MPR
ASSOCIATES INC.
ENGINEERS

Evaluation of Cook Recirculation Sump Level for Reduced Pump Flow Rates

Revision 0

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QUALITY ASSURANCE DOCUMENT
This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of 10CFR50 Appendix B, as specified in the MPR Quality Assurance Manual.

1.0 PURPOSE

The purpose of this evaluation is to determine minimum water level in the Cook containment recirculation sump as a function of total pump flow. The minimum water level will ensure satisfactory hydraulic sump performance over the expected range of flows. This range includes flows lower than those tested in the original development of the sump design.

2.0 METHODOLOGY

The minimum water level as a function of flow is developed using the results of Alden Research Laboratory's 1978 testing, supplemental information provided by Alden in 1998, and classic weir wall flow correlations. Correlations for flow over weir walls and prevention of vortexing are used with the data from the 1978 tests to develop the minimum water levels for satisfactory performance.

3.0 BACKGROUND

Figure 1 shows the basic geometry of the sump. The sump is rectangular in plan, roughly 18 ft long and 10.5 ft wide. Figure 2 provides the sump details. A crane wall divides the sump into two portions, an upstream portion with a free surface and a downstream portion with a top below the water surface. The sump floor is at El. 591'-1", whereas the containment floor is at El. 598'-9-3/8". A curb with its top at El. 599'-4-3/8" is provided at the sump entrance. Two 18" outlet pipes (with 24" diameter bellmouths), placed 7' center to center, take off from the back wall of the downstream covered portion, with their centers at El. 595'-6". Each pipe leads to the suction side of one of two trains of ECCS pumps. A vertical steel grating and a fine mesh screen are provided along the curb at the sump entrance.

In 1978, as part of the qualification of the Cook sump design, Alden Labs performed model testing of the actual sump configuration (Reference 2). The overall purpose of the testing was to confirm satisfactory sump performance for conditions of maximum pump flow and potential blockage of sump gratings or other flow paths. At the time, AEP considered that 620'-10" was the minimum sump level possible following a LOCA, so the testing confirmed that the sump arrangement was acceptable for maximum flow at a water level of 602'-10".

Recently, AEP has determined that the level may be lower than 602'-10" under certain conditions. However, the ECCS pump flows for these conditions are less than maximum design flow. The purpose of this evaluation is to estimate the minimum water level for low pump flow conditions.

During the 1978 testing, two phenomena were identified which could degrade pump/sump performance. These were:

- Vortexing - The formation of vortices in the sump may allow air intrusions into the suction flow and the pump. Available pump performance data shows that when the air fraction reaches about 2%, pump performance begins to degrade. Thus, vortexing must be avoided.

- Weir wall effects - To reach the sump suction pipes, the flow must pass over the curb at elevation 599'-4 3/8". Sufficient depth must be maintained at the curb so that flow "over" the curb matches the pump flow (i.e., that a flow imbalance does not occur).

This evaluation considers each of these effects.

4.0 EVALUATION

4.1 Minimum Water Level Based on Alden Vortexing Considerations

A correlation for assessing potential swirl and vortexing is provided in the supplemental information from Alden Labs (Reference 1). This calculation is based on results of the 1978 Alden hydraulic model study of the Cook containment sump.

Formation of free and sub-surface vortices and flow swirl intensity depend on the Froude Number, F, the circulation induced by the approach flow to the sump, and the flow patterns in the sump near the two pipe entrances (e.g., flow separations and eddies). In this case, as free surface vortices can form upstream of the crane wall, the Froude number, F, is defined as:

$$F = \frac{V}{\sqrt{gS}} \qquad (1)$$

Where: V = Average velocity of flow at the pipe bellmouth entrance.
S = Submergence from top of curb.

The velocity is representative of the downward flow upstream of the crane wall. Because the horizontal flow area upstream of the crane wall is much larger than the pipe area, local downward velocities would not be higher than the suction bell velocities. Therefore, the average velocity of flow at the pipe bellmouth entrance is used. The value of S used is representative of the depth above the horizontal area of downward flow upstream of the crane wall.

The Froude Number is the parameter which controls vortexing and swirls. The minimum water level providing satisfactory hydraulic performance for a lower flow than that tested in the 1978 Alden model can be determined by keeping the respective Froude Numbers essentially the same between the two cases. By equating the Froude Number for the new conditions under consideration with the earlier 1978 model Froude Number, F_m,

$$F_m = \frac{V}{\sqrt{gS_{min}}} \tag{2}$$

The minimum water level above the curb top for the new conditions may be calculated by

$$S_{min} = \frac{V^2}{gF_m^{\ 2}} \tag{3}$$

The model Froude Number is based on the 1978 Alden report test case considering a flow of 9,500 gpm. This flow gave satisfactory performance with up to 50% grating/screen blockage for a water elevation of 602'-10". These values are used in equation (2) to calculate F_m.

