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FLOWS UNDER VARIED SUPPLY CONDITIONS

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GRAPHICAL DETERMINATION OF K EMERGENCY FLOWS
UNDER VARIED SUPPLY CONDITIONS

October 18, 1965

by
Stephen S. Jones

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GRAPHICAL DETERMINATION OF K EMERGENCY FLOWS
UNDER VARIED SUPPLY CONDITIONS

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INTRODUCTION

The K Reactor's last ditch emergency cooling system was greatly improved by the installation of a diesel powered emergency pumping station. This and two steam-driven, low-lift pumps (one at each 190 Building) were installed under Project CGI-844. This system still has the problem of coolant flow interdependence between the two reactors. Thus, the diesel coolant flow divides at its entrance to the high pressure cross-tie (HPCT) and may flow to both KE and KW Reactors. The amount of coolant going to the stricken reactor is determined by the requirement of equal back pressure from each reactor.

The emergency coolant flow problem is further complicated by a continued line corrosion in the HPCT which slowly decreases the amount of emergency flow available. Line cleaning on a two-year schedule is required to maintain an adequate last ditch system, but this is expensive both in direct cost and outage time. Furthermore, line cleaning frequency could increase under year round bulk temperature operation.

A possible means of extending the period between line cleanings is to include the low pressure cross-tie (LPCT) inter-tie, and the service water pumps which supply it, as an additional source of last ditch emergency flow to a stricken K Reactor.

To determine the stricken reactor flow under varied conditions of HPCT line corrosion, service water pumping and line variations, etc., a graphical trial and error solution was developed and is presented herein. To be accurate, this method requires an experimental flow check of the system and an updating of the experimental curves every 6-12 months or every time there is a significant change in the reactor flow characteristics.

SUMMARY

This report presents a graphical solution to the complex emergency flow problem at the K Reactors. It includes the effects of service water flow to the stricken reactor through the low-pressure cross-tie (LPCT) and the addition of the emergency steam pump to the service water system.

Included in this analysis are the important effects of high-pressure cross-tie line cleaning and the amount of service water pumping (service water usage) that is occurring before the loss of pumping power at the stricken K Reactor. Working charts for the simplified calculation of emergency reactor flow are included.

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DISCUSSION

General

The K reactor last-ditch emergency system is made up of the following parts:

1. Four low-lift pumps that remain in operation at the unstricken, or aiding, pumping plant and provide adequate cooling flow to their reactor.
2. Two emergency diesel pumps (assuming the failure of one of the three diesel pumps) that start automatically upon the loss of pumping power and provide emergency flow to the high-pressure cross-tie (HPCT). Here the flow splits into a stream to each reactor. The stream size being determined by the requirement of equal arm pressure drop.
3. Two or three service water pumps that remain in operation at the aiding reactor and provide coolant flow to certain base loads as well as a potential flow to the stricken K reactor through the low-pressure cross-tie (LPCT).
4. An emergency steam turbine pump that can serve as a back-up to the low-lift pumps at the aiding reactor or a back-up to the service water pumps that provide emergency flow through the LPCT to the stricken reactor.

Each of these systems has certain basic characteristics that can be determined and expressed graphically. These can then be used to obtain a quick trial-and-error solution for any given combination of conditions. The component characteristics are presented in the following section. For convenience, all the characteristic curves are converted to the same elevation, that of the bottom of the riser pressure, BORP, equal to 466 feet at each K reactor. There are negligible velocity-head effects in the main 24-inch lines; and in the smaller lines these are included as a part of the line resistance. A diagram of the system is shown in Figure 7, on page 26.

