Entergy Operations

Entergy Operations, Inc.
P.O. Box 756
Port Gibson MS 39150
Tel 601-437-2800

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U.S. Nuclear Regulatory Commission
Mail Station P1-137
Washington, D.C. 20555

Attention: Document Control Desk

SUBJECT: Grand Gulf Nuclear Station
Unit 1
Docket No. 50-416
License No. NPF-29
Summary of Calculations Regarding Precipitation in the SLCS Discharge Piping (Revision 1)

GNRO: 91/00061

Gentlemen:

On February 12, 1991 Entergy Operations, Inc., Grand Gulf Nuclear Station (GGNS) met with members of the NRC Staff to discuss the results of calculations performed by GGNS at the request of the Staff to confirm that excessive sodium pentaborate solution precipitation in the Standby Liquid Control System (SLCS) discharge piping does not occur. As a follow-up to that meeting, the Staff requested that GGNS submit a summary description of the calculational methodology and results. That summary was submitted on March 4, 1991.

Subsequently, as discussed with your Staff, an error was discovered in the calculations. We have initiated appropriate quality deficiency actions to address the error. While the error did not affect our conclusions it did require us to modify somewhat our methodology. Therefore, we are resubmitting a summary description of the calculational methodology and results.

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We would appreciate your timely review and closure of this issue.

Yours truly,

WTC/PRS/mtc
attachment: Standby Liquid Control System Calculation Summary (Revision 1)
cc: Mr. D. C. Hintz (w/a)
Mr. J. Mathis (w/a)
Mr. R. B. McGehee (w/a)
Mr. N. S. Reynolds (w/a)
Mr. H. L. Thomas (w/o)
Mr. F. W. Titus (w/a)

Mr. Stewart D. Ebneter (w/a)
Regional Administrator
U.S. Nuclear Regulatory Commission
Region II
101 Marietta St., N.W., Suite 2900
Atlanta, Georgia 30323

Mr. L. L. Kintner, Project Manager (w/a)
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Mail Stop 11D21
Washington, D.C. 20555

STANDBY LIQUID CONTROL SYSTEM

CALCULATION SUMMARY

(REVISION 1)

STANDBY LIQUID CONTROL SYSTEM
CALCULATION SUMMARY

I. Calculation Purpose

The current GGNS Technical Specifications (TS) allow the solution in the Standby Liquid Control System (SLCS) to have a sodium pentaborate concentration of 28.5 weight percent (w/o) when at a solution temperature of 130°F. The issue of whether such a solution is capable of being injected into the reactor vessel without excessive sodium pentaborate precipitation occurring has been raised by the NRC.

To assist in resolving this issue, a calculation was performed to determine how the temperature of the SLCS process flow (starting from the SLCS pump discharge) changes due to ambient temperature conditions (in the vicinity of the SLCS discharge piping) when being injected into the reactor vessel. The resulting sodium pentaborate precipitation is calculated and totalled. Figure 1 contains a schematic of the SLCS piping layout.

The calculation consisted of two parts:

1) Calculation of the SLCS process flow temperature change under steady state conditions (i.e., SLCS discharge piping warmed to SLCS process flow temperature).

2) Calculation of the SLCS process flow temperature immediately after SLCS initiation (i.e., SLCS discharge piping in the containment is initially at 70°F and the drywell portion of piping is initially at 110°F) until process flow temperature exceeds saturation temperature of the SLCS solution.

The results of the calculation a· · used to demonstrate analytically that excessive precipitation does not occur.

II. Scoping Calculation

Before reviewing the calculations discussed above, it is instructive to take a look at a simple (and highly conservative) calculation which should serve to place an upper bound on the amount of precipitation which could occur in the GGNS SLCS design. While we do not credit this calculation in resolving the question posed by the NRC, it is nonetheless useful in placing the precipitation issue in perspective and serving as a check on calculation results.

The scoping calculation assumes that the SLCS discharge piping (including drywell piping) is initially at 70°F. The SLCS solution is discharged at 130°F and 28.5 w/o sodium pentaborate.

