April 5, 2006

Note To: J. Wermiel

From: E. Throm

Subject: SSIB POST-LOCA CONTAINMENT REPORT

F. Akstulewicz asked me to review the subject report (attached) and provide feedback directly to you.

The treatment of the initial containment conditions is not addressed, for example pressure, temperature and humidity. For a realistic evaluation, these would be nominal values. However, since the evaluation is also conservative, for example, no credit for containment heat structures, it is likely that the initial assumptions are not important. These two point could be clearer.

Because of the "importance" of NPSH, I asked Rich Lobel to look over the NPSH section and he provided mark-up pages 36 to 40. His mark-ups should be considered since they clarify the NPSH issue and how the staff considers NPSH (e.g., using SRP 6.2.2 not Safety Guide 1.)

Overall, while the evaluation tends to overestimate the potential for sump heatup and reduced NPSH, it does show that improvements in available NPSH occur over time. The improvement would be larger with less conservatism in a licensee's evaluations.

**Table 7:** *Computed Residence Times from the Sump through the Vessel back to the Sump*

| | Residence time | | | | | |
|---|---|---|---|---|---|---|
| | 1,870 s | | 1 day | | 30 days | |
| **Component** | **Time** | **Temp** | **Time** | **Temp** | **Time** | **Temp** |
| Sump to HPI pump(1) | 50 s | 234°F | 50 s | 170°F | 50 s | 125°F |
| HPI pump to cold leg(2) | 10 s | 234°F | 10 s | 170°F | 10 s | 125°F |
| Cold leg (from HPI injection to vessel inlet) | 90 s | 137°F | 60 s | 118°F | 75 s | 105°F |
| Downcomer | 110 s | 155°F | 135 s | 119°F | 180 s | 105°F |
| Lower plenum | 80 s | 156°F | 160 s | 119°F | 215 s | 105°F |
| Core | 80 s | 209°F | 115 s | 154°F | 155 s | 119°F |
| Upper Plenum to break | 140 s | 238°F | 150 s | 182°F | 210 s | 131°F |
| Break to sump(3) | 5 s | 238°F | 5 s | 170°F | 5 s | 125°F |
| Sump | 12,205 s | 234°F | 11,860 s | 170°F | 11,640 s | 125°F |

(1) - Estimated; 24" diameter pipe, 25 ft in length plus 6" diameter pipe, 15 ft in length (in series)

(2) - Estimated; 6" diameter pipe, 60 ft in length plus 3" diameter pipe, 75 ft in length (in series)

(3) - Estimated; break height is approximately 47 ft above sump water surface (time < 5 sec)

**Table 8:** *Computed Residence Times from the Sump through the Containment Sprays back to the Sump*

| | Residence time | | | | | |
|---|---|---|---|---|---|---|
| | 1,870 s | | 1 day | | 30 days | |
| **Component** | **Time** | **Temp** | **Time** | **Temp** | **Time** | **Temp** |
| Sump to containment spray pump(1) | 20 s | 234°F | 20 s | 170°F | 20 s | 125°F |
| Containment spray pump to SDC HX(2) | 5 s | 234°F | 5 s | 170°F | 5 s | 125°F |
| SDC HX to top of containment(3) | 15 s | 136°F | 15 s | 118°F | 15 s | 105°F |
| Top of containment to sump(4) | 5 s | 136°F | 5 s | 118°F | 5 s | 105°F |
| Sump(5) | 12,205 s | 234°F | 11,860 s | 170°F | 11,640 s | 125°F |

(1) - Estimated; 24" diameter pipe, 25 ft in length

(2) - Estimated; 8" diameter pipe, 15 ft in length plus 10" diameter pipe, 10 ft in length (in series)

(3) - Estimated; 8" diameter pipe, 125 ft in length plus 4" diameter pipe, 60 ft in length (in series)

(4) - Estimated; top of containment is approximately 180 ft above sump water surface (time < 5 sec)

(5) - Same as computed in the primary loop

to ensure proper operation of the pump.

determined by test

### 4.2 Net Positive Suction Head

To avoid cavitation in centrifugal pumps, the pressure of the fluid at all points within the pump must remain above saturation pressure. Net positive suction head is used as a measure to determine if the pressure of the liquid being pumped is adequate to avoid cavitation. The net positive suction head available is the difference between the pressure at the suction of the pump and the saturation pressure for the liquid being pumped. The net positive suction head required is the minimum net positive suction head necessary to avoid cavitation. In regulatory terms, this means that the NPSH required is the amount of suction head, over vapor pressure, required to prevent more than 3% loss in total head of the first stage of the pump at a specific capacity.

