Calculation No. ATD-0117
Revision 0

Project No. 9012-26
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Date: May 11, 1992

Evaluation of NPSH requirements for HPCS, RHR, and RCIC pumps and backpressure limitations of RCIC turbine following station blackout

COMMONWEALTH EDISON COMPANY

LASALLE COUNTY STATION

UNITS 1 & 2

WIN 1218
SAFETY RELATED

Prepared By:	Adam Landry	Date:	5/11/92
Prepared By:	[illegible]	Date.	5-11-92
Reviewed By:	[illegible]	Date:	5-11-92
Approved By:	Robert J [illegible]	Date:	5-11-92

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3.0 Purpose & Scope

The purpose of this calculation is to verify that following station blackout, NPSH requirements for RCIC, HPCS, and RHR pumps are satisfied, and that the RCIC turbine backpressure does not exceed the turbine trip limit.

To determine if the NPSH requirements of the pumps will be met, the highest possible suppression pool temperature, the lowest possible chamber pressure, and the lowest possible pool level following the station blackout are considered.

To determine if the RCIC turbine will trip due to high backpressure, the highest possible chamber pressure, the highest possible pool level, and the highest possible RCIC turbine exhaust flow following the station blackout are considered.

4.0 Design Input

1. The initial conditions of the suppression pool are taken from Reference 7.

2. Conservative conditions of the suppression pool following station blackout are taken from Reference 1a.

3. Conservative conditions of the drywell following station blackout are taken from Reference 1b.

4. Minimum suppression pool water levels following station blackout are taken from Reference 1d.

5. Required net positive suction head values of 1.5 feet for the HPCS pump at a flow of 6250 GPM, 11.5 feet for the RHR pump at a flow of 7200 GPM, 15 feet for the RCIC pump at a flow of 600 GPM, and the limiting conditions to meet these NPSH requirements are taken from Reference 1c.

6. The layout of the RCIC turbine exhaust piping is provided in Reference 2.

7. Pipe size and schedule for the RCIC turbine exhaust piping are taken from References 4 and 5.

8. The equations for velocity in a pipe and for Reynold's number are taken from Reference 10.

9. The equations for ideal gases and relative humidity and the values for the gas constants are taken from Reference 10.

10. Values for the losses associated with valves and fittings located in the RCIC turbine exhaust piping are provided in Reference 6b and Reference 8.

11. The values of temperature, pressure, and specific volume for saturated liquid water and saturated water vapor are taken from Reference 9. Where necessary, the values have been determined by linearly interpolating between the values in the table.

12. The values of internal energy for saturated liquid water and saturated water vapor are taken from Reference 11.

13. The values for the viscosity of water and the friction factor, f, are taken from Reference 3.

14. The equation for frictional losses is taken from Reference 6a.

15. The setpoint for RCIC turbine trip due to high backpressure is 25 psig and is taken from Reference 13.

5.0 Assumptions

1. Both the drywell and the suppression chamber are assumed to be leak-tight.

2. The temperature of the suppression chamber is assumed to be the same as the pool temperature, and no credit is taken for heat transfer to the concrete and steel structures in the airspace.

3. To determine a low suppression chamber pressure for the evaluation of the pumps' NPSH requirements, pressure increases due to pool evaporation and drywell venting are not considered.

4. To determine a high suppression chamber pressure for the RCIC turbine backpressure analysis, 100% relative humidity is assumed.

5. To determine an increase in pressure of the suppression chamber due to the venting from the drywell, an instanteous mass transfer of a homogeneous mixture of air and water vapor is assumed to occur to balance the pressure between the drywell and the suppression chamber.

6. In the RCIC turbine backpressure analysis, all steam vented from the drywell to the suppression pool is assumed to condense.

7. In the RCIC backpressure analysis, it is assumed that after the RPV has been depressurized to 165 psia, the RPV pressure will be maintained between 165 psia and 200 psia. Also, since RCIC turbine flow decreases as RPV pressure decreases, an exhaust flow is determined at an RPV pressure of 200 psia by linear interpolation of the exhaust flow versus RPV pressure data in Reference 1a.

6.0 Approach

To determine if the net positive suction head requirements for the HPCS, RHR, and RCIC pumps will be met following a station blackout, the worst case values of temperature and water level in the suppression pool and pressure in the suppression chamber are determined. This includes the lowest water level the pool would be expected to reach, the highest possible pool temperature, and the lowest possible suppression chamber pressure. The limiting condition of these parameters such that the NPSH requirements of the pumps are met and that flashing does not occur in the suction piping are provided in Reference 1c. Flashing occurs in the suction piping when the pressure of the water drops below its vapor pressure.

Worst case conditions for NPSH of the RCIC pump are taken four (4) hours and fifteen (15) minutes following station blackout with the RCIC system used for decay heat removal. After this time, RPV pressure is decreased, and steam flow to the RCIC turbine is stopped, thus shutting off the RCIC pump. Worst case conditions for the HPCS and RHR pumps are taken four (4) hours and fifteen (15) minutes following station blackout with the HPCS system used for decay heat removal (Reference 1a). At this time, pool cooling becomes available and the RHR pumps are started.

Reference 1a provides the maximum pool temperatures, and Reference 1d provides the low water levels. The pressure in the suppression chamber is calculated based on the temperature in the pool and air behaving as an ideal gas. To be conservative, an increase in suppression chamber pressure caused by pool evaporation and drywell venting is not considered. If the suppression chamber pressure is less than the vapor pressure corresponding to the pool temperature, boiling has occurred. The conditions in the pool are then balanced to create thermodynamic equilibrium.

Reference 1c provides the limiting conditions of pool level and temperature and chamber pressure. The worst case values are then compared with the limiting conditions to determine in NPSH requirements are met.

To determine if the RCIC turbine will trip due to high backpressure, the pressure in the suppression chamber and the pressure drop of the exhaust through the pipe and the sparger must be determined. To be conservative, the maximum possible suppression chamber pressure is calculated, the maximum water level is determined, and the maximum RCIC turbine exhaust flow based on the pressure in the reactor pressure vessel is used to calculate the pressure drop.

The suppression chamber pressure is maximized by conservatively assuming the drywell vents to the suppression chamber, and that a minimum pressure differential will exist. The pressure differential is based on the hydrostatic pressure that has to be overcome before the drywell can vent into the wetwell.

The maximum water level is calculated by using the conservative results of Reference 1a which maximizes steam and leakage flow into the suppression pool.

If the suppression chamber pressure and the pressure drop of the exhaust through the pipe and sparger are less than RCIC turbine backpressure trip setpoint, the turbine will not trip during the station blackout due to high backpressure.

7.0 Calculations

For details, see Attachment - 10.1 - Hand Calculations

Evaluation of the RCIC Pump NPSH requirements:

$NPSH_R$ (Pump Inlet Centerline)	= 15 Feet
Flow Rate	= 600 GPM
Maximum Pool Temperature	= 217.1°F
Minimum Pool Level	= 695'-0"
Minimum Chamber Pressure	= 19.1 psia
$NPSH_A$ (Pump Inlet Centerline)	= 22.6 Feet
Minimum Water Pressure - Vapor Pressure	= 9.8 Feet

Evaluation of the HPCS Pump NPSH Requirements:

$NPSH_R$ (Pump Inlet Centerline)	= 1.5 Feet
Flow Rate	= 6250 GPM
Maximum Pool Temperature	= 234.2°F
Minimum Pool Level	= 695'-0"
Minimum Chamber Pressure	= 22.5 psia
$NPSH_A$ (Pump Inlet Centerline)	= 16.5 Feet
Minimum Water Pressure - Vapor Pressure	= 9.2 Feet

Evaluation of the RHR Pump NPSH Requirements:

