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UNCERTAINTY ANALYSIS OF EMERGENCY COOLING SYSTEM FLOWS

INTRODUCTION

The Emergency Cooling System (ECS) for SRP reactors is designed to provide core cooling for postulated incidents. Recently, tests were completed in L Reactor to better define pipeline and fitting loss coefficients that are needed to predict ECS flows(1). Because the ECS flows in Reference 1 are primarily based on experimental data, an experimental uncertainty exists in those flows and respective loss coefficients. The uncertainty analysis and resulting uncertainties of the Reference 1 ECS flows are discussed in this report.

SUMMARY

The maximum flow uncertainty for a loss of coolant accident (LOCA) is 5.4%. Similarily, the maximum flow uncertainty for a loss of pumping accident (LOPA) is 6.4%. The Kline-McClintock(2) single sampling uncertainty analysis method was used to determine the LOPA and LOCA uncertainties. The uncertainty analysis considered manometer, flow, pump-head, elevation, and where applicable, fuel and top shield flow resistance uncertainties.

DISCUSSION

Background

Accident scenarios which require the ECS are analyzed using the FLOOD84 computer code(3). A key input parameter to FLOOD84 is the ECS flow expected from the three ECS injection systems. Because low ECS flows can restrict reactor power, accurate determinations of ECS flows are required to avoid overly conservative restrictions on reactor power.

Prior to the recent ECS flow tests in L Reactor (1), the ECS flows were calculated from analytical methods with a minimal amount of experimental data(4). The uncertainty in these calculated flows was ±17%(5). Such a large uncertainty would have resulted in ECS limits being excessively conservative. However, other factors in FLOOD84 needed revision and implementation of assembly power ECS limits based on the Reference 4 flows has been delayed.

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To prevent the overly conservative ECS power limits and potential restrictions in reactor power which would occur from using the Reference 4 flows and Reference 5 uncertainties, ECS flows were experimentally determined in L Reactor. Because experimental data has an uncertainty due to measurement nonidealities, the measured ECS flows have an uncertainty in their values. The flow uncertainties must be considered when determining ECS flows which are input to the FLOOD84 computer code.

Analysis

To calculate flow, Reference 1 starts with an equation of the general form

$$H = K(Q/1000)^2 \quad (1)$$

where H = pump head or piping pressure loss, ft of H_2O
K = loss coefficient, ft of H_2O/gpm^2
Q = flow, gpm

Loss coefficients are documented for the various segments of ECS piping in Figure 1. For an assumed ECS flow the head loss is determined for each applicable pipe segment. Then the head loss terms are totaled for a given flow path. If the pump-head curve which uniquely defines a head/flow combination matches the calculated head loss with the assumed ECS flow, then the assumed flow is correct. If the assumed flow has a calculated head loss which does not match the correct head on the pump-head curve, then a new flow is assumed. Iterations continue until the assumed flow and calculated head loss match the unique head/flow combination on the pump-head curve.

In Reference 1, the experimental results were used to determine the loss coefficient values in Equation 1 for the various ECS pipe segments. The experiment measured pressure losses for a series of flows. Then, the loss coefficients were determined from the flow and pressure loss data. Because the elbows in the ECS lines were turned for the tests, it was not possible to run the system for expected ECS flows. As a result, once the loss coefficients were determined the ECS flows were calculated using the iterative technique discussed in the previous paragraph.

The uncertainty in an ECS flow is determined by first rearranging Equation 1.

$$Q = 1000\ (H/K)^{0.5} \quad (2)$$

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The Kline-McClintock method for calculating the flow uncertainty in Equation 2 gives

$$W_Q = \{ (\frac{\partial Q}{\partial H} W_H)^2 + (\frac{\partial Q}{\partial K} W_K)^2 \}^{0.5} \quad (3)$$

where W_i = uncertainty in appropriate units of ith variable

Performing the mathematical operations in Equation 3 and dividing the results by Equation 2 gives

$$\frac{W_Q}{Q} = \frac{1}{2} \{ (\frac{W_K}{K})^2 + (\frac{W_H}{H})^2 \}^{0.5} \quad (4)$$

To calculate the flow uncertainty, uncertainties in the pump-head and loss coefficient terms must be determined.