We assume that the discharge piping must be heated uniformly to approximately 130°F (the steady state temperature reached during SLCS injection). Until the piping reaches 130°F all SLCS solution passing through the piping is assumed to transfer heat to the piping represented by a final solution temperature of 70°F (i.e., each lbm of SLCS solution cools down from 130°F to 70°F regardless of the actual piping temperature). The total precipitate is then calculated based on a SLCS solution temperature of 70°F.

First, we calculate the total amount of heat necessary to raise the SLCS discharge piping from 70°F to 130°F.

The SLCS discharge piping mass[1] is:

Diameter	Length	Lbm/ft	Total
2"	4.68'	5.02	23.49
1.5"	166.09'	3.63	602.91
3"	3.25'	10.25	33.31
			659.71 lbm

The necessary heat transfer is:

$$Q = Mc_p \Delta T$$

where: M = mass of discharge piping (lbm)

c_p = stainless steel specific heat (BTU/lbm°F)

ΔT = final - initial pipe temperature (°F)

= (659.71 lbm) (0.12 BTU/lbm°F) (130 - 70°F)

= 4750 BTU

[1]The HPCS discharge piping is ignored due to the low piping surface contact area to volume ratio for the SLCS solution and the resultant low heat transfer.

The heat lost per lbm of SLCS solution is given by:

$Q/M = c_p \Delta T$

where: M = 1 lbm of SLCS solution

c_p = SLCS solution specific heat (BTU/lbm°F)

ΔT = initial - final SLCS solution temperature (°F)

= (0.82488 BTU/lbm°F) (130 - 70°F)

= 49.49 BTU/lbm

Therefore, the amount of SLCS solution required to raise the discharge piping temperature to 130°F is :

4750 BTU/49.49 BTU/lbm = 96 lbm

At 70°F, the sodium pentaborate solution concentration has been reduced to 16 w/o compared to the initial concentration of 28.5 w/o. The total amount of precipitation is:

M_p = (28.5 w/o - 16 w/o) (96 lbm)/100

= 12.0 lbm

As will be discussed in more detail later, this is clearly a negligible quantity of precipitation.

III. General Assumptions

Although the scoping calculation result may be conclusive, time and temperature dependent calculations were performed.

The following are the major assumptions used in both the steady state and transient parts of the calculation:

1) The temperature of the SLCS sodium pentaborate solution (process flow) is assumed to be 130°F at the SLCS pump discharge.

2) The SLCS flow rate for two pumps is assumed to be 82.4 gpm.

3) No credit is taken for insulation on the SLCS discharge piping.

4) The ambient temperature in the containment is assumed to be 70°F (i.e., the SLCS discharge piping in the containment is initially at 70°F).

5) The ambient temperature in the drywell is assumed to be 110°F (i.e., the SLCS discharge piping in the drywell is initially at 110°F).

6) The initial sodium pentaborate concentration of the process flow is assumed to be 28.5 w/o.

7) The amount of sodium pentaborate precipitation is assumed to vary linearly between 114°F (28.5 w/o) and 70°F (16 w/o). In other words, a lbm of SLCS solution that is cooled to 70°F will precipitate 0.125 lbs. (0.285 lbs. - 0.16 lbs.) of sodium pentaborate.

8) No credit is taken for redissolving precipitate as the SLCS solution temperature increases in the drywell.

IV. <u>Steady State Condition Calculation Methodology</u>

The process flow temperature change due to ambient temperatures was calculated by first determining the total heat transfer rate by free convection and radiation. Then dividing the total heat transfer rate by the process fluid mass flow rate to obtain the enthalpy change per pound mass (lbm). The temperature change is then calculated by dividing the enthalpy change by the specific heat of the SLCS solution. These calculations were performed separately for each of ten pipe sections of the system piping model.

V. <u>Steady State Calculation Results</u>

Once the piping reaches steady state temperatures, the total temperature drop from when the solution leaves the pump discharge until it reaches the reactor vessel is only 0.22°F. Therefore, the temperature losses to the ambient are very small and do not cause any excessive sodium pentaborate precipitation to occur since the resulting final solution temperature (129.78°F) remains above the saturation temperature (114°F).

