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CGI-844 DIESEL PUMP FLOW TRANSIENTS

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CGI-844 DIESEL PUMP FLOW TRANSIENTS**DECLASSIFIED**INTRODUCTION

A major revision to the K-Reactors secondary and last ditch emergency coolant water supply system has been initiated as Project CGI-844(6).^{*} A portion of this project will include the installation of a completely independent pumping station and associated piping for the last ditch emergency coolant system to both areas. This will replace the inter-reactor cross tie system now in existence at the K-Reactors.

The last ditch pumping station will be equipped with three diesel driven pumps, rated at 18,000 gpm with a 185 foot total discharge head. The pump building (182-K) will be physically located at the hydraulic midpoint between KE and KW reactors. The diesel pump water reservoir or surge tank will be supplied by gravity flow from the 190 clear wells in both areas.

The 182 pump diesel motors will be activated upon receiving a signal signifying an electrical power failure in either or both areas or upon receiving a low front riser pressure signal from either 105 Building.

The physical layout and dimensions of the modified design can be obtained from prints H-1-23802, H-1-23804, H-1-23805 and H-1-23811. A simplified layout is shown in Figure 1. A review of the transient problems that could conceivably be experienced during severe coolant flow demand is important to determining the adequacy of the proposed design of the last ditch emergency coolant system. Upon request from Reactor Modification Design Operation, the following three problems were investigated:

1. Is the proposed 182 Building pump surge tank large enough to sustain a water surge from the 190 clear wells through the 48" I.D. supply line if the three diesel driven pumps were to suddenly stop after equilibrium flow had been attained?
2. What would be the initial water level drawdown in the 182 pump surge tank for the hypothetical case of the three 182 pumps instantaneously attaining a flow rate of 40,000 gpm?
3. Will two of the three 182-K pumps be sufficient to supply adequate cooling water to one stricken reactor** following a primary power failure combined with a failure of the secondary coolant flow system at the same reactor?

SUMMARY

Differential equations describing the proposed 182-K flow system for the three transient cases were solved by numerical analysis. The results of the calculations indicate that the revised physical dimensions of the 182-K pump reservoir

* Refers to bibliography.

** A stricken reactor will hereafter mean one at which the secondary coolant supply fails following a scram caused by power failure to the primary coolant system.

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are adequate to sustain the worst possible water surge following a complete and instantaneous stoppage of the three diesel pumps. The revised dimensions will include a minimum tank height increase of 2 feet over the original height of 472 feet above sea level.

The originally designed 182 pump reservoir is adequate to sustain the worst possible water drawdown, a distance of 8.2 feet below the static liquid level of 470 feet above sea level. The revised reservoir height dimension will not affect the drawdown level calculation.

Two 182-K diesel driven pumps will adequately cool one stricken reactor after a complete loss of power to the primary and secondary coolant pumps at that reactor. Adequate cooling will mean maintaining a 90°F bulk outlet temperature following a scram from equilibrium operation at 4,500 MW. The pumping transients covered in the study include coolant flow decay from five and six 190-K pump operation.

DISCUSSION

A. 182-K Pump Reservoir Tank

As stated earlier, there are two outstanding flow transient problems associated with the 182-K pump reservoir or surge tank. The first problem is that of determining the capacity of the tank with respect to a water surge upon stopping the three diesel pumps instantaneously.

Sketch I was used in formulating the differential equations that describe the transient system.

A "worst case" was postulated in which all three 182 pumps were supplying a total equilibrium flow of 40,000 gpm (previously determined) just prior to being stopped. The flow to the pump surge tank was being supplied entirely from the KW clearwells through the 48" supply line; the KE clearwells are considerably closer to the 182-K Building which, if included in the calculations, would reduce the transient mass of the system. For this case, it is assumed that both of the KE clearwells are drained completely as a result of some undetermined phenomenon.