$NPSH_R$ (Pump Inlet Centerline)	= 11.5 Feet
Flow Rate	= 7200 GPM
Maximum Pool Temperature	= 234.2°F
Minimum Pool Level	= 695'-0"
Minimum Chamber Pressure	= 22.5 psia
$NPSH_A$ (Pump Inlet Centerline)	= 16.2 Feet
Minimum Water Pressure - Vapor Pressure	= 9.2 Feet

Evaluation of the RCIC Turbine Backpressure:

4 Hours Following Station Blackout

RCIC Turbine Backpressure Trip Setpoint	= 25 psig
Maximum Chamber Pressure	= 19.9 psig
Maximum Water Level	= 700'-2"
RCIC Turbine Exhaust Flow	= 8910 lb/hr
Friction Losses Through Exhaust Pipe	= 0.21 psi
Pressure Drop Through Sparger	= 2.95 psi
Maximum RCIC Turbine Backpressure	= 23.1 psig

4 Hours and 15 Minutes Following Station Blackout

RCIC Turbine Backpressure Trip Setpoint	= 25 psig
Maximum Chamber Pressure	= 21.3 psig
Maximum Water Level	= 700'-4"
RCIC Turbine Exhaust Flow	= 8910 lb/hr
Friction Losses Through Exhaust Pipe	= 0.21 psi
Pressure Drop Through Sparger	= 3.02 psi
Maximum RCIC Turbine Backpressure	= 24.5 psig

8.0 Results

NPSH requirements for the RCIC, HPCS, and RHR pumps will be met following a station blackout. The required NPSH for the RCIC pump at 600 GPM is 15 feet, and the available NPSH is 22.6 feet. The required NPSH for the HPCS pump at 6250 GPM is 1.5 feet, and the available NPSH is 16.5 feet. The required NPSH for the RHR pump at 7200 GPM is 11.5 feet, and the available NPSH is 16.2 feet.

The RCIC turbine will not trip due to high back pressure following a station blackout. The backpressure trip setpoint is 25 psig, and the maximum calculated backpressure is 23.1 psig fours hours following station blackout and 24.5 psig fours hours and 15 minutes following station blackout.

9.0 References

1. Sargent & Lundy Calculations:

   a. 3C7-0390-001, Revision 1, 5-11-92, Suppression Pool Temperature Transient Following Station Blackout

   b. 3C7-0390-002, Revision 1, 5-11-92, Drywell Temperature Transient Following Station Blackout

   c. ATD-0070, Revision 1, 3-25-92, Limiting Operating Conditions for Net Positive Suction Head (NPSH) for HPCS, LPCS, RCIC, and RHR Pumps

   d. 3C7-0189-001, Revision 2, 5-21-90, LaSalle Station Blackout Condensate Inventory Copying Assessment

2. Sargent & Lundy Piping Drawings:

   a. M-844, Sheet 1, Revision AT, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 1

   b. M-844, Sheet 2, Revision AF, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 1

   c. M-844, Sheet 3, Revision AC, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 1

   d. M-844, Sheet 4, Revision AK, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 1

   e. M-844, Sheet 5, Revision AG, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 1

   f. M-944, Sheet 1, Revision W, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 2

   g. M-944, Sheet 2, Revision P, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 2

   h. M-944, Sheet 3, Revision R, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 2

i. M-944, Sheet 4, Revision V, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 2

j. M-944, Sheet 5, Revision T, Reactor Core Isolation Coolant Piping, LaSalle County Station, Unit 2

3. LaSalle County Station, Units 1 & 2, Sargent & Lundy Mechanical Drawing List, 4-03-92

4. Sargent & Lundy Line List Drawings:

   a. M-3101, Revision AL, Reactor Core Isolation Coolant System Line List, LaSalle County Station, Unit 1

   b. M-3147, Revision AG, Reactor Core Isolation Coolant System Line List, LaSalle County Station, Unit 2

5. Piping Design Table "105LS" Revision D, LaSalle County Station

6. Sargent & Lundy Mechanical Standards:

   a. MES-2.10, Revision F, Pipe Sizing Data

   b. MES-2.16, Revision E, Pressure Drop: Fittings, Valves, & Discontinuities

   c. MAS-22, Revision E, Preparation, Review & Approval of Mechanical Department Design Calculations

7. LaSalle County Station UFSAR, Volume V, Chapter 6, Engineered Safety Features, Revision 8, 4-17-92.

8. Crane Technical Paper 410, 1988 Printing

9. ASME Steam Tables, 1967 Edition

10. Marks' Standard Handbook for Mechanical Engineers, Ninth Edition

11. Fundamentals of Classical Thermodynamics, 3rd Edition, Wylen & Sonntag, 1985

12. Sargent & Lundy Instrument Data Sheet PS00-C, Revision X, LaSalle County Station, Units 1 & 2

13. Sargent & Lundy Instrument Data Sheet PS248, Revision A, Pressure Switches, LaSalle County Station, Units 1 & 2

14. User's Manual for Compare/MODT-PC Computer Program (03.7.322-1.0), 1-28-92

15. Sargent & Lundy Structure Drawing S-325, Revision P, Reactor Containment Liner Plate Cross Section, LaSalle County Station, Unit 1

16. LaSalle County Station, Units 1 & 2, Sargent & Lundy Structural Drawing List, 4-03-92

17. Mechanical Engineering Reference Manual, Michael R. Lindeburg, 8th Edition, 1990.

10.0 Attachments

10.1 Hand Calculations (39 Pages)

REVIEW METHOD SHEET

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This calculation has been reviewed by me according to the method(s) checked below.

1. Computer Aided Calculations

a ✓	Review to determine that the computer program(s) has been validated and documented, is suitable to the problem being analyzed, and that the calculation contains all necessary information for reconstruction at a later date.
b	Review to determine that the input data as specified for program execution is consistent with the design input, correctly defines the problem for the computer algorithm and is sufficiently accurate to produce results within any numerical limitations of the program.
c	Review to verify that the results obtained from the program are correct and within stated assumptions and limitations of the program and are consistent with the input.
d	Review validation documentation for temporary changes to listed, or developmental, or unique single application programs, to assure that methods used adequately validate the program for the intended application.
e	Review of code input only, since the computer program has sufficient history of use at Sargent & Lundy in similar calculations.
f	Review arithmetic necessary to prepare code input data.
g	Other:

2. Hand Prepared Design Calculations

a ✓	Detailed review of the original calculations.
b	Review by an alternate, simplified, or approximate method of calculation.
c	Review of a representative sample of repetitive calculations.
d	Review of the calculation against a similar calculation previously performed.

3. Revisions

a	Editorial changes only.
b	Elimination of unapproved input data without altering calculated results
c	Other:

4. Other

Reviewer: [signature] Date 5-11-92

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ATTACHMENT 10.1

HAND CALCULATIONS

Form. GQ-3.08.1 Rev. 2

M3553.001 6-90

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7.0 CALCULATIONS

7.1 INITIAL POOL CONDITIONS

7.2 EVALUATION OF NPSH REQUIREMENTS FOR RCIC PUMP

7.3 EVALUATION OF NPSH REQUIREMENTS FOR HPCS AND RHR PUMPS

7.4 MAXIMUM PRESSURE DIFFERENTIAL WHERE VENTING CAN NOT OCCUR BETWEEN DRYWELL AND WETWELL WITH RCIC SYSTEM OPERATION

7.5 MAXIMUM SUPPRESSION CHAMBER PRESSURE 4 HOURS FOLLOWING SBO WITH RCIC SYSTEM OPERATION

7.6 MAXIMUM SUPPRESSION CHAMBER CONDITIONS 4 HOURS & 15 MINUTES FOLLOWING SBO WITH RCIC SYSTEM OPERATION

7.7 MAXIMUM POOL LEVEL FOLLOWING SBO WITH RCIC SYSTEM OPERATION

7.8 FRICTION LOSSES THROUGH EXHAUST PIPING

7.9 PRESSURE DROP THROUGH EXHAUST PIPE SPARGER

7.10 RCIC TURBINE BACKPRESSURE CALCULATIONS BASED ON WORST CASE SUPPRESSION CHAMBER CONDITIONS

7.11 RCIC TURBINE BACKPRESSURE CALCULATION BASED ON WORST CASE EXHAUST FLOW

Form GO 3.08.1 Rev. 2

	REF
7.1 DETERMINE INITIAL MASSES OF AIR AND WATER VAPOR IN SUPPRESSION CHAMBER	
MINIMUM POOL WATER VOLUME = 128,800 FT^3 (TABLE 6.2-3, SH 2)	7
CHAMBER PRESSURE = 15.45 PSIA = 0.75 psig	7
CHAMBER TEMPERATURE = 105°F	1a
RELATIVE HUMIDITY = 100%	7
CHAMBER FREE VOLUME = 165,100 FT^3 (TABLE 6.2-1, SH 1)	7
TOTAL SUPPRESSION CHAMBER VOLUME	
$V_W = 128,800 + 165,100 = 293,900\ FT^3$	
AT $T = 105°F$	
$P_{SAT} = 1.10$ PSIA	9
AT R.H. = 100%	
$P_V = P_{SAT}$	10
$P_V = 1.10$ PSIA	
$P_a = P_{air} + P_v$ = CHAMBER PRESSURE	10
$P_{air} = P_a - P_v$	
$= 15.45 - 1.10$	
$= 14.35$ PSIA	
FIND MASS OF WATER VAPOR ORIGINALLY IN AIR SPACE	
AT RH = 100%	
$\rho_v = \rho_{SAT}$	10

REF

At T = 105°F

$\rho_{SAT} = 0.00328\ lb/ft^3$ 9

$\rho_v = 0.00328\ lb/ft^3$

$m_v = V\rho_v$

$= (165,100)(.00328)$

$= \underline{542\ lb}$

FIND MASS OF AIR ORIGINALLY IN AIR SPACE

$m_{air} = \frac{P_{air} V}{R_{air} T}$ 10

$R_{air} = 53.3\ \frac{ft \cdot lbf}{lbm\,°R}$ 10

$m_{air} = \frac{(144)(14.35)(165,100)}{(53.3)(460+105)}$

$= \underline{11,329\ lb}$

REF

7.2 DETERMINE WORST CASE CONDITIONS IN WETWELL TO EVALUATE IF NPSH REQUIREMENTS FOR THE RCIC PUMP WILL BE MET FOLLOWING A 4-HR STATION BLACKOUT AND A 15 MINUTE PERIOD BEFORE POOL COOLING BECOMES AVAILABLE — 1a

MAX POOL TEMPERATURE = 217.1 °F — 1a

MIN POOL LEVEL = 695'-0" — 1d

CALCULATE INCREASE IN SUPPRESSION CHAMBER PRESSURE DUE TO TEMPERATURE RISE IN WETWELL.

TO BE CONSERVATIVE, EVAPORATION AND DRYWELL VENTING ARE NOT CONSIDERED

POOL CONDITION AT t = 4hrs & 15 MIN (w/LEAKAGES) — 1a

$t = 15298.7$ SEC

$T_{WATER} = 217.1°F$

$m_{WATER} = 7.960 \times 10^6$ lbm

$\bar{V}_{217.1°F} = 0.016755$ ft³/lb — 9

$V_{WATER} = (7.960 \times 10^6)(.016755)$

$= 133,370$ FT³

$V_a = V_W - V_{WATER}$

$= 293,900 - 133,370$

$= 160,530$ FT³ (CHAMBER FREE VOLUME)

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AIR TEMPERATURE IS ASSUMED TO BE SAME AS POOL TEMPERATURE

$$P_{air} = \frac{m_{air} R_{air} T_a}{V_a}$$ 10

$$= \frac{(1329)(53.3)(460+217.1)}{(144)(160,530)}$$

$$= \underline{17.7 \text{ psia}}$$

$$P_v = \frac{m_v R_v T_a}{V_a}$$ 10

$$R_v \cong 85.8 \ \frac{ft \cdot lbf}{lbm\,°R}$$ 17

$$P_v = \frac{(542)(85.8)(460+217.1)}{(144)(160530)}$$

$$= \underline{1.4 \text{ psia}}$$

$$P_a = P_{air} + P_v$$
$$= 17.7 + 1.4$$
$$= \underline{19.1 \text{ psia}}$$

SUPPRESSION CHAMBER PRESSURE = 19.1 PSIA

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TEMPERATURE OF SATURATED WATER VAPOR AT P = 19.1 psia IS 225.5 °F. 9

SINCE THE POOL TEMPERATURE IS 217.[illegible] °F, THE POOL IS SUB-COOLED.

THE LOWEST WATER LEVEL WHERE SATURATED WATER CONDITIONS WILL RESULT IN MEETING NPSH REQUIREMENTS FOR THE RCIC PUMP IS DETERMINED BY USING THE VALIDATED COMPUTER SPREADSHEET USED IN REFERENCE 1c.

THE RESULTS FROM THE SPREADSHEET SHOW THAT NPSH REQUIREMENTS FOR THE RCIC PUMP ARE MET WITH SATURATION CONDITIONS AT A POOL LEVEL OF ABOUT 694'-4". AT POOL LEVELS HIGHER THAN THIS LEVEL, NPSH REQUIREMENTS WILL STILL BE MET IF THE WATER IS AT SATURATED CONDITIONS, AT POOL LEVELS LOWER THAN THIS LEVEL, SUB-COOLED WATER CONDITIONS WILL BE NECESSARY TO MEET NPSH REQUIREMENTS.

THE RESULTS FROM THE SPREADSHEET ALSO SHOW THAT AT A POOL TEMPERATURE OF 217.1 °F, A POOL LEVEL OF 695'-0", AND A CHAMBER PRESSURE OF 19.1 psia, FLASHING DOES NOT OCCUR IN THE SUCTION PIPING, AND THE AVAILABLE NPSH FOR THE PUMP IS 22.6 FEET AT THE PUMP INLET CENTERLINE, WHICH IS MORE THAN THE REQUIRED NPSH OF 15 FEET.

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REACTOR CORE ISOLATION COOLING PUMP LIMITING OPERATING CONDITIONS

FLOW RATE	600 GPM	NPSHr	15.0 FEET
PIPE ID	7.981 INCHES	SUCTION LINE L/D	238.89
VELOCITY	3.85 FT/SEC	SUCTION LINE K	0.480
PUMP INLET ELEVATION	676.06 FEET	STRAINER LOSSES	0.6 PSI
STRAINER ELEVATION	687.50 FEET	CHECK VALVE LOSSES	0.8C FEET
TOP OF PIPE ELEVATION	688.83 FEET		

POOL LEVEL (FEET)	CHAMBER PRESS (PSIG)	POOL TEMP (F)	CONV. FACTOR (FT/PSI)	VAPOR PRESS (PSIA)	DENSITY (LB/FT^3)	VISCOSITY (CENTIPOISE)	REYNOLD'S NUMBER	FRICTION FACTOR	SUCTION LINE LOSSES (FEET)	VAPOR PRESS (FEET)	STATIC HEAD (FEET)	CHAMBER PRESS (FEET)	NPSHa AT PUMP (FEET)	NPSHa MIN IN SYSTEM (FEET)
695.00	4.4	217.1	2.412	16.25	59.70	0.275	8.26E+05	0.0152	3.19	39.20	18.94	46.1	22.8	9.8
694.30	30.7	275.0	2.479	45.41	58.09	0.205	1.08E+06	0.0150	3.22	112.57	18.24	112.5	15.0	2.2
694.30	30.0	274.0	2.477	44.70	58.12	0.206	1.07E+06	0.0150	3.22	110.72	18.24	110.7	15.0	2.2
694.30	20.0	258.8	2.459	34.70	58.55	0.220	1.01E+06	0.0150	3.21	85.33	18.24	85.3	15.0	2.2
694.30	10.0	239.4	2.435	24.70	59.12	0.243	9.25E+05	0.0151	3.20	60.14	18.24	60.1	15.0	2.3
694.30	0.0	212.0	2.407	14.70	59.83	0.283	8.04E+05	0.0152	3.19	35.38	18.24	35.4	15.0	2.3

