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Revision 1

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OAK RIDGE OPERATIONS OFFICE
ATOMIC ENERGY COMMISSION

STUDY NO. IV-303-1
REVISION 1

LOSS-OF-PRESSURE ACCIDENT
HOT LEG PIPING FAILURE
(BLOWER BEHAVIOR CONSIDERED)

MASTER

EXPERIMENTAL GAS COOLED REACTOR

Facsimile Price \$ 3.60

Microfilm Price \$ 1.40

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

Prepared by
ALLIS-CHALMERS MANUFACTURING COMPANY
Atomic Energy Division
Nuclear Power Department
Washington, D. C.

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Study IV-303-1
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Revision 1

LOSS-OF-PRESSURE ACCIDENT
HOT LEG PIPING FAILURE
(BLOWER BEHAVIOR CONSIDERED)

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NOTE:

This study was prepared during the early stages of the Title II detailed design of the Experimental Gas Cooled Reactor. The calculations in this report are based upon a design core pressure drop of 8.0 psi. Subsequent to these calculations, the design core pressure drop was changed to 10.25 psi, and more exact system volumes became available.

Additional analyses performed in Studies IV-303-2 and IV-303-3 showed that quick-closing valves and quick-opening valves could be eliminated from the coolant system with no adverse levitation effects on the reactor core. The bottom plate design included sufficient anchors into the grid support to preclude plate levitation. The core design includes one separate gas seal at each fuel channel.

A subsequent change in attemperator volume required re-evaluation of the analyses and established the need for motion limiters on the hot leg portion of the reactor coolant system. Study IV-303 examined the hot leg rupture, based upon the final design of the coolant system including the motion limiters included in the design as the result of Study IV-303-4.

LOSS-OF-PRESSURE ACCIDENT
HOT LEG PIPING FAILURE
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I. OBJECTIVE

The purpose of this study is to determine pressure differentials across coolant system components which are more accurate than those presented in Study No. 225 (Title I), by considering the blowers' influence during the transient state following a rupture in one hot leg of the Experimental Gas Cooled Reactor Coolant System.

II. CONCLUSIONS

1. The levitation forces to which the core graphite is subjected depend upon the type of gas seal used to prevent bypass of reactor coolant around the graphite columns. If the gas seal is located at the periphery of the column, the entire graphite area is subjected to the pressure differential. The use of a separate gas seal at each fuel channel results in only a portion of the graphite column cross-sectional area exposed to the pressure differential thereby reducing the upward force on the core graphite. Using such seals, and with the core bottom plate anchored to the support grid, the core pressure differentials do not result in core levitation even if no quick-closing valves are used.

2. The incorporation of "quick-closing" valves in the reactor coolant system reduces the differential pressure across the core and limits the lifting force to which the core will be subjected if a seal design which exposes the entire graphite column cross-sectional area to the pressure differential were used.

3. The analyses performed in this study confirm the conclusions reached in Study No. 225 (Title I): i.e., that a large instantaneous rupture of the reactor coolant system results in lifting the core when the entire graphite area is exposed to the differential, and that the "quick-closing valves" only limit but do not eliminate the lifting.

III. RECOMMENDATIONS

1. A separate gas seal should be installed at each fuel channel rather than one gas seal per column.

2. Quick-opening valves in the bypass lines around the reactor should be evaluated to determine whether use of such valves would result in lower pressure differentials than those calculated for quick-closing valves.

IV. ASSUMPTIONS

1. Rupture occurs instantaneously in one hot leg outside the biological shield. The exhaust flow area from the rupture is equivalent to twice the cross-sectional flow area of the pipe and the configuration of the pipe ends is such that the exhaust flows do not oppose each other.

2. Blowers are assumed to behave in the following two ways:

a. No flow exists through the blowers when the pressure differential across the blowers is greater than the surge pressure ("blowers surging" condition).

b. During the short depressurization time, the coolant velocity through the blowers remains constant at the normal velocity ("blowers' considered" condition).

3. The reactor coolant undergoes adiabatic expansion.

4. The reactor coolant system is idealized as several gas volumes and fluid flow resistances. The following items are considered as gas volumes:

a. Top plenum of reactor

b. Bottom plenum of reactor

c. Both steam generators.

The following items are considered as fluid flow resistances:

a. Reactor core

b. Steam generator and hot leg piping in the unruptured loop

c-d. Both sides of the ruptured hot leg piping

e-f. Both cold legs and steam generators.

5. When "quick-closing" valves are considered, additional fluid flow resistances are added for the cold leg and the reactor core side of the rupture in the hot leg piping.

6. Helium escapes from reactor coolant system with sonic velocity at both nozzles of the ruptured pipe.

V. DISCUSSION

The equations governing the transient state following the rupture for the various parts of the coolant system were derived and programmed for the Bendix G-15 computer. The determination of core levitation forces considers gravitational pressure of the core stack coming from the graphite, fuel assemblies, dummy assemblies, and top grid weights and the pressure uplift force coming from the graphite and fuel assemblies cross-sectional area. Distortion of the core structure or displacement of the columns relative to the bottom plate structure and rupture of the temperature barrier are not considered.

On the basis of an improved analytical representation of the coolant system better than those employed in Study No. 225 (Title I), the case of surging blowers (i.e., both cold legs blocked after accident) has been re-run on the Bendix G-15 computer and the results plotted (Figures 1 and 4).

Similar results have been obtained and plotted on Figures 5 to 9 for the case where the pressure developed by the blowers is considered. Blower behavior during the transient state following the accident was determined from the characteristics of the VA-705 compressor during normal operating conditions. It was assumed that the blowers retain their normal operating velocity during the short time considered after the accident; consequently, higher differential pressure and lifting forces on the core are obtained when the blowers are considered.

All the results obtained refer to an instantaneous rupture of hot leg piping immediately downstream of the attemperator and such that the exhaust flow area is twice the cross-sectional area of the pipe; i.e., the largest possible failure which is close to the reactor and consequently which results in the highest net upward force on the core stack.

Comparative results for the maximum lifting pressure on the core as a function of various delays in the "quick-closing" valves are shown in Figure 10. For both cases of blower operation, the maximum pressure is higher than the gravitational pressure. Figure 11 shows the estimated core levitation as a function of the different delayed starts of the "quick-closing" valves.

For the design delayed start of 50 milliseconds, a maximum core levitation of 3/4 in. is obtained when the blowers surge and about 1-1/2 in. when the blowers operate normally.

Since the signal which initiates the corrective action will probably rely on the differential pressure across the "quick-closing" valve, a plot of mass flow from the reactor side of the ruptured hot leg is indicated on Figure 7. (The mass flow is almost the same for both cases of blower behavior.)

