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TASK #2 SCOPE:

To determine the accuracy of and uncertainties involved in using the 3% head loss value of NPSH Required (NPSHR) for the reactor ECCS core spray and residual heat removal pumps (using the pumps in the Sultzer / Browns Ferry Report as examples of the types of pumps to be considered). Further, recommend how this information can be included in criterion for the NPSR margin.

HARDWARE SCOPE:

- Core Spray (CS) and Residual Heat Removal (RHR) centrifugal pumps, similar to Browns Ferry units

TECHNICAL EVALUATION:

Principal Consultant and Pump Specialist, Allan R. Budris, P.E., used his four decades plus experience on centrifugal pumps and their suction (and cavitation) condition, to determine the accuracy of and uncertainties involved in using the 3% head loss value of NPSH Required (NPSHR) for the reactor ECCS core spray and residual heat removal pumps (using the pumps in the Sultzer / Browns Ferry Report as examples of the types of pumps to be considered). Any positive variance from the factory NPSHR test to the actual field NPSHR will reduce the run-out flow rate of the ECCS pumps, as shown in figures 1 and 2 (for the RHR and CS pumps). This could limit the RHR and/or CS pumps from reaching the critical flow rates required during a reactor accident.

1. Accuracy of 3% Pump NPSHR: If the 3% NPSHR is to be used as the minimum allowable NPSHA, it must be established with reasonable accuracy. The following methods, which have different levels of accuracy, could be considered to determine the NPSHR of a centrifugal pump:
 - a. An actual NPSH factory tests of the specific pump in question, tested in accordance with the Hydraulic Institute Standard (ANSI/HI 1.6): Figures 1 and 2 show one (of two) type of HI test (constant NPSHA) for the RHR and CS NPSHR performance. This is the most accurate (gold standard) method of determining the NPSHR (3%) of a pump. For best accuracy, the test should be conducted at the rated speed, and impeller diameter, with the NPSHA controlled by a vacuum pump. The individual measurement, allowable HI test fluctuations and instrument accuracy are shown in Table 1. The resulting net NPSHR accuracy of this method would be expected to be in the +/- 1 to 2 feet range (or +/- 2.5% to +/- 5%, whichever is larger), depending on the accuracy of the instrumentation and air content of the test liquid. If possible this method should be the preferred method.
 - b. The second most accurate method for determining the NPSHR of a pump would be to conduct a Hydraulic Institute NPSH test of a similar model and size pump, at the same speed and impeller diameter. The accuracy of this method for the three different RHR Sultzer pumps was in the range of +/- .1 to +/- 4 feet, as shown in figure 3. Generally the accuracy of this method would be expected to be in the range of +/- 2 to +/- 4 feet, (or +/- 5% to +/-15%, whichever is greater). The accuracy of this method depends on the accuracy of the test method and:
 - i. Impeller wearing ring clearance: A greater clearance increases the wearing ring leakage, and thus NPSHR, of a pump by increasing the gross flow through the impeller eye, and disturbing the incoming flow stream. The impact of this effect is not large with new pumps (within the manufacture's tolerance range), but can be quite large as this clearance opens with operation.
 - ii. The cast thickness of the leading edges of the impeller vanes (or impeller eye diameter): The cast vane thickness will vary from one impeller to the next, with the amount of variation dependent on the type of casting method used. Thicker vanes (or smaller impeller eyes) cause more blockage which increases the NPSHR of a pump.
 - c. The third most accurate method would be to conduct a Hydraulic Institute NPSH test on a model pump, if testing of the full size pump is not feasible. The accuracy of this method would not be expected to be as good as the results from a full size similar pump (since scaling errors are also introduced), so it is more likely in the +/- 3 to +/- 5 feet (or 7% to +/-18%) accuracy range, whichever is greater.