VI. <u>Transient Condition Calculation Methodology</u>

While the drywell piping temperature was assumed to be initially at 110°F, it was necessary to account for the cooling effects of the 70°F demineralized water in the containment portion of the SLCS piping. Using methodology similar to that discussed below (but incorporating the physical properties of water), an initial drywell piping temperature profile was calculated, prior to modeling the injection of SLCS solution.

The transient calculation for injecting SLCS solution modeled the SLCS piping from the SLCS pump discharge to the reactor vessel in variable length increments. Each increment contained 0.8685 lbm of SLCS solution, which corresponds to a one foot increment in 1.5 inch diameter piping. The calculation also verified that the SLCS flow was turbulent at all locations in the discharge piping so as to assure that no thermal stratification occurred.

The first step was to calculate the transit time through the pipe increment. The SLCS flow rate used was 82.4 gpm for the common discharge piping and 41.2 gpm in the piping which is upstream of the point where the discharge piping from each SLCS pump meets. Dividing the SLCS flow rate by the cross sectional area for the appropriate pipe internal diameter gave the SLCS solution velocity through the piping. Dividing the increment's piping length by the solution velocity gave the transit time for that pipe increment.

The second step was to calculate the area that the slug of SLCS solution had in contact with the pipe wall for the appropriate diameter of discharge piping.

The third step was to calculate the heat transfer rate per ft^2 of contact area for each increment of piping. The calculation for the heat transfer rate was performed using a computer program. The heat transfer rate was calculated for each increment of piping.

The enthalpy change was then calculated as a product of the heat transfer rate and the transit time divided by the slug mass (0.8685 lbm). The temperature change of the SLCS solution was calculated by dividing the enthalpy change by the specific heat of the SLCS solution. The temperature change of the piping was similarly calculated by dividing the amount of heat transferred ($\dot{Q}$ * transit time) by the product of the mass of steel for the pipe section and the piping specific heat ($M * c_p$).

Finally, the amount of precipitation (if any) for each slug of SLCS solution was calculated. Precipitation was assumed to occur if the solution temperature was less than 114°F (the saturation temperature for 28.5 w/o sodium pentaborate solution) and was calculated separately for the containment and drywell piping.

The preceding steps were performed separately for each slug of SLCS solution until SLCS solution temperature exceeded 114°F at the RPV injection point.

An additional calculation was performed to determine the period of time during which sodium pentaborate precipitation was possible - in other words, the amount of time required to heat up SLCS piping sufficiently that SLCS solution is injected into the RPV at a temperature greater than 114°F. The transient calculation was terminated when the SLCS solution temperature exceeded 114°F at the RPV. Therefore, the time required to pump the solution mass calculated for the transient case, added to the transit time for each piping section, determines the duration of the precipitation transient.

VII. Sample Transient Calculation

A sample calculation demonstrating the above described methods for the first slug of SLCS solution in the last full 1 foot section of common 1-1/2" diameter piping in the drywell follows:

The transit time for this 1 foot increment:

$T_{(1\text{-}1/2"D)}$ = increment length/fluid velocity

= 1 ft / 14.96 fps = 0.066845 seconds

At this location the calculated initial SLCS solution temperature (t_b) is 74.69°F, the pipe temperature (t_w) is 77.161°F, the SLCS solution velocity is 14.96 ft/sec, and the internal pipe diameter is 1-1/2". The heat transfer coefficient is given by (Source - Mark's Standard Handbook for Mechanical Engineers, 8th ed., Page 4-64, equation 6c):

$$h_m = 160*(1+0.012t_f)V_s^{0.8}/(D_i)^{0.2}$$

where: h_m = mean value of h for entire surface (BTU/hr ft²°F)

t_f = film temperature = $(t_w + t_b)/2$ (°F)

t_w = pipe wall temperature

t_b = SLCS solution temperature

V_s = average fluid velocity (ft/sec)

D_i = inside pipe diameter (inches)

$= 160 * (1+0.012 * 75.9255) * 14.96^{0.8}/1.5^{0.2}$

= 2455.45 BTU/hr ft²°F

The heat transfer rate at this location is therefore:

$$\dot{Q} = h_m * A_s * \Delta T$$

where: h_m = mean film coefficient (BTU/hr ft²°F)

A_s = surface contact area (ft²)