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7.3 DETERMINE WORST CASE CONDITIONS IN WETWELL TO EVALUATE IF NPSH REQUIREMENTS FOR THE HPCS AND RHR PUMPS WILL BE MET FOLLOWING A 4-HR STATION BLACKOUT AND A 15 MINUTE PERIOD BEFORE POOL COOLING BECOME AVAILABLE	
HPCS PUMP OPERATES DURING STATION BLACKOUT UNTIL 15 MINUTES FOLLOWING END OF STATION BLACKOUT, WHEN RHR PUMPS ARE USED AND THE POOL IS COOLED	
MAX POOL TEMPERATURE = 234.2 °F	1a
MIN POOL LEVEL = 695'-0"	1d
CALCULATE INCREASE IN SUPPRESSION CHAMBER PRESSURE DUE TO TEMPERATURE RISE IN WETWELL	
TO BE CONSERVATIVE, EVAPORATION AND DRYWELL VENTING ARE NOT CONSIDERED.	
POOL CONDITIONS AT t = 4 hrs 15 MIN (W/LEAKAGES)	1a
$t = 15306.20$ sec	
$T_{WATER} = 234.2$ °F	
$M_{WATER} = 7.739 \times 10^6$ lbm	
$Q_{WATER} = 1.565 \times 10^9$ Btu	

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REF

$\bar{V}_{234.2} = 0.016881 \ ft^3/lb$ 9

$V_{WATER} = (7.739 \times 10^6)(.016881)$

$= 130,642 \ ft^3$

$V_a = V_w - V_{WATER}$

$= 293,900 - 130,642$

$= 163,258 \ ft^3$

AIR TEMPERATURE IS ASSUMED TO BE SAME AS POOL TEMPERATURE

$$P_{AIR} = \frac{m_{air} R_{air} T_a}{V_a}$$

$$= \frac{(11329)(53.3)(460 + 234.2)}{(144)(163,258)}$$

$= \underline{17.8 \ PSIA}$

$$P_v = \frac{m_v R_v T_a}{V_a}$$

$$= \frac{(542)(85.8)(460 + 234.2)}{(144)(163258)}$$

$= \underline{1.4 \ PSIA}$

REF

$$P_a = P_{air} + P_v$$
$$= 17.8 + 1.4$$
$$= \underline{19.2 \text{ PSIA}}$$

SUPPRESSION CHAMBER PRESSURE = 19.2 psia

TEMPERATURE OF SATURATED WATER VAPOR AT P = 19.2 psia IS 225.8 °F. THEREFORE, A BOILOFF WOULD OCCUR IF VENTING FROM THE DRYWELL AND EVAPORATION DOES NOT OCCUR. 9

ASSUME BOILING OCCURS. A MASS OF THE POOL WILL BECOME WATER VAPOR, THUS INCREASING THE CHAMBER PRESSURE. THE AMOUNT OF WATER THAT BOILS IS LIMITED BY THE MASS REQUIRED TO PRESSURIZE THE CHAMBER TO THE SATURATION CONDITIONS CORRESPONDING TO THE POOL TEMPERATURE. THE BOILOFF WILL CAUSE A SMALL DECREASE IN POOL TEMPERATURE.

REF

GUESS FINAL CONDITIONS

$T = 233.75\ °F$

$P = 22.3$ psia (SATURATION) 9

$U_f = 202.05$ Btu/lb 11

$U_g = 1083.61$ Btu/lb 11

UUL = POOL ENERGY = 1.565×10^9 BTU 1a

WML = POOL MASS = 7.739×10^6 lbm 1a

WMBOIL = (UUL − WML * U_f) / (U_g − U_f) 14

$= (1.565 \times 10^9 - 7.739 \times 10^6 * 202.05) / (1083.61 - 202.05)$

$= 1514.42$ lbm

$\bar{V}_{233.75} = 0.016878$ ft³/lb 9

POOL VOLUME = $7.739 \times 10^6 \times .016878$

$= 130{,}619$ FT³

(NOTE: REDUCTION IN POOL MASS FROM WATER BOILING IS NEGLIGIBLE)

AIR SPACE VOLUME = 293,900 − 130619

$= 163{,}281$ FT³

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$$P_{air} = \frac{M_{air} R_{air} T_a}{V_a}$$

$$= \frac{(11329)(53.3)(460 + 233.75)}{(144)(163281)}$$

$$= 17.8 \text{ PSIA}$$

$$P_v = \frac{m_v R_v T_a}{V_a}$$

$$= \frac{(1514.42 + 542)(85.8)(460 + 233.75)}{(144)(163281)}$$

$$= 5.2 \text{ PSIA}$$

$$P_a = 17.8 + 5.2$$
$$= 23.0 \text{ PSIA}$$

THESE RESULTS INDICATE THAT AT 4 HOURS AND 15 MINUTES FOLLOWING STATION BLACKOUT, THE POOL CONDITIONS WILL BE SATURATED AT JUST UNDER 234 °F (BETWEEN 22.3 AND 22.5 PSIA) IF THE DRYWELL DOES NOT VENT TO THE SUPPRESSION CHAMBER OR IF NO EVAPORATION OCCURS. IF VENTING OR EVAPORATION OCCURS, AND THE PRESSURE IN THE SUPPRESSION CHAMBER INCREASES ABOVE 22.5 PSIA, THE POOL WILL BE AT A SUB-COOLED CONDITION WITH A TEMPERATURE OF 234.2 °F.

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HPCS PUMP:

RESULTS FROM THE ATTACHED SPREADSHEET SHOW THAT AT A WATER LEVEL OF 686'-0", SATURATED WATER CONDITIONS WILL RESULT IN MEETING NPSH REQUIREMENTS FOR THE HPCS PUMP. AT POOL LEVELS HIGHER THAN THIS LEVEL, NPSH REQUIREMENTS WILL STILL BE MET IF THE WATER IS AT SATURATED CONDITIONS. AT POOL LEVELS LOWER THAN THIS LEVEL, SUB-COOLED WATER CONDITIONS WILL BE NECESSARY TO MEET NPSH REQUIREMENTS.

THESE RESULTS ALSO SHOW THAT AT A POOL TEMPERATURE OF 234.2°F, A POOL LEVEL OF 695'-0", AND A CHAMBER PRESSURE OF 22.5 psia, FLASHING DOES NOT OCCUR IN THE SUCTION PIPING, AND THE AVAILABLE NPSH FOR THE PUMP IS 16.5 FEET AT THE PUMP INLET CENTERLINE, WHICH EXCEEDS THE NPSH REQUIREMENT OF 1.5 FEET.

RHR PUMP:

RESULTS FROM THE ATTACHED SPREADSHEET SHOW THAT A WATER LEVEL OF 690'-6", SATURATED WATER CONDITIONS WILL RESULT IN MEETING NPSH REQUIREMENTS FOR THE RHR PUMP. AT POOL LEVELS HIGHER THAN THIS LEVEL, NPSH REQUIREMENTS WILL STILL BE MET IF THE WATER IS AT SATURATED CONDITIONS. AT POOL LEVELS LOWER THAN THIS LEVEL, SUB-COOLED WATER CONDITIONS WILL BE NECESSARY TO MEET NPSH REQUIREMENTS.

THESE RESULTS ALSO SHOW THAT AT A POOL TEMPERATURE OF 234.2°F, A POOL LEVEL OF 695'-0", AND A CHAMBER PRESSURE OF 22.5 psia, FLASHING DOES NOT OCCUR IN THE SUCTION PIPING, AND THE AVAILABLE NPSH FOR THE PUMP IS 16.2 FEET AT THE PUMP INLET CENTERLINE, WHICH EXCEEDS THE NPSH REQUIREMENT OF 11.5 FEET.

