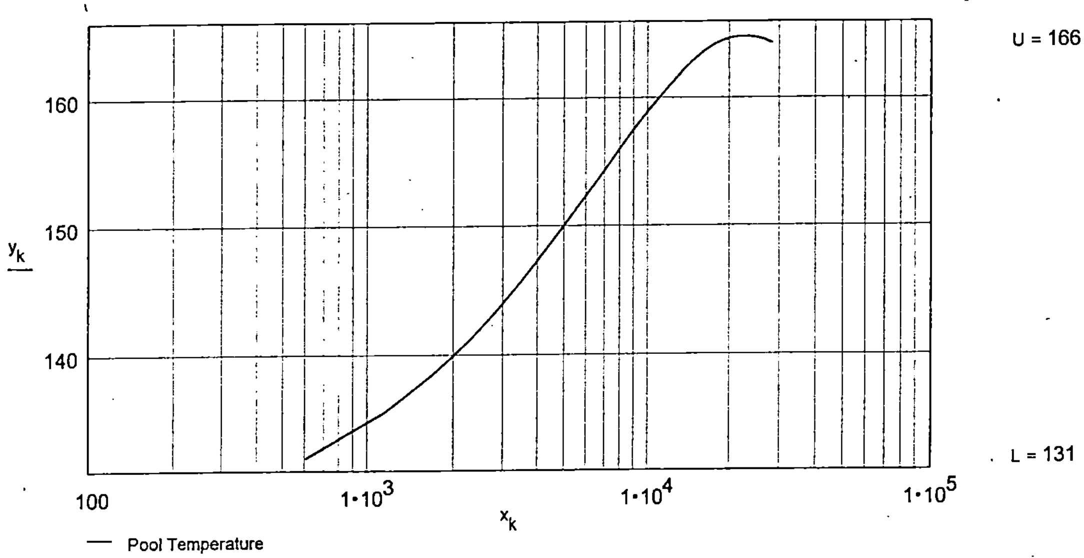
Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes pr GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor ha added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 84.0$ service water temperature

$$f(x,y) \equiv \frac{Q(x)\cdot \frac{2578}{1.02}\cdot \frac{1000}{3600}\cdot 3413\cdot 1.0 + PHT + SENSHT\cdot e^{-\frac{x}{7200}} - (y - T_{sw})\cdot HXK}{(124194)\cdot 62.054}$$

Enter starting and ending values of x, the number of intervals for the integration, and the initial value of y.

startx ≡ 600 endx ≡ 28000 n ≡ 50 intervals inity ≡ 132



max(y) = 164.808

Pressure Calculation

$R \equiv 53.34$

$LPCI \equiv \dfrac{5000}{7.4805 \cdot .0164 \cdot 60}$

$CS \equiv \dfrac{4500}{7.4805 \cdot .0164 \cdot 60}$

$Vdw \equiv 158236$

$Ma \equiv 19284$

$Vww \equiv 108000$

$Qpmp \equiv 2 \cdot 700 \cdot .70696 \cdot 0.0$

$Qpmpc \equiv 800 \cdot .70696 \cdot 0.0$

note pump heat set to zero for initial basis type calc

$Pvb \equiv 0.5$

$$Tatm_k \equiv \frac{\left[y_k - \dfrac{HXK \cdot \left(y_k - 95\right) - Qpmp}{LPCI}\right] \cdot LPCI + \left[Q\left(x_k\right) \cdot .2578 \cdot 1000 \cdot \dfrac{3413}{3600 \cdot CS} + y_k + \dfrac{Qpmpc}{CS} + \dfrac{SENSHT \cdot e^{-\frac{x_k}{7200}}}{CS}\right] \cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK \cdot \left(y_k - 95\right) - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from t ASME tables.

$$S = \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}$$

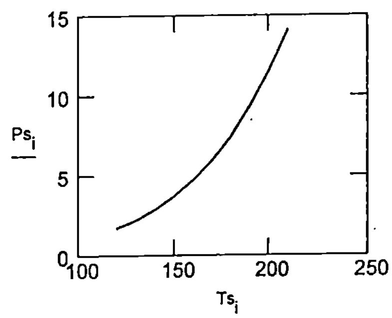
$$Ts := S^{<0>}$$

$$Ps := S^{<1>}$$

$$i := 0..9 \qquad vs := \mathrm{pspline}(Ts, Ps)$$

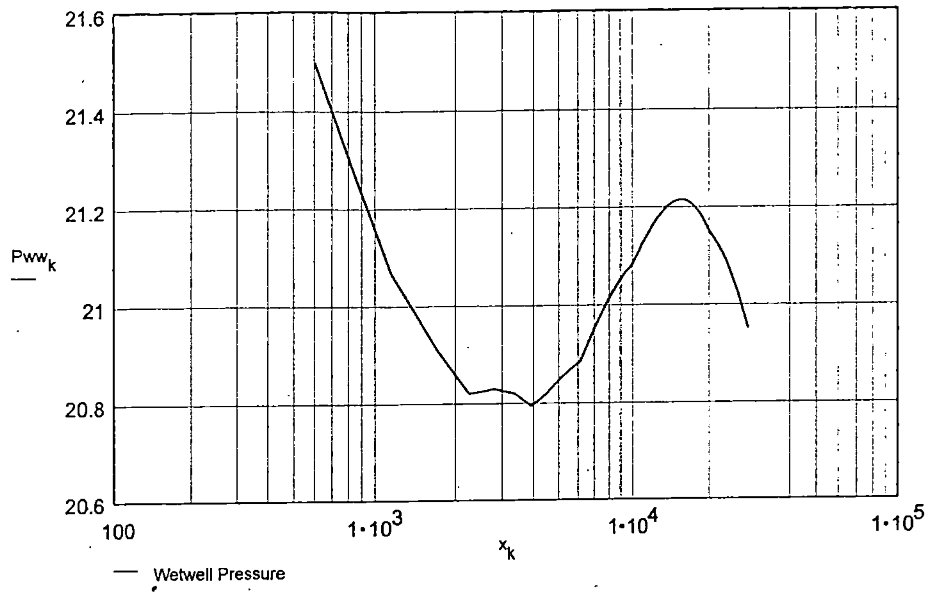
$$Psat_k := \mathrm{interp}(vs, Ts, Ps, Tatm_k)$$

$$Psatw_k := \mathrm{interp}(vs, Ts, Ps, Twatm_k)$$

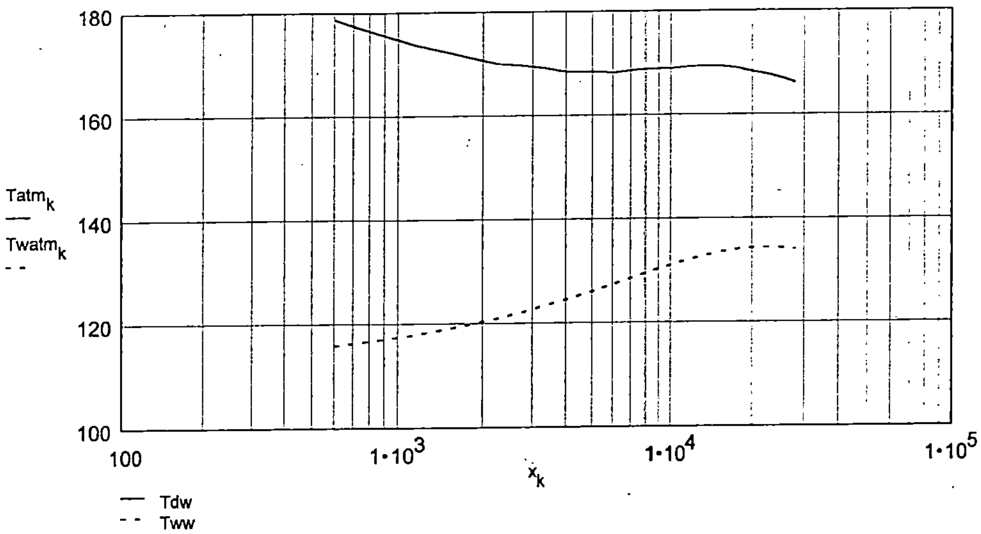


$$Maww_k := \frac{144\cdot\left(Psat_k - Psatw_k + Pvb\right) + Ma\cdot R\cdot\frac{Tatm_k + 460}{Vdw}}{R\cdot\frac{Tatm_k + 460}{Vdw} + R\cdot\frac{Twatm_k + 460}{Vww}}$$