The accepted industry practice is.

It is desirable ~~that~~ for acceptable pump performance that

~~The condition that must exist to avoid cavitation is that~~ the net positive suction head available ~~must~~ be greater than or equal to the net positive suction head required.

NPSH margin can be calculated as:

$$NPSH_{margin} = NPSH_{available} - NPSH_{required} \quad \text{(Equation 1)}$$

where $NPSH_{available}$ is defined as:

$$NPSH_{available} = H_a - H_{vapor} + H_{static} - H_{friction} \quad \text{(Equation 2)}$$

SRP 6.2.2 As the licensee's licensing-basis methodology assumes that the containment pressure ($H_a$) is equal to the saturated vapor pressure of the sump fluid ($H_{vapor}$), the available NPSH calculated by the licensee (denoted $NPSH_{available, \sout{SG1}}$ SRP, since the assumption that $H_a = H_{vapor}$ is derived from ~~Safety Guide 1~~) is just the difference between the static head of water above the pump suction ($H_{static}$) and the friction losses in the suction piping ($H_{friction}$):

$$NPSH_{available,\ SG1} = H_{static} - H_{friction} \quad \text{(Equation 3)}$$

SRP 6.2.2

Then the NPSH margin, consistent with ~~Safety Guide 1~~, can be defined as:

$$NPSH_{margin,\ SG1} = NPSH_{available,\ SG1} - NPSH_{required} \quad \text{(Equation 4)}$$

To include modeling of the effect of subcooling from containment overpressure, values for $H_a$ and $H_{vapor}$ were computed from the RELAP5 results.

The containment pressure head ($H_a$) was calculated using the containment pressure from volume 900-02, which was considered to best represent the pressure existing over the surface of the containment pool. Pressure (psi) may be converted to head (ft) using the following equation:

$$\text{Head (ft)} = \text{Pressure (psi)} * 2.31 / \text{Specific Gravity} \quad \text{(Equation 5)}$$

The saturated vapor pressure of the sump fluid ($H_{vapor}$) can also converted to a head term using Equation 5 above.

Then the containment overpressure head ($H_{overpressure}$) can be defined as follows:

Would prefer not to use the term overpressure. Accident ... stet

$$H_{overpressure} = H_a - H_{vapor} \quad \text{(Equation 6)}$$

To find the $NPSH_{margin}$ that includes containment overpressure head, the desired quantity, the following equation is used:

$$NPSH_{margin} = NPSH_{margin,\ SG1} + H_{overpressure} \quad \text{(Equation 7)}$$

The plant-specific data used was chosen from Case 1ABA M, one of several dozen NPSH cases calculated by the licensee. This case was chosen for a number of reasons, including (1) it was a cold-leg large-break LOCA, (2) it modeled a single operating containment spray pump, (3) it had a small value of $NPSH_{margin,\ SG1}$ (which emphasizes the contribution of the containment overpressure head), and (4) it represented a plant condition created by a single failure. Case 1 ABA M was not the most limiting case with respect to NPSH margin (in fact, a failure of a sump suction valve to open is shown to result in a value of $NPSH_{margin,\, SG1}$ of -10.06 ft prior to manual corrective action being taken). However, the input parameters for the most limiting case were sufficiently dissimilar to the input parameters used in the RELAP5 simulation that it would not be appropriate to combine these two sets of data. Further, the plant conditions and NPSH results associated with the most limiting failure are not considered representative of a typical PWR, and would not be expected to persist through the long-term portion of the calculation.