An additional plot of the mass flow from the steam generator side of the failure has been incorporated in order to evaluate the depressurization times of the coolant through both sides of the rupture.

The depressurization time through the steam generator end of the loop can be estimated at approximately one second. The depressurization time through the reactor side of the ruptured loop is estimated to be about 5 seconds. It is concluded that the incorporation of the 4 "quick-closing" valves in the reactor coolant system will considerably reduce the lifting forces on the core, but it is also to be noted that these valves are not sufficient to eliminate the lifting of the core even if it were possible to initiate closure at the instant of failure.

VI. REFERENCES

1. A-C Study No. 225 (Title I), dated August 14, 1959, Differential Pressure across Core following a Reactor Coolant System Rupture.
2. Trip Report No. ACF-GCPR-1082, dated April 9, 1959.
3. KE-EGCR Information Bulletin No. 12, dated June 5, 1959.
4. Data, KE TWX 20, June 24, 1959, from Mr. A. L. Lindsay.
5. Drawing No. 5917-EGCR-P13 (Title I), Reactor Coolant System - Piping Arrangements and Details.

REACTOR COOLANT SYSTEM DEPRESSURIZATION

(BLOWERS CONSIDERED)

Going on with the analysis done in Study No. 225, the depressurization analysis has now included the blowers behaviour during the transient state following the rupture in the hot leg.

This case is analyzed according to the following sketch:

As before the system is idealized as capacitances (without fluid flow resistances): T, B, S and S' and fluid flow resistances (without capacitances): N, N', H, C, L and L'. No heat transfer was considered in this analysis.

EQUATIONS: The equations governing the process for the different parts of the reactor coolant system are as follows:

A. FLUID FLOW RESISTANCES

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Ruptured Hot Leg:

Reactor side

As in the previous analysis the same expression for the mass flow can be derived:

$$W_N = \frac{2 A_N \sqrt{\delta g \frac{A}{R}} \sqrt{\frac{\delta+1}{2}}}{4 [A_N^2 \delta g 2 k_N + 1 - \frac{\delta^2}{4}]} \left\{ -\delta + \sqrt{\delta^2 + 4 [A_N^2 \delta g 2 k_N + 1 - \frac{\delta^2}{4}]} \right\} \frac{p_r}{\gamma T_r} \quad (I)$$

Steam Generator side

An expression similar to (I) can be derived for the other side:

$$W_{N'} = \frac{2 A_{N'} \sqrt{\delta g \frac{A}{R}} \sqrt{\frac{\delta+1}{2}}}{4 [A_{N'}^2 \delta g 2 k_{N'} + 1 - \frac{\delta^2}{4}]} \left\{ -\delta + \sqrt{\delta^2 + 4 [A_{N'}^2 \delta g 2 k_{N'} + 1 - \frac{\delta^2}{4}]} \right\} \frac{p_s}{\gamma T_s} \quad (II)$$

Reactor Core: As before

$$W_C = \sqrt{\frac{p_A^2 - p_r^2}{2 k_c \frac{R}{A} T_c}} \quad (III)$$

Sound Hot Leg: Depending on the mass flow direction, the following expression can be derived:

$$W_H = \sqrt{\frac{p_s^2 - p_r^2}{2 k_H \frac{R}{A} T_s}} \quad \text{if } p_s > p_r \quad (IV)$$

$$W_H = -\sqrt{\frac{p_r^2 - p_s^2}{2 k_H \frac{R}{A} T_r}} \quad \text{if } p_r > p_s \quad (V)$$

Cold Legs: Similarly as before for every loop

$$W_P = \sqrt{\frac{p_s^2 - p_r^2}{2 k_P \frac{R}{A} T_s}} \quad (\text{sound loop}) \quad (VI)$$

$$W_{P'} = \sqrt{\frac{p_r^2 - p_s^2}{2 k_{P'} \frac{R}{A} T_r}} \quad (\text{ruptured loop}) \quad (VII)$$

B. CAPACITANCES

Top Plenum: A set of four differential equations can be established for the top plenum

The procedure is the same as indicated in Study No. 225.

The equations are:

From the constant volume condition $\dot{V}_T = - \frac{V_T}{m_T} \dot{m}_T \quad (VIII)$

From the mass conservation principle $\dot{m}_T = W_H + W_C - W_N \quad (IX)$

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From the ideal gases law

$$\dot{T}_T = \frac{T_T}{P_T} \dot{P}_T + \frac{T_T}{V_T} \dot{V}_T \quad (IX)$$

From the conservation of energy for adiabatic processes:

If $W_H > 0$

$$\dot{P}_T = \frac{R\gamma}{\mu V_T} (W_C T_B + W_H T_S - W_H T_T) \quad (X)$$

If $W_H < 0$

$$\dot{P}_T = \frac{R\gamma}{\mu V_T} (W_C T_B - W_H T_T - W_H T_T) \quad (X')$$

Steam Generators:

Ruptured Loop

On the same basis as before the following set of differential equations can be obtained

$$\dot{V}_S' = - \frac{V_S'}{m_S^2} \dot{m}_S' \quad (XI)$$

$$\dot{m}_S' = -W_H' - W_P' \quad (XII)$$

$$\dot{T}_S' = \frac{T_S'}{P_S'} \dot{P}_S' + \frac{T_S'}{V_S'} \dot{V}_S' \quad (XIII)$$

$$\dot{P}_S' = - \frac{R\gamma}{\mu V_S'} (W_H' + W_P') T_S' \quad (XIV)$$

Sound Loop

Similarly as before

$$\dot{V}_S = - \frac{V_S}{m_S^2} \dot{m}_S \quad (XV)$$

$$\dot{m}_S = -W_H - W_P \quad (XVI)$$

$$\dot{T}_S = \frac{T_S}{P_S} \dot{P}_S + \frac{T_S}{V_S} \dot{V}_S \quad (XVII)$$

If $W_H > 0$

$$\dot{P}_S = - \frac{R\gamma}{\mu V_S} (W_H + W_P) T_S \quad (XVIII)$$

If $W_H < 0$

$$\dot{P}_S = \frac{R\gamma}{\mu V_S} (W_H T_T - W_P T_S) \quad (XVIII')$$

Bottom Plenum:

$$\dot{V}_B = - \frac{V_B}{m_B^2} \dot{m}_B \quad (XIX)$$

$$\dot{m}_B = -W_C + W_P + W_P' \quad (XX)$$

BLOWERS CONSIDERATION
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$$\dot{T}_B = \frac{T_B}{P_B} \dot{P}_B + \frac{T_B}{V_B} \dot{V}_B \quad (XXI)$$

Assuming adiabatic processes through the blowers

$$\dot{P}_B = \frac{R\gamma}{\mu V_B} \left[-W_C T_B + W_P T_s \left(\frac{P_B}{P_s} \right)^{1-\frac{1}{\gamma}} + W_P T_s \left(\frac{P_B}{P_s} \right)^{1-\frac{1}{\gamma}} \right] \quad (XXII)$$

BLOWERS: The blowers behavior during the transient state following the accident can be inferred from the expected performance of the VA-705 Compressor (Data from Allis-Chalmers, 4-9-59 on Trip Report No. ACF-GCPR 1082).