$$Pww_k := Maww_k\cdot R\cdot\frac{Twatm_k + 460}{Vww\cdot 144} + Psatw_k$$



max(Pww) = 21.496



DATA

	Time sec	WW Press psia	WW air T deg F	DW Temp deg F	WW Pool T deg F
Variable	x_k	Pww_k	$Twatm_k$	$Tatm_k$	y_k
	600	21.496	115.825	178.689	132
	1148	21.065	117.821	173.764	135.547
	1696	20.908	119.49	171.55	138.513
	2244	20.817	120.908	170.06	141.033
	2792	20.826	122.175	169.682	143.283
	3340	20.818	123.31	169.152	145.299
	3888	20.792	124.317	168.475	147.089
	4436	20.815	125.215	168.377	148.684
	4984	20.845	126.035	168.376	150.142
	5532	20.865	126.783	168.297	151.47
	6080	20.882	127.46	168.206	152.674
	6628	20.925	128.083	168.426	153.78
	7176	20.963	128.661	168.603	154.808
	7724	20.996	129.197	168.738	155.76
	8272	21.023	129.692	168.831	156.639
	8820	21.046	130.147	168.885	157.448
	9368	21.063	130.565	168.899	158.189
	9916	21.076	130.946	168.876	158.866
	10464	21.1	131.295	168.984	159.487
	11012	21.123	131.62	169.1	160.065
	11560	21.143	131.922	169.193	160.601
	12108	21.161	132.202	169.264	161.098
	12656	21.176	132.46	169.314	161.557
	13204	21.188	132.698	169.344	161.979
	13752	21.198	132.916	169.354	162.367
	14300	21.205	133.115	169.345	162.721
	14848	21.21	133.296	169.316	163.042
	15396	21.212	133.459	169.269	163.333
	15944	21.212	133.606	169.204	163.593
	16492	21.209	133.736	169.122	163.824
	17040	21.205	133.851	169.022	164.028
	17588	21.198	133.95	168.906	164.204
	18136	21.189	134.035	168.774	164.355
	18684	21.179	134.105	168.625	164.48
	19232	21.166	134.162	168.461	164.581
	19780	21.151	134.205	168.282	164.658
	20328	21.14	134.237	168.149	164.714
	20876	21.132	134.261	168.047	164.756
	21424	21.123	134.277	167.938	164.786
	21972	21.113	134.287	167.822	164.803
	22520	21.102	134.29	167.698	164.808
	23068	21.09	134.286	167.568	164.802
	23616	21.077	134.277	167.431	164.785
	24164	21.063	134.261	167.287	164.757
	24712	21.049	134.24	167.137	164.719
	25260	21.034	134.212	166.981	164.671
	25808	21.018	134.18	166.818	164.613
	26356	21.002	134.142	166.65	164.546
	26904	20.985	134.1	166.476	164.47
	27452	20.967	134.052	166.296	164.386

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* File name:                                 Server: NFS_HP4SI2                *
* Directory:                                                                   *
* Description: PrntFile text                                                   *
*              January 8, 1997                      5:44pm                     *
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*                       N  NN F         S K K   R R                            *
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*                       N   N F      SSS  K   K R   R                          *
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********************************************************************************
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*                         L      SSS  TTTTT                                    *
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*                         L      SSS    T    ::                                *
*                         L         S   T                                      *
*                         L     S   S   T    ::                                *
*                         LLLLL  SSS    T    ::                                *
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Dresden SUPPRESSION POOL HEATUP CALCULATIONS
1/2 Case with limiting K and 75F Service Water Temperature, initial pool temperature at 75F

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equat describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, poo temperature at 600 seconds, the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. purpose of this model is to provide a representation of the most likely initial licensing basis calculations, to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represen May-Witt curve values.

$i \equiv 1..9$

$t_i \equiv$	$p_i \equiv$
600	.02549
1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \mathrm{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP, converted to B note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2\cdot 700 + 1\cdot 800)\cdot .70696\cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 296.96$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximatel MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^{8}\cdot .70}{7200}$$

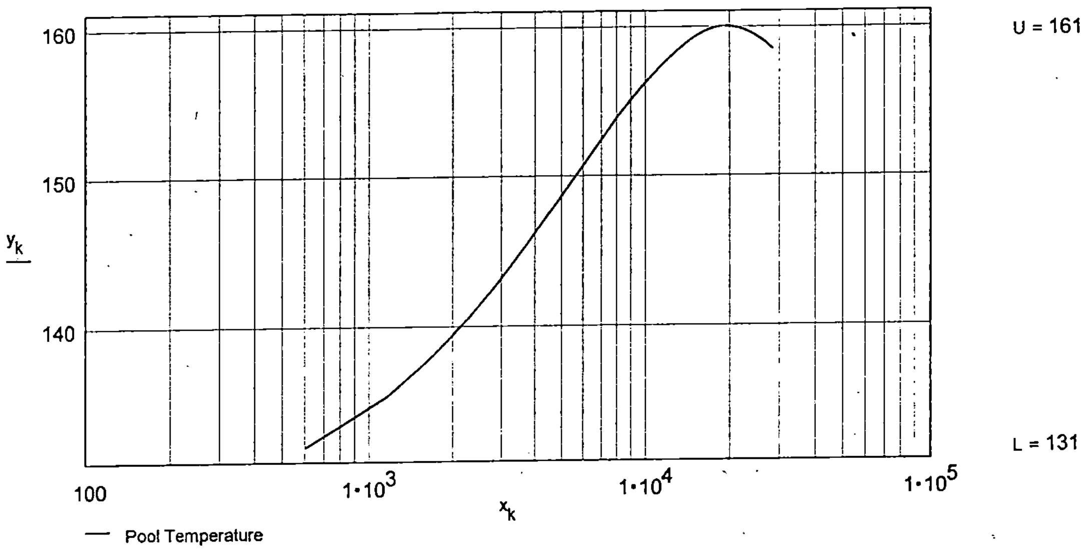
Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes pr GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor ha added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 75.0$ service water temperature

$$f(x,y) \equiv \frac{Q(x)\cdot\frac{2578}{1.02}\cdot\frac{1000}{3600}\cdot 3413\cdot 1.0 + PHT + SENSHT\cdot e^{-\frac{x}{7200}} - (y - T_{sw})\cdot HXK}{(124194)\cdot 62.054}$$

Enter starting and ending values of x, the number of intervals for the integration, and the initial value of y.

startx ≡ 600 endx ≡ 28000 n ≡ 50 intervals inity ≡ 132



max(y) = 159.97

Pressure Calculation

$R \equiv 53.34$ $\qquad$ $LPCI \equiv \dfrac{5000}{7.4805 \cdot .0164 \cdot 60}$ $\qquad$ $CS \equiv \dfrac{4500}{7.4805 \cdot .0164 \cdot 60}$

$Vdw \equiv 158236$ $\qquad$ $Ma \equiv 19284$

$Vww \equiv 108000$ $\qquad$ $Qpmp \equiv 2 \cdot 700 \cdot .70696 \cdot 0.0$ $\qquad$ $Qpmpc \equiv 800 \cdot .70696 \cdot 0.0$

note pump heat set to zero for initial basis type calc

$Pvb \equiv 0.5$

$$Tatm_k \equiv \frac{\left[y_k - \dfrac{HXK \cdot\ y_k - 95\ - Qpmp}{LPCI}\right] \cdot LPCI + \left[Q\ x_k\ \cdot 2578 \cdot 1000 \cdot \dfrac{3413}{3600 \cdot CS} + y_k + \dfrac{Qpmpc}{CS} + \dfrac{SENSHT \cdot e^{-\frac{x_k}{7200}}}{CS}\right] \cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK \cdot\ y_k - 95\ - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from t ASME tables.

$$S := \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}$$

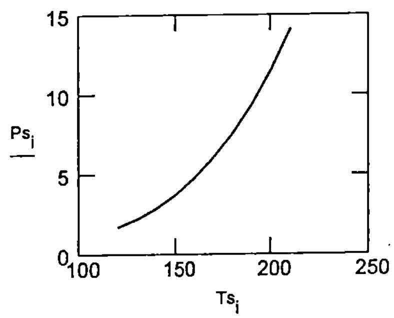
$Ts := S^{<0>}$

$Ps := S^{<1>}$

$i := 0..9$ $\qquad$ $vs := \mathrm{pspline}(Ts, Ps)$

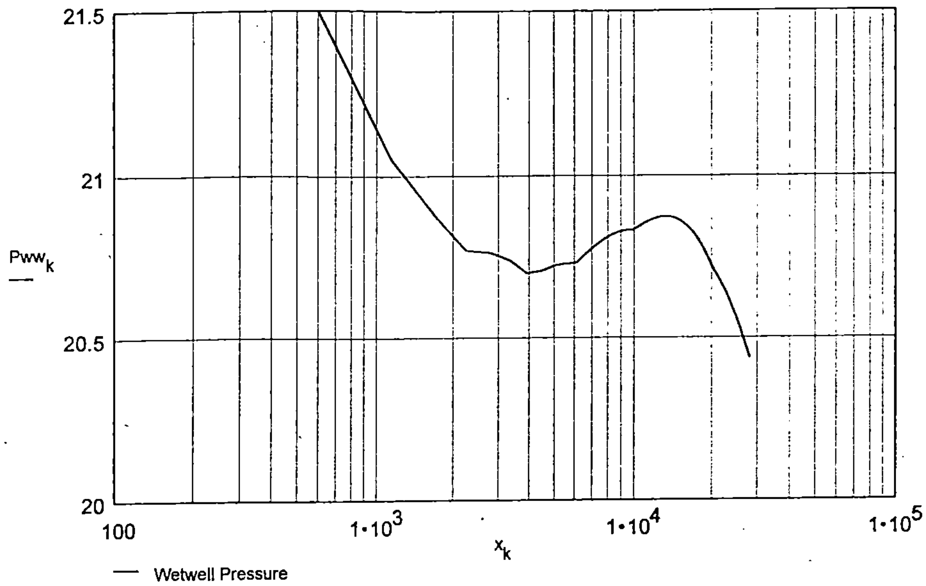
$Psat_k := \mathrm{interp}\ vs, Ts, Ps, Tatm_k$