SKETCH I

The two equations depicting the system in transient are:

(1) Mass balance

$$S \rho V = \rho A \frac{dx}{dt}$$

where V = velocity through the 48" pipe (ft/sec)
 A = cross-sectional area of surge tank (ft²)
 S = cross-sectional area of 48" supply line (ft²)
 t = time (sec)
 x = vertical height of water in surge tank (ft)
 and ρ = density of water (lb/ft³)

(2) Force balance

$$S \frac{dP}{dt} - \tau_w b dL + \rho \frac{Z}{g_c} S + c \left(\frac{dx}{dt} \right)^2 = \frac{m}{g_c} \frac{dv}{dt}$$

where b = wetted perimeter (ft)
 c = a dimensional constant
 f = fanning friction factor
 L = length of pipe (ft)
 m = mass of water in transient (lbs mass)
 P = pressure at any point in the 48" pipe (psf)
 τ_w = local shear force related to fluid friction

$$= \frac{f \rho V^2}{2 g_c} \quad (\text{lb}_f/\text{ft}^2)$$

To simplify the calculations, the following assumptions were made:

- (1) Non-compressible flow
- (2) No temperature effects
- (3) The kinetic energy term at the surface of the water in the surge tank is negligible. $\left(\frac{dx}{dt} \right)^2 = 0$
- (4) The friction force in the surge tank is negligible.

Rearranging equations (1) and (2) and inserting the appropriate values for the constants results in equations (3) and (4).

$$(3) \quad dx = .026 v \, dt$$

$$(4) \quad dv = dt \left[.023 (h-x) - .0027 v^2 \right]$$

where h = height above sea level of the water level in the 190 clearwell.
 For all practical purposes, the water level in the clearwell will remain constant at 470 feet above sea level.

Equations (3) and (4) were simultaneously solved by numerical analysis using 5 second time intervals. With the equilibrium flow of 40,000 gpm just prior to stopping the pumps and with the designed cross-sectional area of 480

square feet for the surge tank, the maximum height of a water surge would be 3.9 feet above the normal static liquid level (470 feet above sea level). The exact solution to the equations, 4.25 feet above the normal static liquid level, was obtained by C. L. Goss(8). This data was previously reported in a letter(11) indicating that the tank height as originally designed was two feet low. The tank height was subsequently redesigned to include the two foot increase in height necessary to contain a total four foot surge.

The maximum surge height was also determined for the same system but with the cross-sectional area of the surge tank increased to 560 square feet. The numerical solution in this case indicated a maximum insurge of 3.0 feet above the normal static liquid level. These calculations indicate that maximizing the cross-sectional area of the surge tank when held to the original outside design dimensions of the proposed 182-K Building is inadequate as a design alternative.

The second flow transient problem associated with the pump surge tank is that of determining the maximum water drawdown in the surge tank immediately following the initiation of emergency coolant flow from the 182-K Building.

Sketch II was used to determine the system equations.

SKETCH II

A "worst case" was postulated to approach the hypothetical case in which the three diesel pumps are actuated together and instantaneously attain a total flow rate of 40,000 gpm.

The system equations are identical to problem I with the exception of the new constant term in the mass balance equation. Equation (5) is the modified mass balance.

$$(5) \quad dx = \left[12.6V - 89 \right] \frac{dt}{480}$$

Equations (4) and (5) were simultaneously solved by numerical analysis, again using 5 second time increments. The maximum water level drop for the assumed case would be 8.2 feet below the normal static water level. After about 220 seconds with a constant flow of 40,000 gpm, an equilibrium water level of six feet below the normal static water level will be obtained. A drawdown of 8.18 feet for the same case was obtained by C. L. Goss with the use of the Donner analog computer⁽⁸⁾. This data also was previously reported⁽¹¹⁾. No changes were necessary in the existing building design.

B. 182-K Pump Transient Run

The third transient flow problem is related to the adequacy of the proposed last ditch emergency coolant system for the K-Reactors. The modified system is designed to supply at least 32,000 gpm to meet the design criteria as set forth in HW-64908⁽⁶⁾. The problem, as stated, is to determine the time necessary to obtain equilibrium flow from the 182-K pumps for a postulated "worst case". This "worst case" is as follows:

1. Prior to the BPA power failure, both reactors are operating at 4,500 mw.
2. The secondary flow system steam generator fails at KW Reactor. It is assumed that the coolant piping components remain intact during the flow transient.
3. The primary flow decay after the BPA power failure is from five 190 pump sets at both KW and KE.
4. One of the three 182-K pumps fails upon actuation and the remaining two pumps must supply flow to the stricken KW Reactor. It is assumed that KE Reactor is adequately supplied by a modified secondary flow system of two low lift pumps and one steam turbine pump.⁽⁶⁾

The 190 pump pressure decay curves for the two areas are shown in Figure III.