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HIGH PRESSURE CORE SPRAY PUMP LIMITING OPERATING CONDITIONS

FLOW RATE	6250 GPM	NPSHr	1.5 FEET
PIPE ID	23.250 INCHES	SUCTION LINE L/D	200.57
VELOCITY	4.72 FT/SEC	SUCTION LINE K	1.294
PUMP INLET ELEVATION	674.83 FEET	STRAINER LOSSES	0.886 PSI
STRAINER ELEVATION	679.17 FEET	CHECK VALVE LOSSES	0.25 FEET
TOP OF PIPE ELEVATION	682.17 FEET		

POOL LEVEL (FEET)	CHAMBER PRESS (PSIG)	POOL TEMP (F)	CONV. FACTOR (FT/PSI)	VAPOR PRESS (PSIA)	DENSITY (LB/FT^3)	VISCOSITY (CENTIPOISE)	REYNOLD'S NUMBER	FRICTION FACTOR	SUCTION LINE LOSSES (FEET)	VAPOR PRESS (FEET)	STATIC HEAD (FEET)	CHAMBER PRESS (FEET)	NPSHa AT PUMP (FEET)	NPSHa MIN IN SYSTEM (FEET)
695.00	7.8	234.2	2.430	22.47	59.26	0.251	3.21E+06	0.0121	3.69	54.60	20.17	54.7	16.5	9.2
686.00	30.7	275.0	2.479	45.41	58.09	0.205	3.85E+06	0.0120	3.73	112.57	11.17	112.5	7.4	0.1
686.00	30.0	274.0	2.477	44.70	58.12	0.206	3.84E+06	0.0120	3.73	110.72	11.17	110.7	7.4	0.1
686.00	20.0	258.8	2.459	34.70	58.55	0.220	3.62E+06	0.0121	3.72	85.33	11.17	85.3	7.4	0.1
685.00	10.0	239.4	2.435	24.70	59.1[illegible]	0.243	3.31E+06	0.0121	3.70	60.14	11.17	60.1	7.5	0.1
686.00	0.0	212.0	2.407	14.70	59.83	0.283	2.88E+06	0.0122	3.68	35.38	11.17	35.4	7.5	0.1

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RESIDUE HEAT REMOVAL PUMP LIMITING OPERATING CONDITIONS

FLOW RATE	7200 GPM	NPSHr	11.5 FEET
PIPE ID	22.624 INCHES	SUCTION LINE L/D	140.37
VELOCITY	5.75 FT/SEC	SUCTION LINE K	0.000
PUMP INLET ELEVATION	675.17 FEET	STRAINER LOSSES	1.176 PSI
STRAINER ELEVATION	679.17 FEET	CHECK VALVE LOSSES	0.00 FEET
TOP OF PIPE ELEVATION	682.17 FEET		

POOL LEVEL (FEET)	CHAMBER PRESS (PSIG)	POOL TEMP (F)	CONV FACTOR (FT/PSI)	VAPOR PRESS (PSIA)	DENSITY (LB/FT^3)	VISCOSITY (CENTIPOISE)	REYNOLD'S NUMBER	FRICTION FACTOR	SUCTION LINE LOSSES (FEET)	VAPOR PRESS (FEET)	STATIC HEAD (FEET)	CHAMBER PRESS (FEET)	NPSHa AT PUMP (FEET)	NPSHa MIN IN SYSTEM (FEET)
695.00	7.8	234.2	2.430	22.47	59.26	0.251	3.80E+06	0.0121	3.73	54.60	19.83	54.7	16.2	9.7
690.50	30.7	275.0	2.479	45.41	58.09	0.205	4.56E+06	0.0120	3.78	112.57	15.33	112.5	11.5	4.5
690.50	30.0	274.0	2.477	44.70	58.12	0.206	4.54E+06	0.0120	3.78	110.72	15.33	110.7	11.5	4.5
690.50	20.0	258.8	2.459	34.70	58.55	0.220	4.29E+06	0.0120	3.76	85.33	15.33	85.3	11.6	4.6
690.50	10.0	239.4	2.435	24.70	59.12	0.243	3.92E+06	0.0121	3.73	60.14	15.33	60.1	11.6	4.6
690.50	0.0	212.0	2.407	14.70	59.83	0.283	3.40E+06	0.0121	3.70	35.38	15.33	35.4	11.6	4.6

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7.4 DETERMINE MINIMUM PRESSURE DIFFERENTIAL BETWEEN DRYWELL AND WETWELL WITH VENTING POSSIBLE 4HRS & 15 MIN FOLLOWING A STATION BLACKOUT AND WITH RCIC SYSTEM OPERATION

MINIMUM POOL LEVEL = 695'-0" — 1d
ELEVATION OF BOTTOM OF DOWNCOMER = 687'-10" — 15

MINIMUM SUBMERGENCE OF DOWNCOMER

$$695'\text{-}0" - 687'\text{-}10" = 7.17'$$

MAX POOL TEMPERATURE (w/o LEAKAGES) — 1a
AT t = 4 hrs 15 min

$$T = 211.7\,°F$$

$$\bar{V}_{211.7°F} = .016717\ ft^3/lb$$ — 9

$$\Delta P = \frac{7.17}{144(.016717)}$$

$$= 2.98\ psi$$

MINIMUM PRESSURE DIFFERENTIAL = 2.98 psi

REF

7.5 DETERMINE MAXIMUM SUPPRESSION CHAMBER PRESSURE RESULTING FROM VENTING OF DRYWELL 4 HOURS FOLLOWING STATION BLACKOUT WITH RCIC SYSTEM OPERATION

SUPPRESSION POOL CONDITIONS AT $t = 4$ HRS 1a
(W/O LEAKAGE INTO POOL)
$t = 14406.27$ SEC
$T = 207.7$ °F
$M_{WATER} = 7.885 \times 10^6$ lbm
$Q_{WATER} = 1.385 \times 10^9$ Btu

$\bar{V}_{207.7°F} = 0.016689$ ft³/lb 9
$V_{WATER} = (7.885 \times 10^6)(.016689)$
$= 131,593$ FT³

$V_a = V_W - V_{WATER}$
$= 293,900 - 131,593$
$= 162,307$ FT³

AIR TEMPERATURE IS ASSUMED TO BE SAME AS POOL TEMPERATURE

$$P_{air} = \frac{M_{air} R_{air} T_a}{V_a}$$

$$= \frac{(11329)(53.3)(460 + 207.7)}{(144)(162307)}$$

$= 17.25$ PSIA

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R.H. = 100%

$\rho_v = \rho_{SAT}$
$= 0.034425\ lb/FT^3$ 9

$m_v = V_a \rho_v$
$= (162307)(.034425)$
$= 5588\ lb$

$P_v = P_{SAT}$
$= 13.49\ PSIA$ 9

$P_a = P_v + P_{air}$
$= 13.49 + 17.25$
$= \underline{30.74\ PSIA}$

DRYWELL CONDITIONS AT t = 4 hrs 1b

t = 14,400 SEC
T_a = 258.52 °F
P_a = 50.145 PSIA
V_a = 173860 FT^3
m_v = 14434 lbm
M_{air} = 10203 lbm
R.H. = 100%

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GUESS % OF AIR & WATER VAPOR MIXTURE THAT VENTS FROM DRYWELL TO WETWELL

