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KE DOWNCOMER DEVELOPMENT TEST - ~~IP 778~~

INTERIM REPORT

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INTERIM REPORT

by

Stephen S. Jones
Stephen S. Jones

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KE DOWNCOMER DEVELOPMENT TEST-IP-778

INTERIM REPORT

INTRODUCTION

This test was performed to investigate the effects of increased reactor flow upon the downcomer pressures and water levels. Recent theoretical studies had confirmed earlier ones that indicated a relatively weak downcomer approach box structure with an allowable working pressure of 4 psig. Since a flooded approach box would yield pressures in excess of 4 psig on the lower approach box plates and since downcomer flows approaching the flooding point were planned, experimental values of the downcomer pressures as the reactor flow is increased were obtained.

The initial test results indicated that our concern was justified. Therefore, under Design Change #1052, the approach box walls were stiffened to withstand a working pressure of 10 psig and a maximum allowable pressure of 15 psig. In addition, minor modifications were made to the approach box baffling and to the downcomer orifice plate. Additional test results were obtained after the completion of this design change with still further increases in reactor flow. However, only about 40 per cent of the planned reactor flow increase was attained. Further flow increases will be delayed several months until the completion of the thorium irradiation program. Therefore, this interim report summarizes the test results to date, and discusses system or operational changes indicated by these results that are in addition to those made under the Design Change #1052.

Along with the reactor tests summarized in this report, studies were conducted on a scaled model at the Washington State University Albrook Hydraulic Laboratory. It is anticipated that a detailed comparison of the results obtained with the K Downcomer in this test and model results may lead to a determination of the proper temperature scaling factor to use for interpretation of the model results to reactor operation. The model results are to be analyzed and will be the subject of a separate report.

SUMMARY AND CONCLUSIONS

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The basic downcomer requirements are that normal operating pressures shall not exceed the maximum allowable working pressures, and transient peak pressures shall not exceed 1.5 times these maximum allowable pressures. In addition, the downcomer shall not be operated more than 95 per cent full of water and the water level in the approach box shall be low enough to clear the upper tie bars without undue agitation. These criteria were used to judge the operation of the KE Downcomer as monitored by the development test.

The experimental data obtained in progressing about half way through the proposed reactor coolant flow increase are presented and analyzed in this interim report. The results are presented for variations in effluent flow and temperature at conditions before and after the installation of two baffle plates in the approach box and a 24 per cent opening of the orifices in downcomer channels #5, 6, and 7 (completed under Design Change #1052). They are summarized as follows:

1. Downcomer Approach Box: Under reactor operating conditions there was no significant change in approach box wall pressures, but the change in downcomer channel flows indicated a considerable increase in the water surface turbulence in the box. The water level corresponded to a wall pressure of 4 psig combined with an allowable pressure of 4 and 10 psig before and after the design change. The extrapolated approach box capacity is about 240,000 gpm under steady-state conditions.
2. Downcomer: At full level operation the flow in the downcomer channels #1 through #5 is so limited by severe cavitation in the entrance elbow that increasing the orifice-free area in channel #5 produced no increase in the channel #5 flow. In the higher channels the flow is limited by the orifice, and there was a 15 per cent increase in the flow in channels #6 and #7 when the free orifice area was increased 24 per cent. In the top channels (#8 through #10) the design change produced a decrease in channel #8 flow and an increase in flow in channels #9 and #10. This can only be explained as an increased surface turbulence in the approach box that yielded intermittent higher elevation flow levels with less flow continuity. The pseudo downcomer water level (location of 0 psig static pressure) in the downcomer channels was changed from channels #5, 6, and 7 running over 95 per cent full to their running less than 60 per cent full following the design change. The downcomer steady-state capacity is estimated to be 245,000 gpm.

A detailed analysis was made of the downcomer flow distribution in the various channels, and based upon this analysis and the test results, the following additional downcomer changes should be considered: 1) Streamline the downcomer channel entrances by the use of bullet-nosed plugs in the honeycomb junction pipes; 2) streamline the approach box to yield smoother and more direct flow into the downcomer channels; 3) supply a flow stream into the bottom of the entrance curvature in channel #1 in order to avoid a pressure drop down to the point of severe cavitation.

Thus far, this development test has yielded considerable information and insight into the nature of the K Downcomer coolant flow characteristics. It is anticipated, however, that additional test results will be required:

1. To investigate the important parameter of variation in the effluent free air plus vapor as the river water temperature changes through the range of 2 to 22 C.
2. To determine the effects of operating with the near or far rear riser temperatures several degrees above the bulk average.
3. To follow the effects of increased downcomer flow in steps of 3000 to 6000 gpm.

Downcomer model studies have been conducted at the Albrook Hydraulic Laboratory, Washington State University, under conditions similar to those at the reactor. Comparison studies of the model and prototype results are required.

And finally, the important potential problem of the effect of temperature transients has yet to be investigated. Work on this will probably be done on the model and may also require a reactor production test.

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DISCUSSION

1. General

Because of the indicated low strength of the K-Downcomer approach box⁽¹⁾ combined with the apparent possibility of exceeding its allowable working pressure under emergency transient conditions,⁽²⁾ such as a pumping power failure or a reactor power surge, this Development Test was prepared to follow the effects of increasing the downcomer flow from 212,000 to 218,000 gpm.⁽³⁾ Thus far, less than half of this flow increase has been attained, but a significant change was made in the KE and KW Downcomers under Design Change #1052⁽⁴⁾ and the results of this change along with produced by the flow increase are presented in this interim report.

The K-effluent flow configuration and the various components, not including the effluent basins, are shown in Figure 1.

The weakest part of the effluent system is the downcomer approach box that serves as a free surface stilling chamber for combining the flow of the near and far risers and delivering this flow to the downcomer through its entrance elbow.

The honey-combed elbow serves to fill the downcomer channels consecutively, as the total downcomer flow is increased. This maintains the minimum amount of free-fall kinetic energy by keeping the lower channels water filled. Thus, the potential elevation energy of the water in the approach box is absorbed by channel friction rather than being released in open channel free-fall.

The orifice plate near the bottom of the downcomer serves to absorb the kinetic energy of the falling water, and permits gradient flow of the water from the downcomer to the retention basins without any chance of suction pressures on the water in the reactor. Thus, the requirement of no drainage of the reactor under emergency conditions is maintained. The downcomer channel flow is determined by one or more of the following:

- a. The orifice plate flow resistance,
- b. The downcomer channel flow resistance,
- c. The downcomer entrance - elbow flow resistance,

The downcomer total flow is made up of the sum of the flows in its 1 to 10 flowing channels. An increase in the entrance-elbow flow resistance will be reflected immediately in a higher approach box water level and therefore a greater pressure on the walls of this relatively weak structure. Any increase in the channel orifice-plate flow resistance will cause an increase in the channel water level and may or may not affect the approach box water level depending upon whether a flow continuum exists between the two locations.

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FIGURE 1 - DOWNCOMER PIPING ARRANGEMENT

The details of the downcomer hydraulics, together with the corresponding test results and significance are summarized in the various following sections of this report. To expedite its functional use, the calculational details are presented in five report appendixes while the body of the report is reserved for a discussion of the important test interim results and their significance.