ΔT = SLCS solution temperature - pipe temperature (°F)

= 2455.45 BTU/hr ft²°F * 0.3927 ft² * (-2.471)°F

= -2382.7 BTU/hr = -0.66186 BTU/sec

The enthalpy change per lbm of SLCS solution while traversing this pipe increment:

$$\Delta H = \dot{Q} * T_{U-1/2*D}/M_s$$

where: $\dot{Q}$ = heat transfer rate at this location (BTU/sec)

$T_{U-1/2*D}$ = increment transit time (sec)

M_s = mass of solution in this increment (lbm)

= -0.66186 BTU/sec * 0.066845 sec/0.8685 lbm

= -0.051 BTU/lbm

The temperature change across this increment:

$$\Delta T = \Delta H / c_p$$

where: ΔH = enthalpy change (BTU/lbm)

c_p = SLCS solution specific heat (BTU/lbm°F)

= -0.051 BTU/lbm/0.82488 BTU/lbm°F = -0.06183°F

Therefore, the SLCS slug temperature upon exiting this increment is:

74.69°F - (-0.06183)°F = 74.75°F

The mass of sodium pentaborate precipitated from this slug in the SLCS piping:

$$M_p = \Delta C * M_s$$

where: ΔC = (28.5 w/o - saturation w/o at this slugs lowest solution temperature)/100

M_s = mass of solution in this increment (lbm)

= (28.5 w/o - 17.05 w/o) * 0.8685 lbm/100

= 0.09944 lbm

Finally, the change in piping temperature is:

$$\Delta T = (\dot{Q} * T_{U-1/2*D}) / (M * L * c_p)$$

where: ΔH = heat transferred by the SLCS slug (BTU)

M = piping mass (lbm/ft)

L = length of this increment (ft)

c_p = stainless steel specific heat (BTU/lbm°F)

= (-0.66186 BTU/sec * 0.066845 sec)/(3.63 lbm/ft * 1 ft. * 0.12 BTU/lbm°F)

= -0.1016°F

And, the piping temperature after the SLCS slug exits this increment is:

77.161°F + (-0.1016°F) = 77.059°F

All of the values calculated above approximate the values calculated by the computer program algorithm.

VIII. Transient Calculation Results

The total amount of sodium pentaborate precipitation was calculated to be 6.993 lbm.

The duration of the precipitation transient was calculated to be 79.4 seconds. After this time, the SLCS solution temperature at the RPV injection point remains above 114°F.

IX. Safety Significance of Precipitation

SLCS injection is designed to meet a 3% shutdown requirement and includes a 25% margin to allow for uncertainties such as imperfect mixing in the core, leakage, etc. A minimum of 5800 lbm of sodium pentaborate is necessary to fulfill this requirement. The 6.993 lbm of sodium pentaborate which may precipitate during injection represents only 0.001% of the minimum sodium pentaborate weight - a negligible amount compared to the 25% margin.

Since little published information exists on the precipitation of sodium pentaborate, GGNS conducted a controlled laboratory experiment to observe and record the behavior of an approximate 28.5 w/o sodium pentaborate solution when cooled below its saturation temperature of 114°F. Briefly, a solution of 28.3 w/o sodium pentaborate was prepared and heated to 130°F. The heat source was removed and the solution cooled to room temperature (approximately 77°F). The solution was constantly stirred at rates well below those necessary to reach turbulent flow conditions.

Various observations were made:

- Visible precipitation did not occur until approximately 100°F when cooling down
- At room temperature the mixture exhibited a cloudy, "milky" appearance with fine particles of precipitate suspended throughout
- Upon discontinuing agitation, a small amount of precipitate settled in a thin layer on the bottom of the flask - no plating of precipitate was observed on the flask walls or bottom surface
- Upon reheating, the precipitate readily redissolved prior to reaching its saturation temperature

Based on these observations, the small amount of calculated precipitate would not inhibit SLCS injection. The precipitate which forms is very fine and remains in suspension unless flow is stagnant. Plate-out does not occur to any observable extent. Therefore, the precipitate would be injected into the RPV and redissolve upon mixing.