Despite efforts to match as closely as possible the input parameters of the licensee's calculation to the input parameters of the RELAP5 simulation, certain inconsistencies appear present. Most notably, the licensee assumes that both shutdown cooling heat exchangers are aligned for heat removal for all of the licensee's NPSH cases analyzed, regardless of how many containment spray pumps are operating. The RELAP5 model, for which only two shutdown cooling alignments were run, considered (1) one spray pump and one heat exchanger and (2) two spray pumps and two heat exchangers, neither of which directly corresponds to the assumptions made for Case 1 ABA M. Of further note, a 700 gpm inconsistency seems to exist between the flow rates passing through both the containment spray pumps and shutdown cooling heat exchangers in the RELAP5 model as compared to the licensee's calculations. Specifically, in the RELAP5 model, the flow rate apparently modeled was approximately 1,420 gpm per spray pump/heat exchanger, whereas for all the single pump scenarios modeled by the licensee, the spray pump flows were approximately 2,150 gpm. (The root cause of this apparent discrepancy may have been a lack of specificity between spray pump flow and spray nozzle flow, since, under the conditions modeled, a HPSI pump is drawing approximately 700 gpm from the discharge of the containment spray pumps and injecting directly to the reactor vessel.)

The primary conclusion to be drawn from the above discussion is that this calculation of $NPSH_{margin}$ should be interpreted as a generic sample calculation, rather than a high-fidelity plant-specific analysis. It should also be noted that the significance of the modeling discrepancies mentioned above would gradually diminish over time and would eventually converge as the system reaches quasi-equilibrium (perhaps 5-10 days). In this context, the apparent discrepancies noted above do not unduly detract from the merit of this sample calculation.

Figure 28 shows the calculated $NPSH_{margin}$ for the first 24 hours and 30 days respectively following a loss-of-coolant accident (LOCA).

For Case 1 ABA M, the value of $NPSH_{available,\, SG1}$ is only 0.25 ft. Therefore, a small vertical offset notwithstanding, Figure 28 is essentially a representation of containment overpressure head as a function of time.

The RELAP5 code does not include sophisticated models for simulating transient containment thermal-hydraulics, such as those necessary to compute peak containment pressure and temperature. Since the calculation of NPSH margin takes as inputs the containment pressure and sump fluid temperature, the transient portion of the RELAP5 computation of NPSH margin should likewise not be expected to be highly accurate. This expectation is seemingly confirmed by Figure 28, which shows a sharp downward spike occurring at approximately 20 minutes, during which time the $NPSH_{margin}$ predicted by RELAP5 briefly drops below zero. It should be noted that the time of minimum $NPSH_{margin}$ is prior to the switchover to sump recirculation mode. As a result of the shortcomings of the RELAP5 code in modeling transient containment thermal-hydraulics, this code's predictions of $NPSH_{margin}$ are quite uncertain in the short-term (i.e., within approximately the first 24 hours after the accident, but particularly within the first several hours). Once the significance of the transient effects has diminished, however, the RELAP5 code can effectively model the quasi-steady-state transfer of heat and mass in containment. Therefore, despite the noted deficiencies regarding transient effects, the RELAP5 code can effectively model the long-term containment pressure and sump fluid temperature with sufficient accuracy to adequately represent the long-term NPSH margin for a typical plant.

It should be noted that the $NPSH_{margin}$ does not include a reduction to account for a debris bed that may be present on the suction strainer.

There appears to be a slight inconsistency in the $NPSH_{required}$ data furnished by the licensee. Even if the observed inconsistency implies an error, however, the magnitude of the error would be very small (approximately 0.2 ft) and, thus, insignificant for the purpose of this calculation.

The amount of overpressure available may significantly exceed the design differential pressure of the suction strainers. For instance, one replacement suction strainer for a different plant has a design differential pressure of 5 psi (approximately 11.55 ft of head loss). For existing PWR sump screens, the design differential pressure may be significantly smaller than this value. If the structural failure of a suction strainer would occur at a differential pressure smaller than the available overpressure, then the actual margin provided by containment overpressure would be less than the amount calculated as being available. Detrimental consequences of sump screen structural failure could include the loss of sump recirculation and potential adverse effects to flowpaths being used to take suction from the sump. Investigation of these effects was not within the scope of this report.

It is further noted that containment overpressure head would not be a source of margin for plants with partially submerged sump strainers, since overpressure does not act to help push water through partially submerged strainers. Therefore, when considering the failure mode of loss of flow, partially submerged strainers should still be assumed to fail once the head loss across the sump screen exceeds half the submerged height of the screen, whether or not overpressure is present. Further discussion of this failure mode associated with partially submerged sump screens is provided in Regulatory Guide 1.82, Revision 3.