The flow of 9,500 gpm is first converted to cfs as follows:

$$Q = 9{,}500\text{gpm} * \frac{0.002228}{1\text{gpm}} = 21.17\text{cfs} \tag{4}$$

The pipe bell has an inside diameter of 2 ft. The corresponding pipe bell area and velocity at the pipe bell entrance are therefore:

$$\text{Area} = \pi r^2 = 3.14\text{ft}^2 \tag{5}$$

$$V = \frac{Q}{A} = 6.74\text{ft/s} \tag{6}$$

The submergence from the top of the curb is

$$S_{min} = 602.83\text{ft} - 599.36\text{ft} = 3.47\text{ft} \tag{7}$$

The results from equations (6) and (7), along with a gravitational acceleration of 32.2 ft/sec^2, are used in equation (2) to solve for a model Froude Number of 0.64.

The model Froude Number can now be used in equation (3) to determine minimum required water elevation for the new conditions. Flow rates between 1,000 gpm and 15,000 gpm are considered. Velocity at the bellmouth entrance is calculated as in equations (4), (5), and (6). Gravitational acceleration is as before. Results of the application of equation (3) are shown in Table 1. Figure 3 graphically depicts the minimum water elevation based on vortexing considerations.

It is important to note that this method of calculating minimum required water elevation results in a minimum elevation of at least 607' for a flow rate of 15,000 gpm. The 1978 testing concluded that 602'-10" was acceptable for this flow rate. These results show that the correlation used to assess vortexing is conservative.

4.2 Minimum Water Level Based on Alden Critical Flow Considerations

The second method considered in the Alden supplemental report (Reference 1) is based on a "critical depth", Y_c. This critical depth is a function of the total approach flow, Q_t, to the sump and the available width, B, over which the flow takes place:

$$Y_c = \left(\frac{q^2}{g}\right)^{\frac{1}{3}} \qquad (8)$$

Where: Y_c = Critical flow depth (ft)
q = Q_t/B is the discharge per unit width ($ft^3/sec/ft$)
g = gravitational acceleration (32.2 ft/sec^2)

The upstream water level relative to the top of the curb needed to maintain the supply of flow to the sump is 1.5 Y_c. For conservatism, Alden increased the factor to 2.0 Y_c. Therefore, the minimum required water elevation is the elevation of the top of the curb plus $2Y_c$:

$$MWE = 599.36 + 2Y_c \qquad (9)$$

Where: MWE = Minimum water elevation (ft)

The possibility of 50% of the gratings/screen at the sump entrance being blocked by insulation debris (fibrous and/or metallic) is considered in the critical depth calculation. Only half the length of the available curb (9 ft) is considered when calculating the critical depth. Impervious blockage of the entire bottom portion of the grating/screen is considered unrealistic and is not included in the Alden evaluation.

Table 2 shows results of the application of equations (8) and (9) to determine the required minimum elevation for flow rates between 1,000 gpm and 15,000 gpm. The results are documented in the Alden 1998 report. Figure 4 graphically shows the results of the Alden critical depth calculations.

The 1978 Alden report (Reference 2) states on page 21 that 602'-3" is the required minimum elevation for adequate flow over the curb into the deep portion of the sump. The results in Table 2 show only 600' to 601' of water is needed to provide adequate flow, depending on flow rate. These results suggest the above Alden critical depth calculations may not be conservative.

4.3. Minimum Water Level Based on the Classic Weir Wall Correlation

A "classic" weir wall correlation can be used to calculate flow for a given configuration. The following equation may be applied to the weir under consideration:

$$Q = CLh^{\frac{3}{2}} \tag{10}$$

where:
Q = Flow rate
C = Weir wall coefficient
L = Length of weir
h = Height of water above weir

The equation may be solved for C as follows:

$$C = \frac{Q}{Lh^{\frac{3}{2}}} \tag{11}$$

The 1978 Alden report states that 602'-3" represents a lower limit for balancing the inflows and outflows over the curb. This water elevation may be used to solve for the weir wall coefficient for the sump configuration. This coefficient is then used to determine water elevations for given flows for the new conditions. Thus, the minimum elevation is determined using classic correlations with coefficients based on actual sump testing.

In a follow-up discussion with Alden (Reference 3), it was determined that the limiting test condition was an elevation of 602'-3", no blockage, and a flow rate of 15,400 gpm. The weir coefficient resulting from these conditions is (using equation 11):

$$C = \frac{15{,}400\text{gpm}}{18\text{ft}(2.89\text{ft})^{\frac{3}{2}}} = 174.1 \tag{12}$$

This weir coefficient is applied to flow rates between 1,000 gpm and 15,000 gpm, with 50% blockage of the grating/screen at the sump entrance assumed. Equation (10) was solved for h to determine the necessary elevation:

$$h = \left(\frac{Q}{CL}\right)^{\frac{2}{3}} \tag{13}$$

The variable h is the height above the weir wall, or above the curb. To find the necessary minimum water elevation, MWE (in ft), h must be added to the height of the curb:

$$\text{MWE} = h + 599.36\text{ft} \tag{14}$$

Results of equations (13) and (14) are presented in Table 3. Figure 5 graphically displays the minimum water elevation for given flow rates.

