ATTACHMENT V-1. NUREG/CR-6224 HEAD LOSS CALCULATION TEMPERATURE ASSESSMENT

In support of General Safety Issue (GSI)-191, “Potential Impact of Debris Blockage on Emergency Recirculation During Design-Basis Accidents at PWRs”, a sensitivity study has been performed to determine the appropriate range of temperatures for applying the pressure drop correlation obtained from NUREG/CR-6224 across a debris blocked sump screen of a pressurized water reactor (PWR) containment. The sensitivity study is intended to address operating and calculational conditions which are beyond the range of testing. Specifically, the objective of this study is to recommend an acceptable application range for pool water temperature.

Testing to measure the pressure drop across a debris blocked sump screen was performed at temperatures between ~70 and ~140ºF. The conditions for sump pump operation should correspond to the containment pressure and water temperature that exist at and after the start of the recirculation phase. The following tables, which were obtained from NUREG/CR-6808, provide a more realistic picture of containment and sump conditions for typical PWR large dry and ice condenser containments at the start of the post-LOCA recirculation phase. It should be noted that the actual plant requirements exceed the tested temperature conditions.

Table 1: Typical PWR Large Dry Containment Conditions After Start of Recirculation

	Large Break LOCA			Medium Break LOCA			Small Break LOCA		
	recirc start			recirc start			recirc start		
Time after start of LOCA	27 min	2 hr	24 hr	57 min	2 hr	24 hr	3 hr	12 hr	24 hr
Containment pressure (psig)	7	1.5	0	3	4.2	1.5	3	1	0.75
Containment temperature (°F)	163	115	95	140	148	120	140	115	110
Pool temperature(°F)	187	125	100	145	147	125	150	125	118

Table 2: Typical PWR Ice Condenser Containment Conditions After Recirculation Start

	Large Break LOCA			Medium Break LOCA			Small Break LOCA		
	recirc start			recirc start			recirc start		
Time after start of LOCA	17 min	2 hr	24 hr	57 min	2 hr	24 hr	35 min	5 hr	24 hr
Containment pressure (psig)	4.5	3	2	4	1.8	1.4	4.2	2.25	1.8
Containment temperature (°F)	105	98	100	110	87	90	110	92	95
Pool temperature(°F)	159	148	126	146	117	104	137	120	114

The NUREG/CR-6224 head loss correlation is an empirically derived equation which is dependent on water properties, flow velocity, and debris properties. Only the water properties exhibit large changes in value as a function of temperature. Using the recommended bounding calculational debris properties from LA-UR-04-1227, pressure drop calculations across a clogged screen with varying amounts of Nukon and

Nukon/CalSil were performed for different approach velocities and water temperatures. It can be concluded that the calculated pressure drop decreases with increasing temperature. The pressure drop decrease is primarily attributed to the reduction in water viscosity with increases in temperature. Therefore, assuming that the head loss relation correctly accounts for the fluid properties and that the debris properties and characteristics do not change with temperature, the head loss calculation should be able to be applied to a wide range of water temperatures as long as the appropriate fluid properties are used.

The NUREG/CR-6224 pressure drop correlation was developed to calculate one-phase pressure drop, and has not been validated and cannot be applied to two-phase flow conditions. Pressure drop can significantly increase with two-phase flow. Two-phase condition can result from two causes. As pressure decreases downstream of the screen, noncondensible gas dissolved in the water can come out of solution and/or hot water can flash into steam. Either or a combination of these two phenomena can result in two-phase flow with increased pressure drop.

In order to prevent water flashing, the pressure downstream of the sump screen must always remain above the saturation pressure at the sump water temperature. Calculations have been performed to estimate the point at which significant void fraction is created downstream of the sump screen as a result of air coming out of solution or as a result of liquid flashing. The release of air from solution can produce nucleation sites which can increase the possibility of steam formation and flashing. A sensitivity analysis was performed during which the water upstream of the sump screen is assumed to contain the maximum amount of dissolved air for a range of water temperatures and containment pressures. The maximum dissolved air mass in subcooled water is determined from the information on air equilibrium concentration contained in reference 4. Assuming homogeneous conditions, the void fraction downstream of the screen is calculated for different sump screen pressure drops, and upstream temperature and pressure conditions. Figures 1 and 2 plot the downstream void fraction as a function of water temperature for two containment pressures and three assumed sump screen pressure drops. It is assumed that the excess air above the saturated air condition downstream of the sump screen is immediately released as gas. This study reflects the requirement that the pressure downstream of the screen remain above the saturation pressure at the sump water temperature.

The study results indicate that the condition at which a significant void fraction occurs downstream of the sump screens is dependent on containment pressure and sump water temperature. It should be stated that the NUREG/CR-6224 head loss equation is not appropriate for calculating pressure drops which result in large downstream void fractions. However, the void fraction which can result in pump cavitation problems is very low and within the range of application of the correlation and testing. It is generally accepted that a pump will experience cavitation problems when its inlet void fraction exceeds about 0.03 (3%) (Reference 5). Using a 3% void fraction limit for conditions downstream of the sump screens, the sensitivity study identified the acceptable sump pool temperature operating range. Table 3 and Figure 3 illustrate the relationship between the maximum allowable sump pool temperature, containment pressure and sump screen pressure drop. The recommended temperature value reflects the inclusion of a conservative margin of at least 5ºF. Because the void fraction assessment was performed for a range of assumed sump screen pressure drops, the results provided can be applied to any sump screen pressure drop calculational method including the NUREG/CR-6224 correlation.

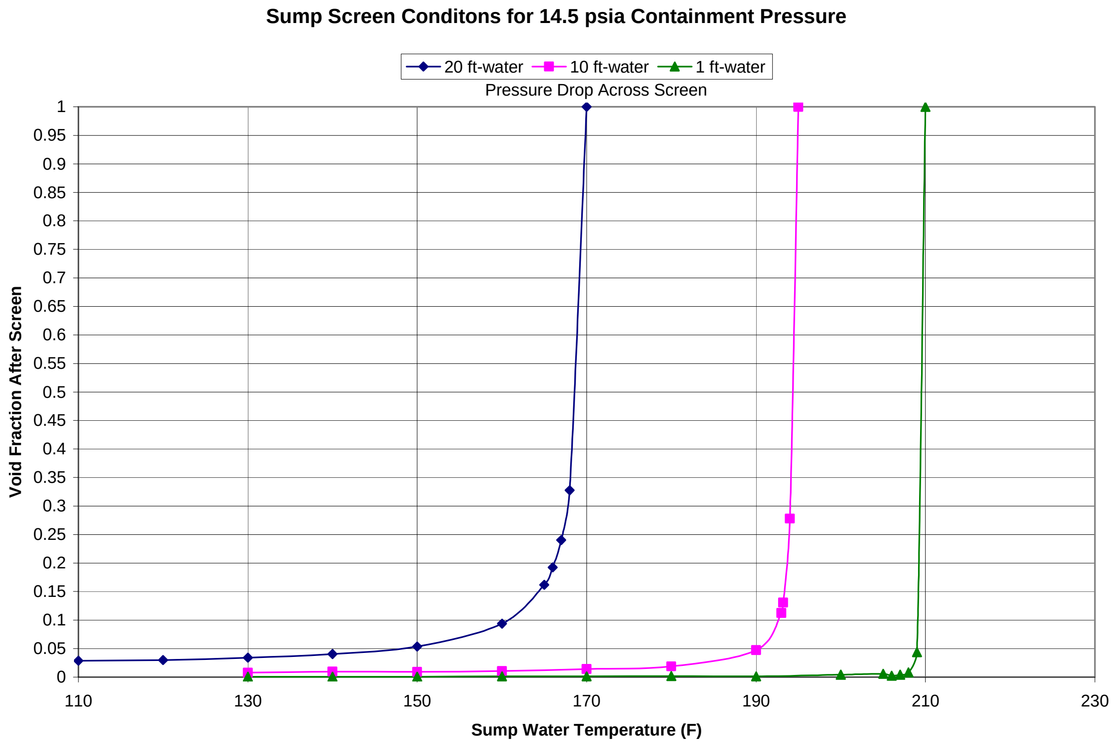

Figure 1: Downstream Void Fraction Versus Water Temperature at 14.5 psia

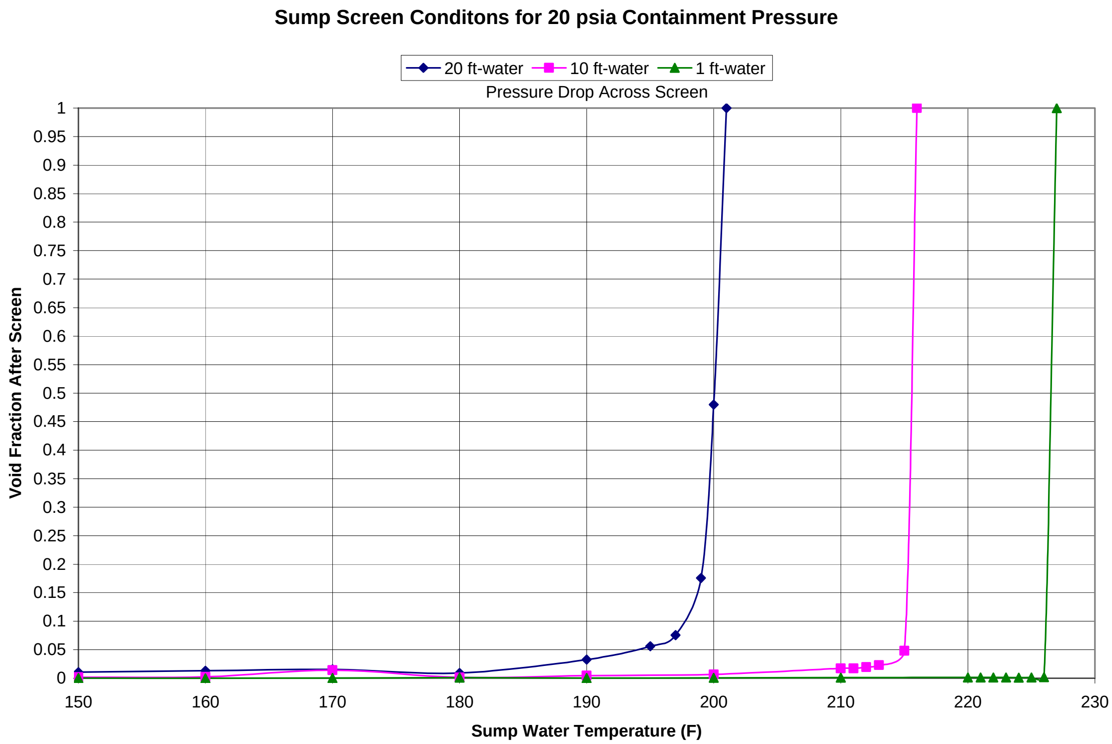

Figure 2: Downstream Void Fraction Versus Water Temperature at 20 psia

Table 3: Acceptable Range of Sump Pool Water Temperature

Containment Pressure (psia)	Pressure Drop Across Sump Screen (ft-water)	Acceptable Sump Pool Water Temperature (ºF) for Void Fraction < 0.03
14.5	1	< 200
14.5	10	< 180
14.5	20	< 120
20	1	< 220
20	10	< 210
20	20	< 180

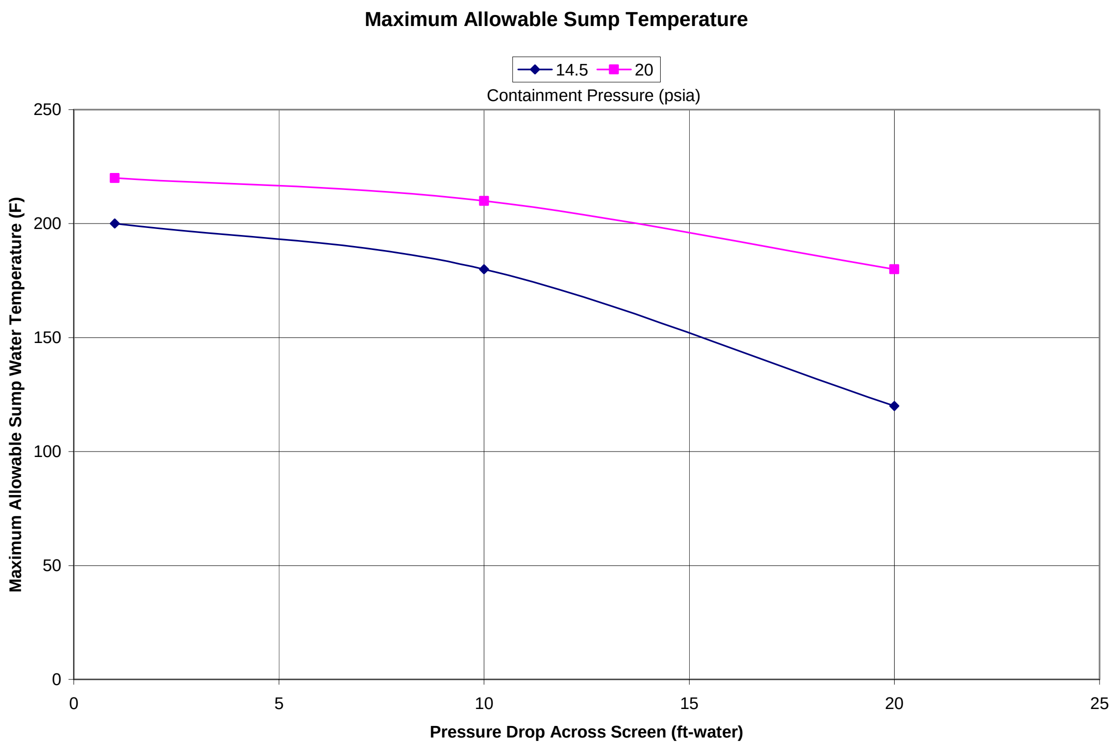

Figure 3: Screen Pressure Drop Versus Maximum Allowable Sump Water Temperature for Downstream Void Fraction < 0.03

References

1. "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," U. S. Nuclear Regulatory Commission, NUREG/CR-6224, October 1995.
2. "GSI-191: Experimental Studies of Loss-of-Coolant-Accident-Generated Debris Accumulation and Head Loss with Emphasis on the Effects of Calcium Silicate Insulation," Los Alamos National Laboratory, LA-UR-04-1227, April 2004.

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4. "Contribution to the Theory of Two-Phase Blowdown Phenomenon," Hutcherson, M. N., Argonne National Laboratory, ANL-75-82, December 1975.
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