The uncertainty in the pump-head curve for each ECS source other than the new emergency pumps must be estimated. For the cooling water headers and booster pump where the data originally used to determine the curves were not available, the following procedure was used. First, an initial head uncertainty corresponding to a flow measurement uncertainty of 5% was used. The flow uncertainty accounts for flow measurements when the head curves were first determined. Then, 1% of the nominal pump-head was added to this initial head uncertainty to obtain the total pump-head uncertainty, W_H in Equation 4. The 1% considers a typical manometer uncertainty which would have measured the pump head (pressure) during a test.

As an example for the [redacted] pump-head curve, the pump-head uncertainty for the expected ECS flows is 5.2%. Using a similar procedure, the pump-head uncertainty for the booster pump is 1.8%. These 5.2% and 1.8% uncertainties are applicable to LOCA cases. The pump-head uncertainty for the booster pump is much lower than for [redacted] because for the booster pump, an assumed 5% flow variation has an almost negligible effect on pump-head. For [redacted], an assumed 5% flow variation has a large effect on pump-head.

In comparison to the booster pump and [redacted] cases, a different technique was used to calculate the pump-head uncertainty for the emergency pumps. A different technique was used because the data used to develop the head curve was available. Consequently, the scatter in the data was used to estimate the head uncertainty. Because the emergency pump-head data was available, pump-head uncertainties for each ECS combination were determined. Table 1 lists these uncertainties. The pump-head curves for the emergency pumps and [redacted] are similar in that small flow variations have a measurable effect on head. The uncertainties in Table 1 are smaller than the 5.2% head uncertainty for the [redacted] pump-head curve because the data for estimating the pump-head uncertainties of the emergency pumps are available.

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In addition to the data uncertainties, the pump-head uncertainties for the LOPA cases in Table 1 consider uncertainties in the top shield resistance and pipe elevations with respect to zero grade in the 105-building. The top shield uncertainty was assumed to be 10% of the top shield correction. The elevation uncertainty was 0.5 inches, double the minimum dimension on applicable ECS piping diagrams. For the LOPA cases where [redacted] is a source, the [redacted] pump-head uncertainty is 6.4%. The pump-head uncertainties for the booster pump source are 2.9% for a single ECS system on, 3.3% for two ECS systems on, and 4.0% for three ECS systems on.

The uncertainty in the loss coefficient of Equation 1 was determined by rearranging Equation 1 as

$$K = H(1000/Q)^2 \qquad (5)$$

and completing a Kline-McClintock analysis of this equation. The uncertainties in the head and flow terms of Equation 5 were determined from the L-Area data. The flowmeters were accurate to 1% and the flowmeter signal was assumed to have a 1% uncertainty for a combined uncertainty of 1.4%. The head uncertainty in Equation 5 accounted for manometer reading, water density, and piping elevation uncertainties. These uncertainties are well defined from the available data.

Each set of flow data (50 points were used) was used to calculate a loss coefficient value. The various coefficient values for each ECS source and system configuration were averaged. When the coefficient uncertainty calculated from the Kline-McClintock method was applied to the average loss coefficient, the resultant range of coefficient values did not encompass all the individual coefficient values. As a result, an additional uncertainty value was added to the Kline-McClintock values to account for the non-repeatability of the data. For the piping routes leading to point four in Figure 1, 1% was added to the Kline-McClintock values. For piping routes from point four, 2% was added. Only 1% was added to the piping routes leading to point four because there was not much scatter in the data. Larger scatter was expected and found in the data for the piping routes from point 4 because the piping tees in these routes are a significant portion of the pipe head loss. Also, head losses through piping tees are subject to large head uncertainties. Table 2 summarizes the final loss coefficient uncertainties. Of the 50 data points, the uncertainites in Table 2 when applied to the average loss coefficient for a piping segment would produce a loss coefficient range that covered 45 points. Three of the five points which are outside the range are for the cases where all three ECS systems are operating. However, these cases are not the limiting cases in ECS studies.