In the long-term, for the sample calculation performed, approximately 30 ft of containment overpressure head exists over the majority of the 30 days following the LOCA. As qualified above, the available overpressure head could provide margin against head loss due to chemical effects and accumulating debris.

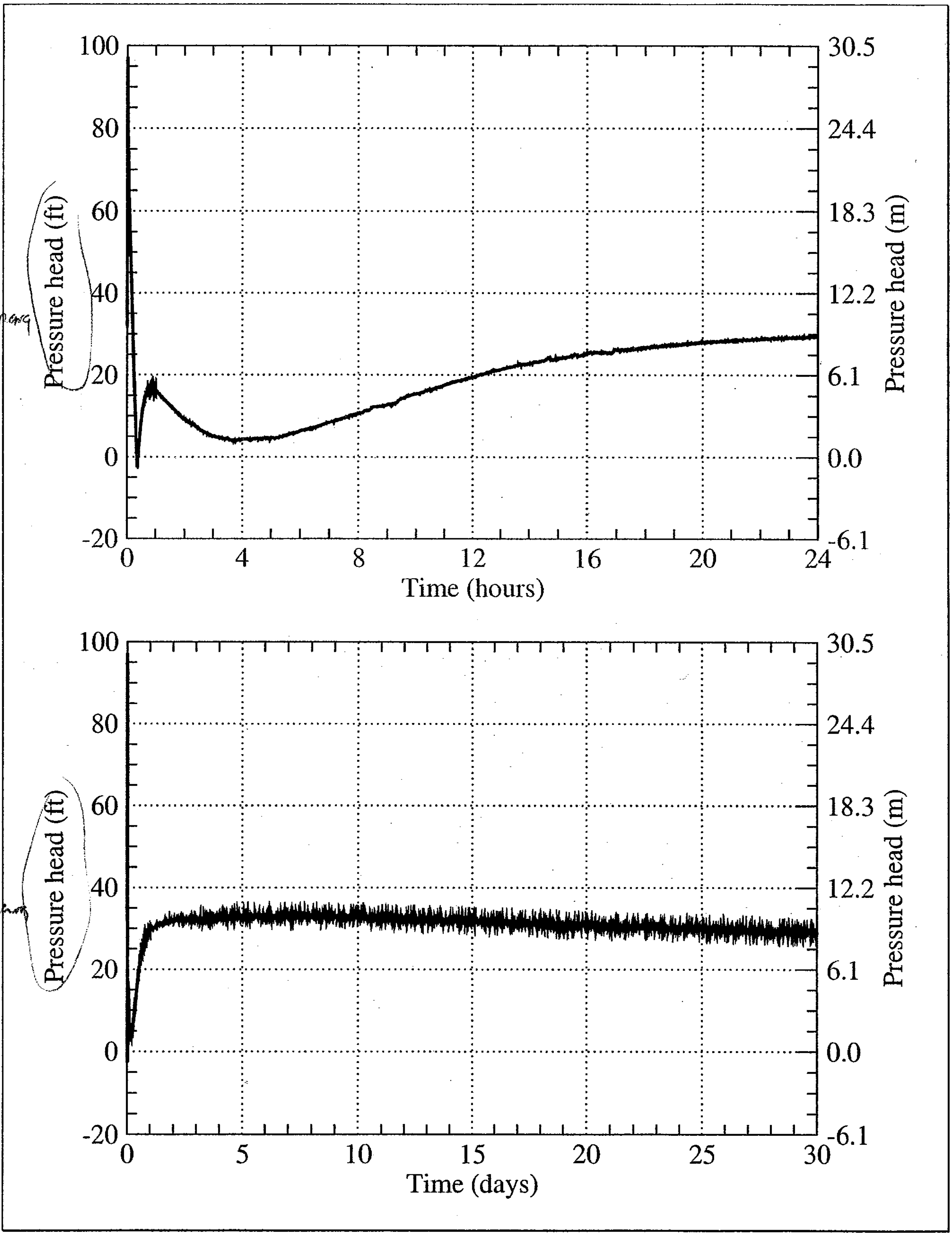


**Figure 28:** *NPSH Margin Sample Calculation, Case 1 ABA M*