System Characteristics

A. Stricken Reactor

A detailed analysis was recently made of the K reactor tube flows. This showed the turbulent-laminar transition occurring at flows corresponding to a total reactor flow of less than 16,000 gpm. Therefore, the assumption made in Figure 32 of HW-76299¹ is incorrect. The Δp_f curve remains linear down to about 20,000 gpm, or well below the emergency flow values of 26,000 to 32,000 gpm. The modified reactor BORP curves for the KE and KW reactors are presented in Figures 1 and 2. These are based upon Δp_f linearity and the experimental data obtained by the process engineers R. D. Hickman and S. A. Wood. They include curves for all four riser flow and for the emergency flow case of flow to the A and B riser only². Actually, in the case of diesel plus service water flow, we have most of the emergency flow through the A and B risers with 5 to 15 per cent flow through the C, D side. This yields a pressure flow characteristic that has not yet been determined. It is approximated as curve p_{R_s} in Figure 1, shown as the dashed line just below the 20° A&B³ curve. Under

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emergency flow conditions velocity-head effects are negligible and the reactor flow pressure relation is:

$$(p_B - \Delta p_s) = K_1 G_R^{1.85} \quad (1)$$

where: G_R = Total reactor emergency flow - 1000 gpm.

p_B = Bottom of riser pressure (i.e., 466 elev.) psig.

Δp_s = Elevation of cross-over water level above BORP in Ft x .443 and values are given in HW-72699, page 40¹.

K_1 = A constant proportional to the reactor flow resistance.

Using experimental values of p_B from Reference 2 and corresponding values of Δp_s from Figure 18, page 40, of Reference 1, we obtain a linear log-log curve for any given resistance condition. The best straight line is drawn through the experimental points and a working chart of the reactor BORP versus flow is then obtained according to equation (2):

$$p_B = \Delta p_f + \Delta p_s \quad (2)$$

where: Δp_f is the linear curve obtained as the best solution of the relation ship:

$$\Delta p_f = K_1 G_R^{1.85} \quad (3)$$

B. Aiding Reactor

Here the riser flows are essentially equal and thus a single riser pressure versus flow curve is obtained. Again this is based upon the latest experimental data obtained by Hickman and Wood and is shown in Figure 2.

C. Diesel Emergency Pumps

The maximum allowable speed for these pumps is 750 rpm. Considering two-pump operation at this speed, we have one resultant pressure at the high-pressure cross-tie junction for any given total flow. From this point, the flow splits according to the back pressure from each reactor. We can arbitrarily assume a flow split, however, and determine the diesel pump supply curve to each reactor based upon this assumed HPCT line flow and flow resistance or pressure-drop. Arbitrarily, the KE reactor was assumed to be the stricken reactor in every case; and a family of diesel pump flow supply curves were determined as a function of the total diesel pump flow and the fractional flow to each reactor for present and cleaned (all but the new parallel line) conditions. The HPCT line pressure-drop curves are given in Figures 3 and 4. Their use in the determination of the family of diesel pump supply curves is shown in Table I.

These diesel pump supply curves in terms of the fractional flow split are presented in Figures 1 and 2 which also contain the reactor flow demand curves.

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TABLE I
DIESEL PUMP REACTOR SUPPLY CURVES

Diesel Pumping Conditions		HPCT Line Condition	Stricken Reactor (KW)				Aiding Reactor (KW)			
Total Flow 1000 gpm	X-Tie Junction Pressure p.*		Fract. of Diesel Flow f _S	Flow 1000 gpm G _{DS}	Line Resist. Psi ΔP_{HPCT}	Reactor Supply BORP PBS	Fract. of Diesel Flow f _A	Flow 1000 gpm G _{DA}	Line Resist. Psi ΔP_{HPCT}	Reactor Supply BORP PBA
39	81	Uncleaned	.60 .65 .70 .75 .80	23.4 25.4 27.3 29.3 31.2	28.0 31.5 37.0 42.0 47.0	52.0 48.5 43.0 38.0 33.0	.40 .35 .30 .25 .20	15.6 13.6 11.7 9.7 7.8	11.0 8.5 6.5 4.5 3.0	69.0 71.5 73.5 75.5 77.0
42	70	Uncleaned	.60 .65 .70 .75 .80	25.2 27.3 29.4 31.5 33.6	32.0 37.0 42.0 47.0 54.0	38.0 33.0 28.0 23.0 16.0	.40 .35 .30 .25 .20	16.8 14.7 12.6 10.5 8.4	12.0 9.0 7.0 5.0 3.5	58.0 61.0 63.0 65.0 66.5
44	62	Uncleaned	.60 .65 .70 .75 .80	26.4 28.6 30.8 33.0 35.2	34.0 39.0 45.0 52.0 59.0	28.0 23.0 17.0 10.0 2.0	.40 .35 .30 .25 .20	17.6 15.4 13.2 11.0 8.8	13.0 10.5 8.0 5.5 4.0	49.0 51.5 54.0 56.5 58.0
39	81	Cleaned single lines and old parallel line**	.60 .65 .70 .75 .80	23.4 25.4 27.3 29.3 31.2	17.5 19.5 23.5 26.0 28.5	53.5 51.5 47.5 45.0 42.5	.40 .35 .30 .25 .20	15.6 13.6 11.7 9.7 7.8	7.5 5.7 4.2 3.0 2.1	72.5 74.3 75.8 77.0 77.9
42	70	Cleaned single lines and old parallel line**	.60 .65 .70 .75 .80	25.2 27.3 29.4 31.5 33.6	20.0 23.5 26.0 30.0 34.0	50.0 46.5 44.0 40.0 36.0	.40 .35 .30 .25 .20	16.8 14.7 12.6 10.5 8.4	8.5 6.5 5.0 3.8 2.4	61.5 63.5 65.0 66.2 67.6

* Corrected to elevation of BORP

** New part of parallel line not cleaned.

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D. Service Water and Steam Pump Characteristics

The service water pump characteristics are presented in Figure 5. The solid lines in this figure represent the pumping flows from 2 or 3 SW pumps or 2 SW pumps plus a steam pump. These pump discharge pressures* were corrected to the uniform 466-foot elevation used in this analysis and for the service water loop pressure-drop from the pumps to the valve pit. In the case of the steam pump, there was a further correction for the pressure loss in the cross-tie between the steam pump and the service water system.

The dashed lines in this figure represent the normal flow usage of the service water pumping system. These curves were obtained by using the test and maximum service water flow rates and assuming the relationship:

$$G_{SW_B} = [K_2(p_{SW_V} - 5)]^{0.54} \quad (4)$$

where: G_{SW_B} = Base load service water flow in 1000 gpm (normal or maximum service water usage).

p_{SW_V} = Valve pit service water loop pressure corrected to BORP elevation - psig.

K_2 = Represents the net effective flow resistance of the service water normal usage systems, and 5 in the static elevation correction.

The dotted lines in Figure 5 are the flow resistance curves for LPCT and for the service water flow in the process lines from the 165 Building to the reactor. These have fixed resistance values for any given flow. There appears to be considerable corrosion resistance in the LPCT line, however, and line cleaning should considerably reduce this pressure-drop.

In order to obtain a service water supply curve at the stricken reactor, it is necessary to determine one further resistance. This is the pressure-drop in going from the service water loop at the stricken reactor into the process water system. At present, the service water can enter the process system either through two 12-inch diameter connecting lines with 12-inch #SE valves or through 6-inch diameter bypass lines if the SE valves are closed. A further decrease in flow resistance could be produced by enlarging these connecting lines to the size of the service water loop, i.e., 24-inch diameter. The corresponding flow resistance characteristics of these service water to process connections are presented in Figure 6.

E. Service Water Flow to Stricken Reactor

The amount of the service water flow to the stricken reactor during an emergency event is determined as shown in Table II. The SW flow path is:

* The service water pump flow characteristics were obtained from Reference 3 rather than the BPF. This yields a lower and more conservative pumping flow. This allows for the effects of line and pump corrosion.

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TABLE II

SERVICE WATER SUPPLY TO STRICKEN REACTOR

Case No.	SW Pumping Conditions			165-KW Building. (Aiding Area)				165-KE Building (Stricken Area)			105 Building BORP Psig
	Pumps In Operation In Emergency		Service Water Supply Conditions	Assum. Valve Pit Press. P_{165A} Psi*	Total Pump. Flow G_{SW} 1000 gpm	Flow To Normal Usage G_{Ba}	Flow To KE G_{LPCT}	Valve Pit Press. P_{165S}	Flow To Normal Usage G_{Bs}	Emerg. Flow G_{SWs}	
	No. SW Pumps	No. Steam Pumps									
B-1	3	0	a) Test SW Usage b) 6" Connecting Lines	80 85 90	15.0 14.4 13.7	6.5 6.8 7.0	8.5 7.6 6.7	49 60 69	4.8 5.5 6.0	3.7 2.1 0.7	2.5 44.0 67.0
B-2	3	0	a) Max. SW Usage b) 6" Connecting Lines	65 70 75	16.2 15.8 15.4	7.4 7.7 8.0	8.8 8.1 7.4	33 42 51	4.8 5.6 6.4	4.0 2.5 1.6	— 20.0 41.0
B-3	3	0	a) Test SW Usage b) 12" Connect- ing Lines	70 80 85	15.8 15.0 14.4	6.0 6.5 6.8	9.8 8.5 7.6	31 49 60	3.4 4.8 5.5	6.4 3.7 2.1	22.6 46.5 59.0
B-4	3	0	a) Max. SW Usage b) 12" Connect- ing Lines	65 70 75	16.2 15.8 15.4	7.4 7.7 8.0	8.8 8.1 7.4	33 42 51	4.8 5.6 6.4	4.0 2.5 1.6	29.5 40.5 50.3
B-5	3	0	a) Test SW Usage b) New 24" Con- necting Lines	60 65 70	16.6 16.2 15.8	5.6 5.8 6.0	11.0 10.4 9.2	12 21 34	1.4 2.6 3.7	9.6 7.8 5.5	8.5 18.7 32.5
B-6	3	0	a) Max. SW Usage b) New 24" Con- necting Lines	60 65	16.6 16.2	7.0 7.4	9.6 8.8	22 33	3.6 4.8	6.0 4.0	20.3 32.3

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* SW pump discharge pressure corrected to valve pit location and BORP elevation.

TABLE II (Cont'd)

Case No.	SW Pumping Conditions		165-KW Building (Aiding Area)				165-KE Building (Stricken Area)			105 Building	
	Pumps In Operation In Emergency		Service Water Supply Conditions	Assum. Valve Pit Press. P ₁₆₅ [*] P _{sig} ^A	Total Pump. Flow G _{SW} 1000 gpm	Flow To E Normal Usage G _B _a	Flow To KE G _{LPCT}	Valve Pit Press. P ₁₆₅ _s	Flow To Normal Usage G _B _s	Emerg. Flow G _{SW} _s	BORP Psig P _R _s
	No. SW Pumps	No. Steam Pumps									
C-1	2	1	a) Test SW Usage b) 12" Conn. Steam Pump to SW and SW to Process	70 75 80	15.5 13.9 11.7	6.0 6.3 6.6	9.5 7.6 5.1	36 50 76	4.0 4.9 6.4	5.5 2.7 X	30.0 48.0
C-2	2	1	a) Max. SW Usage b) 12" Conn. Steam Pump to SW and SW to Process	60 65 70	17.8 16.8 15.5	7.0 7.4 7.7	10.8 9.4 7.8	13 28 43	2.4 4.2 5.8	8.4 3.2 2.0	X 26.0 42.0
C-3	2	1	a) Max. SW Usage b) New 24" Steam Pump Conn. - 12" Conn. SW to P	65 70 75 74	19.0 16.8 14.2 14.8	7.4 7.7 8.0 7.9	11.6 9.1 6.2 6.8	12 35 56 52	2.0 5.0 6.8 6.4	9.6 4.1 X 0.4	X 31.7 -- 52.0
C-4	2	1	a) Test SW Usage b) New 24" Steam Pump Conn. - 12" Conn. SW to P	70 75	16.8 14.3	6.0 6.3	10.8 8.0	23 47	2.8 4.8	8.0 3.2	12.0 45.0
D-1	2	1	a) Test SW Usage b) New 24" Steam and SW Conn.	70 75	16.8 14.3	6.0 6.3	10.8 8.0	23 47	2.8 4.8	8.0 3.2	21.0 46.0

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* SW pump discharge pressure corrected to valve pit location and BORP elevation.

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1. There is service water flow from the service water pumps at the aiding reactor that are still operating (and from the emergency steam pump if it is assumed to start) through the service water loop to the 165 Building valve pit.
2. Here the flow diverts to the normal service water usage (assumed to all occur at this point) according to the valve-pit pressure and to the low-pressure cross-tie (LPCT).
3. The service water arriving at the 165 valve pit of the stricken reactor is again diverted to the normal service water usage according to the pressure.
4. The remaining service water flows through the service water to process connections (Curves (1), (2), or (3) of Figure 6) into the process system.
5. And finally, there is a small additional process line pressure-drop before a service water supply point is obtained of service water flow versus riser pressure, p_R , at the stricken reactor. The determination of this service water flow supply curve at the stricken reactor for various cases is summarized in Table II.

Graphical Solution of K Emergency Flow

The charts developed in this report are based as much as possible upon experimental data. All conditions are modified, however, to yield all characteristic curves at the common elevation of BOPR (166 feet). For simplicity, this analysis considers KE as the stricken reactor and KW as the reactor with secondary pumping. It is expected that under the reverse conditions, the results obtained from this analysis would be directly applicable, but probably would yield an emergency flow 2 to 4 per cent too low. Thus, applying these charts to a stricken KE or KW reactor would yield conservative results.

The easiest way to explain the use of these charts is by example. Therefore, two examples are included:

Example I: No LPCT Flow, Uncleaned HPCT Lines After 2.5 Years of Corrosion (Following Previous Line Cleaning)

The graphical solution of this problem for uncleaned HPCT lines is shown in Figures 1 and 2 and the various trials are summarized in Table III. The following steps are involved:

1. Assume a value of A and B riser pressure at the stricken reactor ($P_R = 40.0^*$)
2. From Figure 1 determine the total stricken reactor flow ($G_S = 30.0$) and by interpolation of the diesel fractional flow curves determine the fraction of the diesel pump flow going to the stricken reactor ($f_S = .831$).
3. Since the diesel pumps supply all of the stricken reactor flow, then $G_{DS} = G_S = 30.0$ and $G_D = G_{DS}/f_S = 36.2$. Likewise, the value of $f_A = 1 - f_S = .169$ and $G_{DA} = f_A G_D = 6.2$.
4. From Figure 2 determine the aiding reactor BOPR as the intersection of the f_A flow fraction curve ($f_A = .169$) with the diesel flow to this reactor ($G_{DA} = 6.2$) and this yields a pressure of 73 psig.

* The arrowed lines in Figures 1 and 2 depict the final trial and the resultant numbers are included here.

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TABLE III

GRAPHICAL FLOW ANALYSIS (HPCT FLOW ONLY) (Flow in 1000 gpm)
 FOUR LOW-LIFT PUMPS AT AIDING REACTOR

HPCT Line Condition	Stricken KE Reactor			Diesel Pumping			Aiding KW Reactor				
	Assumed Riser Pressure BORP Psig P_{RS}	From Figure 1		Flow To Stricken Reactor G_{DS}	Total Flow G_D	Flow To Aiding Reactor G_{DA}	Fract. of Diesel Flow f_A	From Figure 2			Calc. Reactor Flow $G_L + G_{DA}$
		Total Flow G_S	Fract. Diesel Flow f_S					Riser Press. BORP P_{RA}	L.L. Pump Flow G_L	Total Reactor Flow G_A	
Uncleaned	41.0	30.9	.855	30.9	36.2	5.3	.145	72	56.8	61.3	62.1
(Graphical Example I Case Ia)	40.0	30.0	.831	30.0	36.2	6.2	.169	73	55.8	62.0	62.0
Cleaned	41.0	30.9	.758	30.9	40.8	9.9	.242	66.5	62	57.3	71.9
	42.0	31.7	.790	31.7	40.1	8.4	.210	71	58.0	60.6	66.4
	43.0	32.5	.829	32.5	39.2	6.7	.171	72.5	56.2	61.7	62.9
	43.2	32.7	.839	32.7	39.0	6.3	.16	73	55.7	62.0	62.0

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5. At this riser pressure the reactor flow from the four low-lift pumps is $G_L = 55.8$ and the total reactor flow (according to the reactor flow demand curve) is 62.
6. And finally, if this total reactor flow is equal to the sum of the low-lift and diesel pump flows; i.e., ($G_A = G_L + G_{DA}$) the problem is correctly solved. If there is significant disagreement, then a new value of stricken reactor riser pressure is assumed and the graphical solution repeated until the reactor supply is equal to the reactor demand.

Example II: Two service water pumps and a steam pump through the present 12-inch SE 1 and 2 bypass lines and three low-lift pumps at the aiding reactor (20 C):

The service water emergency flow supply characteristics are obtained from the pertinent case in Table II and plotted on Figure 1.

Two curves are shown in Figure 2, one for maximum SW usage during reactor operation and one for normal usage. This particular example is for normal SW usage and involves the following steps:

1. Assume a value of average riser pressure at the stricken reactor ($P_{RS} = 42.8$) and determine the service water flow to the stricken reactor ($G_{SWs} = 3.4$, for normal SW usage). Also determine the total flow to the stricken reactor ($G_S = 33.0$).
2. At this same total flow, determine the A+B riser pressure ($P_{RA} = 43.6$) and determine the chart location of f_S as the intersection of $P_{RA} = 43.6$ with the diesel pump flow to the stricken reactor ($G_{DS} = G_S - G_{WS}$; $G_{DS} = 29.6$).
3. An interpolation of f_S from Figure 1 yields $f_S = 0.733$; therefore, the total diesel pump flow is $G_D = G_{DS}/f_S = 40.4$ and, likewise, $f_A = 1 - f_S = .269$ and $G_{DA} = f_A G_D = 10.8$.
4. Now going to Figure 2, the problem is solved in a manner identical to example I. The aiding reactor BORP, determined by the intercept of f_A with G_{DA} , is 67 psig, and the aiding reactor low-lift pump flow and the total reactor flow corresponding to this BORP are 46.6 and 57.7, respectively. And the final check is that the sum of the low-lift pump (46.6) and the diesel flow (10.8) is also equal to the total reactor flow from the BORP pressure demand curve (57.7); i.e., $G_A = G_L + G_{DA}$.

CONCLUSIONS

1. HPCT Line Cleaning

It is expected that recleaning this HPCT line (even excluding the new parallel part of the system) will yield a 7 percent increase in emergency flow. To

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TABLE IV

GRAPHICAL FLOW ANALYSIS, 2-SW PUMPS + STEAM PUMP
WITH 3-LL PUMPS AT AIDING REACTOR

HPCT Line Condition	Stricken KE Reactor						Diesel Pumping			Aiding KW Reactor			
	Assumed Riser Pressure Avg* PR _S		From Figure 1				Total Flow G _D	Flow to Aiding Reactor G _{DA}	Fract. of Total f _A	From Figure 2			Calc. Reactor Flow (G _{DA} +G _L) G' _A
			Total Flow G _S	SW Flow G _{SW_S}	Diesel Flow G _{DS}	Fract. of Total Diesel Flow f _S				Riser Pressure BORG PR _A	LL Pump Flow G _L	Total Reactor Flow G _A	
Uncleaned	41	41.8	31.6	3.7	27.9	.71	39.3	11.4	.29	73	41.7	62	53.1
	40	40.8	30.7	3.9	26.8	.665	40.3	13.5	.335	66	46.4	56.9	59.9
	40.3	41.1	31.0	3.8	27.2	.681	40.0	12.8	.319	69	45	59.2	57.8
	40.2	41.0	30.9	3.9	27.0	.673	40.1	13.1	.327	68	45.8	58.4	58.9
Cleaned	42	42.8	32.4	3.6	28.8	.695	41.5	12.7	.305	61	50.8	53	63.5
(Graphical	43	43.8	33.2	3.4	29.8	.74	40.3	10.5	.26	68	45.8	58.4	56.3
Example II	42.8	43.6	33.0	3.4	29.6	.733	40.4	10.8	.267	67	46.6	57.7	57.4
Case IVb)													

* An estimated value close to that of the A-B riser pressure.

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obtain optimum capacity from this method would require line cleaning nearly once a year. This 600 pound line could be downgraded to 150 pounds and could withstand the erosive effects of quite a few line cleanings before line replacement would be required. In fact, its additional useful life should be at least 15 years.

2. HPCT Line Protection

To avoid the reactor down time and costs associated with these line cleanings, it would be highly desirable to inhibit or protect this line after its next cleaning. Studies of protective coatings that can be installed in situ with guaranteed protection against sufficient flaking or sluffing-off to cause a flow blockage problem have been unsuccessful to date. It may be that a method of line corrosion inhibition is possible that will extend the time between costly line cleanings by several years.

3. Service Water Back-up Through the Low-Pressure Cross-Tie

A means of obtaining increased emergency flow is already in place and operable. This is the low-pressure cross-tie line between the service water loops at the KE and KW pumping plants. Although this system has the advantage of immediate availability, it has the disadvantage of greatly complicating an already complicated emergency pumping system. Its use fundamentally involves some decrease in system reliability and may only be tolerable on a temporary basis. To improve its reliability, the pumping requirement may be made that one less than the number of operating service water pumps at each reactor is assumed to stay in operation during a power failure emergency. For instance, with the normal compliment of three service water pumps in operation at each power plant we could be sure of only two of these in operation following a maximum credible power failure. As shown in Table V, this would cause a flow increase of 4 per cent over that provided by the diesel pumps alone.

4. Decreased Service Water to Process Line Resistance

The two most important means of obtaining increased service water flow to a stricken reactor are:

- a) Decrease the normal demand on the service water system.
- b) Decrease the flow resistance of the connecting lines between the service water and the process system.

The demands upon this service water system are varied both in number and amount. Therefore, it will be quite difficult to control the amount of normal service water usage. As indicated in Table V, the change between normal and high service water usage at the time of a power failure would cause a loss of 3 per cent in emergency cooling. With proper control of service water usage, it is believed that a gain of 5 per cent would be possible in emergency flow between the cases of maximum and controlled service water usage.

In the case of the connecting line resistance between the service water and the process system, there are several significant conclusions:

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- a) It is advantageous to have the 12-inch SE valve open in place of or in parallel with the 6-inch bypass valves. This yields a reactor emergency flow increase of about 5 percent.
- b) Going to 24-inch lines and valves in the service water to process water interties appears to be of no advantage because of the probability of severe cavitation of the two operating service water pumps. The theoretical pump discharge pressures are well below the point of cavitation cut-off.

5. Use of Emergency Steam Pump to Contribute to Service Water System

At the present time, the emergency steam pump is essentially non-functional. The aiding reactors low-lift pumps and the emergency diesel pumps are considered to be a single last-ditch system. The most serious single component failure in this system, aside from certain basic valves and piping that must remain intact, is a diesel pump. Therefore, only two of the three diesel pumps are assumed to start and the rest of the system is considered to function properly. This means that four low-lift pumps must continue in operation at the aiding reactor. Under these conditions, the steam pump is non-functional.

If the reliability of secondary system should degrade to the point where it would no longer be prudent to assume only one failure in this large and complex system (182 diesel building and 165 and 190 boiler and pumping buildings), then we must consider the optimum usage of the 190 Building emergency steam pump. There are two basic ways of using this steam pump flow:

- a) As a back-up to the secondary low-lift pumps at the aiding reactor. Whenever one or two low-lift pumps on a common turbo-generator are lost, or when the generator itself is lost, then the emergency steam pump will start (provided it was connected to the boiler feeding this turbo-generator) and yield the equivalent of three low-lift pump flow to the aiding reactor. Thus, it will tend to assure adequate diesel flow to the stricken reactor by producing a higher back pressure at the aiding reactor.
- b) As a segment of the service water system that pumps part of its flow directly to the stricken K Reactor. Used in this manner, it will directly increase the stricken K Reactor's flow.

At the present time, there is considerable unreliability attached to the start-up of this steam pump. It will not start up if:

- 1) The low-lift pump(s) failure or the turbo-generator failure occurs on the boiler that is not connected to the steam pump.

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- 2) There is a failure of the boiler that is connected to the steam pump.

Thus, from a reliability point of view, this emergency steam pump could be assured of starting for less than 50 percent of the loss of power incidents. This could be improved in the following two manners:

- 1) Continuously operate the third boiler and have it isolated to the emergency steam pump.
- 2) Keep only three low-lift pumps on emergency power and substitute the emergency steam pump for the fourth low-lift pump.