The first approach to this problem was to make the following assumptions:

1. The 190 KW pump discharge pressure decay follows the BORP curve in Figure III regardless of the contribution of the 182 pumps.
2. The momentum effect of those portions of the 182 discharge line from 182 building to the 24 inch line junction and from the 24 inch line junction to KE Reactor are negligible compared to that from the 24 inch junction to KW Reactor. (See Figure I)

3. Flow versus BORP is the same as that given in HW-59892 (3) and in HW-68536(9).
4. Incompressible flow.
5. No density or viscosity effects.

Sketch III shows the system as defined.

SKETCH III

Equations 6 and 7 are derived from the continuity equation

$$(6) \quad V_3 = V_1 + V_2$$

$$(7) \quad V_1 = V_2$$

where V is the fluid velocity in the associated piping (ft/sec)

A momentum balance is made for each pipe section using the form

$$Fdt = \frac{m}{g_c} dv$$

where F = force applied to the section (lb_f)

dt = time increment, (5 sec)

m = mass of the section (lb_m)

dv = velocity change in the section over the small time increment (ft/sec)

The piping system is divided into two sections and the momentum balance applied.

$$(8) \quad \Delta t \quad (P_J - P_2 - \Delta P_f + \Delta Z) \frac{2\pi D_1^2}{4} = \left[\frac{M_1 + M_2}{g_c} \right] \Delta V_1$$

$$(9) \quad \Delta t \quad (P_2 - P_D - \Delta P_f) \frac{\pi D_1^2}{4} = \frac{2M_3}{g_c} \Delta V_1$$

Combining equations (8) and (9) and inserting the appropriate values for constants results in

$$(10) \quad \Delta V_1 = (P_J - P_D - \Delta P_f + 2.04) (0.2181)$$

where P is pressure in psig.

Equation (10) was used to calculate the change in velocity over 5 second time increments. Average values of P_J (pressure at the 24" line junction point) and P_D (190 pump decay pressure) were used. The junction pressure P_J was found by assuming an average flow from the 182 pumps and using the corresponding value from the pump characteristic curve shown in Figure II. A back check is made for each trial until the calculated 182 flow approached the assumed value.

A determining factor in the combined momentum and continuity equation (10) is the large mass of the system. Determination of equation (10) and a sample calculation of the step by step method of solution are included in the appendix.

The solution to equation (10) using 5 second time intervals, is shown in graphical form in Figure VII. Equilibrium flow supplied by the two diesel pumps is arrived at in about 67 seconds from the time of the BPA power failure. This assumes that the 190 pumps start decaying immediately following a power failure; there is essentially no switching delay.

Included in Figure VII is the bulk demand coolant flow rate plotted as a function of time after power failure. This demand flow rate was determined for the design criterion of maintaining a 90°C bulk outlet temperature for summer conditions, i.e., an inlet temperature of 20°C. The heat generation in a K-Reactor following a scram was obtained from HW-42970⁽¹⁾. The total time delay for an effective scram following a power failure was assumed to be 1.9 seconds. The free fall of the vertical rods was assumed to be 1.1 seconds to reach 85 to 90 per cent of full insertion and a switching delay of 0.8 seconds was assumed.

The proposed reactor power level just prior to the scram was assumed to be 4,500 MW. This power level is somewhat conservative in that it most likely will not be reached with a five 190 pump operation and the present equilibrium bulk limit of 95°C.

Under the assumptions as previously indicated, the flow from two 182 pumps will be adequate to maintain an outlet temperature of 90°C. This data was reported to D. F. Watson on January 18, 1961⁽¹¹⁾.

A further refinement to the method of calculation was attempted with negligible results. This refinement was to include the assumption that the BORP pressure would change from the calculated decay curve by an amount proportional to the 182 flow. The method of calculation was to assume both a BORP (Bottom of Riser Pressure) and an average 182 flow and then calculate a 182 flow based

on the resulting pump discharge pressure. The trial and error steps were continued until the two flows matched. As can be seen in Figure VI, the decrease in 190 decay flow did not increase the BORP substantially. The revised system curve intercepts the pump curves, at the appropriate rpm, in the flat portion of the curves. This method of calculation was abandoned for the method described earlier.

An additional set of calculations were performed for the case of flow decay from six 190 pump pairs. The calculated 190 pump pressure decay for this case is shown in Figure IV. The resulting 182 flow is shown in Figure VII. The necessary coolant flow from 182-K is obtained considerably sooner than necessary in this case, indicating that the "worst case" would be flow decay from five 190 pump sets.