$Psatw_k := \mathrm{interp}\ vs, Ts, Ps, Twatm_k$

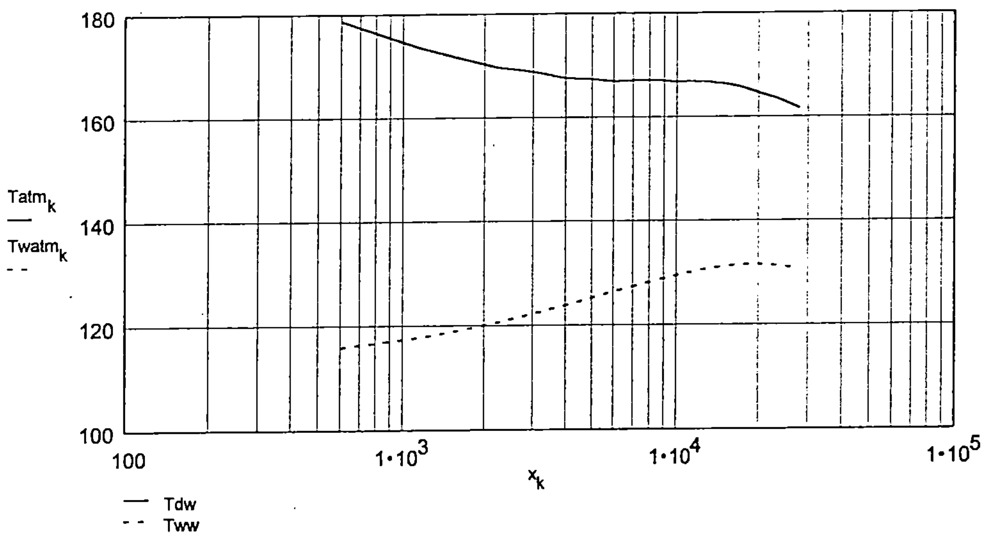


$$Maww_k := \frac{144 \cdot \ Psat_k - Psatw_k + Pvb \ + Ma \cdot R \cdot \dfrac{Tatm_k + 460}{Vdw}}{R \cdot \dfrac{Tatm_k + 460}{Vdw} + R \cdot \dfrac{Twatm_k + 460}{Vww}}$$

$$Pww_k := Maww_k \cdot R \cdot \frac{Twatm_k + 460}{Vww \cdot 144} + Psatw_k$$



max(Pww) = 21.496



DATA

Variable	Time sec x_k	WW Press psia Pww_k	WW air T deg F $Twatm_k$	DW Temp deg F $Tatm_k$	WW Pool T deg F y_k
	600	21.496	115.825	178.689	132
	1148	21.047	117.715	173.619	135.359
	1696	20.874	119.281	171.264	138.141
	2244	20.768	120.597	169.635	140.48
	2792	20.761	121.765	169.12	142.554
	3340	20.737	122.802	168.458	144.397
	3888	20.696	123.714	167.651	146.018
	4436	20.705	124.519	167.425	147.447
	4984	20.72	125.248	167.299	148.743
	5532	20.726	125.906	167.098	149.912
	6080	20.729	126.496	166.887	150.961
	6628	20.758	127.033	166.99	151.915
	7176	20.781	127.528	167.052	152.793
	7724	20.8	127.981	167.074	153.599
	8272	20.814	128.395	167.058	154.335
	8820	20.824	128.772	167.004	155.004
	9368	20.828	129.112	166.913	155.609
	9916	20.829	129.418	166.786	156.152
	10464	20.84	129.693	166.793	156.641
	11012	20.851	129.946	166.81	157.09
	11560	20.86	130.177	166.806	157.501
	12108	20.866	130.387	166.782	157.874
	12656	20.869	130.578	166.74	158.212
	13204	20.87	130.749	166.679	158.517
	13752	20.869	130.902	166.599	158.789
	14300	20.866	131.037	166.503	159.029
	14848	20.86	131.156	166.389	159.24
	15396	20.853	131.258	166.258	159.422
	15944	20.843	131.345	166.111	159.576
	16492	20.832	131.416	165.949	159.703
	17040	20.818	131.474	165.771	159.804
	17588	20.803	131.517	165.578	159.881
	18136	20.786	131.546	165.37	159.934
	18684	20.768	131.563	165.148	159.963
	19232	20.747	131.567	164.912	159.97
	19780	20.726	131.559	164.662	159.956
	20328	20.707	131.54	164.46	159.922
	20876	20.692	131.514	164.29	159.877
	21424	20.676	131.482	164.115	159.82
	21972	20.659	131.445	163.934	159.753
	22520	20.641	131.401	163.747	159.675
	23068	20.623	131.352	163.554	159.588
	23616	20.604	131.298	163.356	159.492
	24164	20.585	131.239	163.153	159.387
	24712	20.565	131.174	162.944	159.273
	25260	20.544	131.106	162.731	159.151
	25808	20.523	131.032	162.512	159.02
	26356	20.502	130.955	162.289	158.882
	26904	20.48	130.873	162.062	158.737
	27452	20.457	130.787	161.829	158.584

Dresden SUPPRESSION POOL HEATUP CALCULATIONS
1/2 Case with limiting K and 84F Service Water Temperature, initial pool temperature at 95F

This calculation is based on the use of a Runge-Kutta solution method to numerically evaluate the first order differential equation describing the behavior of the suppression pool following the completion of the blowdown from the vessel. It uses boundary conditions taken from GENE-770-26-1092, GENE-637-042-1193, and the Quad Cities FSAR. These are the decay heat, pool temperature at 600 seconds, the K value for the heat exchanger,and a term to account for sensible heat of the vessel metal. The purpose of this model is to provide a representation of the most likely initial licensing basis calculations, to allow the effects of reduced HX performance and lower service water temperatures to be assessed.

The following vectors represent the decay heat input to the problem. These are based on the GE supplied data and represent May-Witt curve values.

$i \equiv 1..9$

$t_i \equiv$	$p_i \equiv$
600	.02549
1000	.02229
2000	.01841
4000	.01512
6000	.01353
10000	.01201
20000	.01008
40000	.008125
60000	.007394

Q(x) defines a linear interpolation of the above vectors for use in the calculation

$Q(x) \equiv \mathrm{linterp}(t, p, x)$

PHT is the pump heat input, with CCSW and LPCI considered to be 700 HP and the Core Spray at 800 HP, converted to BTU/SEC

note that pump heat is set to zero for this original basis calculation

$PHT \equiv (2\cdot 700 + 1\cdot 800)\cdot .70696\cdot 0.0$

HXK is the heat removal rate of the LPCI HX in BTU/Sec-F

$HXK \equiv 296.96$

SENSHT is the sensible heat stored in the thick metal structures, added to the pool in exponential fashion as BTU/sec, note that this term is adjusted to provide a reasonable match to vendor base calculations, with the total sensible heat being approximately 100 MBTU, assuming a fraction remaining at 1000 seconds.

$$SENSHT \equiv \frac{10^8\cdot .70}{7200}$$

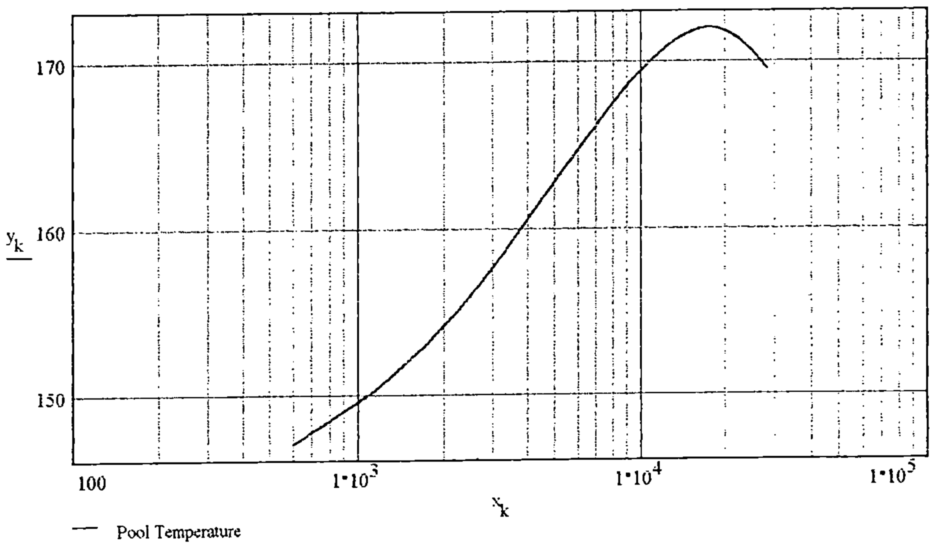
Enter the derivative of y as f(x,y): (Note that x=time(seconds and y=Temperature) Pool Volume is based on final volumes provided by GE in base calculations (vapor space of 108000 cubic feet, yielding a pool volume of 124194 ft3) Note that a 1.02 factor has been added to provide a 100% rated power consistent with original calculations