ASSUME HEAT & MASS ADDITIONS FROM DRYWELL VENTING EQUAL HEAT & MASS LOSSES TO EVAPORATION IN WETWELL

SAY 25% MASS TRANSFER

DETERMINE NEW WETWELL CONDITIONS

$$P_{air} = \frac{M_{air} R_{air} T_a}{V_a}$$

$$= \frac{(11329 + .25(10203))(53.3)(460 + 207.7)}{(144)(162307)}$$

$$= 21.13 \text{ psia}$$

$P_V = P_{SAT} = 13.49$ psia 9

$$P_a = P_{air} + P_v$$
$$= 21.13 + 13.49$$
$$= \underline{34.6 \text{ psia}}$$

SUPPRESSION CHAMBER PRESSURE = 34.6 psia
= 19.9 psig

SUPPRESSION POOL TEMPERATURE = 207.7°F

REF

DETERMINE NEW DRYWELL CONDITIONS

SINCE DRYWELL WILL REMAIN AT 100% RELATIVE HUMIDITY

$R.H. = \rho_v / \rho_{SAT}$

$\rho_v = \frac{m_v}{V}$

$= \frac{(.75)(14434)}{173860}$

$= 0.062266 \ lb/ft^3$

$\rho_{SAT} = \rho_v$

$\bar{V}_{SAT} = 1/\rho_{SAT}$

$\bar{V}_{SAT} = 16.060 \ ft^3/lb$ 9

$T = 241.0 \ °F$

$P_{SAT} = 25.43 \ psia$ 9

$P_v = P_{SAT}$

$P_v = 25.43 \ psia$

$P_{air} = \frac{M_{air} R_{air} T_a}{V_a}$

$= \frac{.75(10203)(53.3)(460 + 241.0)}{(144)(173860)}$

$= 11.42 \ psia$

REF

$P_a = P_v + P_{air}$
$= 25.43 + 11.42$
$= 36.85$ PSIA

DRYWELL PRESSURE = 36.9 PSIA
DRYWELL TEMPERATURE = 241.0 °F

$\Delta P = P_{a,DRY} - P_{a,WET} = 36.9 - 34.6 = 2.3 psi < 2.99 psi$

DETERMINE ENERGY ADDITION TO POOL FROM VENTING:

25% OF AIR
$m_{air} = .25(10203) = 2551$ lbm

25% OF WATER VAPOR
$m_v = .25(14434) = 3609$ lbm

TO BE CONSERVATIVE, ASSUME MAX. DRYWELL CONDITIONS FOR ENERGY ADDITION TO POOL

AT T = 258.52 °F
$U_{air} = 122.8$ Btu/lb 11

AT T = 207.7 °F
$U_{air} = 114.0$ Btu/lb 11

ENERGY LOST FROM AIR TO POOL
$Q_{air} = m_{air} \Delta U$
$= 2551(122.8 - 114.0)$
$= 22,449$ Btu

REF

AT $T = 258.56\ ^\circ F$

$U_g = 1090.1\ Btu/lb$ 11

$G_v = 3609 (1090.1)$

$= 3.934 \times 10^6\ Btu$

TOTAL ENERGY ADDED TO POOL BY VENTING

$Q_{TA} = Q_{AIR} + Q_V$

$= 22449 + 3.934 \times 10^6$

$= 3.957 \times 10^6\ Btu$

TOTAL MASS ADDED TO POOL

$M_A = 3609\ lbm$

NOTE: AIR BUBBLES TO SURFACE, WATER VAPOR CONDENSES, THEREFORE, AIR MASS IS ADDED TO ATMOSPHERE, WATER MASS IS ADDED TO POOL.

TOTAL MASS LOST FROM POOL DUE TO EVAPORATION

M_V AT 4 HOURS $= 5588\ lbm$

M_V AT $t = 0$ $= 542\ lbm$

$M_{evap} = 5588 - 542$

$= 5046\ lbm$

REF

TOTAL ENERGY LOSS FROM POOL DUE TO EVAPORATION

TO BE CONSERVATIVE, DETERMINE ENERGY LOSS FROM POOL AT MAX. POOL TEMP

$u_{fg} = 900.6$ Btu/ 11

$Q = (5046)(900.6)$
$= 4.544 \times 10^6$ Btu

NET ENERGY DECREASE IN POOL

ENERGY LOST TO EVAPORATION − ENERGY ADDED BY VENTING

$4.544 \times 10^6 - 3.957 \times 10^6 = \underline{0.587 \times 10^6 \text{ Btu}}$

NET MASS DECREASE IN POOL

MASS LOST TO EVAPORATION − MASS ADDED FROM VENTING

$5046 - 3609 = \underline{1437 \text{ lbm}}$

THE NET EFFECTS OF VENTING AND EVAPORATION ON POOL MASS AND POOL ENERGY ARE NEGLIGIBLE.

SUPPRESSION POOL TEMPERATURE = 207.7°F
SUPPRESSION CHAMBER PRESSURE = 34.6 PSIA

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7.6 DETERMINE MAXIMUM SUPPRESSION CHAMBER PRESSURE RESULTING FROM VENTING OF DRYWELL 4 HOURS AND 15 MINUTES FOLLOWING STATION BLACKOUT WITH RCIC SYSTEM OPERATION

DRYWELL CONDITIONS AT $t = 4$ hr 15 MIN — 1b

$T_a = 256.80\ °F$
$P_a = 49.104$ psia
$M_v = 14043$ lbm
$M_{air} = 10203$ lbm
R.H. = 100%

PRESSURE IN DRYWELL IS LOWER AT 4 HRS 15 MIN THAN AT 4 HOURS. THEREFORE, VENTING STOPS.

SUPPRESSION CHAMBER CONDITIONS AT $t = 15298.70$ sec (W/O LEAKAGE INTO POOL) — 1a

$T = 211.7\ °F$
$m_{WATER} = 7.917 \times 10^6$ lbm

$\bar{V}_{211.7°F} = 0.016717\ ft^3/lb$ — 9

$V_{WATER} = (7.917 \times 10^6)(.016717)$
$= 132348\ ft^3$

$V_a = V_w - V_{WATER}$
$= 293,900 - 132348$
$= 161,552\ ft^3$

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AIR TEMPERATURE IS ASSUMED TO BE SAME AS POOL TEMPERATURE

AIR VENTED FROM DRYWELL TO WETWELL REMAINS IN WETWELL

$$P_{air} = \frac{M_{air} R_{air} T_a}{V_a}$$

$$= \frac{(11329 + .25(10203))(53.3)(460 + 211.7)}{(144)(161552)}$$

$$= 21.36 \text{ psiA}$$

RH = 100%

$$P_v = P_{SAT}$$
$$= 14.61 \text{ psiA}$$ 9

$$P_a = P_{air} + P_v$$
$$= 21.36 + 14.61$$
$$= \underline{35.97 \text{ psiA}}$$

SUPPRESSION POOL TEMPERATURE = 211.7°F
SUPPRESSION CHAMBER PRESSURE = 36.0 psiA

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7.7 DETERMINE MAX WATER LEVEL IN SUPPRESSION POOL WITH RCIC PUMP IN OPERATION FOLLOWING A STATION BLACKOUT

EL. OF SUPPRESSION POOL FLOOR = 673'-4¼" 15
INITIAL VOLUME OF WATER IN POOL = 128,800 FT^3 7
INITIAL EL OF WATER IN POOL = 699'-6½"

INITIAL HEIGHT OF WATER IN POOL
(699-6½") - (673'-4¼") = 26'-2¼" (26.19')

AREA OF WATER SURFACE
128,800 / 26.19 = 4918 FT

VOLUME IN POOL AT t = 4 hr = 131,593 FT^3

HEIGHT OF POOL AT t = 4 hr
131593 / 4918 = 26.76'

EL. OF WATER IN POOL AT t = 4 hr
673'-4¼" + 26.76' = 700.11'
≅ 700'-2"

VOLUME IN POOL AT t = 4 hr 15 MIN = 132,348 FT^3

HEIGHT OF POOL AT t = 4 hr 15 MIN
132348 / 4918 = 26.91'

EL. OF WATER IN POOL AT t = 4 hr 15 MIN
673'-4¼" + 26.91' = 700.26'
= 700'-4"

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7.8 CALCULATE PRESSURE DROP OF EXHAUST FROM RCIC TURBINE EXHAUST TO SUPPRESSION POOL FOR CONDITIONS 4 HOURS FOLLOWING STATION BLACKOUT