2. Approach Box Water Level

Every foot increase of water level in the approach box represents about 0.5 psi increase in pressure on the box sloping end plates and a 0.25 psi average pressure increase on the approach box walls. Therefore, it is important to monitor the box water level. Because of the high radiation levels during reactor operation this must be measured remotely. The procedure used was to measure the approach box lower wall pressures and the pressure at the top of the box, with the expectation that the pressure difference in ft. of water would yield a direct measure of the approach box water level above the pressure tap. A review of the first test results showed this expectation to be incorrect. It was necessary to correct the pressure tap readings for negative velocity effects at the taps. The procedure for taking this into consideration is presented in Appendix I.

The variation in the box water level with effluent flows and with effluent temperatures for pre and post Design Change #1052 conditions, is summarized in Figures 2 and 3. Here a comparison is presented of the approach-box water level obtained from three different sources:

- a. The known height of each channel entrance and the measured number of flowing channels.
- b. The O-a downcomer wall tap corrected for velocity head according to water level values visually observed under various cold flow conditions.
- c. The enlarged O-b downcomer wall tap also corrected for velocity head in the same manner.

The following conclusions concerning the approach box water level as a function of the reactor cold flow are drawn from the test results summarized in Figure 2:

- a. An extrapolation of the cold flow approach box water level to higher flows yields an indicated flow capacity of 240,000 gpm. This is the point at which the level reaches the top of the downcomer entrance elbow.
- b. There was no pronounced effect of the downcomer modifications upon the approach box water level under cold flow conditions.

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FIG. 2. NO. DOWNCOMER APPROACH BOX WATER LEVEL

DOWNCOMER FLOW -1000 gpm

- c. There is good agreement ($\sim 5\%$) at high flow and reasonably good agreement at low flow ($\sim 15\%$) between the water level indicated by the number of flowing downcomer channels and that obtained from the wall pressure taps, corrected for velocity head effect.
- d. There was no apparent increase in the accuracy of the water level pressure measurements when the tap size was increased to conform to recommended dimensions.

The effects of reactor operation upon the approach box water level is shown in Figure 3. The following conclusions are presented based upon this graphical presentation of the test results:

- a. The water level increased slowly with effluent temperature up to a value of 80 C and then increased quite rapidly with further temperature increases.
- b. The box water level reached the top of the inlet elbow at 95 C for conditions before the downcomer modification and at 97 C (extrapolated) for post design change conditions.
- c. There was good agreement between the three methods of determining this water level elevation.

3. Downcomer Channel Flow

The complexities of the K Downcomer flow become apparent when one considers that there are 10 flow channels, each with 3 parallel flow sections, two (now three*) types of orifice geometries, two sizes of flow channels, and at least three possible modes of downcomer flow into these channels. In view of these complexities advantage was taken of the energy absorbing orifice plate to obtain an explicit indication of the flow in the downcomer channels #1, 3, 5, 7, and 9. This involved not only measuring the pressure-drop across an outer section of the noted channels but a determination of the channel flow indicated by the measurement. The details of this determination are presented in Appendix II, and orifice flow characteristic curves are presented in Figure III-1 on page 35.

The number of channels with remote measurement of the orifice pressure-drop was kept to a minimum because of:

- a. The difficulty in extending any more pressure lines from the downcomer to the site of remote pressure measurement.
- b. The costs associated with the extra instrumentation and reactor downtime involved in additional channel pressure-drop measurements.

However, the complexity of the downcomer honeycomb arrangement made it quite difficult to determine the flow in the unmeasured channels from that in the measured. To improve this situation, measurement of the #10 channel pressure-drop was effected in August and #4 channel in November.

* Part of Design Change #1062 (u)

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FIG. 3 KE DOWNCOMER APPROACH-BOX WATER LEVEL

EFFLUENT BULK TEMP. - °C

The only confirmation we have of this procedure for determining the downcomer channel flow is a comparison of the total of all the channel flows with the measured flow input. The procedure and problems associated with this parameter are discussed in the next section.

4. Downcomer Flow

To determine the downcomer theoretical flow it is necessary to sum the flows in the ten downcomer channels. This requires the calculation of the flow in the channels with a measured orifice pressure-drop combined with the determination of the flow in the unmeasured channels. The complex geometry does not permit correct flow interpolation between channels; therefore, we have resorted to an analysis of the channel flow entrance conditions and an extrapolation of these conditions between a channel with measured orifice pressure-drop and the adjacent identical unmeasured channel.

There are three possible modes of flow into the K Downcomer elbow, and thus into the downcomer proper. These are:

- a. Open channel flow, similar to flow over a dam spillway.
- b. A flow continuum with full channel flow from the elbow entrance down through the channel orifice-plate.
- c. A flow discontinuity downstream of the channel entrance caused by severe cavitation and a pressure-drop down to the water saturation pressure.

The first type of flow occurs in one or more of the upper downcomer channels where the effective approach box water level is not above the top of these channels and free overflow can occur. The second type of flow occurs in a full channel, where the temperature, velocity, and channel curvature are low enough that flow limiting cavitation does not occur at the channel entrance. The equation for this type of flow is given as follows:

$$G_n = 3.6 S_n \sqrt{\frac{\bar{V}_a^2}{2g} + (X_L - X'_a) + .01 \left(L_{en} + \frac{\pi n \Delta \ell}{2} + L_n \right) \Delta H_f} \quad (1)$$

In this equation* the value of $\bar{V}_a^2/g$ is not accurately known, the value of L_{en} , the equivalent channel entrance length, is not known at all, and the values of X'_a and L_n are also quite inaccurate. Therefore, it is not readily used in the absence of more complete experimental data.

* See Appendix III for equation nomenclature.

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The third type of flow occurs under submerged channel flow conditions where the fluid velocity and/or temperature are sufficient to cause flow limiting cavitation at the channel entrance. The flow is similar to free discharge through an orifice down to saturation pressure according to the equation: (2)

$$G_n = 3.6 C_d S_n \sqrt{H_n^* - H_a^*} \quad (2)$$

Where C_d is the discharge coefficient. Although this equation applies only to the case of a flow discontinuity at the channel entrance it was arbitrarily applied to all channels operating under submerged flow conditions. The use of this simplified equation was justified by the following considerations:

- The value of this channel entrance coefficient (C_d) was determined empirically from the measured orifice pressure-drop, the measured water level above the channel floor, H_n^* , and the saturation pressure of the water, H_s^* .
- The channel coefficient, determined in this manner, represented not only an entrance loss coefficient but the total flow resistance required to yield the observed flow, whether or not the flow was in cavitation.
- It was not necessary to determine the unknown point of transition from discontinuous to continuous channel flow, because this equation was assumed to apply to both.
- The effect of errors in the determination and use of this coefficient were minimized by using it only between adjacent channels. In other words it was only used to determine the flow in channel $n+1$ from the measured flow in channel n .