$T_{sw} \equiv 84.0$ service water temperature

$$f(x,y) \equiv \frac{\left(Q(x)\cdot\frac{2578}{1.02}\cdot\frac{1000}{3600}\cdot 3413\cdot 1.0 + PHT + SENSHT\cdot e^{-\frac{x}{7200}}\right) - (y - T_{sw})\cdot HXK}{(124194)\cdot 62.054}$$

Enter starting and ending values of x, the number of intervals for the integration, and the initial value of y

startx≡600 endx≡28000 n≡50 intervals inity≡147



U = 173

L = 146

max(y) = 171.999

Pressure Calculation

$R \equiv 53.34$

$LPCI \equiv \frac{5000}{7.4805 \cdot .0164 \cdot 60}$

$CS \equiv \frac{4500}{7.4805 \cdot .0164 \cdot 60}$

$Vdw \equiv 158236$

$Ma \equiv 19284$

$Vww \equiv 108000$

$Qpmp \equiv 2 \cdot 700 \cdot .70696 \cdot 0.0$

$Qpmpc \equiv 800 \cdot .70696 \cdot 0.0$

note pump heat set to zero for initial basis type calc

$Pvb \equiv 0.5$

$$Tatm_k \equiv \frac{\left[y_k - \frac{HXK \cdot (y_k - 95) - Qpmp}{LPCI}\right] \cdot LPCI + \left(Q(x_k) \cdot 2578 \cdot 1000 \cdot \frac{3413}{3600 \cdot CS} + y_k + \frac{Qpmpc}{CS} + \frac{SENSHT \cdot e^{-\frac{x_k}{7200}}}{CS}\right) \cdot CS}{LPCI + CS}$$

$$Twatm_k \equiv y_k - \frac{HXK \cdot (y_k - 95) - Qpmp}{LPCI}$$

This File estimates Psat based on temperature input. It is a curve fit interpolation between 120 and 200 degrees of data from the 1967 ASME tables.

$$S := \begin{bmatrix} 120 & 1.6927 \\ 130 & 2.223 \\ 140 & 2.8892 \\ 150 & 3.7184 \\ 160 & 4.7414 \\ 170 & 5.9926 \\ 180 & 7.511 \\ 190 & 9.34 \\ 200 & 11.526 \\ 210 & 14.123 \end{bmatrix}$$

$Ts := S^{<0>}$

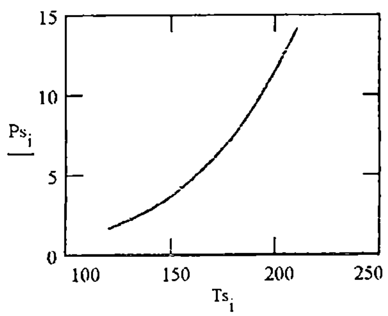
$Ps := S^{<1>}$

$i := 0 .. 9$

$vs := \mathrm{pspline}(Ts, Ps)$

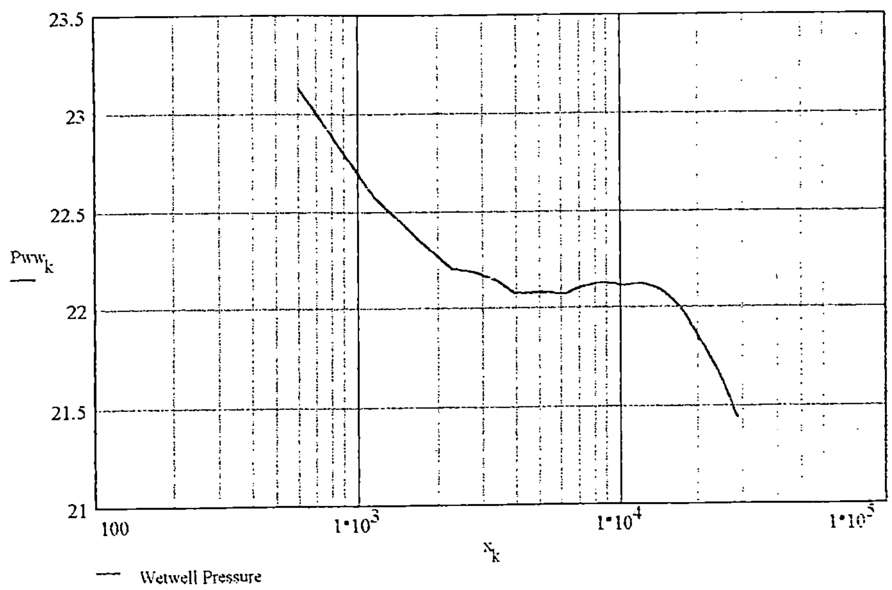
$Psat_k := \mathrm{interp}\left(vs, Ts, Ps, Tatm_k\right)$

$Psatw_k := \mathrm{interp}\left(vs, Ts, Ps, Twatm_k\right)$

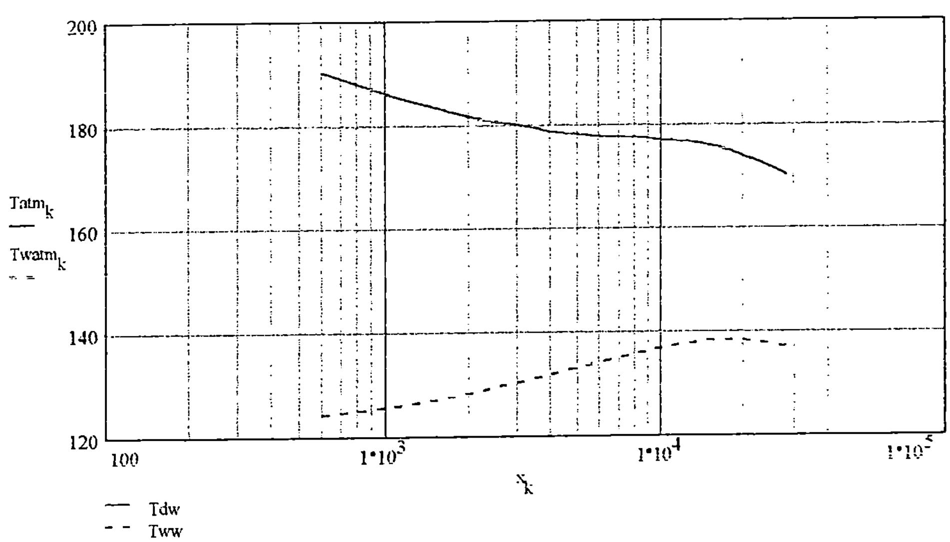


$$Maww_k := \frac{144 \cdot \left(Psat_k - Psatw_k + Pvb\right) + Ma \cdot R \cdot \dfrac{Tatm_k + 460}{Vdw}}{R \cdot \dfrac{Tatm_k + 460}{Vdw} + R \cdot \dfrac{Twatm_k + 460}{Vww}}$$

$$Pww_k := Maww_k \cdot R \cdot \frac{Twatm_k + 460}{Vww \cdot 144} + Psatw_k$$



max(Pww) = 23.123



DATA

	Time sec	WW Press psia	WW air T deg F	DW Temp deg F	WW Pool T deg F
Variable	x_k	Pww_k	$Twatm_k$	$Tatm_k$	y_k
	600	23.123	124.267	190.237	147
	1148	22.567	126.087	185.071	150.234
	1696	22.344	127.583	182.621	152.893
	2244	22.201	128.833	180.9	155.112
	2792	22.179	129.934	180.295	157.068
	3340	22.136	130.906	179.544	158.796
	3888	22.074	131.755	178.65	160.304
	4436	22.072	132.497	178.339	161.623
	4984	22.077	133.166	178.13	162.811
	5532	22.072	133.764	177.847	163.874
	6080	22.063	134.296	177.556	164.818
	6628	22.086	134.776	177.581	165.671
	7176	22.103	135.214	177.567	166.45
	7724	22.114	135.613	177.514	167.159
	8272	22.12	135.974	177.424	167.8
	8820	22.12	136.298	177.298	168.375
	9368	22.116	136.587	177.137	168.889
	9916	22.106	136.842	176.941	169.342
	10464	22.11	137.068	176.881	169.744
	11012	22.113	137.272	176.832	170.107
	11560	22.114	137.456	176.763	170.434
	12108	22.112	137.62	176.676	170.725
	12656	22.108	137.765	176.572	170.983
	13204	22.1	137.892	176.45	171.208
	13752	22.091	138.002	176.311	171.403
	14300	22.079	138.095	176.156	171.568
	14848	22.065	138.172	175.986	171.705
	15396	22.048	138.233	175.799	171.814
	15944	22.03	138.28	175.598	171.897
	16492	22.009	138.312	175.382	171.955
	17040	21.986	138.331	175.152	171.989
	17588	21.962	138.337	174.907	171.999
	18136	21.935	138.33	174.649	171.986
	18684	21.907	138.311	174.378	171.952
	19232	21.877	138.28	174.094	171.897
	19780	21.846	138.237	173.798	171.822
	20328	21.819	138.185	173.549	171.728
	20876	21.795	138.126	173.335	171.624
	21424	21.771	138.062	173.115	171.509
	21972	21.746	137.992	172.89	171.386
	22520	21.72	137.918	172.661	171.254
	23068	21.694	137.838	172.427	171.113
	23616	21.667	137.754	172.188	170.964
	24164	21.64	137.666	171.945	170.807
	24712	21.612	137.574	171.698	170.642
	25260	21.583	137.477	171.446	170.471
	25808	21.555	137.376	171.191	170.292
	26356	21.525	137.272	170.931	170.106
	26904	21.496	137.164	170.667	169.914
	27452	21.466	137.052	170.4	169.716

Attachment 5

Safety Evaluation Justifying the Proposed Change

Safety Evaluation

Review of documents in support of containment strainer replacement modifications revealed that the differential pressure that would be expected at design flow rates is approximately 5.8 feet versus the 1 foot value presently in the FSAR and NPSH calculations.