5.0 SUMMARY

The minimum water level may be limited by weir wall effects or vortexing depending on the flow rate. The method selected for developing minimum water level for the Cook sump is as follows:

- At low flow rates (less than about 9,300 gpm), weir wall effects are limiting and the "classic" weir wall correlation is used. This correlation is more conservative than the Alden "critical depth" approach and is based on actual testing of the Cook sump geometry.
- At high flows (greater than 9,500 gpm), the minimum water level is 602'-10", as determined in the 1978 testing.
- Between about 9,300 gpm and 9,500 gpm, the minimum water level is limited by vortexing. In this range the conservative correlation recommended by Alden is used.

The results of this approach are shown in Table 4 and Figure 6.

During recirculation phase, the maximum flow rate from the sump corresponds to two RHR trains operating and two containment spray pumps operating. The design pump flow rates for each of these systems are 3,000 gpm and 3,200 gpm, respectively, for a total flow rate of 12,400 gpm. The minimum required sump water elevation for a flow of 12,400 gpm is 602'-10".

The minimum sump flow rate during recirculation mode corresponds to one RHR train functioning with a design pump flow rate of 3,000 gpm, and containment sprays not functioning due to low containment pressure. The minimum sump water elevation for a flow rate of 3,000 gpm according to Figure 6 is approximately 600'-11". Thus, depending on the sump average flow rate, the correlations developed in this evaluation could reduce the required elevation by almost two feet.

6.0 REFERENCES

1. Letter to Mr. John Ripak of Indiana Michigan Power Company from Mahadevan Padmanabhan of Alden Research Laboratory, Inc., "Evaluation of Required Minimum Submergence at D.C. Cook Containment Sump with One Train Operating", January 8, 1998.

2. Padmanabhan, M., "Hydraulic Model Investigation of Vortexing and Swirl Within a Reactor Containment Recirculation Sump", Alden Research Laboratory, Inc., September, 1978.

3. Telephone conversation between R. Keating (MPR), J. Ripak (AEP), and M. Padmanabhan (ARL), January 22, 1999.

Table 1
Minimum Water Elevation Based on Alden Vortexing Considerations

Q_t (gpm)	Q_t (cfs)	V (ft/sec)	S_{min} (ft)	MWE (ft)
1,000	2.228	0.71	0.038	599.40
2,000	4.456	1.42	0.153	599.51
3,000	6.684	2.13	0.344	599.70
4,000	8.912	2.84	0.611	599.97
5,000	11.140	3.55	0.954	600.31
6,000	13.368	4.26	1.374	600.73
7,000	15.596	4.97	1.870	601.23
8,000	17.824	5.68	2.443	601.80
9,000	20.052	6.39	3.092	602.45
9,500	21.166	6.74	3.445	602.81
10,000	22.280	7.10	3.817	603.18
11,000	24.508	7.81	4.619	603.98
12,000	26.736	8.51	5.497	604.86
13,000	28.964	9.22	6.451	605.81
14,000	31.192	9.93	7.482	606.84
15,000	33.420	10.64	8.589	607.95

Table 2
Minimum Water Elevation Based on Alden Critical Depth Calculation
(50% Blockage of Grating/Screen Assumed)

Q_t (gpm)	Q_t (cfs)	$q = Q_t/B$ (ft^3/sec/ft)	Y_c (ft)	MWE (ft)
1,000	2.228	0.248	0.124	599.61
2,000	4.456	0.495	0.197	599.75
3,000	6.684	0.743	0.258	599.88
4,000	8.912	0.990	0.312	599.98
5,000	11.140	1.238	0.362	600.08
6,000	13.368	1.485	0.409	600.18
7,000	15.596	1.733	0.453	600.27
8,000	17.824	1.980	0.496	600.35
9,000	20.052	2.228	0.536	600.43
9,500	21.166	2.352	0.556	600.47
10,000	22.280	2.476	0.575	600.51
11,000	24.508	2.723	0.613	600.59
12,000	26.736	2.971	0.650	600.66
13,000	28.964	3.218	0.685	600.73
14,000	31.192	3.466	0.720	600.80
15,000	33.420	3.713	0.754	600.87

Table 3
Minimum Water Elevation Based on Classic Weir Wall Correlation
(50% Blockage of Grating/Screen Assumed)

Q_t (gpm)	h (ft)	MWE (ft)
1,000	0.741	600.10
2,000	1.177	600.54
3,000	1.542	600.90
4,000	1.868	601.23
5,000	2.167	601.53
6,000	2.447	601.81
7,000	2.712	602.07
8,000	2.965	602.32
9,000	3.207	602.57
9,500	3.324	602.68
10,000	3.440	602.80
11,000	3.666	603.03
12,000	3.885	603.24
13,000	4.098	603.46
14,000	4.305	603.67
15,000	4.508	603.87

Table 4
Recommended Minimum Water Elevation

Q_t (gpm)	h (ft)	MWE (ft)
1,000	0.74	600.10
2,000	1.18	600.54
3,000	1.54	600.90
4,000	1.87	601.23
5,000	2.17	601.53
6,000	2.45	601.81
7,000	2.71	602.07
8,000	2.96	602.32
9,000	3.21	602.57
9,300	3.30	602.66
9,500	3.45	602.81
11,000	3.47	602.83
12,000	3.47	602.83
13,000	3.47	602.83
14,000	3.47	602.83
15,000	3.47	602.83