- d. Another method with reasonable accuracy that might be considered would be to use the ANSYS CFX cavitation model software. The accuracy of this method would be expected to be less than for actual tests, and probably similar to a model test, since not all physical factors can be accurately modeled. The accuracy would likely be in the ± 3 to ± 5 feet range (or 7% to $\pm 18\%$ range), whichever is greater.
 - e. Finally, an NPSH field test could be performed (as shown in figures 1 & 2), if calibrated instruments (with proper straight runs of piping before and after the instruments) can be provided, the suction pressure can be throttled, and the flow rate can be varied and accurately measured. In some respects this could be the most accurate test, since any field speed changes or suction piping influence would be included in the test. The accuracy of this method is strongly dependent on how close the test can be to the Hydraulic Institute test criteria. A fair estimate of accuracy of this method would probably then be in the ± 1 to ± 10 feet range (or 2.5 to $\pm 30\%$ range), whichever is greater.
2. Field conditions that further impact the accuracy of the installed pump 3% NPSHR:
- a. Actual field pump speed: NPSHR varies as the square of the pump speed, which does change with changes in the motor slip. Operation at less than the full rated motor power, and/or high efficiency motors tend to reduce motor slip. This can cause the pump to operate at slightly higher speeds in the field, compared to a factory test speed with the factory calibrated motor. The RHR 1785 RPM and CS 3580 RPM factory speeds could actually be higher in the field, which could increase the NPSHR from 0% to about 1%.
 - b. Liquid temperatures impacts the NPSHR of a pump. As water temperature increases, the size of the cavitation vapor bubbles get smaller, thus creating less blockage. At a water temperature of 210 degrees F, the NPSHR value will be reduced by about 1 foot. This effect provides a small positive variation (margin).
 - c. Using insufficient lengths of pump suction piping (after a disturbing fitting), in the field, can impact the pump NPSHR. Straight inlet pump pipe lengths less than those listed in Tables 1 and 2 of the Task #1 Report, could increase the pump NPSHR due to disturbances in the inlet flow stream. Non-uniform flow generates higher local velocities in a pump inlet, which causes lower local static pressures, and thus more liquid to flash into vapor, which would increase the NPSHR. This affect is the greatest when the pump is operating in the suction recirculation region. A rough estimate of the impact of the suction piping on the pump NPSHR would be from zero effect for good piping, to a 3 feet increase (or 10%, whichever is greater) for poor piping, for operation above the suction recirculation flow region.
 - d. The air content of the test liquid: Hot water typically holds less air, which comes out of solution when cavitation bubbles are formed. This decreases the air/vapor impeller inlet blockage, thus slightly decreasing the NPSHR value. On the other hand, the spraying action inside the containment shell will tend to entrain more air. We, therefore, do not know if this phenomena will increase or decrease the field NPSHR of the pump. An estimate of the impact of the dissolved and entrained air content (of the water) on the pump NPSHR would be from zero for a low air content, to a +2 feet increase (or 5%, whichever is greater) for higher entrained or dissolved air levels.

3. Recommendation on how the above information can be included in criterion for the NPSH Margin Requirement:
 - a. Based on the above factory and field variation factors, it definitely appears that some variation would be expected between the controlled factory pump suction performance test, and the actual field pump NPSHR(3%) values.
 - b. These pump test related and system related NPSHR(3%) variation factors are summarized in Tables 2 and 3, along with totals for the individual average variations, for each possible test method.
 - c. These “Average Total” values should be considered for inclusion in the criterion for the final “NPSH Margin” requirement.

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APPENDIX – A

(Tables & Figures)

Table 1: Hydraulic Institute Test Fluctuation and Accuracy

Measurement	Acceptable fluctuation of test readings +/-%	Accuracy of the instrument +/-%
Capacity	2.0	1.5
Differential Head	2.0	1.0
Discharge Head	2.0	0.5
Suction Head	2.0	0.5
Pump Speed	0.3	0.3

Table 2: NPSHR Variation Summary (feet)

TYPE VARIATION	NPSHR TEST METHOD (feet)				
	HI Factory	HI Similar	Model	ANSYS CFX	Field
NPSH Test	+/- 1 to 2	+/- 2 to 4	+/- 3 to 5	+/- 3 to 5	+/- 1 to 10
Field Speed	0 to +.5	0 to +.5	0 to +.5	0 to +.5	0 to +.5
Suction Piping	0 to +3	0 to +3	0 to +3	0 to +3	0 to +3
Water Temperature	-1	-1	-1	-1	-1
Water Air	0 to +2	0 to +2	0 to +2	0 to +2	0 to +2
TOTAL (AVG)	+3'	+5'	+6'	+6'	+7.5'

Table 3: NPSHR Variation Summary (Percent)

TYPE VARIATION	NPSHR TEST METHOD (Percent)				
	HI Factory	HI Similar	Model	ANSYS CFX	Field
NPSH Test	+/- 2.5 to 5	+/- 5 to 15	+/- to 18	+/- 7 to 18	+/- 2.5 to 30
Field Speed	0 to +1	0 to +1	0 to +1	0 to +1	0 to +1
Suction Piping	0 to +10	0 to +10	0 to +10	0 to +10	0 to +10
Water Temperature	- 3%	- 3%	- 3%	- 3%	- 3%
Water Air	0 to + 5%	0 to + 5%	0 to + 5%	0 to + 5%	0 to + 5%
TOTAL (AVG)	+9%	+15%	+17.5%	+17.5%	+21%