Evaluations utilizing the increased strainer head loss showed that there was insufficient head for the ECCS pumps with no credit for containment over pressure and existing Technical Specification limits on suppression pool and ultimate heat sink temperature. Discussions were held with NRR staff concerning limitation of suppression pool temperatures and/or ultimate heat sink temperatures to allow operation with no more than the 2 psig presently discussed in the Dresden UFSAR. NPSH calculations prepared utilizing the increased strainer head loss showed that a maximum limit of 75 F on initial suppression pool and ultimate heat sink temperatures would provide adequate NPSH with 2 psig of containment over pressure during the first 10 minutes of the accident and require no credit over pressure beyond 10 minutes. This evaluation showed that the Core Spray pumps would cavitate during the first 10 minutes of the accident and the NPSH deficiency would be 3.3 feet.

As documented in the UFSAR, previous NPSH calculations showed that there was a 3 foot deficit in LPCI pump NPSH during the first 10 minutes after accident initiation during certain accident conditions. Cavitation testing performed prior to Dresden licensing demonstrated the ability of the pumps to withstand cavitation for at least 1 hour without damage. This was accepted by the NRC in an SER dated January 4, 1977. The UFSAR describes a containment over pressure (2 psig) which would assure adequate pump NSPH. Therefore the ability of the ECCS pumps to meet the post-LOCA NPSH requirements was shown by either the presence of containment over pressure **or** by demonstrating the acceptability of pump cavitation.

The as-found ECCS strainer differential pressure requires the use of containment over pressure **and** cavitation to meet the LOCA NPSH analyses. The basis for Technical Specification 3.7 states that containment pressure is not required to maintain adequate NPSH for the ECCS pumps. Therefore the margin of safety is reduced and an Unreviewed Safety Issue exists.

The table below shows the impact on NPSH as a result of the increase in strainer head loss and placement of limits on suppression pool and ultimate heat sink temperatures:

	NPSH
Original NPSH analyses	- 3.0 feet
Revisions to analyses to incorporate issues raised during 1996 ISI	- 2.8 feet
NPSH loss due to strainer head loss discovery *	- 6.7 feet
Subtotal for NPSH margin decrease	-11.5 feet
Added NPSH margin due to lower suppression pool/UHS temperatures	+ 3.6 feet
Credit for 2 psig containment over pressure (1st 10 minutes)	+ 4.6 feet
Total margin following License Amendment	- 3.3 feet

* Strainer head loss at runout flow

As shown above, original margin is essentially restored with credit for 2 psig containment over pressure and the 75 F limit on suppression pool and ultimate heat sink temperatures. However, as shown above, there is an overall reduction of 0.3 feet in NPSH margin which leads to an Unreviewed Safety Question.

The cavitation test report demonstrates the ability of the pumps to withstand cavitation without damage for at least 1 hour. Operator action is credited at 10 minutes to throttle the pumps to eliminate cavitation. Calculations show that the pumps can deliver adequate flow during the first 10 minutes even under cavitating conditions. The operators are trained to throttle the pump if cavitation conditions occur during long term containment cooling. Calculations demonstrate that sufficient flow is available long-term under throttled conditions to achieve containment cooling.

The restriction of 75 F on suppression pool and ultimate heat sink temperature provides for equipment operation within the bounds of existing analyses.

ECCS pump performance does not contribute to or affect initiation of a LOCA, therefore, the probability of an accident is not increased.

A minimum of 2 psig over pressure is available until after containment cooling is initiated. The LPCI and Core Spray pumps are capable of performing their design functions with respect to coolant injection post LOCA with 2 psig over pressure. This ensures that core cooling is provided and peak clad temperatures remain within limits. No containment over pressure is necessary for adequate NPSH for long term containment cooling. Therefore, onsite and offsite doses as described in the UFSAR are not impacted.

This change does not result in any physical change to the plant or modes of operation. No new failure modes are introduced. The cavitation tests demonstrated the ability of the ECCS pumps to cavitate for at least 1 hour without damage. The operators have been trained to recognize cavitation conditions (oscillating flow and discharge pressure) and to protect their equipment by throttling flow if evidence of cavitation exists. The control room has indication of both discharge pressure and flow on each division of Core Spray and LPCI. The restrictions in suppression pool and ultimate heat sink temperature do not cause the equipment to operate outside of the present design basis. Therefore the probability or consequences of a malfunction of equipment important to safety is not increased.

An analysis has been performed which evaluates the effects of this change on peak clad temperature. The previous LOCA analysis resulted in a peak clad temperature of 2030 degrees F. The calculation performed consistent with the conditions described in the amendment show that the peak clad temperatures rises to 2163 F, but remain within acceptable limits.

In conclusion, it is determined that no significant impact to safety will result from this proposed change. However, an Unreviewed Safety Question does exist due to the dependance on cavitation, as well as containment over pressure during the first ten minutes after an accident and the minor (0.3 foot) increase in ECCS pump NPSH margin.

Attachment 6

Cavitation Test Report, Bingham Pump Company, 1969

Correspondence between ComEd and Sulzer-Bingham Pump Co. regarding cavitation test report.

Discussion of test pump vibrations and comparison to Dresden pumps.

ENGINEERS AND MANUFACTURERS OF—CENTRIFUGAL PUMPS • HYDRAULIC TURBINES • VALVES • NUCLEAR COMPONENTS

Bingham-Willamette Company
A DIVISION OF GUY F. ATKINSON COMPANY

Main Offices and Factory — 2800 N. W. FRONT AVENUE • PORTLAND, OREGON 97210

November 2, 1976

PLEASE REPLY TO:

S/N-270425

Sargent and Lundy
55 East Monroe St.
Chicago, Illinois 60603

Attn: Mr. R. Goebbert
Mail Code 31-0-55

Reference: Commonwealth Edison Co.
Residual Heat Removal Pump
Serial Number 270425
Cavitation Test Report

Gentlemen:

Confirming our telephone conversation of this date, we are pleased to advise that the subject pump will operate at approximately 5800 gpm with 32.3' NPSH available for up to a period of 10 minutes without impairing future operation of the pump. After this period it will be possible to revert to normal operation for a period of approximately two (2) weeks.

For your review, we are attaching a complete copy of our Cavitation Test Report on this unit and you will note on Page 4 of 4 the various data taken under cavitation conditions. Also, you will note that on Page 3 these cavitation conditions were maintained for a period of one (1) hour.

Should you require any additional information in this regard, please let us know.

Very truly yours,

BINGHAM - WILLAMETTE COMPANY

V. L. GEORGE
DISTRICT SALES MANAGER

VLC/bw
Attachment

S-1

BINGHAM PUMP COMPANY

Engineers and Manufacturers of

HORIZONTAL & VERTICAL CENTRIFUGAL • TURBINE • AXIAL FLOW • WET RING VACUUM PUMPS

Main Offices and Factory •• 2800 N. W. FRONT AVENUE •• PORTLAND, OREGON 97210

REF: S.O. 280685
(Pumps Nos. 270419/26)

CAVITATION TEST REPORT

12x14x14-1/2 CVDS Pump

GENERAL ELECTRIC APED
QUAD CITIES I & II
RESIDUAL HEAT REMOVAL PUMPS
P.O. 205 H0386
OUR S.O. 270419/26

ATTACHED IS THE REPORT OF THE CAVITATION TEST RUN ON PUMP NO. 270425 ON MAY 15 & 16, 1969.

SUBJECT: CAVITATION TEST
12x14x14-1/2 CVDS Pumps

For this test, Pump No. 270425 was set up in a closed loop on the large suppression tank. All set ups, instrumentation and testing procedures were in strict accordance with the standards of Hydraulic Institute and ASME Ptc 8.2. Upon completion of witness and NPSH testing, pump was disassembled for inspection. This inspection revealed the following:

Shaft Sleeve: Excellent condition - only minor scratches from small particles which passed through separator.

Bearing: Excellent condition - only minor scratches as on sleeve.

Impeller: Excellent condition, except wear surfaces showed some evidence of wear from larger particles in water and lower wear surface showed one groove.

Seal: Excellent condition.