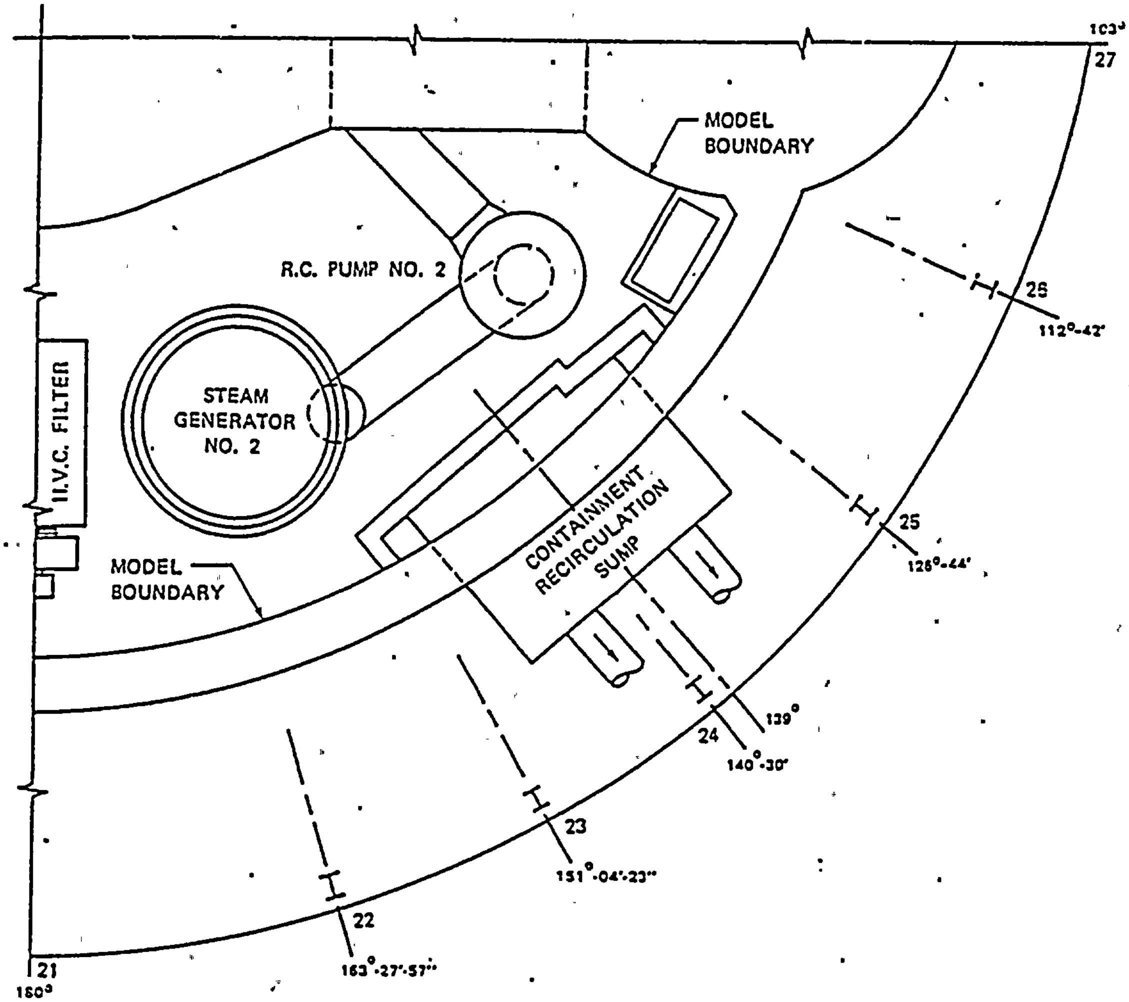


FIGURE 1 LOCATION OF SUMP WITHIN CONTAINMENT BUILDING

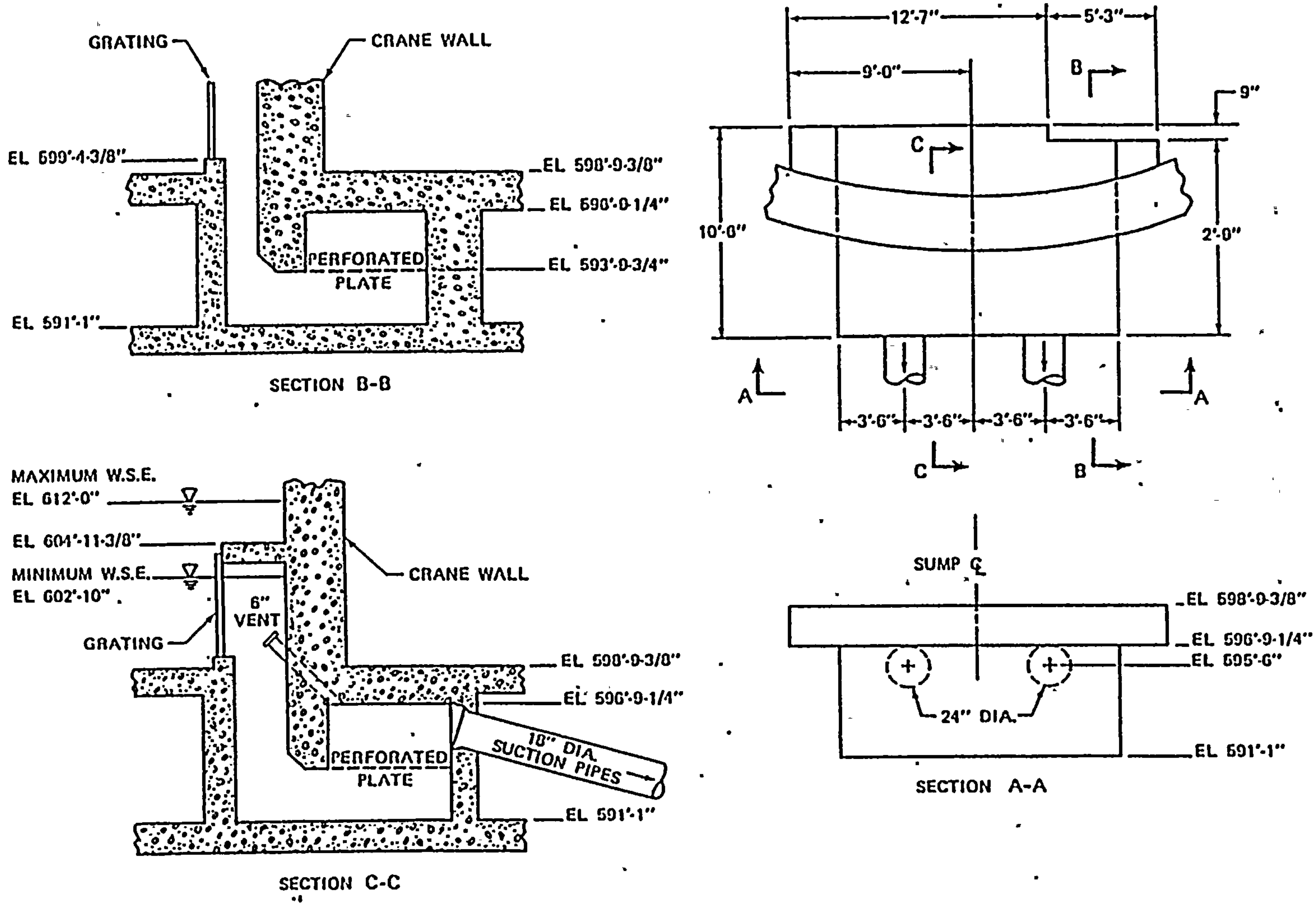