A. NORMAL OPERATING CHARACTERISTICS

The pressure coefficient ψ on function of the ratio Q/N is given for a certain range.

An analytical expression can be obtained for that given range, for instance as

$$\frac{Q}{N} = a + b\psi + c\psi^2$$

Considering the three points (Fig. 2)

Q/N (CFM/RPM)	$\psi = \frac{g H_2}{n u^2}$
4.2	0.316
4.8	0.255
5.4	0.169

Thus:

$$4.2 = a + b(0.316) + c(0.316)^2 \quad (1)$$

$$4.8 = a + b(0.255) + c(0.255)^2 \quad (2)$$

$$5.4 = a + b(0.169) + c(0.169)^2 \quad (3)$$

$$0.6 = -b(0.061) - c(0.034831) \quad (2) - (1) = (1')$$

$$0.6 = -b(0.086) - c(0.036464) \quad (3) - (2) = (2')$$

$$0 = -b(0.025) - c(0.001633) \quad (2') - (1')$$

$$b = -0.06532 c$$

$$\text{Replacing in (1') : } 0.6 = (0.061)(0.06532)c - (0.034831)c$$

$$= -0.030846 c$$

$$c = -19.45$$

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$$b = -(0.06532)(-19.45) = 1.27$$

$$\text{From Eq. (1): } 4.2 = a + (0.316)(1.27) + (-19.45)(0.316)^2 \\ = a + 0.401 - 1.94$$

$$a = 5.74$$

$$\frac{Q}{N} = 5.74 + 1.27 \psi - 19.45 \psi^2$$

Assuming adiabatic compression by the blowers and pressures from KE Information Bulletin No. 12, the blowers entrance temperature comes out to be

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}}$$

$$T_1 = 510 + 460 = 970^\circ R$$

$$P_2 = 300.5 \text{ psia}$$

$$P_1 = 315 \text{ psia}$$

$$\gamma = \frac{5}{3}$$

$$T_2 = (970) \left(\frac{300.5}{315} \right)^{2/5} = \frac{970}{(1.048)^{2/5}} = 491^\circ F$$

As Fig. 1 on Trip Report is for $p = 301.1 \text{ psia}$ instead of 300.5 psia and $T = 489^\circ F$ instead of $491^\circ F$ no significant deviations are expected

$$\text{Inlet Mass Flow per Blower: } W = 213,300 \text{ lb/hr}$$

$$\text{Inlet He Density: } \rho = \frac{0.37 \times 300.5}{951} = 0.117 \text{ lb/ft}^3$$

$$\text{Inlet Volumetric Flow: } Q = \frac{213,300}{60 \times 0.117} = 30.4 \times 10^3 \text{ cfm}$$

As the pressure rise is $\Delta p = 14.5 \text{ psi}$, the revolutions per minute $N = 6,560 \text{ RPM}$

$$\text{From the surge line } \Delta p_{\text{surge}} = 17 \text{ psi} = 2,448 \text{ lb/ft}^2$$

The adiabatic head of compressor during normal operation:

$$H_a = \frac{\Delta p}{\rho} = \gamma \Delta p = \frac{RT}{\mu P} \Delta p = (386.2) \frac{951}{300.5} (14.5) = 17.7 \times 10^3 \text{ ft}$$

No. of compressor stages $n = 5$

$$\text{Mean blade velocity: } u = 660 \frac{6560}{6780} = 639 \text{ ft/sec}$$

$$\text{Pressure coefficient } \psi = \frac{g H_a}{n u^2} = \frac{32.17 \times 17.7 \times 10^3}{5 \times (639)^2} = 0.277$$

$$\text{From Fig. 2, as } \frac{Q}{N} = \frac{30.4}{6.56} = 4.63 \therefore \psi = 0.274$$

check

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Then, for $N = 6,560 \text{ RPM}$

$$Q = 37.6 \times 10^3 + 8.33 \times 10^3 \psi - 0.127 \times 10^6 \psi^2 \quad ; \quad Q \text{ in cfm.}$$

Expressing Q on function of W and replacing ψ by its definition, i.e.

$$Q = \frac{W}{\rho} = \frac{WRT}{\mu p}$$

As Q is given in cfm and W in lb/sec.

$$Q = 60 \times 386 \frac{T}{p} W$$

$$\psi = \frac{9 H_2}{n u^2} = 15.7 \times 10^{-6} \cdot 386 \frac{\Delta p}{p} T$$

Finally

$$W = 1.62 \frac{p}{T} + 2.18 \times 10^{-3} \Delta p - 0.203 \times 10^{-3} \frac{\Delta p^2}{p} T$$

where W in lb/sec.

p lb/ft² (absolute)

Δp lb/ft²

T °R

At normal operating conditions:

$$p = 300.5 \text{ psia}$$

$$\Delta p = 14.5 \text{ psi}$$

$$T = 951^\circ \text{R}$$

$$W = 73.7 + 4.5 - 19.4 = 58.8 \text{ lb/sec} \quad (\text{check})$$

B. TRANSIENT BEHAVIOR

As the time required in building up the differential pressure across the core is smaller than 1sec. (See Study No. 225), the number of revolutions of the blowers ($N = 6560 \text{ rpm}$) can be considered as constant during the transient state, without incurring in appreciable error, therefore, the same expression founded for steady state conditions can be used for transient state.

Consequently two expressions should be added for the blowers behavior during the transient state.