Wear Rings - Case: Excellent - slight wear only.

Shaft: Total runout less than 0.0005".

No damage was evident from this test.

Pictures were taken by G.E. personnel and pump was reassembled for cavitation test. This test consisted of setting the desired capacity and then reducing the suction pressure to various NPSH values until the impeller was cavitating. This was run at capacities of 4000, 5350, and 6000 GPM. Data taken at each point was suction and discharge pressure, capacity, power input, vibration, and water temperature. See curve No. 26992 and pages 1 & 2 of test data for results.

At completion of testing, impeller was removed and inspected by G.E. and Bingham personnel. There was no evidence of any damage to the impeller from cavitating. There was an indication of slight rubbing on bottom impeller wear surfaces. Nothing was evident on case ring.

Pictures of impeller were taken by G.E. and pump was reassembled for run-out cavitation test at 6000 GPM. For this test capacity was set at 6000 GPM. Suction pressure was then reduced until an NPSH value was reached that was below the cavitating point attained on the previous test. However, the discharge valve was opened to maintain 6000 GPM capacity, rather than let the capacity fall back 5%, as this was a more severe test of the pump. This condition was maintained for one hour. See attached data sheet, page 3, for test results.

At conclus

At conclusion of test, impeller was removed and inspected by G.E. and Bingham personnel. Again there was no sign of any cavitating damage to impeller. The only indication of wear appeared on bottom wear ring, which seemed to be slightly "duller" in color, which indicated possibly more rubbing. Bingham Inspection miked the diameter of this area of impeller and it was within drawing tolerance - 8.6070 G.E. personnel photographed impeller.

Pump was reassembled for second run-out cavitation test at 6000 GPM and suction pressure reduced to an NPSH value slightly below the guaranteed value (about 40.2 ft.). The suction pressure was then further lowered until the pump capacity fell off to 5700 GPM. This cavitating condition was maintained for one hour. At this time, the suction pressure was lowered again until the pump capacity dropped to 5400 GPM. The pump was run in this manner for 30 minutes. See attached data sheet, page 4, for test results.

Pump was disassembled for inspection. Condition of impeller was not changed - bottom impeller wear surface still miked 8.6070". Shaft sleeve and bearing in excellent condition, except for a few minor scratches.

Cavitation test was considered complete and pump was released for shipment.

All cavitation testing and inspection witnessed by A. Spivak. Other G.E. personnel present included Tom Day, Norm Peterson and Eldon Bingham.

Leo Garrow
Leo Garrow
Chief Test Engineer
Bingham Pump Company
May 22, 1969

Attached: Curve No.26992
Test Data Sheets 1 thru 4

(280 & 85)

BINGHAM PUMP CO. PORTLAND, OREGON

FORM 280

Pump size & type	STGS.	Customer	Cust. order no.	Bingham pump test
12 × 14 × 14½ CVDS	1	QUAD CITIES G.E. APED. - COMMONWEALTH EDISON	205-HO 386	T-270425-2

Condition	RPM	T. D. Head	G P M	Eff.	Sp. Gr.
Field					
Test					

Assembly	Eye dia	Eye area	Test motor	Job
	7⅜"	72.2 sq in	600 HP CUSTOMERS	

Discharge pipe	Suction pipe	R P M	Eff @ ½	@ ¾	@ 1¼	Tested by	Date
12 in.	14" in.	2600	@ ¾:	@ 1:	@ 1½:	RL/LAG	5-2-6?

Stg.	Imp. patt.	Vane	Imp. max dia.	Imp. test dia.
1	1213 CVDS-1	5	14½"	12 11/16"

Remarks: H_{atm} = 33.09 : 26.1 CURVE NO. 26792

H_v/h_g = 6.8/6000

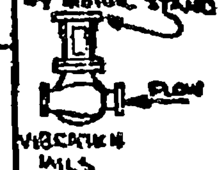
H_{elev} = 41.7

NPSH = H_s + H_{atm} + H_v/h_g − H_{vp} ± H_{elev}

Start: 10:30

Stop: 12:35

Vibration & TDR. of motor stand



Run no.	Speed R.P.M.	Suction HG COL	Suction feet of water	Discharge DWT 'B' PSI	Discharge feet of water	Gage to gage elev.	H_v 5.6 ft per 6000 G P M	Total dynamic head in feet of water	Capacity meter (1.1948) 16" VENTURI in. Hg	in. H_2O	G P M	Power F = 800 watts read		B.H.P. output	Water H.P.	Pump eff.	Vibration mils total	Vibration mils	Mils =	NPS @ ₵ imp
1		16.9	74	171		2.0	156.1	9.52		6000	595		591	236	40		71 / 0.8	37.5	54.0
2		3.3	59	156.1		2.0	154.8	9.52		6000	590		587	206	34.8	2.5 / 0.6		37.5	40.8
3		2.3	49	113.1		2.0	112.8	9.52		6000	555		581	171	23.6	4.0 / 1.0	77 / 1.0	37.3	39.6
4		0.8	46½	107.4		2.0	106.2	9.52		6000	567		584	161	27.6	46 / 0.95		37.3	38.1
5		-0.2	39½	91.2		2.0	93.2	9.52		6000	588		585	141	24.1	5 / 1.0		37.3	37.5
6	4																		
7	9	12.8	124	309.8		1.6	292.6	7.55		5348	618		613	403	65.2	2.0 / 0.8	85 / 1.4	26.3	49.1
8		-4.9	112	258.3		1.6	264.8	7.55		5348	610		606	356	59	1.5 / 1.1	88 / 1.5	26.2	31.3
9		-5.4	71	164		1.6	171	7.55		5348	555		551	221	41.9	4.1 / 1.0	91 / 1.7	36.0	30.6
10																			
11																			
12																			
13																			
14																			

BINGHAM PUMP CO. PORTLAND, OREGON (280285)

FORM 380 REV 5-14-66

Pump size & type	Stage	Customer	Cust. Order No	Bingham Pump Test
12 × 14 × 14½ CVDS	1	G.E. APED. COMMONWEALTH EDISON QUAD CITIES	205-HO 386	T-270425-2

Condition	RPM	T.D. Head	G.P.M.	Eff.	Sp. Gr.
Bills					
Test					

Assembly	Eye Dia.	Eye Area	Test Motor	Job
	7 1/6"	72.2 sq in	600 HP CUSTOMERS	

Discharge Pipe	Suction Pipe	R.P.M.	Eff. @ ¼: @ ½:	@ ¾: @ 1:	@ 1¼: @ 1½:	Tested by	Date
12" in.	14" in.	3600				RL/LAC	5-6-67

Cas.	Imp. Patt.	Vale	Imp. Max Dia.	Imp. Test Dia.
1	1213 CVDS-1	5	14½"	12 11/16"

REMARKS: H_{ATM} = 30.07 = 34.1 CURVE NO. 26192

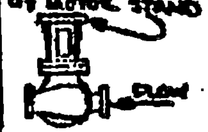
H_v/H_g = 6.8/4000

H_{ELEV} = 41.7

NPSH = $H_s + H_{ATM} + H_v/H_g - H_{VP} \pm H_{ELEV}$

Starts: Stops:

Vibration & Top. of Motor Stand



Suction: HG COL. Discharge: DWT "B" Gage to gage elev.: — H_v: 5.6 ft per 4000 G.P.M. Capacity: Meter f = 1948, 16" VENTURI Power: f = 800

Run No.	Speed R.P.M.	Suction (crossed out)	Suction Feet of Water	Discharge P.S.I.	Discharge Feet of Water	Gage to Gage Elev.	H_v G.P.M.	Total Dynamic Head in Feet of Water	Capacity In. Hg	Capacity (crossed out)	Capacity G.P.M.	Power Watts Read			B.H.P. Output	Water H.P.	Pump Eff. %	Vibration Mils Total / Filter Rdg.	Temp. °F / Vib. Temp.	H_2O °	NPSH @ % NPF
1			7.6	216	[illegible]		.09	491.6	4.22		4000	6.15			611	497	81.3	1.8 / 0.6	94 / 1.8	35.1	42.7
2			-6.3	203	4.7		.09	478.1	4.22		4000	6.03			604	483	79.9	1.6 / 0.6	98 / 2.1	34.8	26.5
3			-12.3	196	452.5		.09	465.7	4.22		4000	6.08			604	470	77.9	1.3 / 0.8		34.8	22.5
4			-13.0	175	404		.09	417.9	4.22		4000	596			590	422	71.5	1.5 / 1.1	100 / 2.2	34.7	21.7
5			-13.3	off					4.05		3920									34.7	21.4
6	(4 03)																				

(260685)

BINGHAM PUMP CO. PORTLAND, OREGON

Pump size & type	Stgs.	Customer	Cust. order no.	Bingham pump test
12 × 14 × 14½ CVDS	1	QUAD CITIES G.E. APED. COMMONWEALTH EDISON	205-HO 386	T-270425-3

Condition	RPM	T. D. Head	G P M	Eff.	Sp. Gr.
Field					
Test					

Assembly: — Eye dia: 7⅞ — Eye area: 72.2 sq in — Test motor: 600 HP CUSTOMERS — Job:

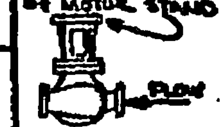
Discharge pipe: 12 in — Suction pipe: 14" in — R P M: 3600 — Eff. @ ½: @ ¾: @ 1½: @ 1: @ 1¼: — Tested by: RL/LAG — Date: 5-8-6[illegible]

Stg.	Imp. patt.	Vane	Imp. max. dia.	Imp. test dia.
1	1213 CVDS-1	5	14½"	12 11/16"

Remarks: H_{ATM} = 30.07 = 34.1 CURVE NO.
H_v/H_g = 68/10,000
H_{ELEV} = 41.7
NPSH = H_{ATM} + H_v/H_g − H_{VP} ± H_{ELEV}

Start: 5:03 P
Stop: 6:10 P

Vibration @ top of motor stand



Meter: f = 1948, 16" VENTURI — Power: f = 800 — H_v 5.6 ft per 10000 G.P.M.