FIGURE 2 DETAILS OF ORIGINAL SUMP

Figure 3
Minimum Water Elevation Based On Alden Vortex Consieration

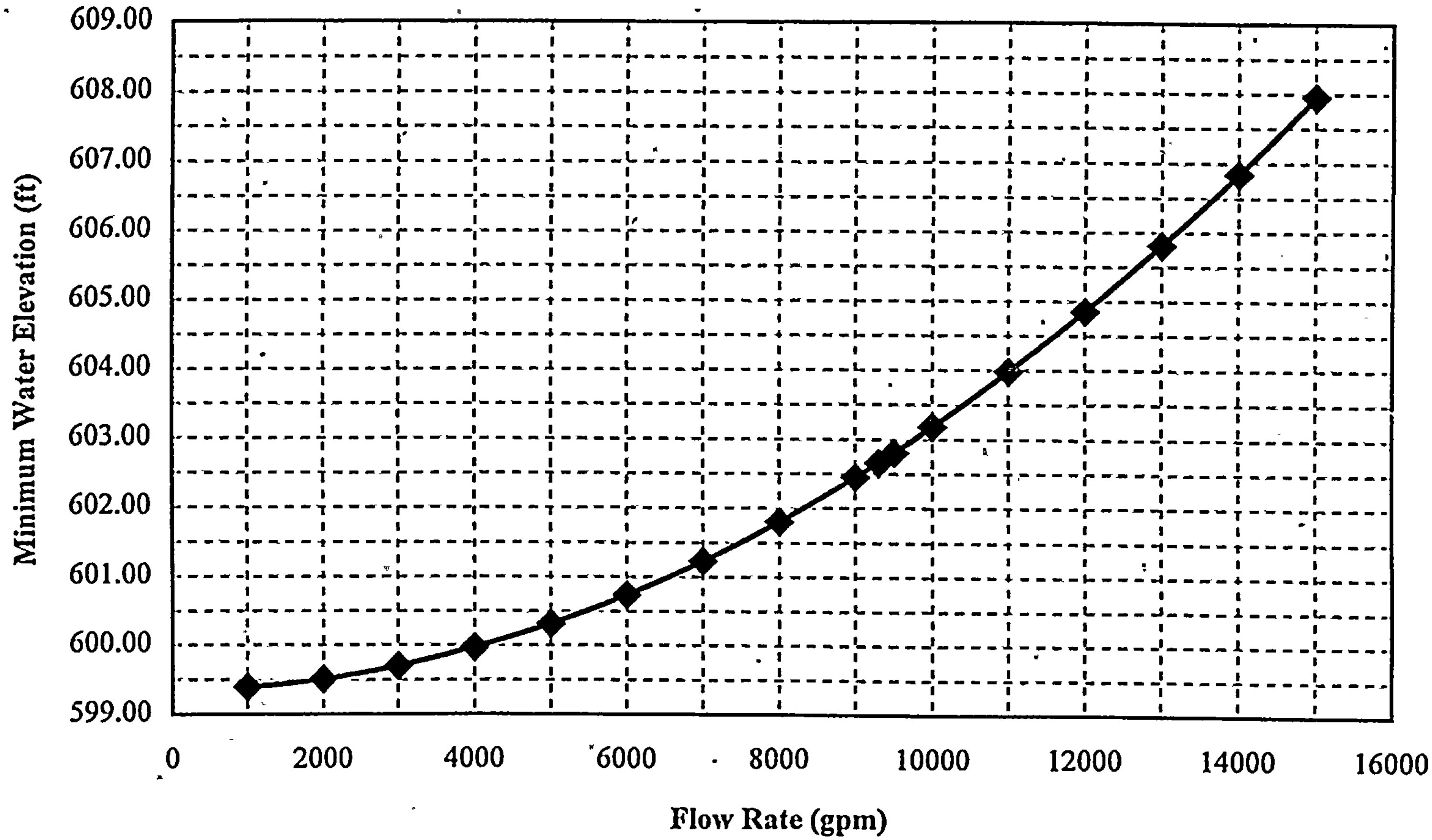