Blower P:

$$W_p = a \frac{p_p}{T_p} + b (p_a - p_p) - c \frac{(p_a - p_p)^2}{p_p} T_p \quad \text{if } p_a - p_p < \Delta p_{\text{surge}} \quad (\text{XXIII})$$

$$W_p = 0 \quad \text{if } p_a - p_p > \Delta p_{\text{surge}} \quad (\text{XXIII}')$$

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But either Eq. (XXIII) or Eq. (XXIII') must render the same value as Eq. (X), that is the same $W_p = \sqrt{\frac{p_s^2 - p_p^2}{2k_1 \frac{R}{\mu} T_s}}$

Therefore p_p must satisfy the equation

$$\sqrt{\frac{p_s^2 - p_p^2}{2k_1 \frac{R}{\mu}}} = a p_p + b (p_B - p_p) T_s - c \frac{(p_B - p_p)^2}{p_p} T_s^2 \quad (X')$$

if $p_B - p_p < \Delta p_{\text{surge}}$

$$p_p = p_B \quad \text{if } p_B - p_p > \Delta p_{\text{surge}} \quad (X'')$$

Now as T_s is used in place of T_p , the coefficients are:

$$a = 1.62 \frac{ft^2 R}{sec}$$

$$b = 2.18 \cdot 10^{-3} \frac{ft^2}{sec} \left(\frac{950}{1240} \right) = 1.67 \cdot 10^{-3} \frac{ft^2}{sec}$$

$$c = 0.203 \cdot 10^{-3} \frac{ft^2}{sec \cdot R} \left(\frac{950}{1240} \right)^2 = 0.119 \cdot 10^{-3} \frac{ft^2}{sec \cdot R}$$

Blower P': In the same way as before the following set of equations can be written:

$$\sqrt{\frac{p_s^2 - p_{p'}^2}{2k_1 \frac{R}{\mu}}} = a p_{p'} + b (p_B - p_{p'}) T_s - c \frac{(p_B - p_{p'})^2}{p_{p'}} T_s^2 \quad (II')$$

if $p_B - p_{p'} < \Delta p_{\text{surge}}$

$$p_{p'} = p_B \quad \text{if } p_B - p_{p'} > \Delta p_{\text{surge}} \quad (II'')$$

where: $a = 1.62 \frac{ft^2 R}{sec}$

$$b = 1.67 \cdot 10^{-3} \frac{ft^2}{sec}$$

$$c = 0.119 \cdot 10^{-3} \frac{ft^2}{sec \cdot R}$$

SYSTEM OF EQUATIONS:

This system of equations can be simplified by elimination of variables in the capacitances.

Top Plenum: From Eq (VII) and Eq. (VIII)

$$\dot{v}_r = - \frac{V_r}{m_r^2} \dot{m}_r = - \frac{v_r^2}{V_r} m_r = - \frac{v_r^2}{V_r} (W_c + W_H - W_N)$$

and the mass m_r is eliminated

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Replacing r_T and $\dot{v}_T$ in $\dot{T}_T$ (Eq. (IX))

$$\dot{T}_T = \frac{T_T}{P_T} \dot{P}_T + \frac{T_T}{V_T} \left(-\frac{V_T^2}{V_T} \right) (W_C + W_N - W_H) = \frac{T_T}{P_T} \dot{P}_T - \frac{T_T}{V_T} \frac{RT_T}{AP_T} (W_C + W_N - W_H)$$

$$\dot{T}_T = \frac{T_T}{P_T} \left[\dot{P}_T - \frac{R}{A} \frac{T_T}{V_T} (W_C + W_N - W_H) \right] \quad (IX')$$

Now the top plenum equations reduce to Eq. (IX') and either Eq. (X) or Eq. (X') as follows:

$$\dot{T}_T = \frac{T_T}{P_T} \left[\dot{P}_T - \frac{R}{A} \frac{T_T}{V_T} (W_C + W_N - W_H) \right] \quad (IX')$$

$$\dot{P}_T = \frac{R\delta}{AV_T} (W_C T_B + W_N T_S - W_H T_T) \quad \text{if } W_H > 0 \quad (X)$$

$$\dot{P}_T = \frac{R\gamma}{AV_T} (W_C T_B - W_H T_T - W_N T_T) \quad \text{if } W_H < 0 \quad (X')$$

Steam Generators:

Ruptured Loop

Using the same manipulations

$$\dot{T}_S = \frac{T_S}{P_S} \left[\dot{P}_S + \frac{R}{A} \frac{T_S}{V_S} (W_N + W_P) \right]$$

By Eq. (XIX) $\dot{T}_S = \frac{T_S}{P_S} \left[\dot{P}_S - \frac{\dot{P}_S}{\gamma} \right] = \frac{T_S}{P_S} \frac{\gamma-1}{\gamma} \dot{P}_S$

as expected for an adiabatic expansion.

The two equations for the steam generator in the ruptured loop are now

$$\dot{T}_S = \frac{T_S}{P_S} \frac{\gamma-1}{\gamma} \dot{P}_S \quad (XX)$$

$$\dot{P}_S = -\frac{R\delta}{AV_S} (W_N + W_P) T_S \quad (XXI)$$

Sound Loop

The two equations are

$$\dot{T}_S = \frac{T_S}{P_S} \left[\dot{P}_S + \frac{R}{A} \frac{T_S}{V_S} (W_N + W_P) \right] \quad (XXII')$$

$$\dot{P}_S = -\frac{R\delta}{AV_S} (W_N + W_P) T_S \quad \text{if } W_H > 0 \quad (XXIII)$$

$$\dot{P}_S = \frac{R\gamma}{AV_S} (W_N T_T - W_P T_S) \quad \text{if } W_H < 0 \quad (XXIV')$$

Bottom Plenum:

$$\dot{T}_B = \frac{T_B}{P_B} \left[\dot{P}_B - \frac{R}{A} \frac{T_B}{V_B} (-W_C + W_P + W_N) \right] \quad (XXV')$$

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$$\dot{P}_B = \frac{R\delta}{A V_B} \left[-W_C T_B + W_D T_D \left(\frac{P_B}{P_D} \right)^{\frac{1}{1-\delta}} + W_E T_E \left(\frac{P_B}{P_E} \right)^{\frac{1}{1-\delta}} \right] \quad (XXII)$$

The final system of equations governing the transient state following a rupture in a hot pipe is established. The equations are associated with a sketch of the reactor coolant system.