Run No.	Speed R.P.M.	Suction HG COL (in.)	Suction Feet of water	Discharge DWT 'B' PSI	Discharge Feet of water	Gage to gage elev.	H_v	Total dynamic head in feet of water	Capacity In. HG	Capacity G.P.M.	Power Watts read	B.H.P. output	Water H.P.	Pump eff. %	Vibration mils Total / Elec.	Vibration Temp °F / VP	$H_{\Delta} =$	NPS @ ft. M
1			-0.1	42	97		2.0	99.1	9.52	6000	587	582	150	25.8	80 / 1.0	74 / 1.0	37.3	37.[illegible]
2			-0.2	41	94.7		2.0	96.9	9.52	6000	585	581	147	25.3	70 / 0.9	78 / 1.1	37.2	37.[illegible]
3			-0.1	40½	93.5		2.0	95.6	9.52	6000	583	580	145	25	80 / 1.0	80 / 1.2	37.1	37.[illegible]
4			-0.1	37½	86.5		2.0	88.6	9.37	5950	582	579	133	23	7.0 / 0.9	88 / 1.5	36.7	36.[illegible]
5																		
6	(S)																	
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		

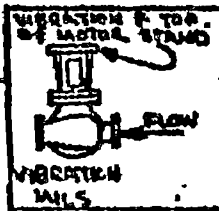
BINGHAM PUMP PORTLAND, OREGON (280685)

Pump size & type	Stgs.	Customer	Cust. order no.	Bingham pump test
2 - 14 × 14½ CVDS	1	QUAD CITIES G.E. APED. COMMONWEALTH EDISON	205-HO 386	T-270425-4

Assembly	Eye dia	Eye area	Test motor	Job
	7⅜"	72.2 sq. in	600 HP CUSTOMERS	

Discharge pipe	Suction pipe	R.P.M.	Tested by	Date
12"	14"	3600	RL/LAG	5-9-69

Imp. patt.	Vane	Imp. max. dia.	Imp. test dia.	Remarks	Start	Stop
1213 CVDS-1	5	14½"	12 11/16"	Hatm = 29.28 = 24.8 CURVE NO. Hvps = 68/1000 Helev = 41.7 NPSH = Hs + Ha + Hv²/2g − Hvp & Helev	10:55 AM	1:00 PM

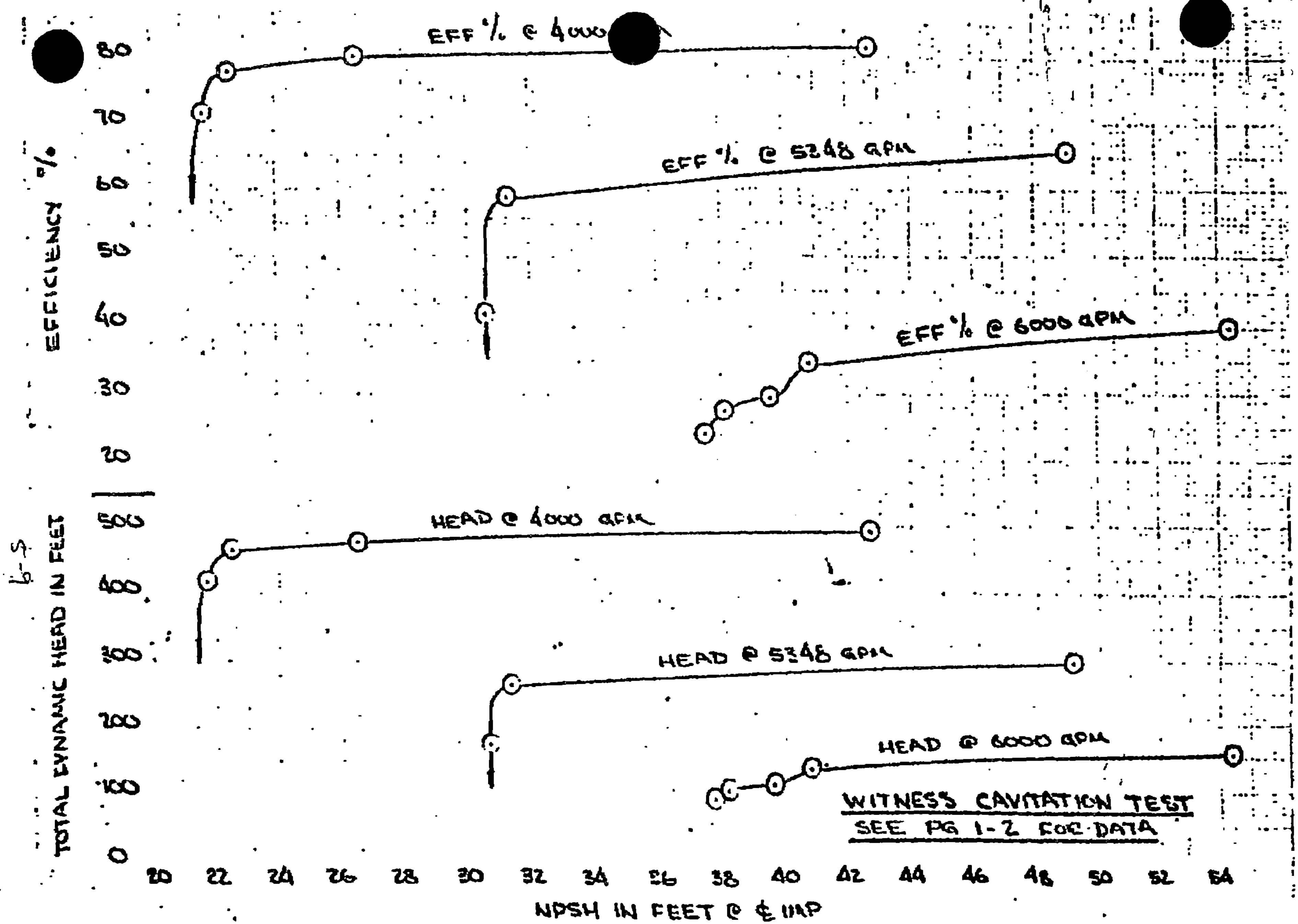


Speed R.P.M.	Suction HG COL feet of water	Discharge DWT 'B' PSI	Discharge feet of water	Gage to gage elev.	H_v 5.6 ft per 1000 GPM	Total dynamic head in feet of water	Capacity meter 1-1948 16" VENTURI in. HG	G.P.M.	Power #=800 watts read			B.H.P. output	Water H.P.	Pump eff. %	Vibration mils total / filter	Vibration	Hs	NPSH @ imp	
	+2.2	53½	123.7		2.0	123.4	9.52	6000	572			585	187	31.8	/	62 / 0.6	38.0	40.3	11
	-2.9	46½	107.4		1.5	112.1	8.6	5700	570			561	163	28.7	8.5 / 1.1	63 / 0.6	37.7	33.8	11
	-2.4	46½	107.4		1.5	113.4	8.6	5700	517			562	163	29	8.0 / 1.0	66 / 0.7	37.6	34.0	11
	-2.2	46½	107.4		1.6	113.8	8.6	5700	565			561	164	29.2	8.0 / 1.0	69 / 0.8	37.5	34.3	12
	-2.0	47	108.5		1.8	112.3	8.6	5700	565			561	163	29.1	8.0 / 1.0	73 / 0.9	37.4	34.4	12
	-2.9	46½	107.4		1.8	112.1	8.6	5700	565			561	161	28.8	8.0 / 1.0	75 / 1.0	37.3	34.4	12
			At 12:30 lowered NPSH (suction pressure) until capacity dropped to 5410 GPM																
	-4.6	40½	93.5		1.6	99.7	7.7	5400	525			520	136	26.1	8.0 / 1.0	75 / 1.0	37.1	32.5	12
	-4.5	40½	93.5		1.6	99.6	7.7	5400	520			515	136	26.4	7.0 / 0.9	78 / 1.1	37.0	32.5	12
	-4.3	40½	93.5		1.6	99.4	7.7	5400	520			515	136	26.3	7.0 / 1.0	80 / 1.2	36.9	32.6	12