When using Equation 3 to calculate the flow uncertainties for LOPA cases, the uncertainties in the fuel resistance were factored into the loss coefficient uncertainty. The fuel resistance uncertainty was assumed to be 10% of the calculated fuel resistance.

Results

Tables 3 and 4 list the ECS flow uncertainties. The results are applicable to P Reactor as well as LKC Reactors. The differences in the P Reactor piping when compared to LKC Reactors are simply longer pipe runs. Because the head loss and flow uncertainty in simple pipe runs is negligible compared to pipe runs with complicated valving and fitting combinations, the flow uncertainty differences in P and LKC Reactors are negligible.

REFERENCES

1. J. H. Hinton, Emergency Cooling System Flows, RTR-2239, Rev. 1, September 6, 1985.

2. S. J. Kline and F. A. McClintock, "Describing Uncertainties in Single-sample Experiments," Mechanical Engineering, January 1953, p. 3.

3. J. P. Church, Computer Program For Calculating Equilibrium Flows and Reactor Damage With Reduced Cooling, DPSTM-130, April 1985.

4. J. H. Hinton, Emergency Cooling System Flows, RTR-2239, May 22, 1985.

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TABLE 1

PUMP-HEAD UNCERTAINTIES FOR EMERGENCY PUMP COMBINATIONS

Emergency Cooling System		LOCA Cases Head Uncertainty, %	
Systems On	Leaking Systems	1 Pump On	2 Pumps On
[redacted]	[redacted]	2.4	4.2
		3.0	2.3
		2.4	4.2
		LOPA Cases	
[redacted]		2.9	4.4
		3.6	3.2
		4.0	3.5
		2.8	4.3
		2.9	4.4

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TABLE 2

Summary of Loss Coefficient Uncertainty Values

Piping Segment	Loss Coefficient Uncertainty, %
[redacted] to point 4	4.1
to point 4	3.9
Booster pump to point 4	3.8
Emergency pump 1 to point 4	3.8
Emergency pump 2 to point 4	3.8
Point 4 to 5', 100% flow	5.6
Point 4 to 2', 100% flow	12.5
Point 4 to 4', 100% flow	9.1
Point 4 to 5', 50/50 flow split	5.9
Point 4 to 4', 50/50 flow split	7.1
Point 4 to 2', 50/50 flow split	6.8
Point 4 to 2', 33% flow split	13.8
Point 4 to 4', 33% flow split	11.8

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TABLE 3

ECS Flow Uncertainties for LOCA

Emergency Cooling System			
Systems On	Leaking Systems	Booster Pump Source, %	
[redacted]	[redacted]	3.4	
		5.4	
		2.9	
		[redacted] Source, %	
[redacted]	[redacted]	4.3	
		3.9	
		Emergency Pump Source, %	
		1 Pump On	2 Pumps On
[redacted]	[redacted]	4.3	4.6
		5.4	5.4
		3.0	3.5

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TABLE 4

ECS FLOW UNCERTAINTIES FOR LOPA

Emergency Cooling System Systems on	Booster Pump Source, %
[redacted]	3.0
	5.6
	4.3
	3.6
	3.7
	3.7
	6.4

Emergency Cooling System Systems on	[redacted] Source, %
[redacted]	5.3
	4.2

Emergency Cooling System Systems on	Emergency Pump Source, % 1 Pump On	Emergency Pump Source, % 2 Pumps On
[redacted]	5.6	5.8
	3.6	3.5
	6.4	6.3
	3.0	3.4
	4.3	4.6

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FIGURE 1

SCHEMATIC OF ECS PIPING

[redacted]

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