Figure 4
Minimum Water Elevation Based On Alden Critical Depth Calculations

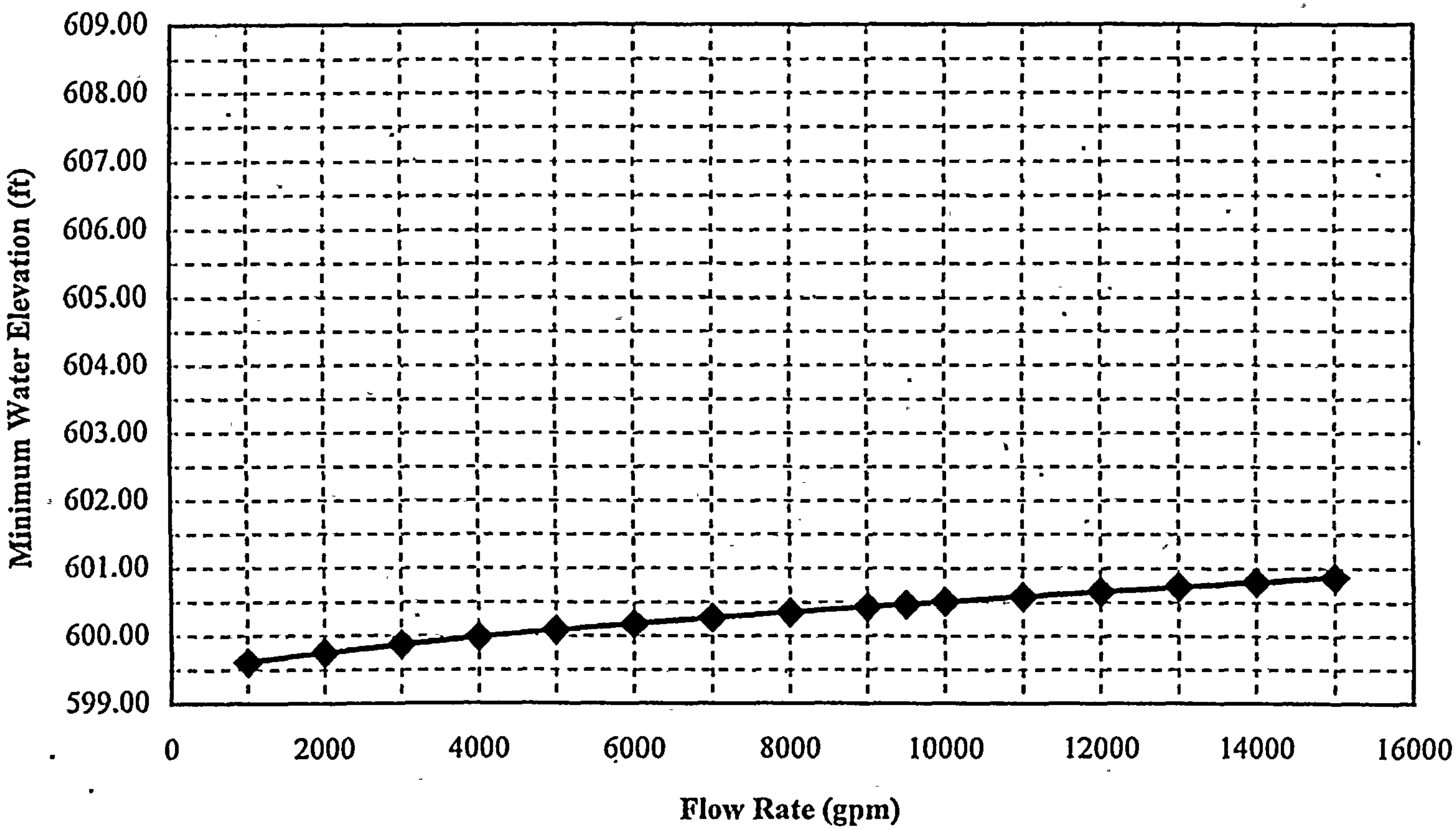


Figure 5