Method (1) is somewhat more expensive, even though the steam pump load can be reduced to a low value during normal reactor operation. There is the increased fuel oil cost, and the much greater problem of boiler maintenance with three-boiler operation except during reactor shutdown.

In summary, then, there is a 7 to 9 percent gain in emergency cooling adequacy with line cleaning. This will need to be done every one to two years unless corrosion inhibition or a suitable protective coating can be provided. The line is strong enough, however, to withstand the gradual erosion of the corrosion and cleaning process. The use of the service water and low-pressure cross-tie provides a slightly greater emergency flow increase than line cleaning, but adds greatly to the system complexity. There appears to be little benefit in increasing the size of service water to process water line intertie above the 12-inch diameter lines already available. A gain of 3 to 5 percent in adequacy is possible; however, if this service water normal usage can be positively limited to a value not more than 7,500 gpm at each reactor. In using this service water system, it would be important to determine the actual service water flow to the stricken reactor by the insertion of flow measuring instrumentation in the connecting lines between the service water loop and the process water system. Apparatus for this determination is available.

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TABLE V
VARIATION IN EMERGENCY FLOW WITH
VARIOUS PUMPING AND LINE CONDITIONS
(Two Diesel Pumps at 750 rpm)

Case	HPCT Line Condition	Service Water Pumping Conditions				Aiding Reactor	Stricken Reactor			
		No. Pumps	Normal SW Usage*	Line Conditions			No. Pumps	SW Flow	Diesel Flow	Total Flow
Ia	Uncleaned					4	0	30.0	30.0	92
	Cleaned						0	32.7	32.7	99
IIa	Uncleaned	3	Avg.		6"	4	2.4	29.1	31.5	98
IIIa	Uncleaned	2	Avg.		12"	4	2.1	28.6	30.7	96
IVa	Uncleaned	3	Avg.		12"	4	3.6	28.2	31.8	99
b	Cleaned	"	"		"	"	3.5	30.4	33.7	105
c	"	"	Max.		"	"	2.6	29.4	32.0	100
Va	Uncleaned	3**	Avg.	12"	12"	4	3.7	28.3	32.0	100
b	Cleaned	"	"	"	"	"	3.3	30.6	33.9	106
c	"	"	Max.	"	"	"	1.9	31.5	33.4	104
VIa	Uncleaned	3**	Avg.	12"	12"	3	3.9	26.8	30.8	96
b	Cleaned	"	"	"	"	"	3.4	29.6	33.0	103
c	"	"	Max.	"	"	"	2.1	29.7	31.8	99
VIIa	Uncleaned	3**	Avg.	24"	12"	3	3.7	27.3	31.0	97
b	Cleaned	"	"	"	"	"	3.4	29.0	32.4	102
c	"	"	Max.	"	"	"	2.3	29.1	31.7	99
VIIIa	Uncleaned	3**	Avg.	24"	24"	3	4.2	27.1	31.3	98

* Service water is used for many purposes, and its flow is not readily controlled. Whatever demand characteristic exists at the time of a power failure will continue to use water during the emergency.

** Two service water pumps plus a steam pump.

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FIGURE 1
REACTOR FLOW AND DIESEL PUMP FLOW TO
STRICKEN REACTOR - 1000 GPM (G_S & G_{DA})

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FIGURE 2
LL PUMP FLOW AND TOTAL FLOW TO
AIDING REACTOR -- 1000 GPM (G_L & G_A)

Low Lift Pump Flow and Aiding Reactor Flow - 1000 gpm

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FIGURE 3
KE-HPCT FLOW CHARACTERISTICS

HPCT Flow - 1000 gpm

RESTRICTED

FIGURE 4
KM-HPCT FLOW CHARACTERISTICS

RECEIVED

FIGURE 5
SERVICE WATER CHARACTERISTICS

FIGURE 6
SERVICE WATER TO PROCESS PRESSURE-DROP

RECEIVED

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FIGURE 7a

LEGEND FOR PROCESS PIPING SCHEMATIC

(See Other Side of Page)

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FIGURE 7b - PROCESS PIPING, SCHEMATIC