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$$W_H = -\sqrt{\frac{P_T^2 - P_S^2}{2k_H \frac{R}{\mu} T_T}} \quad \text{if } P_S < P_T$$

$$W_H = \sqrt{\frac{P_S^2 - P_T^2}{2k_H \frac{R}{\mu} T_S}} \quad \text{if } P_S > P_T$$

$$W_H = \frac{2A_H \sqrt{\delta g \frac{R}{\mu} \frac{\gamma+1}{2}}}{4[A_H^2 \delta g 2k_H + 1 - \frac{\gamma^2}{4}]} \left\{ \sqrt{\delta^2 + 4[A_H^2 \delta g 2k_H + 1 - \frac{\gamma^2}{4}]} - \delta \right\} \frac{P_T}{\gamma T_T}$$

$$W_H' = \frac{2A_H' \sqrt{\delta g \frac{R}{\mu} \frac{\gamma+1}{2}}}{4[A_H'^2 \delta g 2k_H' + 1 - \frac{\gamma^2}{4}]} \left\{ \sqrt{\delta^2 + 4[A_H'^2 \delta g 2k_H' + 1 - \frac{\gamma^2}{4}]} - \delta \right\} \frac{P_S'}{\gamma T_S'}$$

$$\dot{T}_T = \frac{T_T}{P_T} \left[\dot{P}_T - \frac{T_T}{V_T} \frac{R}{\mu} (W_C + W_H - W_H') \right]$$

$$\dot{P}_T = \frac{R\delta}{\mu V_T} (W_C T_B + W_H T_S - W_H' T_T) \quad \text{if } W_H > 0$$

$$\dot{P}_T = \frac{R\delta}{\mu V_T} (W_C T_B - W_H T_T - W_H' T_T) \quad \text{if } W_H < 0$$

$$\dot{T}_S' = \frac{T_S'}{P_S'} \frac{\delta-1}{\delta} \dot{P}_S'$$

$$\dot{P}_S' = -\frac{R\delta}{\mu V_S'} (W_H' + W_P') T_S'$$

$$\dot{T}_S = \frac{T_S}{P_S} \left[\dot{P}_S + \frac{T_S}{V_S} \frac{R}{\mu} (W_H + W_P) \right]$$

$$\dot{P}_S = -\frac{R\delta}{\mu V_S} (W_H + W_P) T_S \quad \text{if } W_H > 0$$

$$\dot{P}_S = \frac{R\delta}{\mu V_S} (W_H T_T - W_P T_S) \quad \text{if } W_H < 0$$

$$\dot{T}_B = \frac{T_B}{P_B} \left[\dot{P}_B - \frac{T_B}{V_B} \frac{R}{\mu} (-W_C + W_P + W_P') \right]$$

$$\dot{P}_B = \frac{R\delta}{\mu V_B} \left[-W_C T_B + W_P T_S \left(\frac{P_B}{P_T} \right)^{1-\frac{\gamma}{\delta}} + W_P' T_S' \left(\frac{P_B}{P_S'} \right)^{1-\frac{\gamma}{\delta}} \right]$$

$$\sqrt{\frac{P_S^2 - P_P^2}{2k_P \frac{R}{\mu}}} = a P_P + b (P_B - P_P) T_S - c \frac{(P_B - P_P)^2}{P_P} T_S^2$$

$$\quad \text{if } P_B - P_P < \Delta P_{\text{surge}}$$

$$P_P = P_B \quad \text{if } P_B - P_P > \Delta P_{\text{surge}}$$

$$\sqrt{\frac{P_B^2 - P_{P'}^2}{2k_{P'} \frac{R}{\mu}}} = a P_{P'} + b (P_B - P_{P'}) T_S' - c \frac{(P_B - P_{P'})^2}{P_{P'}} T_S'^2$$

$$\quad \text{if } P_B - P_{P'} < \Delta P_{\text{surge}}$$

$$P_{P'} = P_S' \quad \text{if } P_B - P_{P'} > \Delta P_{\text{surge}}$$

Note: Arrows indicate the direction for positive mass flow values.

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A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

NOMENCLATURE

A cross-sectional area, ft^2 .
 g gravity acceleration, ft/sec^2 .
 H_a adiabatic head, ft .
 k constant, characteristic for pressure drop ($\Delta p = k W^2 r$), sec^2/ft^5 .
 m weight, lb .
 N rotational speed, RPM .
 n number of stages, dimensionless.
 p absolute pressure, lb/ft^2 .
 Q volumetric flow, cfm .
 R universal gas constant, $\frac{\text{lb ft}}{\text{mole} \cdot ^\circ\text{R}}$.
 T absolute temperature, $^\circ\text{R}$.
 u mean blade velocity, ft/sec .
 V volume, ft^3 .
 v specific volume, ft^3/lb .
 W mass flow, lb/sec .

$\gamma = \frac{c_p}{c_v}$ ratio of specific heats, dimensionless.

$\psi = \frac{g H_a}{n u^2}$ pressure coefficient, dimensionless.

μ molecular weight, lb/mole .

ρ density, lb/ft^3 .

Subscripts

B refers to Bottom Plenum.
 C Reactor Core.
 H Sound Hot Leg.
 L Cold Leg in the Sound Loop.
 L' Ruptured Loop.
 N Nozzle in the Reactor Side.
 N' Steam Generator Side.
 P Blower in the Sound Loop.
 P' Ruptured Loop.

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S refers to Steam Generator in the Sound Loop.

S' Ruptured Loop.

surge Surge Line.

T Top Plenum.

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A

B

CLOSING VALVES

Four quick-closing valves are incorporated in the reactor coolant system and their characteristics were already mentioned in Study No. 225 according data from K.E. Their fluid flow resistance behavior like an orifice, allow us to consider the loss of pressure through the valve as

$$\Delta p = \frac{W^2 r}{2g S_1^2} \left(1 - \frac{S_1}{S_2}\right)^2$$

being S_1 : pipe cross-sectional area, ft²

S_2 contracted cross-sectional area, ft²

Therefore, the fluid flow resistance constant for the reactor side of the ruptured hot leg is actually

$$k_H + \Delta k_H = k_H + \frac{1}{2g S_1^2} \left(1 - \frac{S_1}{S_2}\right)^2$$

and for the cold leg in the ruptured loop, similarly

$$k_L + \Delta k_L = k_L + \frac{1}{2g S_1^2} \left(1 - \frac{S_1}{S_2}\right)^2$$

being S_1/S_2 a series of given values on function of time from K.E. (See page 13 of calculation sheets in Study No. 225).

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CORE LEVITATION

The values of the differential pressure across the core determined by the previous analysis allow us to calculate the levitation of the core by using the Newton's law.

The differential pressure across the core is given by

$$\Delta P_a = p_a - p_r$$

The pressure by gravitational force is $\Delta P_g = \frac{W}{A}$

The stack remain in the same position up to the moment $\Delta P_a = \Delta P_g$ and when $\Delta P_a > \Delta P_g$ the net lifting force is

$$A \Delta p = A (p_a - p_r - \Delta P_g)$$

and the acceleration of the stack

$$a = \frac{g}{W} A \Delta p$$

Starting with the initial conditions: $s_0 = 0$

$$v_0 = 0$$

$$t_0 = 0 \text{ when } \Delta P_a = \Delta P_g$$

the vertical displacement s at every time interval Δt is given by

$$s = s_0 + v_0 \Delta t + \frac{1}{2} a (\Delta t)^2$$

Nomenclature:

A cross-sectional area of the stack (graphite and fuel assemblies), ft^2

a acceleration of the stack, ft/sec^2

g gravity acceleration, ft/sec^2

p_a bottom plenum pressure, lb/ft^2 .

p_r top plenum pressure, lb/ft^2 .

s vertical displacement, ft .

v vertical speed, ft/sec

t time, sec .

W weight of the stack (graphite, fuel assemblies and top grid), lb .

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CONSTANTS:

Ruptured Leg:

Reactor Side:

Hot Leg Internal Diameter $\begin{cases} 1,200^\circ\text{F piping} : 18.98 \text{ in.} \\ 1,050^\circ\text{F piping} : 19.41 \text{ in.} \end{cases}$

Nozzle Cross-sectional Area: $A_N = \frac{\pi}{4} \left(\frac{19.41}{12} \right)^2 = 2.05 \text{ ft}^2$

$$\gamma = 5/3$$

$$g = 32.17 \text{ ft/sec}^2$$

k_N comes out from the normal operating characteristics:

$$T = 1,050^\circ\text{F}$$

$$p = 305 \text{ psia}$$

$$\frac{1}{v} = \frac{0.37 \times 305}{1510} = 0.0748 \frac{\text{lb}}{\text{ft}^3}$$

$$W = \frac{427,000}{2} \frac{\text{lb}}{\text{hr}} = 59.3 \frac{\text{lb}}{\text{sec}}$$

Hot Leg Pressure Drops:

$$1,200^\circ\text{F piping} \quad 0.68 \text{ psi}$$

$$\text{Attemperator} \quad 0.3 \text{ psi}$$

$$1,050^\circ\text{F piping} \quad 1.19 \text{ psi}$$

$$\Delta p = 0.93 \text{ psi}$$

$$k_N = \frac{0.93 \times 144 \times 0.0748}{(59.3)^2} = 2.85 \times 10^{-3} \frac{\text{sec}^2}{\text{ft}^5}$$

$$4A_N^2 \gamma g = 4 \times (2.05)^2 \times \frac{5}{3} \times 32.17 = 904 \frac{\text{ft}^5}{\text{sec}^2}$$

$$2A_N \gamma \bar{g} = 30.1 \text{ ft}^{5/2}/\text{sec}$$

$$4A_N^2 \gamma g (2k_N) = 904 \times 2 \times 2.85 \times 10^{-3} = 5.15$$

$$4 - \gamma^2 = 4 - \frac{25}{9} = \frac{11}{9} = 1.222$$

$$4A_N^2 \gamma g (2k_N) + 4 - \gamma^2 = 4 \left[A_N^2 \gamma g 2k_N + 1 - \frac{\gamma^2}{4} \right] = 4 [] = 6.37$$

$$\gamma^2 + 4 [] = \frac{25}{9} + 6.37 = 9.15$$

$$\sqrt{\gamma^2 + 4 []} = 3.02 \quad ; \quad \left\{ \sqrt{\gamma^2 + 4 []} - \gamma \right\} = \{ \} = 1.36$$

$$\frac{\{ \}}{4 []} = \frac{1.36}{6.37} = 0.212$$

$$R = 1,545 \frac{\text{lb ft}}{\text{mole} \cdot ^\circ\text{R}}$$

$$\mu = 4 \frac{\text{lb}}{\text{mole}}$$

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$$R/\mu = 386 \frac{ft}{R}$$

$$2A_N \sqrt{8g} \sqrt{\frac{\mu}{R}} \sqrt{\frac{8+1}{2}} = 30.1 \sqrt{\frac{8/6}{386}} = 1.76 \frac{\sqrt{R} ft^2}{sec}$$

$$K_N = 2A_N \sqrt{8g} \sqrt{\frac{\mu}{R}} \sqrt{\frac{8+1}{2}} \cdot \frac{\{ \}}{4[\]} = 1.76 \times 0.212 = 0.375 ft^2 \sqrt{R} sec^{-1}$$

Steam Generator Side:

Pressure Drops:

1,050°F piping 1.19 psi

Steam Generator 2.5 psi

$$\Delta p = 1.19 + 1.25 = 2.44 psi$$

$$h_N = \frac{2.44}{0.93} 2.85 \times 10^{-3} = 7.47 \times 10^{-3} \frac{sec^2}{ft^5}$$

$$4A_N^2 8g = 904 \frac{ft^5}{sec^2}$$

$$4A_N^2 8g (2h_N) = 904 \times 7.47 \times 10^{-3} = 13.5$$

$$4 - 8^2 = 1.22$$

$$4[\] = 14.7$$

$$8^2 + 4[\] = 2.78 + 14.7 = 17.5$$

$$\sqrt{8^2 + 4[\]} = 4.18$$

$$\{ \sqrt{8^2 + 4[\]} - 8 \} = \{ \} = 2.51$$

$$\frac{\{ \}}{4[\]} = \frac{2.51}{14.7} = 0.171$$

$$2A_N \sqrt{8g} \sqrt{\frac{\mu}{R}} \sqrt{\frac{8+1}{2}} = 1.76 \frac{\sqrt{R} ft^2}{sec}$$

$$K_N = 2A_N \sqrt{8g} \sqrt{\frac{\mu}{R}} \sqrt{\frac{8+1}{2}} \cdot \frac{\{ \}}{4[\]} = 1.76 \times 0.171 = 0.301 ft^2 \sqrt{R} sec^{-1}$$

Sound Hot Leg:

Pressure Drops:

1200°F piping 0.63 psi

Attenuator 0.3

1050°F piping 1.19

Steam Generator 2.5

Plenum 1.0

} Hot Leg: 2.12 psi

$$\Delta p = 2.87 psi$$

$$h_N = \frac{2.87 \times 144}{(59.3)^2} = 11.8 \times 10^{-3} sec^2 / ft^5$$

Cold Leg: $p = 301 psi$

$T = 510^\circ F = 970^\circ$, but as temperature is referred to the steam

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generator $T = 1240^{\circ}R = 780^{\circ}F$

$$\frac{1}{v} = \frac{0.37 + 301}{1240} = 0.090 \frac{lb}{ft^3}$$

Pressure Drops:

Cold Leg (510°F piping)	0.62 psi	} 0.88 psi
Flow Tube	0.2 psi	
Steam Generator	2.5 psi	

$$\Delta p = 0.88 + 1.25 = 2.13 \text{ psi}$$

$$h_f = \frac{2.13 \times 144 \times 0.090}{(59.3)^2} = 7.87 \times 10^{-3} \text{ sec}^2/ft^5$$

Reactor Core: For inlet conditions:

$$T = 970^{\circ}R$$

$$\rho = 315 \text{ psia}$$

$$\frac{1}{v} = \frac{0.37 \times 315}{970} = 0.120 \frac{lb}{ft^3}$$

$$h_f = \frac{2.5 \times 144 \times 0.120}{(118.6)^2} = 10.4 \times 10^{-3} \text{ sec}^2/ft^5$$

Volumes:

Steam Generator	1,175 ft ³
Top Plenum	4,135 ft ³
Bottom Plenum	4,135 ft ³
Reactor Core	180 ft ³
Hot Duct	375 ft ³
Cold Duct	275 ft ³

Top Plenum and associated volumes: $V_T = 4,135 + 375 + 90 = 4,600 \text{ ft}^3$

Bottom Plenum and associated volumes: $V_B = 4,135 + 275 + 90 = 4,500 \text{ ft}^3$

Steam Generator and associated volumes: $V_S = 1,175 + 187.5 + 137.5 = 1,500 \text{ ft}^3$

Surge Line Pressure: $\Delta p_{\text{surge}} = 17 \text{ psi} = 2,448 \text{ lb/ft}^2$

Weight of the Stack:

Graphite	313,000 lb
Top Grid	36,000 lb
Fuel Assemblies	36,000 lb
W =	435,000 lb

Cross-sectional Area:

Graphite	20,400 in ²	} A = 25,100 in ²
Fuel Assemblies	4,700 in ²	

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Pressure by Gravitational Force

$$\Delta P_g = \frac{W}{A} = \frac{435 \times 10^3}{25.1 \times 10^3} = 17.33 \text{ psi}$$

Initial Pressures and Temperatures

<u>Volume</u>	<u>Temperature</u> °R	<u>Abs. Pressure</u> lb/ft ²
Top Plenum	1510	4.414×10^4
Steam Generator	1240	4.358×10^4
Bottom Plenum	970	4.536×10^4

Closing Valves:

Hot Leg

I. D. 18.98 in

$$A_1 = \frac{\pi}{4} \left(\frac{18.98}{12} \right)^2 = 1.97 \text{ ft}^2$$

$$\Delta k_{H_0} = \frac{1}{2g A_1^2} = 4.01 \times 10^{-3} \text{ sec}^2/\text{ft}^5$$

Cold Leg:

I. D. 21.33 in

$$A_1 = \frac{\pi}{4} \left(\frac{21.33}{12} \right)^2 = 2.48 \text{ ft}^2$$

$$\Delta k_{L_0} = \frac{1}{2g A_1^2} = 2.52 \times 10^{-3} \text{ sec}^2/\text{ft}^5$$

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TIME REQUIRED TO DEPRESSURIZE THE REACTOR COOLANT SYSTEM.

Through the previous analysis for depressurization of the reactor coolant system by failure of hot leg piping, discharge of the exhaust gas into the vacuum was considered in order to simplify the mass flow equations for W_N and $W_{N'}$.

Moreover, the assumption of sonic velocity at both nozzles (maximum exhaust mass flow) was incorporated to the analysis. On this assumption the pressure in either the top plenum or the steam generator in the ruptured loop should be greater than 2.05 times the pressure at the nozzle, because of the ratio:

$$\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}} = \left(\frac{4}{3}\right)^{\frac{5}{2}} = 2.05$$

which is fulfilled when no fluid flow resistance is between the nozzle and the stagnant volume.

Steam generator side mass flow plotted on Fig. 7 is valid up to $\frac{1}{2}$ sec. after accident, approximately. After that time, if the mass flow is expected to follow the trend of the tangent to the mass flow-time curve, then an evacuation time of about 0.9 sec. is obtained.

Considering the behavior of the mass flow curve for the reactor side for the case of blowers surging which has been run up to 2500 in the Bendix G-15 computer

Time t (sec)	Mass Flow W_N (lb/sec)	ΔW_N (lb/sec)	$\Delta W_N / \Delta t$ (lb/sec ²)
1	248.0		
1.5	197.9	50.1	100.2
2	159.5	38.4	76.8

After $\frac{1}{2}$ sec

$$t = 1.5 + \frac{197.9}{100.2} = 1.5 + 1.97 = 3.5 \text{ sec.}$$

After 2 sec

$$t = 2 + \frac{159.5}{76.8} = 2 + 2.08 = 4.1 \text{ sec.}$$

Slope at ~ 2 sec.

$$\left. \begin{aligned} \Delta W &= 162.58 - 160.53 = 2.05 \text{ lb/sec} \\ \Delta t &= 0.03 \text{ sec} \end{aligned} \right\} \frac{\Delta W}{\Delta t} = \frac{2.05}{3} \frac{\text{lb}}{\text{sec}^2}$$

$$t = 2 + 159.5 \frac{3}{2.05} = 2 + 2.33 = 4.33 \text{ sec.}$$

Time is expected to be greater than 4.33 sec.

If an interpolating polynomial of the shape

$$W = At + B + \frac{C}{t}$$

is considered, then:

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$$248.0 = A + B + C \quad (1)$$

$$197.9 = 1.5A + B + \frac{C}{1.5} \quad (2)$$

$$159.5 = 2A + B + \frac{C}{2} \quad (3)$$

$$50.1 = -0.5A + \frac{C}{3} \quad (1) - (2)$$

$$38.4 = -0.5A + \frac{C}{6} \quad (2) - (3)$$

$$11.7 = \frac{C}{6} \quad C = 70.2$$

$$0.5A = -38.4 + 11.7 = -26.7 ; A = -53.4$$

$$B = 248.0 + 53.4 - 70.2 = 231.2 ; B = 231.2$$

$$W = -53.4t + 231.2 + \frac{70.2}{t}$$

$$W = 0 \text{ when } -53.4t^2 + 231.2t + 70.2 = 0$$

$$t^2 - 4.33t - 1.32 = 0$$

$$t = 2.16 + \sqrt{2.16^2 + 1.32} = 2.16 + \sqrt{5.98} = 4.6 \text{ sec}$$

If the representative points are

Time (sec)	Mass Flow (lb/sec)
1.50	197.9
1.75	177.4
2.00	159.5

$$\text{Similarly as before } W = -40.4t + 185.8 + \frac{109}{t}$$

$$W = 0 \text{ when } t^2 - 4.60t - 2.70 = 0$$

$$t = 2.30 + \sqrt{2.30^2 + 2.70} = 2.30 + 2.83 = 5.13 \text{ sec}$$

The time demanded to depressurize the system can be estimated of the order of 5 sec.