The details of the determination of the theoretical total downcomer flow are presented in Appendix III of this report. In summary, the flow in channel ($n+1$), without orifice pressure taps, was obtained by an extrapolation of the channel entrance coefficient from the value determined from channel (n), and a calculation of the channel flow according to the equation:

$$G_{n+1} = G_n \left(\frac{C_{dn}}{C_{dn+1}} \right) \frac{\sqrt{H_n^* - H_a^*}}{\sqrt{H_{n+1}^* - H_a^*}} \quad (3)$$

Values of C_d and (G_{n+1}/G_n) are presented in Figures III-2 and III-3 of Appendix III. It is interesting to note that the C_d ratio increases while the pressure ratio decreases as we increase in channel number.

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A comparison of the total pump input with the sum of the channel flows is presented in Table I. There was relatively close agreement at full cold flow and at reactor operating conditions before the downcomer box and orifice plate modification. After this modification the results indicate a deficiency in the total channel flows at full cold flow and at full power level conditions. The reasons for this are not clear. One possible reason could be a build-up in approach-box water level sufficient to cause overflow into the downcomer by-pass lines. This effect, however, is not indicated by the water level wall taps which show good agreement with the level indicated by the number of flowing channels, nor is it indicated by the data obtained from newly installed pressure taps on one of these overflow lines.

TABLE I
DOWNCOMER FLOW

Test Series	Conditions		No. of Channels w/Flow	Results		Ratio (Channel Flow) Pump Flow	Remarks
	Temp	Satur. Press.		Pump Input	Sum of Channels		
B-1	17	-33	5	65	100	1.54	Pre-Design Change #1052
B-2	17	-33	6	128	164	1.28	
B-3	17	-33	8	202	202	1.00	
B-4	17	-33	8	195	186	.95	
C-2	80	-19	8	209	221	1.05	
C-3	90	-11	8	209	221	1.05	
C-5	92.5	- 8	9	209	220	1.05	
C-7	95	- 6	10	211	216	1.02	
D-1	20	-33	3	66	69	1.04	Post-Design Change #1052
D-2	20	-33	5	136	123	.91	
D-4	20	-33	9	200	178	.90	
E-2	80	-19	8	210	214	1.02	
E-3	90	-11	9	212	227	1.06	
E-7	95	- 6	10	214	188	.88	

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Another possible reason for this total flow imbalance, aside from the inaccuracies introduced by the complex flow geometry, lies in the location of the orifice pressure taps. A comparison between the actual tap location and that recommended by the ASME for a simple concentric orifice is presented in Table II. This shows that the actual orifice locations differ from the recommended location in every case. However, this difference should produce less than a four per cent decrease in the calculated flow. For the case of the modified #5, 6, and 7 channels, the discrepancy should be even less, since both the upstream and downstream pressure tap locations are closer to the recommended values. If this effect is significant, however, our procedure should yield an increase in the ratio of calculated flow output to the measured input flow after the completion of Design Change #1052, and just the opposite effect was observed.

TABLE II
ORIFICE PRESSURE TAP LOCATIONS

Channel No.	Equivalent Diameters*			Distance of Upstream Pressure Tap from Orifice			Distance of Downstream Pressure Tap from Orifice		
	Section Inches	Orifice Inches	Dia. Ratio β	Actual Inches	ASME ⁽⁶⁾ Specification		Actual Inches	ASME ⁽⁶⁾ Specification	
					No. of Diameters	Distance Inches		No. of Diameters	Distance Inches
1, 2, 5-10	3.74	2.875	.768	11.0	1.0	3.74	2.8	.37	1.38
3, 4	3.73	2.875	.772	11.0	1.0	3.59	2.8	.36	1.34
5, 6, 7	7.47	6.41	.860	11.0	1.0	7.47	2.8	.25	1.87

* The significant diameters with respect to the location of the vena contracta are the actual orifice diameter and the diameter of a flow stream representing the portion of the section flow passing through the orifice.

(6) American Soc. Mechanical Engineers. Flowmeter Computation Handbook. New York, N.Y. (1961). Page 153.

The channel flow distributions for various flow cases, pre and post the design change, are presented in Figures 4 and 5. In addition, the fraction of pre-design change flow obtained under post design change conditions is presented at the top of Figure 5. The following significant conclusions are indicated by these charts:

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- a. In channels #1 through 5 there is a marked decrease in flow with increasing temperature. This is caused by vapor blockage in the entrance to these channels.
- b. The increased flow benefits of the opened channel #5 orifice is reduced to zero at 95 C bulk temperature, probably because of severe cavitation in the channel entrance.
- c. The increased flow obtained in channels 6 and 7 because of the opened orifices is counteracted by a marked decrease in the flow in channel #8.
- d. This decreased channel #8 flow and increased flow in the #10 channel for post-design change conditions is an indication of increased approach-box turbulence caused either by the increased reactor flow or by the new baffle plates installed in the box. The latter reason is considered more plausible because of the small increase in reactor flow (not over two per cent). However, before concluding that the new baffle plates are the source of difficulty, there is another parameter that needs investigating. It is the effect of unbalanced rear riser temperatures upon the approach box water level and downcomer flows. The riser temperature instrumentation should be placed in operating order and the rear riser temperatures should be recorded at the time test data is obtained.
- e. Another important parameter is the amount of air plus vapor in the reactor effluent. The water enters the reactor saturated with air at 5 to 20 C. As the effluent temperature is increased, this air comes out of solution and is nearly saturated with water vapor. During the operating period covered by this test, there was not sufficient change in the water inlet temperature to change the free air concentration by more than five per cent of the original amount. Therefore, this parameter was assumed constant over this testing period.

In summary, the change in channel flow with reactor operating temperatures indicates the flow controlling conditions for each channel. At 95 bulk effluent temperature the flow in channels #1 through 5 is controlled, or limited by channel entrance conditions and there is little to be gained by opening the orifice-plate free area in these channels. The channels 6 and 7 appear to have a flow continuum with the channel flow being a direct function of the orifice-plate free opening. The remaining channels appear to have free channel entrance flow because of severe turbulence in the approach box. Improved flow streamlining in the box should increase the flow in all but the top flowing channel, which will be in free flow until the box water level reaches the top of the downcomer. Improved box and elbow entrance streamlining should also reduce the cavitation and/or vapor blocking effects in the entrance elbow and perhaps #5 and #4 channels could be changed to flow continuum channels with a 10 to 30 per cent increase in flow.

5. Downcomer Water Level

Another significant parameter with respect to downcomer operation is the level of water in the downcomer channels. The term water level is only

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FIG. 4 KE DOWNCOMER
CHANNEL FLOW

Pre Design Change #1052

(Total Flow = 210,000 gpm)

CHANNEL
FLOW
1000 gpm

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FIG. 5 KE DOWNCOMER CHANNEL FLOW

CHANNEL FLOW
1000 gpm

Post Design Change #1052

(Total Flow $\approx$ 213,000 gpm)

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significant in the first type of channel flow, i.e., free overflow. In submerged channels (with respect to the approach-box water level), the water level obtained is the channel length above the orifice-plate at which the water pressure is just equal to atmospheric pressure. This is a measure of downcomer flooding, since any length value equal to or greater than the actual channel length means a flooded channel.

The method of determining this downcomer water level is presented in Appendix IV; and the summarized results are given in Figures 5 and 6 for full flow conditions at various effluent temperatures. These show a very marked change in the downcomer channel water levels at full power level between the pre- and post-Design Change #1052 conditions.

The following specific conclusions are presented concerning the downcomer water level:

- a. At pre-design change conditions, full reactor flow, and temperatures above 75 C the channels 5, 6 and 7 were running within 95 per cent of full, i.e., they were within 95 per cent of being limited in flow by the orifice rather than the channel entrance.
- b. Opening the #5, 6 and 7 channel orifices caused a decrease in water level in these channels, at full power level conditions, from 95 down to 60 per cent full.
- c. However, the water level in channels #5, 6, and 7, after completion of the design change is very temperature dependent. This is shown in Figure 7 where the level in channels #5 and 6 increases from 82 per cent full at 20 C to 93 per cent at 80 C and down to 60 per cent at 95 C. Why this occurs is not clear, nor do we know the temperature at which peak levels would occur in these channels. Fortunately, this condition did not carry through to affect the level of the water in the approach box. Further information on this effect is required.
- d. The marked decrease in downcomer level for post-design change conditions combined with the relatively small increase in flow through these three channels indicates that this is the transition region between channel flow continuum and channel cavitation or two-phase flow.
- e. The modified orifice plate (post-Design Change #1052) yields nearly an ideal flat water-level profile at full power level conditions. No immediate changes in the plate are indicated.
- f. The approximate downcomer flow capacity was obtained by considering the channels that were not flow limited at their entrance and estimating the flow increase between the channel operating conditions and the limiting case of 95 per cent full according to the relationship:

$$G_n \text{ max} = G_n \sqrt{\frac{E_w (\text{max})}{E_w}}$$

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The result of this procedure was a downcomer flow capacity of about 230,000 gpm before the design change and 245,000 afterwards.

This concludes an analysis of the parameters considered significant in the program of obtaining maximum downcomer flow with minimum pressurization. For convenience of the reader, the over-all interim conclusions from this testing and analysis were presented in the Summary to this report.

Stephen S. Jones, Senior Engineer
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Research and Engineering Section

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FIG. 6 WATER LEVEL IN KE-DOWN CHANNELS

Pre Design Change #1055

(Total Flow = 210,000 gpm)

EFFECTIVE
WATER LEVEL
17' ABOVE
ZERO LEVEL AT
WHICH PRESSURE
= 0 Psig

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12-85

CHANNEL NO.

FIG. 7 WATER LEVEL IN KE-DOWN CHANNELS

Post Design Change #1052

EFFECTIVE
WATER LEVEL

(Total Flow $\approx 213,000$ gpm)

Ft above
Zero Level at
which Pressure = 0 Psig

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S. S. JONES
10-65

APPENDIX I: APPROACH BOX WATER LEVEL

To account for the low values of approach-box side wall pressures it is necessary to consider the possibility of flow velocity components acting parallel to the pressure-tap axis rather than strictly parallel to the axis of flow in the box. The following equations relate the approach box water level to the observed pressure reading, including these velocity head effects.

1. Rear Face Pressure Reference (Sensing Lines Filled with Water)

$$H_L = 10.3 - (H_c - H_x) + k \bar{V}_a^2 / 2g \quad (I-1)$$

2. Top of Approach Box Pressure Reference (Sensing Lines Filled with Water)

$$H_L = 10.3 - H'_x + k \bar{V}_a^2 / 2g \quad (I-2)$$

And the terms in the above equations are defined below and the constant 10.3 is equal to the elevation of the H_c tap above the box floor.

H_L = Approach box water level, height above the box floor (which is 50.0' above 0'-0") in Ft.

H_c = Top of approach box pressure reading in Ft. of water with reference to the rear face.*

H_x = Approach box side wall pressure tap reading in Ft. of water with reference to the rear face.* (H'_x = reading with reference to tap o-c.)

k = Fraction of average velocity head along the direction of flow that is acting along the pressure tap axis.

$\bar{V}_a$ = Average flow velocity (in direction of flow) at the wall tap location.

By observing the downcomer water level and the pressure tap readings under various cold flow conditions it is possible to obtain an approximate value for k . This follows directly from equations I-1 and I-2 and the velocity relationships.

Wall Taps O-a and O-b

$$\bar{V}_a = 2.23 G_T / S_a \equiv \frac{2.23 G_T}{W(H_{L_a} - X_a)} \quad (1-3)$$

Wall Tap O-b'

$$\bar{V}_a = 2.23 G_T / S_b \equiv \frac{2.23 G_T}{W(H_{L_b} - X_b)} \quad (1-3a)$$

Where $\bar{V}_a$ = Average approach-box flow velocity (along flow axis) at pressure tap location: Ft. per sec.

G_T = Total approach-box flow: 1000 gpm

S = Water flow cross-section at tap location: sq. ft.

H_L = Water level above box floor at tap location - Ft.

* The pressure instrumentation, described in Appendix V, has a reference line extending from the manometer to just outside the box floor, and a means for using Tap o-c as a reference.

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W = Approach box width = 4.0 Ft.

X = Height of approach box floor, at the location of tap X, above the main box floor at the 50' level.

= 3 Ft. for taps O-a and O-b

= 2.5 Ft. for tap O-b'

Thus knowing the water level, the pressure readings, and the approach box average velocity a value of k can be determined for each cold flow measurements. Values of k for various test conditions are presented in Table I-1. For convenience the approach-box average velocity head at taps O-a and O-b' are presented in Figure I-1 for various downcomer flows and observed water levels.

TABLE I-1; APPROACH BOX WATER LEVEL CALIBRATION

WALL TAP	TEST NO.	CONDITIONS			APPROACH BOX							
		Date	Flow	Temp.	Pressure Readings			Observed		Velocity	Velocity	
		1965	1000 gpm	°C	Ft. of Water			Water		Head	Head Coef.	
					H _c	H _x	(H _c -H _x)	Level			k	k avg.
o-a	B-1D	8-13	63	17	16.2	8.1	8.1	5.3	-	3.6	.86	
	-2A		137		16.2	5.6	10.6	6.7	-	7.0	1.00	.93
	-4B		193		15.2	6.9	8.3	8.2	-	6.6	.94	
	D-1	9-20	66		0	9.4	9.4	-	5.2	4.8	.90	
	-2		136		-	11.7	11.7	-	6.4	7.8	1.00	1.04
	-4		202		-	11.5	11.5	-	8.1	7.7	1.21	
	B-1D	8-13	63	20	16.2	9.9	6.3	5.3	-	2.4	.54	
	-2A		137		16.2	10.7	5.5	6.7	-	5.2	.37	.40
	-4B		193		15.2	10.1	5.1	8.2	-	5.4	.56	
o-b'	D-1	9-20	66		0	4.9	4.9	5.4	-	2.5	.01	
	-2		136		-	7.2	7.2	6.0	-	4.8	.79	.40
	-4		202		-	6.1	6.1	8.2	-	6.0	.67	

*Level at o-a tap, other levels are at location of the o-b' tap.

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FIG. I-1: DOWNCOMER APPROACH BOX AVG. VELOCITY HD

APPENDIX II DOWNCOMER CHANNEL FLOW

The downcomer flow past the energy absorbing orifice-plate creates a pressure-drop. By installing pressure taps above and below the orifice the flow in the section being monitored can be estimated from the equation:

$$G_S = \left(\frac{.025 s_o C}{\sqrt{1 - \beta^4}} \right) \sqrt{\Delta H_o} \quad (\text{II-1})$$

Where G_S = Flow in downcomer section containing the orifice pressure taps:
1000 gpm.

s_o = Total orifice per area: sq. inches.

C = Orifice discharge coefficient.

β = Ratio of equivalent orifice to equivalent section diameter.

ΔH_o = Total orifice pressure-drop: ft. of water.

Equation II-1 is often expressed in terms of an overall coefficient, i.e.

$$G_S = .0254 C' \sqrt{\Delta H_o} \quad (\text{II-2})$$

Where $C' = C / \sqrt{1 - \beta^4}$, and for the case of the K orifice plate with beveled round holes the value of C' on an experimental model was found to be 1.0⁽⁷⁾. The orifice plate and channel details are summarized in Table II-1, and the orifice and channel geometry is presented in Figure II-1. There are three parallel flow sections that make up each of the ten flow channels. The outer two sections are identical. The inner section differs slightly, but not enough to make our measurements of the outer section pressure-drop any source of significant error. However, as indicated in Table II-1, this difference in section geometries was considered in determining the total channel flow from the measured section pressure-drop.

In applying the basic orifice equation to the actual K Downcomer a number of simplifying assumptions are required:

1. The orifice free area s_o is assumed equal to the total free cross-sectional area in the orifice plate for the given flow section, i.e. for the plate with holes only:

$$s_o = n \pi d_o^2 / 4 \quad (\text{II-3})$$

Where n = number of orifice holes

d_o = orifice diameter - inches

For the slotted plate:

$$s_o = n' \pi d_o^2 + l w \quad (\text{II-4})$$

Where l = effective slot length - inches

w = effective slot width - inches

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2. The orifice discharge coefficient is assumed to be a constant = 0.82 for all conditions.*
3. An equivalent orifice and pipe, or section diameter were determined as the diameter of a circle having the same total free area as all of the orifice holes per section and as the free area of the channel section. i.e.:

Orifice Equiv. Dia.

$$d_o = \sqrt{4s_o/\pi} \quad (\text{II-5})$$

Section Equiv. Dia.

$$d_p = \sqrt{\frac{4}{\pi} (l_s w_s - n_p \pi d_s^2 / 16)} \quad (\text{II-6})$$

Where s_o = Total free area of section orifice - in.²

l_s = section length - in.

w_s = section width - in.

n_p = no. of quarters of honey-comb junction pipe included in section.

d_s = diameter of honey-comb junction pipe.

4. The important orifice parameter, β , i.e. the ratio of the orifice diameter over the pipe diameter was assumed equal to the ratio of the equivalent orifice and section diameters.

Thus, the section flow was determined from the measured value of orifice pressure-drop and the appropriate values of C , s_o , and β applied to equation (II-1).

The total channel flow was determined on the basic assumption that ΔH_o is the same for all three sections and the central section flow is obtained from the use of equation (II-1) with appropriate changes in s_o and β . The individual section flows and the total channel flow for a pressure drop of 10 feet of water are presented in Table II-1. The channel flows as a function of the measured section pressure-drops are given in Figure III-1 on page 35.

* This value was obtained as the average of the values for channels 1, 2, 5-10 and 3, 4 (pre Design Change) based upon the reported value of $C' = 1.0$ by C. C. Lomax⁽⁷⁾ and the calculated value of β for these channels.

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TABLE II-1

K DOWNCOMER ORIFICE PLATE FLOW CHARACTERISTICS

CHANNEL		SECT	ORIFICE		SLOT		TOTAL		SECTION										CHANNEL	
No.	No.	No.	Dia	Length	Width	Total Area	Equiv Dia	Length	Width	Honey-Comb Pipe		Net Area	Equiv Dia	Dia. Ratio	W-F	Dist to Vena Contr	Orif. Coef	Orif. Pres Drop	Section Flow (From Theo Eq.)	Total Channel Flow
		n	d_o	l	w	A_o	d_o	L_s	w_s	No. of Quarters in Section	d_c	A_r	d_F	β				Δh_o		G_c
1,2,5-10	Outer	9	2.875	--	--	58.5	8.63	15.75	6.6	2	3.5	99.2	11.22	.768	.808	4.0"	.82	10	4.68	--
	Inner	8	2.875	--	--	52	8.15	15.75	6.6	4	3.5	94.4	10.97	.743	.833	--	.82	10	4.04	13.4
3,4	Outer	14	2.875	--	--	91	10.77	15.75	10.0	2	3.5	152.7	13.9	.775	.800	4.7"	.82	10	7.36	--
	Inner	13	2.875	--	--	84.5	10.36	15.75	10.0	4	3.5	147.9	13.68	.759	.817	--	.82	10	6.70	21.4
5,6,7	Outer	5	2.875	6.19	6.19	70.8	9.49	15.75	6.6	2	3.5	99.2	11.22	.845	.700	3.0"	.82	10	6.53	--
	Inner	3	2.875	6.19	7.82	67.9	9.30	15.75	6.6	4	3.5	94.4	10.97	.849	.694	--	.82	10	6.34	19.4

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FIGURE II-1 DOWNCOMER ORIFICE PLATE GEOMETRY

CHANNELS
1, 2, 5-10

CHANNELS
3 & 4

MODIFIED
CHANNELS
5, 6, 7
(Sept. 65)

Design Change
#1052

APPENDIX III - DOWNCOMER FLOW

1. Downcomer Channel Entrance Flows:

The three types of entrance flows free overflow, continuum, and cavitation have the following equations:

A. Free Overflow:

A flow that approximates this condition is the flow over a round crested dam spillway. The equation for this flow, presented by Davis⁽⁸⁾ is:

$$G_n = .448 C_o (W - 2KNH) (H + \bar{V}_a^2 / 2g) \quad (\text{III-1})$$

Where C_o = Discharge coefficient

W = Net length of crest - ft.

K = Pier contraction coefficient = .01

N = No. of piers

H = Head of water above crest - ft.

$\bar{V}_a^2 / 2g$ = Velocity head of approach - ft.

In the application of this equation to the downcomer the term $2KNH$ is negligible, and an approximate value of C_o may be calculated from the measured channel flow, an approximate value of overflow crest height, and the approach velocity head, $\bar{V}_a^2 / 2g$, given in Figure (I-1) on page 26. The values of C_o thus determined, ranged from 20 to 60 compared with values reported by Davis of 3 to 4. Such a large discrepancy casts considerable doubt on the applicability of this dam overflow equation to the case of the upper downcomer channels having unfilled entrance flow. A probable reason for this discrepancy is that the enclosed vertical fall of the water in the downcomer beyond the entrance elbow produces a suction pressure that greatly increases the water overflow and therefore the coefficient of discharge. This may qualitatively explain the discrepancy but it does not provide any quantitative basis for applying a modified equation. Therefore, an estimated flow has been assumed in those channels with unfilled entrance flow conditions and no orifice plate measurements.

B. Flow Continuum:

Application of the Bernoulli equation between the approach box and the location in the downcomer where the pressure is equal to atmospheric yields the equation:

$$G_n = 3.6 S_n \sqrt{\frac{\bar{V}_a^2}{2g} + (x_L - x'_a) + .01 (L_{en} + \frac{\pi n \Delta L}{2} + L_n) \Delta H_f} \quad (\text{III-2})$$

Where G_n = The channel flow 1000 gpm

S_n = Channel free cross-section - ft.²

$\bar{V}_a^2 / 2g$ = The approach box velocity head - ft. and values are given in Figure (I-1).

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- S_n = The flow cross-sectional area in the approach box - ft²
 X_L = The water level in the downcomer above 0' - 0" at which the pressure equals atmospheric
 X'_a = The water level in the approach box above 0'-0"
 Le_n = The channel equivalent entrance length - ft.
 n = The channel no.
 ΔL = The channel height - ft
 L_n = The equivalent channel length - ft.
 ΔH_{fn} = The channel unit pressure drop ft. per 100 ft. of channel

Several terms in the expression ($Le_n + \frac{\pi n \Delta L}{2} + L_n$) are unknown and cannot be readily determined. However, equation (III-2) can be simplified to:

$$G_n = 3.6 S_n \sqrt{\frac{V_n^2}{2g} + (X_L - X'_a) + .01 (Le_n + 53 - X_L) \Delta H_{fn}} \quad (III-3)$$

Where Le_n combines all of the unknown channel flow resistance effects and $53 - S_L$ represents the actual channel length between the approach box and the location of atmospheric pressure.

C. Cavitating Flow:

At high flow rates and at high effluent temperatures cavitation occurs at the inlet section of the lower channels. Under these conditions the flow can be considered as similar to free discharge through an orifice, or restriction, to a discharge pressure equal to the saturation pressure of the water.⁽³⁾ The equation for this flow is:

$$G_n = 3.6 S_n C_d \sqrt{H_n^* - H_s^*} \quad (III-4)$$

Where S_n = Channel free cross-section: sq. ft.

C_d = Entrance discharge coefficient

H_n^* = Approach box water level elevation above channel entrance floor: ft. of water, absolute

and H_s^* = Water saturation pressure: ft. of water, absolute

In the channels with cavitating entrance flow and measured orifice plate pressure drop the channel flow can be determined according to (Figure III-1) and the channel entrance coefficient determined from equation III-4, as follows:

$$C_d = 0.277 G_n / S_n \sqrt{H_n^* - H_s^*} \quad (III-2a)$$

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In the development of the theoretical effect of temperature transients by D. P. Rowe (2) the value of C_d was assumed to be a constant for all the channels. The experimental determination of C_d for the different measured channels is presented in Figures III-2 and III-3. This shows a marked increase in the value of C_d with increasing channel elevation, and with increasing effluent temperature. The increase in C_d with increasing channel elevation is explained by the smaller degrees of flow curvature and the more direct flow approach in the higher channels. The reason for the coefficient increase with increasing temperature is not clear.

The averaged test conditions and the resulting calculated values of the entrance coefficient and the pressure-drop factor $\sqrt{H_n^* - H_a}$ are presented in Table III-1. From this the variation in C_d with channel number and temperature is presented in Figures III-2 and III-3.

Based upon this determination of C_d values the downcomer channel flows in un-measured channels adjacent to measured channels of identical geometry are given by the expression:

$$\frac{G_{n+1}}{G_n} = \frac{C_{d(n+1)}}{C_{dn}} \cdot \frac{\sqrt{H_{n+1}^* - H_a^*}}{\sqrt{H_n^* - H_a^*}} \quad (\text{III-5})$$

The value of this flow ratio for the various channels is also presented in Figures III-2 and III-3

2. Total Downcomer Flow:

The final step in the determination of the total downcomer flow involves summing the individual channel flows, comparing with the measured total flow input, and adjusting the channel flows according to the relationship:

$$G'_n = G_n \left(G_T / \sum G_n \right) \quad (\text{III-6})$$

Where G'_n = The adjusted channel flow

G_T = The total measured flow

and $\sum G_n$ = The summation of the calculated and measured channel flows

The closeness of the expression $(G_T / \sum G_n)$ to 1 is a measure of the accuracy of the basic procedure in determining the individual channel flows, provided none of the pumped flow is diverted away from the downcomer to the over-flow lines or to the cross-under.

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KE - DOWNCOMER RELATIVE CHANNEL FLOWS

TEST SERIES	CONDITIONS		CHANNEL PROPERTIES						TOTAL FLOW ADJUST. $\frac{G_T}{\sum G_n}$
	Temp °C	Total Flow 1000 gpm	Channel Nos.	Approximate Entrance Coef.	C_d^*	Entrance Pressure Factor $\sqrt{\Delta H^*}$		Flow Ratio $\frac{G_{n+1}}{G_n}$	
B	17	205	1 & 2	.48	.49	6.2	6.15	1.01	1.01
			3 & 4	.56	.58	6.1	6.05	1.03	
			5 & 6	.53	.55	6.0	5.9	1.02	
			7 & 8						
C	85	210	1 & 2	.59	.66	4.60	4.5	1.09	.94
			3 & 4	.71	.80	4.5	4.4	1.10	
			5 & 6	.88	.93	4.25	4.2	1.05	
			7 & 8	.83					
	90	210	1 & 2	.70	.78	3.9	3.8	1.09	.95
			3 & 4	.86	.94	3.7	3.6	1.07	
			5 & 6	1.02	1.12	3.5	3.4	1.06	
			7 & 8						
	95	212	1 & 2	.63	.71	3.5	3.4	1.10	.98
			3 & 4	.72	.81	3.3	3.2	1.09	
			5 & 6	1.02	1.11	3.1	3.0	1.05	
			7 & 8	1.14	1.18	2.9	2.8	1.00	
D	20	210	1 & 2	.42	.50	6.2	6.15	1.18	1.12
			3 & 4	.49	.58	6.1	6.05	1.17	
			5 & 6	.77	.85	6.0	5.9	1.08	
			7 & 8						
E	80	212	1 & 2	.51	.63	4.95	4.9	1.22	1.01
			3 & 4	.61	.76	4.8	4.7	1.22	
			5 & 6	.97	1.06	4.6	4.55	1.08	
			7 & 8						
	90	214	1 & 2	.61	.72	4.1	4.05	1.17	.97
			3 & 4	.70	.82	4.0	3.9	1.14	
			5 & 6	1.10	1.20	3.7	3.6	1.06	
			7 & 8	1.16	1.27	3.6	3.5	1.06	
	95	214	1 & 2	.61	.72	3.65	3.6	1.16	1.14
			3 & 4	.68	.80	3.5	3.4	1.14	
			5 & 6	.99	1.10	3.25	3.15	1.08	
			7 & 8	1.32	1.38	3.05	2.95	1.01	

* The second column applies to the higher channel

**

$$\sqrt{\Delta H^*} \equiv \sqrt{H_n^* - H_d^*}$$

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FIGURE III-1 K DOWNCOMER ORIFICE PLATE CHAR.

FIGURE III-2 KE DOWNCOMER FLOW CHAR. (Pre Design Change #1052)

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FIGURE III-3 RE DOWNCOMER FLOW CHAR. (Post Design Change #1052)

CHANNEL NO. [REDACTED]

APPENDIX IV DOWNCOMER WATER LEVEL

The measured pressure above the downcomer orifice plate can be used as a starting point in determining how full each downcomer channel is running. Thus, the height above the orifice plate where the channel pressure is reduced to atmospheric pressure is given by the equation:

$$H_w = H_o + 4.5 + \frac{L}{100} (\Delta H_f) \quad (IV-1)$$

Where X_L = The height of the water level above 0' - 0" at which the line pressure is just equal to atmospheric - ft of H_2O

H_o = The orifice upstream pressure - ft of H_2O

ΔL = The total length of column between H_o and H_w - ft

H_f = the column frictional pressure-drop - ft of water per 100 ft of channel

The channel frictional pressure-drop was determined in an earlier report. (Reference 5, page 24). For convenience it is presented graphically in Figure (IV-1). This indicates negligible downcomer flow through the honey-comb junction pipes for the pressure drop that is available for downcomer flow. Therefore, only flow through the three parallel sections of each channel has been considered in this report.

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FIGURE (IV-1) DOWNCOMER CHANNEL FLOW CHARACTERISTICS

CHANNEL FLOW - 1000 gpm

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APPENDIX V TEST INSTRUMENTATION AND RESULTS1. Test Instrumentation:

Test instrumentation was installed on the rear risers, the downcomer approach box, the entrance elbow, the downcomer orifice plate, and the effluent line to the retention basin. The location of the pressure instrumentation on the approach box and the downcomer entrance elbow is shown in Figure V-1. The location of the pressure taps at the downcomer orifice plate is presented in Figure V-2. The instrumentation not shown in the figures is located as follows:

a. Rear Risers:

1. Far Riser: A pressure tap was installed 8.2 ft. below the center line of the cross-over line, and two temperature elements are situated in the riser 11 ft. below the cross-over center line.
2. Near Riser: There is a pressure tap at 2.8 ft. below the approach-box floor and two temperature elements 2.4 ft. below the floor.

b. Approach-Box and Downcomer Elbow:

At certain locations pressure transducers and strain gages were installed to monitor wall strain and pressure surges. The results of the strain measurements will be reported by Plant Engineering. The pressure surge effects will be presented after reaching the proposed increased flow conditions.

c. Effluent Line:

To monitor the effluent line frictional pressure-drop a pressure tap was installed in the effluent line 6.5 ft. downstream from the outer edge of the downcomer.

2. Test Measurements:a. Approach Pressures:

The downcomer approach pressures are measured with a mercury manometer. Its arrangement and the elevation between pressure the tap and the manometer are shown in Figure V-3. The pressures are measured in two manners:

1. With respect to the rear face pressures by comparing the tap pressure with the reference line (valve R): Note, valve C closed.
2. With respect to the top of downcomer pressure by comparing the tap pressure with the tap (O.C) pressure. (Valves R and O-C closed and valve C opened).

The original pressure measurements were made with a partial water level above the mercury on each side of the mercury manometer. Since then, both arms have been kept full of water. This considerably simplifies the calculation of pressures without any significant loss in accuracy. In obtaining test measurements it is important to:

- a. Keep the manometer lines water filled above the mercury.

FIG. V-3 APPROACH-BOX & ELBOW
PRESSURE MEASUREMENT

- b. Keep all the pressure tap lines water filled by opening them to the water supply (W) and by closing this (W) valve last of all in the pre-measurement test procedure.

With the manometer lines water filled (above the mercury) the tap pressure above the reference, either R or (O-C), is obtained as:

$$\Delta H_x = 0.447 (h_r - h_x) \left(1 - \frac{1}{13.6}\right) \quad (V-1)$$

Where ΔH_x = Tap pressure above the reference - ft of water

h_r = Left-hand mercury column, cm. of Hg. (reference)

h_x = Right-hand mercury column, cm. of Hg. (tap)

and $\left(1 - \frac{1}{13.6}\right) = .926$ = Correction for water columns above mercury.

Similarly, the general equation for the pressure at the tap location is given as:

- (1) Rear Face Reference (R)

$$H_{x_t} = \Delta H_x - (X_t - X_R) \quad (V-2)$$

- (2) Tap of Approach Box Reference (O-C)

$$H_x = \Delta H_x - (X_t - X_C) \quad (V-3)$$

Where H_{x_t} = Pressure at tap X: ft of H_2O

X_t = Elevation of tap above pressure manometer - ft ($X_{ta} = 11.1'$; $X_{tb} = 12.6'$)

and the constants X_R and X_C represent the elevation of the reference tap (R) and the tap (O-C) above the manometer. ($X_R = 71'$; $X_C = 17.9'$).

The most important information desired from this instrumentation is the approach box water level. This is a measure of downcomer flooding; and therefore, an important operating limit. The conversion of the reference tap pressure H_{x_t} to the indicated approach box water level is presented in Appendix I of this report.

- b. Downcomer & Effluent Pressures:

These are measured at a location having an elevation within 0.4 ft. of the elevation of the orifice upstream pressure taps. The arrangement of this pressure measuring instrumentation is shown in Figure V-4. Here, the positive pressures are measured by a Heise Bourdon gage in terms of psig. The negative pressures were measured on the manometer in terms of cm. of mercury. Using this manometer to measure only negative pressures means that it can be maintained free of water to avoid the water arm corrections that complicate the pressure calculations. The orifice pressure measurements are converted to values of upstream orifice pressure head - in ft. of water, and to values of orifice pressure-drop according to the relationships:

FIGURE V-4 DOWNCOMER ORIFICE PRES.
MEASUREMENT

(1) Orifice Upstream Pressure

$$H_{on} = \frac{144}{\rho} p_{on} \quad (V-4)$$

(2) Orifice Downstream Pressure

(a) Positive Pressures

$$H'_{on} = \frac{144}{\rho} p'_{on}$$

(b) Negative Pressures (dry manometer)

$$H'_{on} = .447 (h'_R - h'_{on}) \quad (V-5)$$

(3) Orifice Pressure-Drop

$$\Delta H_o = (H_{on} - H'_{on}) \quad (V-6)$$

and for the above equation:

H_{on} = The upstream orifice pressure for channel N: ft of water

ρ = The effluent water density - lbs per cu ft

p_{on} = The measured orifice upstream pressure-psi

h'_R = The reference (left hand) manometer pressure - cm of Hg

h'_{on} = The orifice downstream (right hand) downstream manometer pressure - cm of Hg

and the prime values H'_{on} etc. represent downstream pressure values.