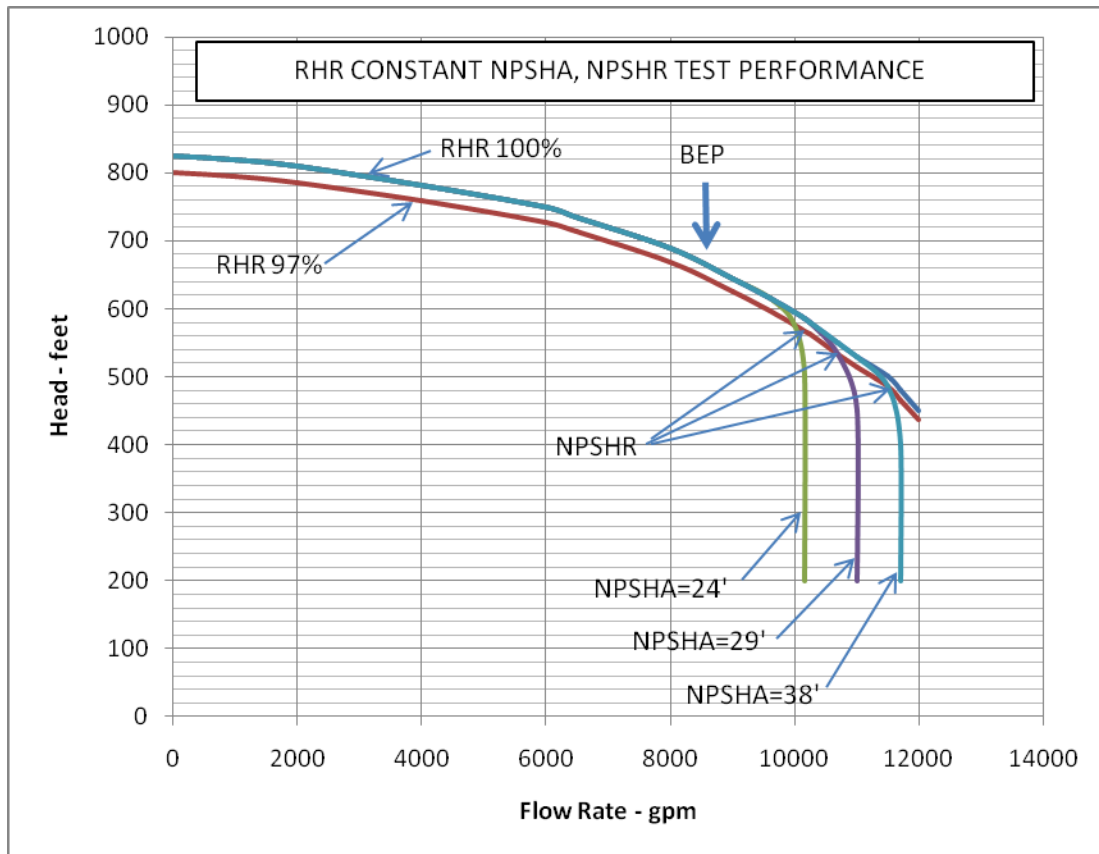


Figure 1: NPSH test with suction head held constant (RHR)

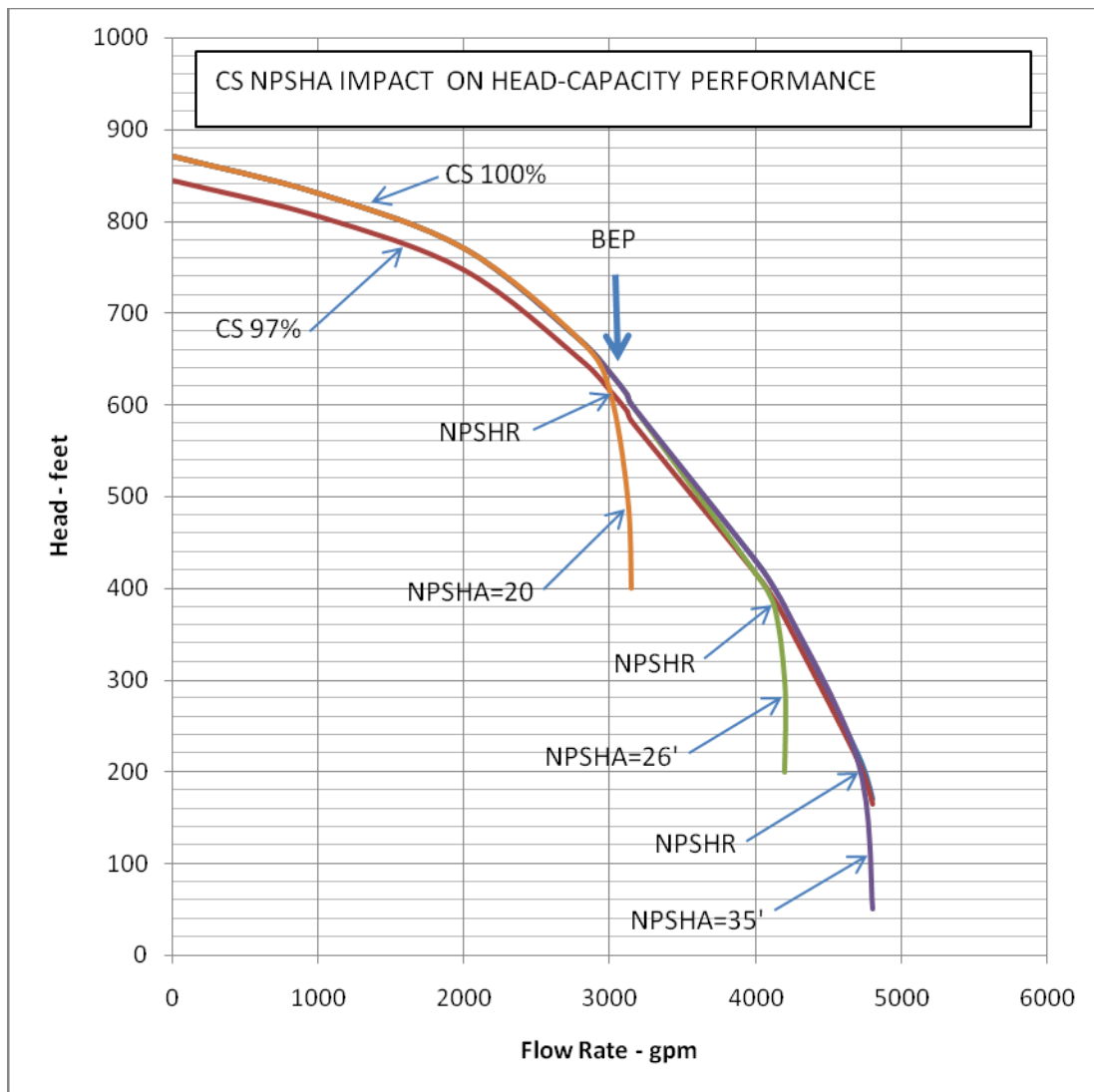


Figure 2: NPSH test with suction head held constant (CS)

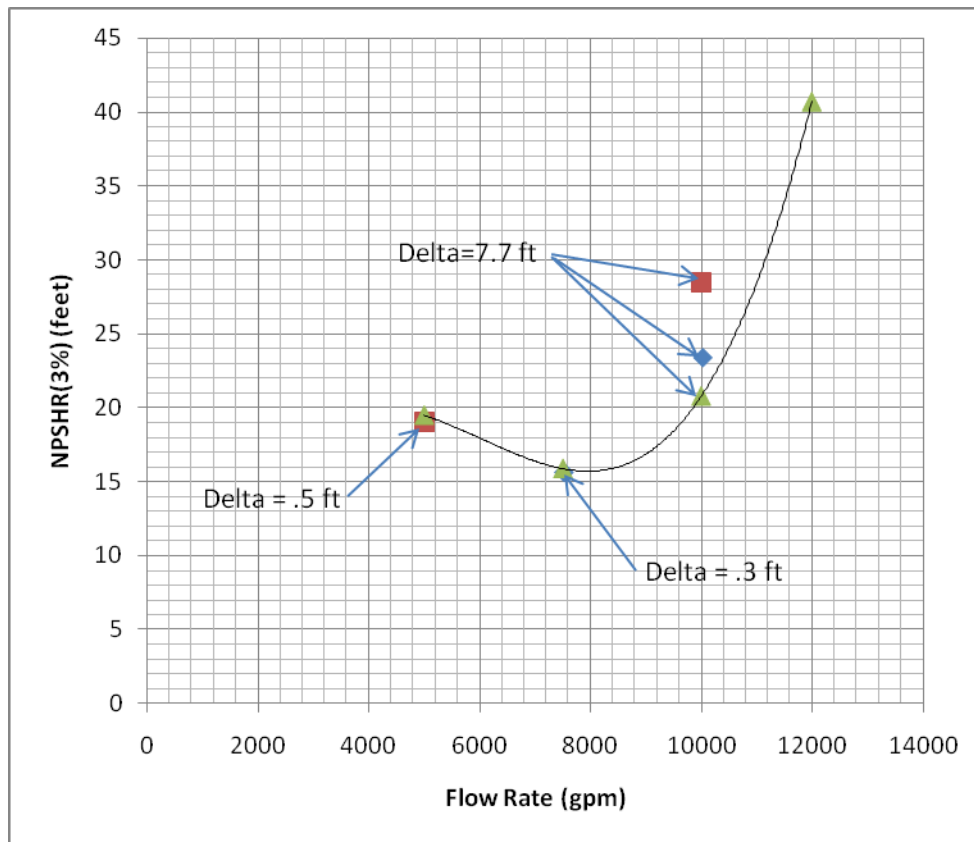


Figure 3: Deviation in NPSHR (3%) values for three similar RHR pumps