LINE NUMBER : RI02A

NOMINAL SIZE : 10" 4

SCHEDULE : 40 5

$d = 10.02''$

$D = 0.835'$

USE TURBINE MASS FLOW RATE AT RPV PRESSURE = 200 psia SINCE RPV WILL BE MAINTAINED BETWEEN 165 psia AND ABOUT 200 psia 1b

AT 165 psia , $w = 8250$ lb/hr 1a

AT 1173 psia , $w = 27250$ lb/hr 1a

INTERPOLATING:

AT 200 psia , $w = 8910$ lb/hr

AT A CALCULATED VALUE FOR SUPPRESSION CHAMBER PRESSURE

$P = 34.6$ psia

$\bar{V} = 12.027$ ft³/lb

$\mu = 0.013$ centipoise

$V = \frac{.0509\, w \bar{V}}{d^2} = \frac{.0509(8910)(12.027)}{(10.02)^2} = 54.3$ FT/SEC 8

$R_E = \frac{6.31 w}{d \mu} = \frac{6.31(8910)}{(10.02)(.013)} = 4.32 \times 10^5$ 8

$f = 0.0156$ 8

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FITTING	QUANTITY	K	L/D	REF
				6b 2a-2e 8
STRAIGHT PIPE - 10"	67'	–	80.24	
ENTRANCE - 8"	1	1.24	–	
10" × 8" REDUCING ELBOW	–	–	–	
1.) 10" L.R. ELBOW	1	–	14	
2.) 10"×8" ENLARGER (H-7)	1	0.12	–	
STANDARD FTB TEE	1	–	60	
90° L.R. BEND	6	–	84	
45° L.R. BEND	1	–	10	
10" × 18" ENLARGER	1	0.44	–	
18"×18"×10" FTB TEE	1	1.11	–	
10"×10"×3/4" FTR TEE	3	–	1.48	
10"×10"×1½" FTR TEE	1	–	2.99	
10"×10"×2" FTR TEE	1	–	3.87	
CHECK VALVE	1	–	50	
GATE VALVE	1	–	8	
TOTAL		2.91	314.58	

$$\Delta P = \left(f\frac{L}{D} + k\right)\frac{V^2}{(2g)(144\bar{V})}$$ 6a

$$= \left[(.0156)(314.58) + (2.91)\right]\frac{(54.3)^2}{(2)(32.2)(144)(12.027)}$$

$\Delta P = 0.21$ psi

THE RCIC TURBINE EXHAUST PIPING LAYOUT FOR UNIT 2 IS SIMILAR TO UNIT 1, AND THE PRESSURE DROP WILL NOT VARY SIGNIFICANTLY. THIS PRESSURE DROP IS CONSERVATIVE 4 HOURS AND [illegible] MINUTES FOLLOWING STATION BLACKOUT. 2f-2j

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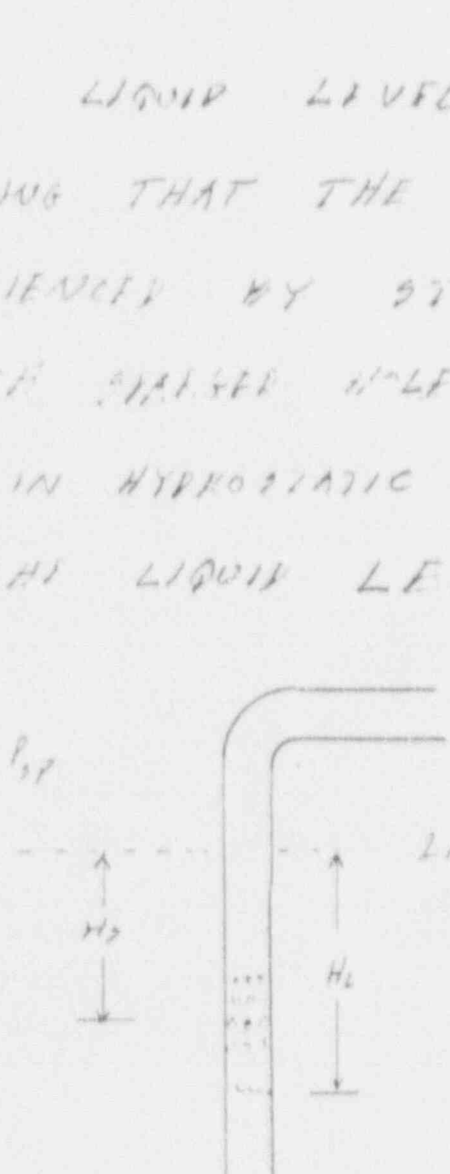
7.9 LIQUID LEVEL IN SPARGER

METHODOLOGY

THE LIQUID LEVEL IS FOUND BY REQUIRING THAT THE PRESSURE DROP EXPERIENCED BY STEAM FLOWING THROUGH SPARGER HOLES BALANCES THE RISE IN HYDROSTATIC DUE TO DEPRESSION OF THE LIQUID LEVEL IN THE SPARGER



$$\rho_w H_L = \rho_w H_S + \Delta P_{holes}$$

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Input data for sparger liquid level calculation

elevation of water level in suppression pool 700' 2" and 700' 4"

elevation of 1st row of holes : 694' 1" Ref 2E

number of holes per circle = 24 Ref. 2E

spacing between rows of holes = 1.25" Ref. 2

RCIC Turbine steam flow = 8910 lb/hr
see section 7.8

specific volume of steam in sparger
= V = 11.9 ft³/lb. Ref 9 (sat. vapor at 35 PSIA)

coefficient of pressure loss for sparger holes = C = 0.6 Ref 8

$$u = C\sqrt{2\times 7\Delta P\times V}$$ Ref. 8

ref 9

density of water (207°F) ρ = 59.74 lb/ft³

diameter of sparger holes, D_s = 0.5 inches Ref 2E

A_h = area of 1 sparger hole, ft² = $\pi .5^2/4\times 144$ = 0.0013635

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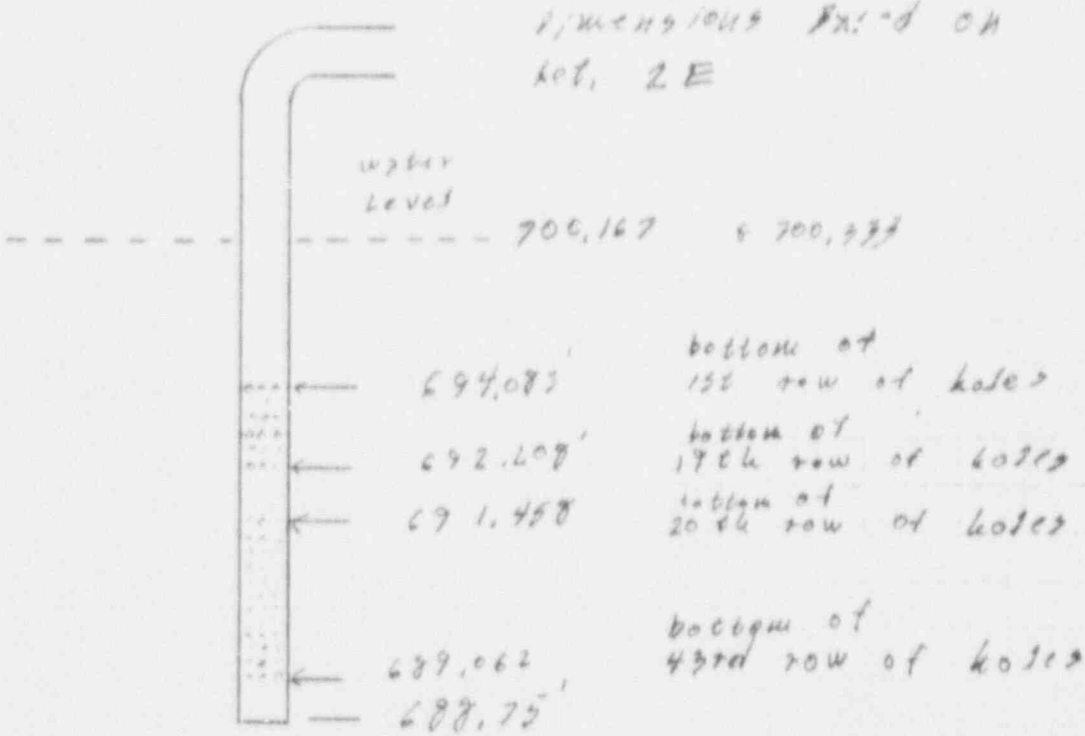
LIQUID LEVEL IN SPARGER



24 1/2" holes per circle.

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Elevation water in suppression pool, E_{SP}, ft	700.167				
Elevation of water in sparger, E_S, ft	693.072				
Elevation difference $H_S = E_{SP} - E_S$, ft	7.095				
Row number	1	2	3	4	5
Elevation of holes, ft, EH	694.083	693.979	693.875	693.770	693.666
Pressure difference across holes, psi $\Delta P_H = \rho_w \cdot (E_H - E_S)/144$	0.421	0.377	0.334	0.291	0.247
Steam velocity in holes, ft/sec $U = C\sqrt{2 \times 32.17 \times \Delta P_H \times 144 \times V}$	129.2	122.4	115.2	107.4	99.1
Mass of steam flow through row of holes lb/hr $W_R = A_h \times U \times 24 \times 3600 / V$	1279	1212	1140	1064	981
Mass of steam flow through all exposed rows of holes lb/hr					
Turbine exhaust flow, lb/hr	3910				
Discrepancy lb/hr					

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Elevation water in suppression pool, E_{SP}, ft	700.167				
Elevation of water in sparger, E_{S}, ft	693.072				
Elevation difference $H_S = E_{SP} - E_S$, ft	7.095				
Row number	6	7	8	9	10
Elevation of holes, ft, EH	693.562	693.458	693.354	693.250	693.143
Pressure difference across holes, psi $\Delta P_H = \rho_W \times (E_H - E_S)/144$	0.204	0.161	0.117	0.074	0.031
Steam velocity in holes, ft/sec $U = C\sqrt{2 \times 32.17 \times \Delta P_H \times 144 \times V}$	90.0	79.8	68.2	59.2	34.3
Mass of steam flow through row of holes, lb/hr $W_R = A_h \times U \times 24 \times 3600/V$	891	791	676	536	345
Mass of steam flow through all exposed rows of holes lb/hr					8914
Turbine exhaust flow, lb/hr					8910
Discrepancy lb/hr					4

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Conclusions

For an RCIC Turbine steam flow of 9928 lb/hr the water level in the sparger would fall low enough to expose 10 rows or 240 holes. The depression in the water level is calculated to be 7.095 ft and corresponds to a pressure difference between the sparger and the suppression pool air space of 2.95 psi. This result applies when the water level in the suppression pool is 700' 2". For the case where the suppression pool water level is 700' 4" the pressure difference between the sparger and suppression pool air space rises to 3.02 psi

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7.10 DETERMINE MAXIMUM BACKPRESSURE OF RCIC TURBINE 4 HOURS FOLLOWING STATION BLACKOUT

SUPPRESSION CHAMBER PRESSURE = 34.6 psia
PRESSURE DROP IN EXHAUST SPARGER = 2.95 psi
FRICTION LOSSES IN EXHAUST PIPE = 0.21 psi

MAXIMUM BACKPRESSURE = 37.8 psia
= 23.1 psig

DETERMINE MAXIMUM BACKPRESSURE OF RCIC TURBINE 4 HOURS & 15 MINUTES FOLLOWING STATION BLACKOUT

SUPPRESSION CHAMBER PRESSURE = 36.0 psia
PRESSURE DROP IN EXHAUST SPARGER = 3.02 psi
FRICTION LOSSES IN EXHAUST PIPE = 0.21 psi

MAXIMUM BACKPRESSURE = 39.2 psia
= 24.5 psig

SINCE THE RCIC TURBINE IS SET TO TRIP ON A BACKPRESSURE OF 25 psig, THE RCIC TURBINE WILL NOT TRIP DUE TO HIGH BACKPRESSURE FOLLOWING A STATION BLACKOUT

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7.11 DETERMINE WORST CASE CONDITIONS FOR RCIC TURBINE BACKPRESSURE ANALYSIS WITH MAXIMUM EXHAUST FLOWS TO VERIFY THAT MAXIMUM BACKPRESSURE DOES NOT OCCUR DURING RPV DEPRESSURIZATION TO 200 PSIA. CONSIDER POOL CONDITIONS WHEN RPV FIRST DROPS UNDER 200 psia & SUPPRESSION POOL CONDITIONS w/o LEAKAGE	1a
$t = 5969.37$ sec	1a
$T = 173.6$ °F	
$M_{water} = 8.022 \times 10^6$ lbm	
$\bar{V}_{173.6°F} = 0.016472$ ft³/lb	9
$V_{WATER} = (8.022 \times 10^6)(.016472)$	
$= 132138$ FT³	

$V_a = V_w - V_{WATER}$

$= 293,900 - 132138$

$= 161,762$ FT³

DETERMINE PARTIAL PRESSURE OF AIR BASED ON MASS OF AIR VENTED AFTER 4 HOURS - WORST CASE VENTING

$M_{air} = 11329 + .25(10203) = 13880$ lb

$$P_{air} = \frac{M_{air} R_{air} T_a}{V_a}$$

$$= \frac{(13880)(53.3)(460 + 173.6)}{(144)(161,762)}$$

$= 20.12$ psia

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$R.H = 100\%$

$P_v = P_{SAT}$

$= 6.51 \text{ psiA}$ 9

$P_t = P_{air} + P_v$

$= 20.12 + 6.51$

$= \underline{26.6 \text{ psiA}}$

CALCULATE PRESSURE DROP IN EXHAUST PIPE

WITH TURBINE FLOW = 27400 lb/hr

$\bar{V} = 15.387 \text{ ft}^3/\text{lb}$ 9

$\mu = 0.013$ centipoise 8

$$V = \frac{.0509 W \bar{v}}{d^2} = \frac{(.0509)(27250)(15.387)}{(10.02)^2} = 213 \text{ FT/SEC}$$

$$R_E = \frac{6.31 W}{d\mu} = \frac{(6.31)(27250)}{(10.02)(.013)} = 1.32 \times 10^6$$

$f = .0141$

$$\Delta P = \left(f\frac{L}{D} + K\right)\frac{V^2}{(2g)(144\bar{v})}$$

$$= [(.0141)(314.58) + (2.91)]\frac{(213)^2}{(2)(32.2)(144)(15.387)}$$

$= \underline{2.34 \text{ psi}}$

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MAXIMUM PRESSURE DROP THROUGH SPARGER

FROM SECTION 7.7 (AT 4 HOURS FOLLOWING STATION BLACKOUT)
MAX POOL LEVEL = 700'-2"

ELEVATION OF BOTTOM OF EXHAUST PIPE — 2c
704'-6" - 15'-9" = 688.75'

MAX WATER LEVEL IN PIPE = 11.42'

$$\Delta P = \frac{11.42'}{(144)(.016472)}$$

$$= \underline{4.81\ psi}$$

SUPPRESSION CHAMBER PRESSURE	=	26.6 psia
PRESSURE DROP IN EXHAUST SPARGER	=	4.81 psi
FRICTION LOSSES IN EXHAUST PIPE	=	2.34 psi
BACKPRESSURE	=	33.8 psia
	=	19.1 psig

RCIC TURBINE WILL NOT TRIP DUE TO HIGH BACKPRESSURE AS RPV DEPRESSURIZES, WHEN EXHAUST FLOWS ARE MAXIMUM, AND THIS WILL NOT BE A WORST-CASE SITUATION