The equilibrium flow from two 182 pumps to the stricken reactor was calculated to be 33,800 gpm with a leakage flow of 3,400 gpm to the other reactor. This leakage flow results from a dynamic equilibrium between the final 182 pump discharge head and the pressure as supplied by the secondary coolant pumps at the non-stricken reactor.

CONCLUSIONS

The following conclusions are based upon the preceeding calculations and assumptions:

1. The 182 pump reservoir (surge) tank will be of adequate size to sustain the worst conceivable water surge of 3.9 feet above the static water surface level; the height of the tank was increased at least two feet above the originally designed height of 472 feet above sea level.
2. The originally designed 182 pump reservoir is adequately sized to handle the worst possible water drawdown of about 8.2 feet below the static water surface level following the initiation of flow from the three pumps.
3. The flow from two 182 diesel pumps is sufficient to adequately cool one stricken reactor for the worst possible conditions following a complete electrical power failure in either or both areas. One pump is insufficient of itself to adequately cool either reactor because of its designed capability.
4. The final equilibrium flow from two 182 pumps to the one stricken reactor is calculated to be 33,800 gpm. The leakage flow to the non-stricken reactor for the equilibrium case will be about 3,400 gpm. The equilibrium condition will be reached about 67 seconds after the power failure for the case of 190 flow decay from five 190 pump sets and in about 105 seconds for the flow decay from six 190 pump sets.

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Reactor Design Analysis

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FIG 1

FIG. II

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FIG. III

190 - MODIFIED PUMP DECAY
5 - PUMP CASE

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FIG IV

190-MODIFIED PUMP DECAY
6-PUMP CASE

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FIG V

K-E LOGARITHMIC 959-110
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 2 CYCLES

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FIG VII

TRANSIENT EMERGENCY FLOW

- ① ACCELERATION OF FLOW FROM 182 K TO 105 KW FOR 5-190 PUMP DECAY
- ② ACCELERATION OF FLOW FROM 182 K TO 105 KW FOR 6-190 PUMP DECAY

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NOMENCLATURE

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a	Fluid acceleration (ft/sec ²)
A	Cross-sectional area of surge tank (ft ²)
b	Wetted perimeter (ft)
c	Dimensional constant, depending upon units desired
D	Inside pipe diameter - ft
f	Fanning friction factor
f'	Revised fanning friction factor ($\frac{L_e}{L} f$)
F	Force (lbf)
F'	Flow (gpm)
g	Acceleration of gravity at sea level (32.2 ft/sec ²)
g _c	Dimensional constant ($32.2 \frac{\text{lbf} \cdot \text{ft}}{\text{lbm} \cdot \text{sec}^2}$)
h	Distance from datum plane to clearwell water level (ft)
L	Distance of pipe line under question (ft)
L _e	Equivalent distance of pipe line including all fittings (ft)
m	mass of the system in question (lbm)
N _{Re}	Dimensionless number - Reynolds number ($\frac{DV\rho}{\mu}$)
P	Pressure (Psi or psf)
R	Flow resistance ($\frac{\Delta P}{F}$) ^{1/2}
s	Cross-sectional area of 48" supply line connecting the clearwells to the 182-K pump reservoir (ft ²)
t	time (sec)
v	Fluid velocity in the system lines (ft/sec)
x	Distance from datum plane to water surface level in 182-K pump reservoir (ft)
z	Elevation of any one point in the system (ft)
μ	Fluid viscosity ($\frac{\text{lbm}}{\text{ft} \cdot \text{sec}}$)
ρ	Fluid density (lbm/ft ³)
τ_w	Fluid shear stress at the pipe wall ($\frac{\text{lbf}}{\text{ft}^2}$)

APPENDIX

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Problem I

Refer to Sketch I.

Mass balance

$$(s) (Q) (v) = (Q) (A) \frac{dx}{dt}$$

$$dx = \frac{s}{A} v dt$$

$$(1) \Delta x = .026 v \Delta t$$

Force balance

$$sdp - \tau_w bL = \frac{ma}{gc}$$

$$\tau_w = \frac{Q f v^2}{2gc}$$

$$dp = [h - x] \rho \left(\frac{g}{gc} \right)$$

$$s [h - x] \rho \frac{g}{gc} - \frac{Q f v^2}{2gc} bL = \frac{m}{gc} \frac{dv}{dt}$$

$$m = \rho sL$$

$$dv = dt \left[.023 (h - x) - \frac{f v^2}{2} \right]$$

$$(2) \Delta v = \Delta t \left\{ .023 (h - x) - .0027 v^2 \right\}$$

Equations 1 and 2 are solved simultaneously for 2 and 5 second time intervals.