X. Conclusion

The results of this calculation confirm that excessive precipitation of sodium pentaborate in the discharge piping will not occur for the conditions analyzed. The minor precipitation which may occur would have no effect on the SLCS safety function.

SLCS PIPING LAYOUT*

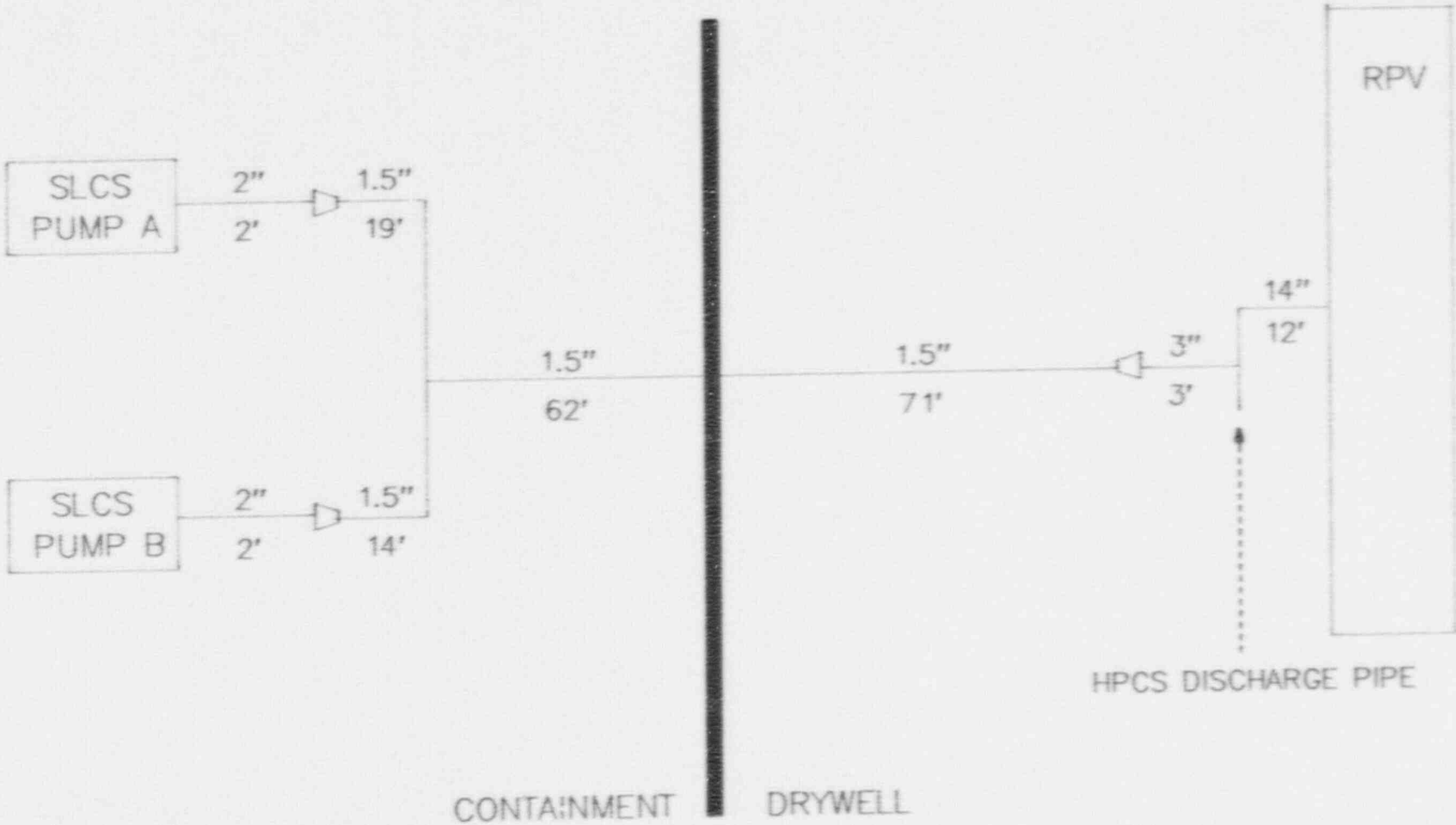

Figure 1

*NOT DRAWN TO SCALE