WITNESS TEST RUN @ PORTLAND, OREGON MAY 9, 1969

A. SPIVAK For G.E. APED

[signature] For Bingham Pump Co



GENERAL ELECTRIC CO AFED COMMONWEALTH EDISON CO. QUAD CITIES, RES. HT. REMOVAL ITEM 1.02 PUMP NO. 270425	CHARACTERISTIC CURVE SHEET **BINGHAM PUMP Co.** 2800 N. W. FRONT AVE. PORTLAND OREGON	IMPELLER MAX. DIA. 14 1/2 MIN. DIA. EYE AREA 72.2 SQ. IN.	12 x 14 x 14 1/2 CVDS PUMP DIA. IMPELLER 12 11/16 · IMPELLER PATT. 1212 CVDS-1 · 3576 R.P.M. N.P.S.H. REQUIRED · REFERENCE · CURVE No. 26992

November 1, 1996

To: Don Spencer
Sulzer-Bingham Pumps

Subject: S/B Pumps 12x14x14.5 (LPCI) and 12x16x14.5 (CS) CVDS
Flow Delivery Under Full Cavitation Conditions

Reference: "Cavitation Test Report - 12x14x14.5 CVDS Pump", Bingham Pump Co. Report dated May 22, 1969

ComEd is currently preparing an evaluation of the Dresden Station Low Pressure Core Injection (LPCI) and Core Spray (CS) systems under post-accident conditions. A portion of this work requires estimating the LPCI/CS pump flows under reduced Net Positive Suction Head (NPSH) conditions.

As part of our research, Reference 1 was located and has been reviewed. Based on this review, ComEd is requesting a discussion from Sulzer-Bingham addressing the following:

1. Published NPSH Required (NPSHR) curves for these pumps are provided on the vendor pump curves. These NPSHR curves are normally based on a 3% reduction in pump developed head. The data in Reference 1 indicates that the pump remains stable for several feet beyond the NPSHR value, which is expected, before the pump head completely collapses. Please include a brief discussion of this.

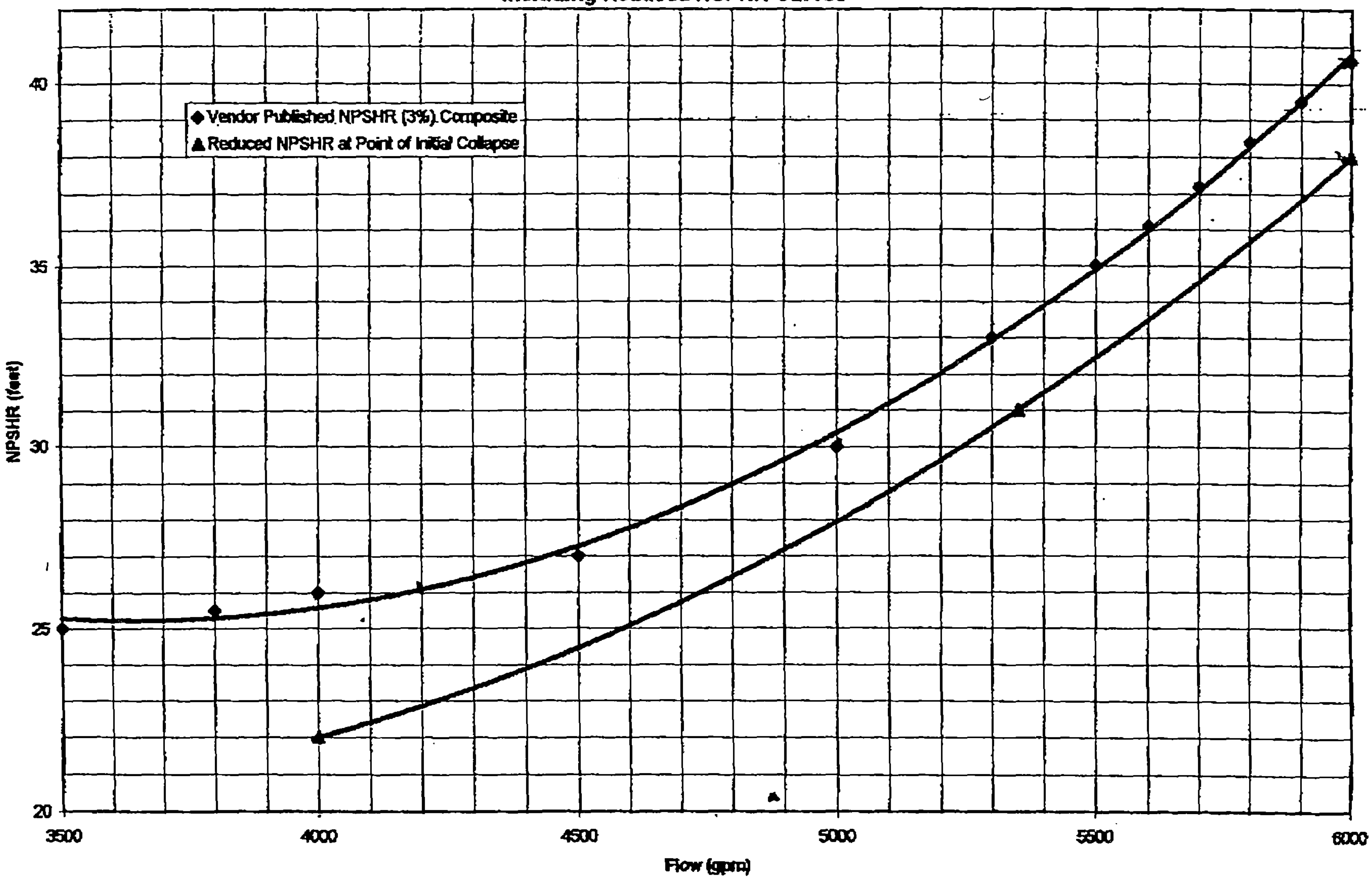
2. The NPSH conditions that can exist post-accident may result in full cavitation of the pump, i.e., complete degradation of pump developed head. It is this point that we are trying to identify in our evaluation. Given a known NPSH Available (NPSHA) that is less than the published NPSHR, we would like to estimate the flow at which the pump will operate in the system. Would it be correct to use the point of initial collapse of the pump developed head (the "bend of the knee") from the data presented in Reference 1?

3. Three separate cavitation tests are presented in Reference 1, at pump flows of 4000, 5350 and 6000 gpm. Utilizing the NPSH values at initial collapse for these flows, we have developed a reduced NPSHR curve for these pumps that represents the point at which full cavitation has been achieved. Please review this curve and offer any comments.

The ultimate goal is to ensure that the methodology we are using to estimate LPCI/Core Spray pump flow post-accident is sound. Any additional comments you may have on this subject would be appreciated.

Harry Balas
Pump Specialist
Commonwealth Edison

LPCI/Core Spray NPSH Required Composite Curve
Including Reduced NSPHR Curves



SULZER BINGHAM PUMPS INC.
2800 NW Front Avenue
P.O. Box 10247
Portland, Oregon USA 97210
Phone: 001-503-226-5200
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TELEFAX

DATE:	01 Nov. 1996	c:	
TO:	Harry Palas	Fax:	815-942-2920 x3103
		Phone:	
FROM:	Don Spencer	Return Fax:	503-226-5568
		Phone:	5418

SUBJECT: Comments To Quad Cities LPCS/CS Pump NPSH Position

I have reviewed your note and our test report on the above subject and am able to comment as follows. My comments mirror the order of statements in your Nov. 1, 1996 fax to me.

1. Industry standard practice utilizes data from a NPSH test that establishes performance based on a 3% head drop. The testing performed by SBPI for the subject pump produced data showing performance for fully degraded suction conditions. This test also investigated pump internal condition after hydraulic limits had been established. It is entirely appropriate to predict pump performance from the fully cavitating test, rather than limit predictions based solely on a less stringent test. The one area where caution should be employed, though, is related to how the pump performs as the suction pressure is reduced. This impeller design incorporates a large eye which can produce flow stability variations at low suction pressures. However, under the scenario that you are reviewing, this should not present short term (less than 6 months) operability concerns.

2. Yes, it is appropriate to use the point of initiation of total head degradation to predict reduced NPSH behavior. In fact, this method would be considered as providing a more accurate prediction of the suction pressure at which fully cavitating operation would occur.

3. The curve you faxed to me depicting both 3% and "total head degradation" performance appears to be reasonable based on the data collected during the test conducted for the 12x14x14.5 CVDS pump on May 15 and 16, 1969.

D Spencer

Don Spencer

PUMP VIBRATIONS: CAVITATION TEST PUMP VS. DRESDEN PUMPS

The pump vibrations experienced during the cavitation testing did not produce any measurable pump degradation. The particular pump tested by the OEM in 1969 was serial number 270425, which is currently installed as the Quad Cities 2A RHR pump. A comparison of the recent vibration history of this pump with the Dresden LPCI and Core Spray pumps indicates that there is little difference between the pumps, with all pumps operating at 0.1-0.2 in/sec, unfiltered, peak-to-peak. Therefore, it is expected that the Dresden LPCI and Core Spray pumps will perform similar to the tested pump, i.e. no vibration-related pump degradation due to cavitation for a period of at least one hour.