3. Test Results

For convenience in comparison with model data and because of the direct relationship between water pressure in ft. and water level elevation, the test results in terms of psig and/or cm. of mercury were all converted to ft. of water head. With this one step performed the basic test results are summarized in the following table.

TEST NO.	DATE	OVERALL CONDITION				FAR RISER		YEAR RISER		APPROACH		BOX	ELBOW				ORIFICE PRESSURES										DISCHARGE	
		Flow 1000 gpm	Temp °C	Sat. °C	Pres. Ft. (Gage)	Temp °C	Pres. Ft.	Tap	Pressures Observed		PRESSURES			Upstream & Downstream Pressures										PRES. Chan. Effl. No. 3 Line				
									H _x	Ft. of H ₂ O H _c Level	H ₁		H _{3a}	H _{3b}	H _{3c}	1	2	3	4	5	6	7	8		9	10		
B-1	6-29	65	15	-33	-	-	-	o-a	1.4	1.8	-16	10.5	7.5	-2.0	26	9.0	2	-1	3	4	6	13						
B-1D	8-13	61	17	-33	14	-	12.4	o-b	11.0						-27.1	0.8	1	1	0.5	-	-	-	-					
B-2	6-29	126	15	-33	-	-	-	o-a	9.9	16.2	5.3	11.5	9.3	-	-	-	-	-	-	-	-	-	-					
B-2A	8-13	137	17	-33	15	-	12.7	o-b	0	0	-15.5	-13	-14	-10.2	26.4	27.4	10.5	1	5.5	6	4	9.5						
B-3	6-29	203	15	-33	-	-	-	o-a	10.7	16.2	6.7	-5.6	-3.8	-4.3	-0.6	-	-	-	-	-	-	-	-					
B-3A	8-19	202	20	-33	16.7	-	13.1	o-b	0	0.2	-9	-9	-7.5	-4.4	32.5	34	31.3	22	9	12.2	15	16						
B-1C	6-29	65	17	-33	14.1	-	12.5	o-a	6	13.5	0.1	-0.2	1.3	3.9	6.1	0.4	0.4	13	12	-	-	-						
B-4	6-29	195	17	-33	-	-	-	o-b	8	9	-7.5	7	6.4	8	8.8	5.8	6.5	6	13.2	16.2	17.6	23.6						
B-4A	6-29	195	17	-33	-	-	12.9	o-b	0	3.7	-11	-8.4	-8.6	-5.1	31.9	32.8	29.6	15.5	10.4	11.1	14.6	14.6						
B-4B	8-13	193	17	-33	17.8	-	13.8	o-b	8.3	15.2	8.2	-	-	-	5.8	0.4	0.2	4.6	12	-	-	-						
C-1	8-1	204	72	-23	18.5	-	14.7	o-a	10.1	11.2	-	-	-	5.3	34	36.5	34.4	26.2	12.2	12.5	17.4	16.5						
B-1A	8-1	207	73	-23	18.8	-	15.6	o-b	10.6	0.2	-0.9	-0.9	4.9	6.3	6.7	0.8	14.5	1.4	11.1	-	-	-						
B-2	8-2	205	85	-16	17.4	-	14.3	o-a	8.5	9.8	-1.1	1.3	-0.4	0.5	8.4	2.2	13.7	8	11.2	-	-	-						
								o-b	9.8	15.7	-	-	-	5	36.0	37.2	36.9	33.6	13.7	13.4	18.7	17.7						
								o-b	10.3						8.2	-0.2	-10.8	-8.0	13.7	-	-	-						

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APP. - V - TABLE V-1a

PE DOWNCOVER TEST DATA

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TEST NO.	DATE	OVERALL CONDITIONS		TAP RISER		TAP RISER		APPROACH POY		ELBOW PRESSURES					ORIFICE PRESSURES										DISCHARGE PRES.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
		Flow	Temp. Sat.	Pres.	Temp.	Pres.	Temp.	Tap	Pressures		Observed	PRESSURES				Upstream & Downstream Pressures																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
									Ft. of H ₂ O	Level		H ₁	H _{2a}	H _{2b}	H _{2c}	for Channel Nos. (Ft. of H ₂ O)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
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APP. - V - TABLE 1a

KE DOWNCOMER TEST DATA

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TEST NO.	DATE	OVERALL CONDITION				FAR RISER		NEAR RISER		APPROACH BOX			ELBOW				ORIFICE PRESSURES						DISCHARGE			
		Flow	Temp	Sat	Pres	Temp	Pres	Temp	Tap	Pressures		Observed	PRESSURES				Upstream & Downstream Pressures						PRES.			
										Ft. of H ₂ O	Water		H ₁	H _{3a}	H _{3b}	H _{3c}	for Channel Nos. (Ft. of H ₂ O)									
																	F _x	F _c	Level	1	3	5		7	9	10
		GPM	°C	Gage	Ft.	°C	Ft.	°C																		
D-1	8-20	202	20	-33	-	-	-	-	o-a	-11.5	-	8.1	-21.5	-17	-	-	31	32	21	16.5	13.5	14.0	17.5	18.4		
									o-b'	-6.1		8.2					14	10.8	-2.2	14.3	10.8	15.9				
D-1A	9-20	200	20	-33	-	-	-	-	o-a	-10.6	0		-	-	-	-	30.3	30.5	21.8	16.8	14.0	14.3	16.4	17.5		
									o-b'	-5.7							12.6	10.8	-3.3	14.3	12.0	14.1				
E-1	9-20	210	90	-18	-	-	-	-	o-a	-9.6	0.4		-	-	-	-	32	34	24	19	10	11.5	-	15		
									o-b'	-5.4							11.5	5	-10.6	8.4	10	9.5				
E-2	9-20	212	90	-11	-	-	-	-	o-a	-0.9	0.2		-	-	-	-	32	31	26	23	14	11.7	-	16		
									o-b'	-2.2							11.7	7	-3.6	-2.2	12.5	10.8				
E-7	9-21	214	95	-7	12.5	95.3	6.6	96.8	o-a	-6.4	0		2.6	-	.7	-	31.5	29.7	25.1	23.4	21.5	18.1	-	15.3		
									o-b'	-3.3							18.8	18.1	13	6	8.2	15.7				
E-7A	9-23	214	94	-5	-	-	-	-	o-a	-	-		-	-	-	-	30.3	30.8	25.3	22.7	20.3	17.6	-	-		
									o-b'	-							18.3	17.3	10.0	3.4	10.1	15.7				
E-7B	10-6	214	95	-7	12.3		6.3		o-a	-2.8	8.5		2.3	-	.7	-2	29	28.8	23.5	21.8	22.4	18.2	21.2	16.3		
									o-b'	-5.6							17.8	15.8	12.2	4.1	6.0	15.1				
E-24	11-12	213	76						o-a								32.3	33	24.8	18.8	12.6	12.2	19.0	16.3		
									o-b'								13.8	10.8	0	5.5	12.4	11.0				
E-25	11-22	212	90	-11					o-a								32.4	31.0	24.7	22.6	15.8	14.1	34.3			
									o-b'								14.0	12.0	6.2	-	0	14.0	14.2	-1.6		

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New Taps Installed on #1 Orifice

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