Problem II

Refer to Sketch II.

$$(3) \Delta v = \Delta t \left\{ .023 (h - x) - .0027 v^2 \right\}$$

Mass Balance

F' out of surge tank - 40,000 gpm

$$\frac{(40,000)}{(60)(7.48)} Q = s Q v - A \rho \frac{dx}{dt}$$

$$(4) \Delta x = \left[(12.6)v - 89 \right] \frac{\Delta t}{480}$$

Equations 3 and 4 are solved simultaneously for 2 and 5 second time intervals.

Problem III

Mass balance (See Figure III)

$$V_1 A_1 \rho + V_2 A_2 \rho = V_3 A_3 \rho$$

$$V_1 = V_2$$

$$m_1 = m_2$$

$$V_3 = 2 v_1 \left(\frac{A_1}{A_3} \right) = 2 V_1$$

$$m_1 = \frac{(1460) (\pi) (2)^2 (62.4)}{4} = 286,000 \text{ lbm}$$

$$m_3 = \frac{(124) (\pi) (2)^2 (62.4)}{4} = 24,000 \text{ lbm}$$

Force balance

$$F \Delta t = \frac{m \Delta V}{g_c}$$

$$(5) \Delta t (P_J - P_D - P_f + \Delta s) (2) \pi \frac{D_1^2}{4} = \frac{(m_1 + m_2)}{g_c} \Delta V_1$$

$$(6) \Delta t (P_2 - P_D - P_f + \Delta s) \pi \frac{D_3^2}{4} = \frac{2 m_3}{g_c} \Delta V_1$$

Conservation of momentum

$$(5) + (6) \Delta t \left(\pi \frac{D_1^2}{4} \right) (P_J - P_D - P_f + \Delta s) = \frac{(m_1 + m_2)}{2} + 2 m_3 \frac{\Delta V_1}{g_c}$$

Solving for ΔV_1 and using 5 second time intervals

$$(7) \Delta V_1 = \left[P_J - P_D - P_f + 2.04 \right] (0.2181) \text{ ft/sec}$$

where $\Delta s = 2.04 \text{ psi}$

$P_J = \text{psi}$

$P_D = \text{psi}$

$P_f = \text{friction drop psi}$

$$\Delta F' = 2 (V_1) (A_1) (7.48) (60)$$

$$= 2,820 \Delta V_1 \text{ gpm}$$

where $\Delta F' = \text{flow from 182-K to KW reactor.}$

Flow leakage to KE reactor

$$F' = \frac{(\Delta P)^{1/2}}{R}$$

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For small flow ranges

$$R = \frac{(\Delta P)^{1/2}}{F'} = \text{Constant}$$

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For the line from P_J to P_D

$$R_1 = \frac{(7)^{1/2}}{10,000 \text{ gpm}} = 2.646 \times 10^{-4}$$

For the KE system from P_D through the reactor

$$R_2 = \frac{(176)^{1/2}}{70,000 \text{ gpm}} = .000190$$

Flow balance for KE

$$(8) \frac{(P_J + 5.19 - P'_D)^{1/2}}{.0002646} + 190 \text{ flow} = \frac{(P_D - 66.7)^{1/2}}{.000190}$$

where P_J = feet of water

P'_D = feet of water (on KE side)

190 flow = gpm

Solution (5 pump decay)

Equations 6 and 7 are solved by trial and error for the 5 second time intervals.

Step	182 Flow Guess	P_J	P_D	V_1	KE Flow	Total 182 Flow
1	2,000 gpm	125.4	120.19	1.58	None	4,456 gpm
2	9,000	118.4	103.19	3.23	None	13,565
3	17,000	107.02	90.69	2.31	None	20,079
4	22,000	99.36	80.19	1.79	None	25,127
5	28,000	92.81	70.19	1.32	3,000	31,849
6	32,000	87.05	63.19	.927	3,359	34,822
7	35,000	82.42	57.19	.284	4,750	37,014
8	37,285	77.92	51.19	Equil.	3,485	37,285