Minimum Water Elevation Based On Classic Weir Wall Calculations

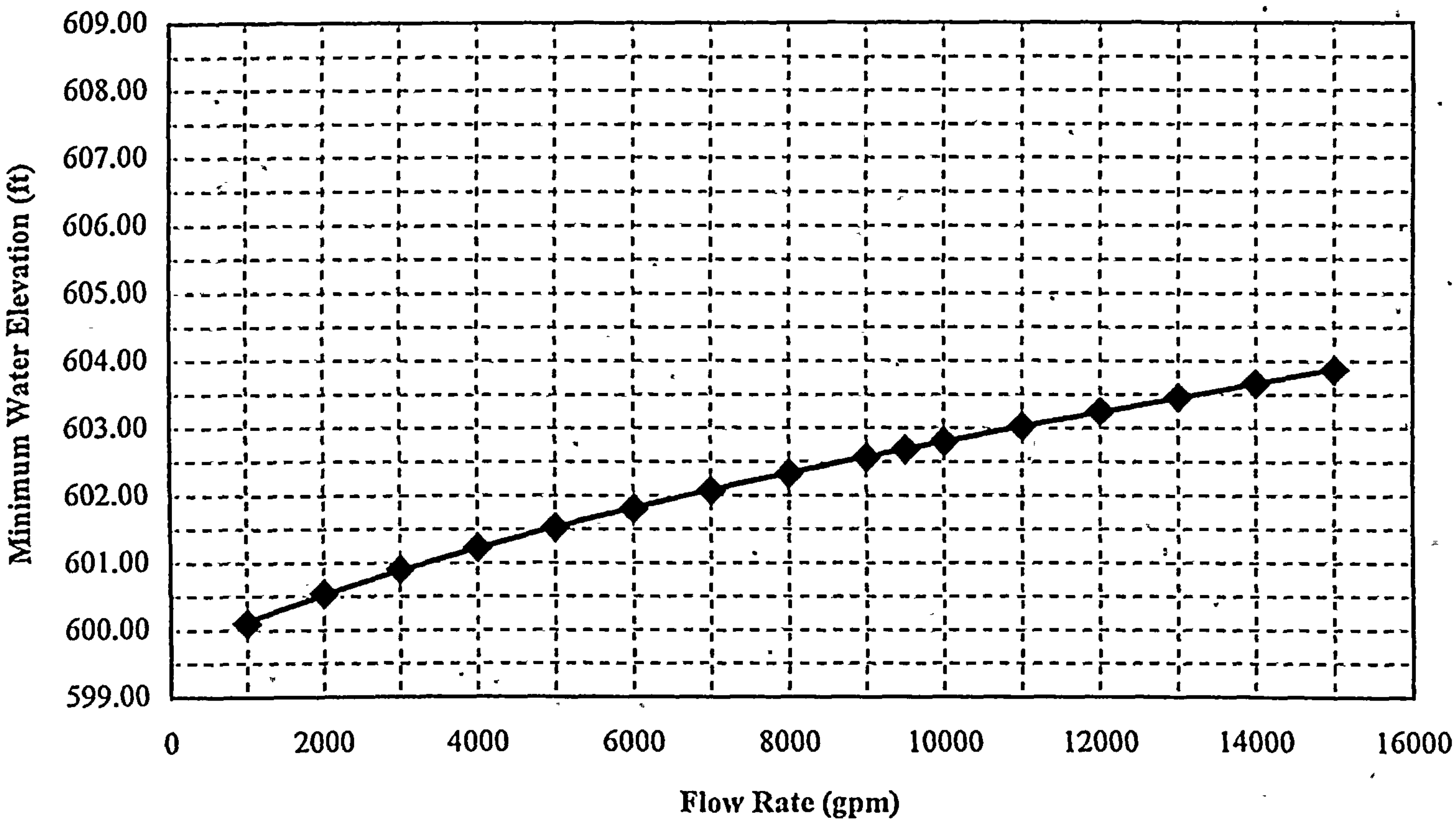
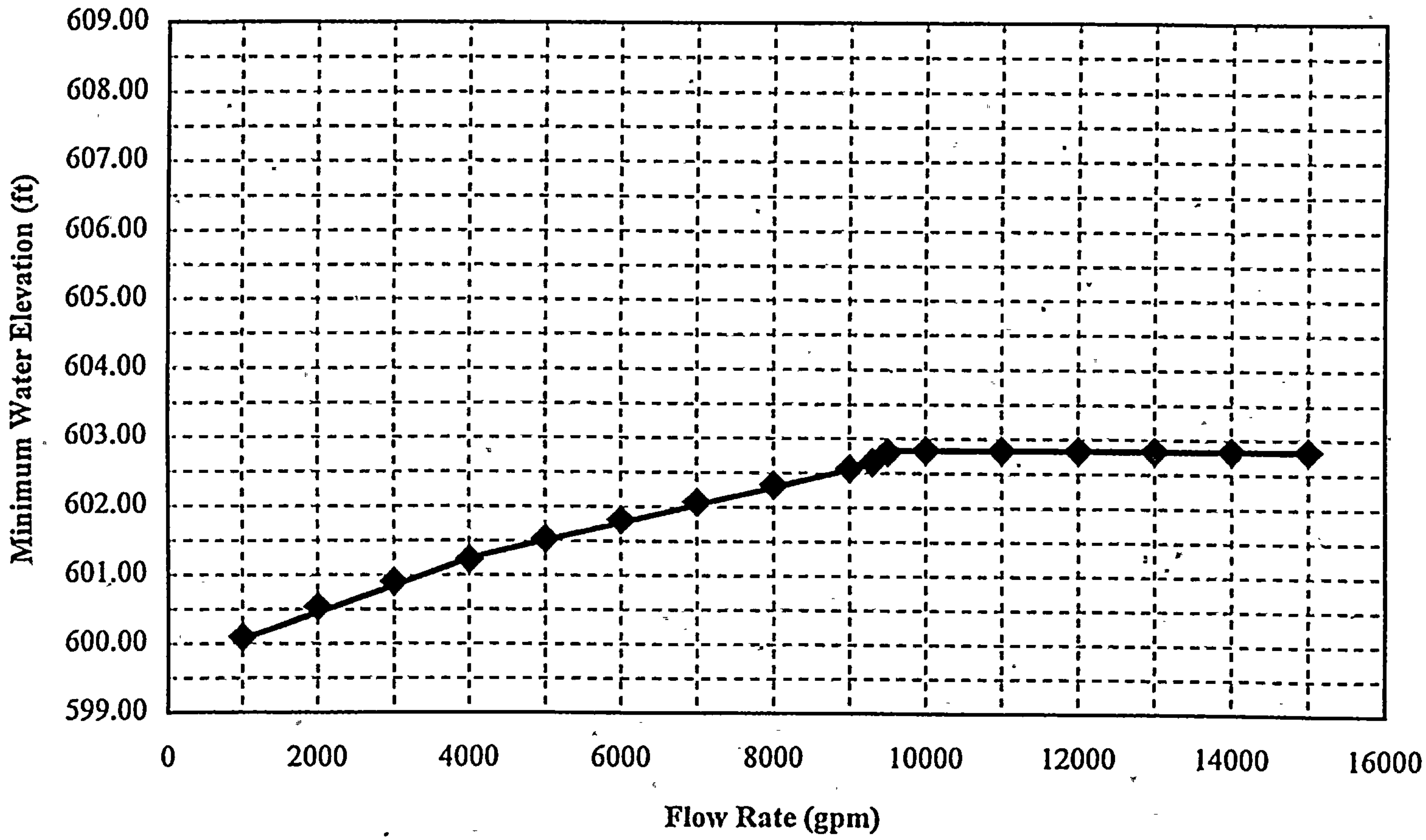