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ALLIS-CHALMERS MFG. CO.

DEPT. 3761

STUDY No. 303-1

LIFTING OF THE REACTOR CORE

The present calculations are in order to obtain the pressures required to overcome the weight of the graphite and fuel assemblies, taking into account the latest design.

Weight of the Top Grid Structure 34,420 lb (from Core Structure Group)

Weight of the Graphite 313,000 lb (from AC Design Data Sheet)

Weight of the Fuel Assemblies 90,900 lb (as follows)

Number of Fuel Assemblies: $6 \times 216 = 1296$ } from AC Design

Weight of one Fuel Assembly 47.56 lb } Data Sheets

Weight of one Upper Dummy Assembly ~ 85 lb } from Thermal Perform

Weight of one Lower Dummy Assembly ~ 50 lb } ance Group.

$$(1296)(47.57) + (85 + 50)(216) = 90.9 \times 10^3 \text{ lb.}$$

The fuel assemblies have a total exposed cross-sectional area

Fuel Channel Diameter: 5.25 in

Sleeve Outside Diameter: 5.00 in

Average Diameter: 5.12 in

Cross-sectional area: $\frac{\pi}{4} (5.12)^2 = 20.6 \text{ in}^2$ per fuel channel

$$\text{Required Pressure: } \Delta p = \frac{90.9 \times 10^3 \text{ lb}}{20.6 \times 216 \text{ in}^2} = 20.4 \text{ psi}$$

The exposed cross-sectional area of the graphite is as follows:

Bellow Seal Diameter 5.75 in. (from Core Structure Group)

Total Fuel Channels Number 232 (from AC Design Data Sheets)

Exposed Cross-sectional Area: $(232) \frac{\pi}{4} (5.75^2 - 5.12^2) = 1.24 \times 10^3 \text{ in}^2$

Seating Force of Bellow Seal: 40 lb per bellow (from Core Structure Group)

$$\text{Net Weight of the Graphite and Top Grid Structure: } 313,000 + 34,400 - (216)(40) = 338.8 \times 10^3 \text{ lb}$$

$$\text{Required Pressure: } \Delta p = \frac{338.8 \times 10^3}{1.24 \times 10^3} = 273 \text{ psi.}$$

This limiting value corresponds to an instantaneous pressure across the core.

If the fuel assemblies and top grid structure are assumed gone when the limiting value for the pressure is reached, then:

Exposed cross-sectional area of the graphite: $(232) \frac{\pi}{4} (5.75^2) = 6.02 \times 10^3 \text{ in}^2$

Net weight of the graphite: $313,000 - (216)(40) = 304,400 \text{ lb}$

$$\text{Required Pressure: } \Delta p = \frac{304.4 \times 10^3}{6.02 \times 10^3} = 50.6 \text{ psi}$$

LIFTING PRESSURE FOR LATEST SEAL DESIGN

1/6/60

SIMILAR TO

DR'N J. A. LANDONI

CH'D A. DeAgazio

APP'D

SCALE = 12

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ALLIS-CHALMERS MFG. CO. DEPT. 3761

STUDY 303-1

Hot Leg Rupture Accident:

The latest calculations showed that a maximum differential pressure across the core of 27.1 psi is reached when no protective devices are incorporated.

For such a circumstance the fuel assemblies are definitely pushed up, and the graphite, if the supporting structure is perfectly rigid, undergoes an upward force of

$$(27.1) (1.24 \times 10^3) = 33.6 \times 10^3 \text{ lb}$$

Explanation: The different values of the maximum differential pressure recently reported are

Study No. 303-1:

Blowers Consideration 31.6 psi

Both Cold Legs Blocked 31.0 psi

Study No. 303-2

Both Cold Legs Blocked 28.1 psi

(The reduction is caused by considering both attenuators as isolated volumes instead of their assimilation to the steam generators and top plenum as in Study No. 303-1).

TWX No. 401 to K.E. dated Dec. 23, 1959

Both Cold Legs Blocked 27.1 psi

(This latest reduction is due to the modifications of the differential pressure across the core: 10.25 psi instead of 8 psi, and estimated reactor coolant system volumes RE Memo from L. E. Malm, Dec. 4, 1959, File 104-1)

1/6/60

SIMILAR TO

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Study 303-1

TRANSIENT STATE OF PRESSURES PRODUCED BY HOT LEG RUPTURE

(NO VALVES)

BLOWERS SURGING

FIGURE 1
303-1

TRANSIENT STATE OF PRESSURES PRODUCED BY HOT LEG RUPTURE QUICK CLOSING VALVES

INITIAL PRESSURE DROPS

Sound Hot Leg: 2.12 psi
 Ruptured Hot Leg: 0.93 psi
 I.D. PIPE: 13.44"

PRESSURE, PSIA

TIME TO DETECT

FAILURE: 0.05 sec TIME TO CLOSE VALVE: 0.1 SEC.

BLOWERS BLOCKED

FIGURE 2
 303-1

TRANSIENT STATE OF PRESSURES PRODUCED BY HOT LEG RUPTURE

(NO VALVES)

BLOWERS CONSIDERED

FIGURE 5
303-1

TRANSIENT STATE OF PRESSURES PRODUCED BY HOT LEG RUPTURE QUICK CLOSING VALVES

PRESSURE, PSIA

INITIAL PRESSURE DROPS

SOUND HOT LEG: 2.12 psi

RUPTURED HOT LEG: 0.95 psi

I.D. PIPE 19.41"

100 TIME TO DETECT

FAILURE: 0.05 sec TIME TO CLOSE VALVE: 0.1 SEC.

DIFFERENTIAL PRESSURE ACROSS CORE

BLOWERS CONSIDERED

FIGURE 6

303-1

Figure III 4303

MASS FLOWS THROUGH EACH SIDE OF THE
RUPTURED HOT LEG.

(NO VALVES)

INITIAL PRESSURE DROPS	
SOUND HOT LEG	2.12 psi
STEAM GENERATOR	2.5 psi
REACTOR SIDE OF THE RUPTURED HOT LEG	0.93 psi

BLOWERS CONSIDERED

FIGURE 7
3031

BLOWERS CONSIDERED

FIGURE B
303-1

REFERENCES

A BLOWERS CONSIDERED

B BLOWERS SURGING.

FIGURE 11
303-1