Figure 6
Required Minimum Water Elevation Based On Various Calculations



ATTACHMENT 10 TO C1099-08

WCAP-15302, "DONALD C. COOK NUCLEAR PLANT UNITS 1 AND 2 MODIFICATIONS TO THE CONTAINMENT SYSTEMS WESTINGHOUSE SAFETY EVALUATION (SECL 99-076, REVISION 3)"

The attached safety evaluation assesses the impact of the final, proposed plant configuration on the Donald C. Cook Nuclear Plant (CNP) Unit 1 and Unit 2 Updated Final Safety Analysis Report (UFSAR) Chapter 14 accident analyses. This evaluation includes the impact of the planned modifications described in this submittal. In addition, the evaluation considers other revised design input parameters generated in response to new procedural requirements in place at CNP, and as a result of issues identified during the recently conducted Expanded System Readiness Reviews supporting CNP restart efforts.. This evaluation includes the following assumptions:

a. All the identified modifications for a particular unit will be in place for the restart of that unit (either CNP Unit 1 or Unit 2).

b. The safety evaluations addressing the structural and mechanical effects of the planned modifications will be documented in the Design Change Packages for the individual modifications.

c. The containment recirculation sump inventory analyses have demonstrated sufficient water level, which is 602'-10" in Mode 1 and greater than Figure 6-8 of Attachment 7 (FAI/99-77, "Containment Sump Level Evaluation for the D.C. Cook Plant") for Mode 3.

d. A separate NRC License Amendment Request has been submitted to the NRC regarding credit for rod cluster control assemblies (RCCA) insertion. This submittal (C0999-11, "License Amendment Request for Credit of Rod Cluster Control Assemblies for Cold Leg Large Break Loss-of-Coolant Accident Subcriticality," dated September 17, 1999) addresses long-term post-LOCA subcriticality.

e. The final impact on each affected Emergency Operating Procedure (EOP) will be addressed as part of a comprehensive EOP review, revision, and validation program.

f. Net positive suction head (NPSH) calculations for the different operating configurations of the emergency core cooling system (ECCS) pumps and containment spray system (CTS) pumps have been completed. The results of these calculations will be provided in a separate submittal addressing Generic Letter (GL) 97-04, "Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps."