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Study IV-303-3
EGCR
Revision 1

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OAK RIDGE OPERATIONS OFFICE

ATOMIC ENERGY COMMISSION

STUDY NO. IV-303-3
REVISION 1

MASTER

LOSS-OF-PRESSURE ACCIDENT
COLD LEG PIPING FAILURE

EXPERIMENTAL GAS COOLED REACTOR

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Prepared by
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Study IV-303-3
EGCR
Revision 1

LOSS-OF-PRESSURE ACCIDENT
COLD LEG PIPING FAILURE

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SEE PREFACE NOTE

APPROVED

June 17, 1960

REVISION 1

December 20, 1962

for 12/28/62
OP 2/28/63

NOTE :

This study considers only a circumferential pipe failure such that the pipeline is severed. The possibility of a longitudinal tear or split in the pipe is not considered. Study IV-303, Revision 1, considers the location and size of longitudinal-type failures and also examines the size of circumferential severances in other portions of the cold leg of the reactor coolant system piping.

Additional design changes and analyses were made in accordance with the recommendations of this study. Quick-opening valves and bypass lines were precluded from further consideration.

LOSS-OF-PRESSURE ACCIDENT
COLD LEG PIPING FAILURE

I. OBJECTIVE

The objective of this study is to determine the differential pressure across the reactor core, and the steam generator and blower in the sound loop in the event of a circumferential piping rupture at the cold leg isolation valve followed by complete displacement of the severed pipe ends. The effect of quick-opening valves in the coolant loop bypass lines upon the pressure differentials is also investigated.

II. CONCLUSIONS

Quick-opening valves in the coolant loop bypass lines reduce the pressure differential across the core and the downward load upon the core support grid which will be developed during a cold leg piping rupture. The differential pressures developed are affected by the bypass line size, valve opening time, and instrument delay time. Table I summarizes the maximum differential pressure developed across the core.

TABLE I

Bypass Line Size (in.)	Instrument Delay (msec)	Valve Opening Time (msec)	Pressure Differential (psi)
16	20	50	17.9
20	20	50	16.3
16	20	100	24.4
20	20	100	22.4
16	50	50	27.0
20	50	50	26.0
16	50	100	31.8
20	50	100	30.2

The pressure differential developed across the core when no bypass lines are used is 59.7 psi. The pressure differentials developed across the blower and steam generator in the sound loop are summarized in Table II.

TABLE II

Bypass Size (in.)	Instrument Delay (msec)	Valve Opening Time (msec)	Pressure Differential (psi)*					
			Blower*	Steam Generator*				
				I	II	III	IV	Total
16	20	50	17.8	0.312	0.055	1.076	0.402	1.845
20	20	50	16.2	0.391	0.069	1.350	0.505	2.315
16	20	100	24.3	0.331	0.059	1.143	0.427	1.960
20	20	100	22.9	0.411	0.073	1.418	0.530	2.432
16	50	50	27.9	0.359	0.064	1.238	0.463	2.124
20	50	50	27.1	0.405	0.072	1.398	0.523	2.398
16	50	100	32.8	0.373	0.066	1.286	0.481	2.206
20	50	100	31.4	0.423	0.075	1.459	0.545	2.502
NO BYPASS LINES OR VALVES			61.2	0.067	0.012	0.230	0.086	0.395

-
- I Exit Loss
 - II Annular Shroud
 - III Differential across Tube Field
 - IV Inlet Loss

*In the sound loop

III. RECOMMENDATIONS

1. Quick-opening valves in the bypass lines around the reactor should be incorporated in the final reactor design unless it can be shown that the temperature barrier, the blower in the sound loop, and the core support grid can withstand the pressure differentials developed.

* 2. The temperature barrier to core plate seal must be able to withstand the pressure differential developed across the core during the accident.

* 3. The core support grid must be able to withstand the pressure differential developed across the core during the accident.

* 4. The core plate to fuel channel seals must be able to withstand the pressure differential developed across the core during the accident.

* 5. The temperature barrier must be able to withstand the pressure differential developed across the core during the accident.

* 6. The blowers and steam generators must be able to withstand the pressure differential developed across the core during the accident.

IV. GIVEN DATA

1. Reactor coolant-loop piping fluid-flow resistances are determined from the following pressure drops at 215,000 lb/hr:

a. Vessel outlet to and including isolation valve	0.48 psi
b. Valve to bypass connection	0.25
c. Bypass to attemperator	0.0
d. Attemperator	0.25
e. Attemperator to steam generator	0.35
f. Steam generator to blower	0.56
g. Blower to bypass connection	0.0
h. Bypass to isolation valve	0.59
i. Isolation valve (included) to vessel inlet	0.28

(Taken from KE Memorandum, Mr. L. E. Malm to Mr. P. A. Martin, dated March 11, 1960.)

*The actual design pressure differentials depend upon selected valve timing and selected bypass coolant size.

2. Bypass fluid flow resistances are determined from the following pressure drops at 215,000 lb/hr:

Bypass Size (in.)	Pressure Drop (psi)
20	1.15
16	2.68

(Reference, KE Memorandum, Mr. L. E. Malm to Mr. P. A. Martin, dated March 11, 1960.)

3. Reactor-vessel volumes are as follows (Reference 4):

a. Top plenum	3200 cu ft
b. Between temperature barrier and reflector	2200 cu ft
c. Bottom plenum	2900 cu ft

4. The total pressure drop in the reactor plenums is 0.45 psi at 427,000 lb/hr (Reference, KE Letter, Mr. Bush to Mr. Banks, dated March 15, 1960).

5. The core design pressure drop is 10.25 psi.

6. The steam-generator volumes are:

a. Outer shell	1100 cu ft
b. Tube field	220 cu ft
c. Inlet and distribution shroud	160 cu ft

(Reference, Process Calculation for EGCR Steam Generators, C. F. Braun Company, March 10, 1960.)

7. The volume of the coolant-loop piping is as follows for each loop:

a. Reactor vessel to attenuator	104.2 cu ft
b. Attenuator	196.0 cu ft
c. Bypass line	
20-in.	62.6 cu ft
16-in.	39.3 cu ft

d. Attenuator to steam generator	68.5 cu ft
e. Blower	51.7 cu ft
f. Steam generator to blower	125 cu ft
g. Blower to isolation valve	112 cu ft
h. Isolation valve to vessel inlet	56 cu ft

(Reference, KE Memorandum, Mr. Malm to Mr. Martin, dated March 11, 1960.)

8. Steam-generator pressure drop at 215,000 lb/hr is 2.0 psi. (Reference, C. F. Braun Process Calculations for EGCR Steam Generators, March 10, 1960.)

V. ASSUMPTIONS

1. Rupture occurs instantaneously in one cold leg immediately upstream of the loop isolation valve.
2. Reactor coolant undergoes adiabatic processes.
3. No flow is assumed through the blowers during the accident.
4. The reactor coolant system is idealized as several gas volumes and fluid flow resistances. Those items considered as gas volumes are:
 - a. The reactor vessel top plenum
 - b. The reactor vessel bottom plenum
 - c. The attenuators
 - d. The steam generator in the sound loop.

Those items considered as fluid flow resistances are:

- e. The reactor core
- f. The coolant loop piping including the bypass lines and valves.
5. The steam generators are later considered as several alternate volumes and fluid flow resistances, in order to evaluate the pressure drop across their different parts.
6. Coolant escapes from the piping rupture with sonic velocity.

VI. DISCUSSION

To obtain the maximum differential pressure across the reactor core, a rupture of loop piping in a manner such that the total exhaust flow area is equal to twice the cross-sectional area of the pipe and such that the exhaust flows do not oppose one another is assumed to occur just upstream of one coolant loop isolation valve. A similar rupture on the vessel side of the isolation valves cannot occur, since piping movement is limited by the biological shield and the free volume inside the biological shield is limited.

The maximum differential pressure across the core, 59.7 psi, occurs when no quick-opening bypass valves are used. Figure I shows the differential pressure, top plenum pressure, and bottom plenum pressure as a function of time after the rupture. Bypass line sizes of 16 in. and 20 in., instrument delay times of 20 msec and 50 msec, and valve opening times of 50 and 100 msec are analyzed to determine the effectiveness of the various combinations of parameters. Analytical results of the four possible combinations of bypass line sizes and valve opening times, all with 50 msec instrument delay time, are plotted on Figure II. Figure III is a plot of four combinations of bypass line sizes and valve opening times with 20 msec instrument delay.

An examination of Figures II and III reveals that the parameter which has the least effect upon the resulting pressure differential is the bypass line size, while the most effective is the instrument delay time in detecting the rupture and signaling valve opening. Figure IV shows the exhaust mass flow for the first 50 msec following the rupture. Since pressure drop is proportional to the square of the mass flow, the pressure drop in the cold leg will be approximately 100 times greater than normal. This pressure drop can be used to detect the rupture and actuate the quick-opening valves, and to identify the failed loop.

For these analyses it is assumed that there is no flow through the blowers for the duration of the depressurization. Although flow through the blowers will definitely occur, complete head characteristics of the blowers are not available. The results, therefore, are the maximum pressure differentials that could exist under the most pessimistic conditions.

VII. REFERENCES

1. A-C Study No. 225 (Title I), Differential Pressure across Core following a Reactor Coolant System Rupture (August 14, 1959).
2. A-C Study IV-303-1, Loss-of-Pressure Accident, Hot Leg Piping Failure (Blowers Considered), (January 11, 1960).
3. A-C Study IV-303-2, Loss-of-Pressure Accident, Hot Leg Piping Failure - Quick-Opening Valves in Reactor Bypass Lines (June 17, 1960).
4. BMI-1397, Model Studies of Flow and Mixing in the PEGCPR.

PRELIMINARY STUDY FOR COLD LEG PIPING RUPTURE

In order to have estimates of the maximum differential pressure across the core following a cold leg piping rupture, using the information already available for the reactor coolant system, the below indicated sketch of the reactor coolant system has been used for the transient state analysis.

Note: Arrows indicate the direction for positive mass flow values

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April 1960

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DR'N J. A. LANDONI

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The system is idealized with capacitances (without fluid flow resistances): $T, B, S, S', A,$ and A' ; and fluid flow resistances (without capacitances): $H_1, H_1', H_2, H_2', C, V, V', L_1, L_1', N,$ and N'

No heat transfer is considered in this analysis.

Due to the lack of information about the blowers for abnormal conditions, and in order to have an upper limit for the maximum differential pressure across the core, the blowers are considered blocking both cold legs when the accident occurs. Consequently the coolant enclosed in both steam generators can only escape through the 1050°F Piping.

EQUATIONS: The equations governing the process for the different parts of the reactor coolant system are as follows, according procedures indicated in previous studies (No. 225, 303-1, 303-2)

A. FLUID FLOW RESISTANCES:

NOZZLE N:

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

NOZZLE N':

$$W_{N'} = \frac{2A_{N'} \gamma \sqrt{g} \frac{h}{R} \sqrt{\frac{\gamma+1}{2}}}{4[A_{N'}^2 \delta g^2 2(k_{v'} + k_N) + 1 - \frac{\gamma^2}{4}]} \left\{ -\delta + \sqrt{\delta^2 + 4[A_{N'}^2 \delta g^2 2(k_{v'} + k_N) + 1 - \frac{\gamma^2}{4}]} \right\} \frac{p_{A'}}{\gamma T_{A'}} \\ W_{N'} = K_{N'} \frac{p_{A'}}{\gamma T_{A'}} \quad (II)$$

By-Pass Line V:

$$W_V = \sqrt{\frac{p_A^2 - p_B^2}{2(k_v + k_{L2}) \frac{R}{\mu} T_A}} \quad \text{if } p_A > p_B \quad (III)$$

$$W_V = -\sqrt{\frac{p_B^2 - p_A^2}{2(k_v + k_{L2}) \frac{R}{\mu} T_A}} \quad \text{if } p_B > p_A \quad (III')$$

REACTOR CORE:

$$W_C = \sqrt{\frac{p_T^2 - p_B^2}{2k_c \frac{R}{\mu} T_T}} \quad \text{if } p_T > p_B \quad (IV)$$

$$W_C = -\sqrt{\frac{p_B^2 - p_T^2}{2k_c \frac{R}{\mu} T_B}} \quad \text{if } p_B > p_T \quad (IV')$$

1200°F PIPING:

$$\text{Sound Loop: } W_{H_2} = \sqrt{\frac{p_A^2 - p_T^2}{2k_{H_2} \frac{R}{\mu} T_A}} \quad \text{if } p_A > p_T \quad (V)$$

$$W_{H_2} = -\sqrt{\frac{p_T^2 - p_A^2}{2k_{H_2} \frac{R}{\mu} T_T}} \quad \text{if } p_T > p_A \quad (V')$$

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$$\text{Ruptured Loop: } W_{H_2} = \sqrt{\frac{P_{A'}^2 - P_T^2}{2 k_{H_2} \frac{R}{\mu} T_{A'}}}$$

$$\text{if } P_{A'} > P_T \quad (VI)$$

$$W_{H_2} = -\sqrt{\frac{P_T^2 - P_{A'}^2}{2 k_{H_2} \frac{R}{\mu} T_T}}$$

$$\text{if } P_T > P_{A'} \quad (VI')$$

1,050°F PIPING:

$$\text{Sound Loop: } W_{H_1} = \sqrt{\frac{P_S^2 - P_{A'}^2}{2 k_{H_1} \frac{R}{\mu} T_S}}$$

$$\text{if } P_S > P_{A'} \quad (VII)$$

$$W_{H_1} = -\sqrt{\frac{P_{A'}^2 - P_S^2}{2 k_{H_1} \frac{R}{\mu} T_{A'}}}$$

$$\text{if } P_{A'} > P_S \quad (VII')$$

$$\text{Ruptured Loop: } W_{H_1'} = \sqrt{\frac{P_S^2 - P_{A'}^2}{2 k_{H_1} \frac{R}{\mu} T_{S'}}}$$

$$\text{if } P_S > P_{A'} \quad (VIII)$$

$$W_{H_1'} = -\sqrt{\frac{P_{A'}^2 - P_S^2}{2 k_{H_1} \frac{R}{\mu} T_{A'}}}$$

$$\text{if } P_{A'} > P_S \quad (VIII')$$

B. CAPACITANCES:

BOTTOM PLENUM:

$$\dot{V}_B = -\frac{V_B}{m_B^2} \dot{m}_B$$

from $V_B = \text{const.}$

$$\dot{m}_B = W_C + W_V - W_N$$

from mass conservation

$$\dot{T}_B = \frac{T_B}{P_B} \dot{P}_B + \frac{T_B}{V_B} \dot{V}_B$$

from ideal gases law

$$\dot{P}_B = -\frac{R}{\mu V_B} (W_N T_B - W_C T_T - W_V T_A) \quad \begin{array}{l} \text{if } W_C > 0 \\ \text{if } W_V > 0 \\ \text{if } W_C < 0 \\ \text{if } W_V < 0 \end{array} \quad \begin{array}{l} \text{from} \\ \text{energy} \\ \text{conservation} \end{array}$$

TOP PLENUM:

$$\dot{V}_T = -\frac{V_T}{m_T^2} \dot{m}_T$$

$$\dot{m}_T = W_{H_2} + W_{H_2'} - W_C$$

$$\dot{T}_T = \frac{T_T}{P_T} \dot{P}_T + \frac{T_T}{V_T} \dot{V}_T$$

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$$\dot{p}_T = \frac{R\gamma}{\mu V_T} (W_{H_2} T_A + W_{H_2'} T_{A'} - W_C T_T) \quad \begin{array}{l} \text{if } W_{H_2} > 0 \\ \text{if } W_{H_2'} > 0 \\ \text{if } W_C > 0 \end{array}$$

$$\begin{array}{l} -W_{H_2} T_T \\ -W_{H_2'} T_T \\ +W_C T_B \end{array} \quad \begin{array}{l} \text{if } W_{H_2} < 0 \\ \text{if } W_{H_2'} < 0 \\ \text{if } W_C < 0 \end{array}$$

ATTEMPERATORS:

Sound Loop: $\dot{v}_A = - \frac{V_A}{m_A^2} \dot{m}_A$

$$\dot{m}_A = W_{H_1} - W_{H_2} - W_V$$

$$\dot{T}_A = \frac{T_A}{p_A} \dot{p}_A + \frac{T_A}{V_A} \dot{v}_A$$

$$\dot{p}_A = \frac{R\gamma}{\mu V_A} (W_{H_1} T_S - W_{H_2} T_A - W_V T_A) \quad \begin{array}{l} \text{if } W_{H_1} > 0 \\ \text{if } W_{H_2} > 0 \\ \text{if } W_V > 0 \end{array}$$

$$\begin{array}{l} -W_{H_1} T_A \\ +W_{H_2} T_T \\ +W_V T_B \end{array} \quad \begin{array}{l} \text{if } W_{H_1} < 0 \\ \text{if } W_{H_2} < 0 \\ \text{if } W_V < 0 \end{array}$$

Ruptured Loop: $\dot{v}_A = - \frac{V_A'}{m_A'^2} \dot{m}_A'$

$$\dot{m}_A' = W_{H_1'} - W_{H_2'} - W_{N'}$$

$$\dot{T}_A' = \frac{T_A'}{p_A'} \dot{p}_A' + \frac{T_A'}{V_A'} \dot{v}_A'$$

$$\dot{p}_A' = \frac{R\gamma}{\mu V_A'} (W_{H_1'} T_{S'} - W_{H_2'} T_{A'} - W_{N'} T_{A'}) \quad \begin{array}{l} \text{if } W_{H_1'} > 0 \\ \text{if } W_{H_2'} > 0 \\ \text{if } W_{N'} > 0 \end{array}$$

$$\begin{array}{l} -W_{H_1'} T_{A'} \\ +W_{H_2'} T_T \end{array} \quad \begin{array}{l} \text{if } W_{H_1'} < 0 \\ \text{if } W_{H_2'} < 0 \end{array}$$

STEAM GENERATORS:

Sound Loop: $\dot{v}_S = - \frac{V_S}{m_S^2} \dot{m}_S$

$$\dot{m}_S = -W_{H_1}$$

$$\dot{T}_S = \frac{T_S}{p_S} \dot{p}_S + \frac{T_S}{V_S} \dot{v}_S$$

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$$\dot{p}_s = \frac{R\gamma}{\mu V_s} (-W_{H_1} T_s) \quad \text{if } W_{H_1} > 0$$

$$(W_{H_1} T_A) \quad \text{if } W_{H_1} < 0$$

$$\text{Ruptured Loop: } \dot{V}_s = - \frac{V_s'}{m_s^2} \dot{m}_s$$

$$\dot{m}_s = -W_{H_1}'$$

$$\dot{T}_s = \frac{T_s'}{p_s} \dot{p}_s + \frac{T_s'}{V_s} \dot{V}_s$$

$$\dot{p}_s = \frac{R\gamma}{\mu V_s} (-W_{H_1}' T_s) \quad \text{if } W_{H_1}' > 0$$

$$(W_{H_1}' T_A) \quad \text{if } W_{H_1}' < 0$$

Elimination of variables for all the capacitance equations render the final set
BOTTOM PLENUM:

$$\dot{T}_B = \frac{T_B}{p_B} \left[\dot{p}_B + \frac{R}{\mu} \frac{T_B}{V_B} (W_N - W_C - W_V) \right] \quad (IX)$$

$$\dot{p}_B = - \frac{R\gamma}{\mu T_B} (W_N T_B - W_C T_T - W_V T_A) \quad \text{if } \begin{matrix} W_C > 0 \\ W_V > 0 \end{matrix}$$

$$+ W_C T_B \quad W_C < 0$$

$$+ W_V T_B \quad W_V < 0 \quad (X)$$

TOP PLENUM:

$$\dot{T}_T = \frac{T_T}{p_T} \left[\dot{p}_T - \frac{R}{\mu} \frac{T_T}{V_T} (W_{H_2} + W_{H_1}' - W_C) \right] \quad (XI)$$

$$\dot{p}_T = \frac{R\gamma}{\mu V_T} (W_{H_2} T_A + W_{H_1}' T_A - W_C T_T) \quad \text{if } \begin{matrix} W_{H_2} > 0 \\ W_{H_1}' > 0 \\ W_C > 0 \end{matrix}$$

$$- W_{H_2} T_T \quad \text{if } W_{H_2} < 0 \quad (XII)$$

$$- W_{H_1}' T_T \quad \text{if } W_{H_1}' < 0$$

$$+ W_C T_B \quad \text{if } W_C < 0$$

ATTENPERATORS:

$$\text{Sound Loop: } \dot{T}_A = \frac{T_A}{p_A} \left[\dot{p}_A + \frac{R}{\mu} \frac{T_A}{V_A} (W_{H_2} + W_V - W_{H_1}') \right] \quad (XIII)$$

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$$\dot{p}_A = \frac{R\delta}{\mu V_A} (W_{H_1} T_s - W_{H_2} T_A - W_V T_A) \quad \begin{array}{l} \text{if } W_{H_1} > 0 \\ \text{if } W_{H_2} > 0 \\ \text{if } W_V > 0 \end{array} \quad \begin{array}{l} -W_{H_1} T_A \\ +W_{H_2} T_T \\ +W_V T_B \end{array} \quad \begin{array}{l} \text{if } W_{H_1} < 0 \\ \text{if } W_{H_2} < 0 \\ \text{if } W_V < 0 \end{array} \quad (XIV)$$

$$\text{Ruptured Loop: } \dot{T}_{A'} = \frac{T_{A'}}{P_{A'}} \left[\dot{p}_{A'} + \frac{R T_{A'}}{\mu V_{A'}} (W_{H_2'} + W_N - W_{H_1'}) \right] \quad (XV)$$

$$\dot{p}_{A'} = \frac{R\delta}{\mu V_{A'}} (W_{H_1'} T_s - W_{H_2'} T_{A'} - W_N T_{A'}) \quad \begin{array}{l} \text{if } W_{H_1'} > 0 \\ \text{if } W_{H_2'} > 0 \\ \text{if } W_{H_1'} < 0 \\ \text{if } W_{H_2'} < 0 \end{array} \quad \begin{array}{l} -W_{H_1'} T_{A'} \\ +W_{H_2'} T_T \end{array} \quad (XVI)$$

STEAM GENERATORS:

$$\text{Sound Loop: } \dot{T}_s = \frac{T_s}{P_s} \left[\dot{p}_s + \frac{R T_s}{\mu V_s} W_{H_1} \right] \quad (XVII)$$

$$\dot{p}_s = \frac{R\delta}{\mu V_s} (-W_{H_1} T_s) \quad \begin{array}{l} \text{if } W_{H_1} > 0 \\ \text{if } W_{H_1} < 0 \end{array} \quad (W_{H_1} T_A) \quad (XVIII)$$

$$\text{Ruptured Loop: } \dot{T}_{s'} = \frac{T_{s'}}{P_{s'}} \left[\dot{p}_{s'} + \frac{R T_{s'}}{\mu V_{s'}} W_{H_1'} \right] \quad (XIX)$$

$$\dot{p}_{s'} = \frac{R\delta}{\mu V_{s'}} (-W_{H_1'} T_{s'}) \quad \begin{array}{l} \text{if } W_{H_1'} > 0 \\ \text{if } W_{H_1'} < 0 \end{array} \quad (W_{H_1'} T_{A'}) \quad (XX)$$

PRELIMINARY STUDY FOR COLD LEG
PIPING RUPTURE

April 1960

SIMILAR TO

DR'N J. A. LANDONI

CH'D A. DeAGAZIO

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STUDY No. 303-3

1. ESTIMATE OF THE PRESSURE DROPS IN THE DIFFERENTS PARTS OF THE STEAM GENERATORS

Previously the system was idealized by pure capacitances and pure fluid flow resistances, but actually every steam generator has distributed capacitances and fluid flow resistances.

In order to have an estimate for the pressure drops during the transient state, the equivalent or fictitious length for the fluid flow resistances can be evaluated considering that the normal operating pressure drops are originated by the same mass flow; i. e.

Item	Pressure Drop	Average Specific Volume	Length
i	Δp_i	$\bar{v}_{i,NO} \propto \frac{T_{i,NO}}{P_{i,NO}}$	$\Delta L_i \propto \frac{\Delta p_{i,NO}}{\bar{v}_{i,NO}}$

The sketch shows the fluid flow resistance side of the differents parts of the steam generator.

The capacitance side can be assumed proportional to the above calculated lengths, then the mass flow during the transient state grows as

$$\Delta W \propto \Delta V \propto L_i - L_{i-1} = \Delta L_i$$

As the differential pressure Δp is proportional to the product $W^2 v$, we can write for every item i of the steam generator:

$$\Delta p_i \propto \int W^2 v dL$$

being

$$W \approx W_{i-1} + \frac{W_i - W_{i-1}}{\Delta L_i} L$$

$$\text{Thus } \Delta p_i \propto \int_0^{\Delta L_i} \left[W_{i-1} + \frac{W_i - W_{i-1}}{\Delta L_i} L \right]^2 \bar{v} dL \approx \bar{v}_i W_{i-1}^2 \Delta L_i + 2 \frac{\bar{v}_i}{\Delta L_i} W_{i-1} (W_i - W_{i-1}) \frac{\Delta L_i^2}{2} + \bar{v}_i \frac{(W_i - W_{i-1})^2}{\Delta L_i^2} \cdot \frac{\Delta L_i^3}{3}$$

$$\Delta p_i \propto \bar{v}_i W_{i-1} W_i \Delta L_i + \frac{\bar{v}_i}{3} (W_i^2 + W_{i-1}^2 - 2 W_i W_{i-1}) \Delta L_i$$

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$$\Delta p_i \propto (W_i^2 + W_{i-1}^2 + W_i W_{i-1}) \bar{v}_i \Delta L_i$$

Consequently

$$\Delta p_i = \Delta p_s \cdot \frac{(W_i^2 + W_{i-1}^2 + W_i W_{i-1}) \bar{v}_i \Delta L_i}{\sum_j \bar{v}_j (W_j^2 + W_{j-1}^2 + W_j W_{j-1}) \Delta L_j} \approx \Delta p_s \frac{(L_i^2 + L_{i-1}^2 + L_i L_{i-1}) \Delta p_{i,NO}}{\sum_j (L_j^2 + L_{j-1}^2 + L_j L_{j-1}) \Delta p_{j,NO}}$$

$$\Delta p_i \approx \Delta p_s \frac{\Delta p_{i,NO} (L_i^2 + L_{i-1}^2 + L_i L_{i-1})}{\sum_j \Delta p_{j,NO} (L_j^2 + L_{j-1}^2 + L_j L_{j-1})}$$

2. ESTIMATE OF THE TOTAL PRESSURE DROP ACROSS THE STEAM GENERATOR

Going on with the dual representation of the steam generator, the differential pressure across it can be established on function of the differential pressure $p_s - p_A$ obtained by solving equations (I) to (XX).

In the sketch:

A refers to the characteristic point for the attenuator.

S steam generator.

S^X upper end of the steam generator (inlet during normal operation)

S^{XX} lower (exit)

In the mass flow diagram W is almost zero at S^{XX} because the blower is assumed blocking the cold leg.

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On the same basis as in 1., it is inferred that at any time t in the steam generator

$$\Delta p(L) = p(0) - p(L) \propto \int_0^L W^2 dL = \left(\frac{W_{H_1}}{L_s}\right)^2 \int_0^L L^2 dL = \left(\frac{W_{H_1}}{L_s}\right)^2 \frac{L^3}{3}$$

$$\Delta p(L) \propto \frac{1}{3} W_{H_1}^2 \left(\frac{L}{L_s}\right)^3 L_s \quad (1)$$

For the entire capacitance representing the steam generator, the coolant is considered at any time with the same physical properties, then

$$L_s \propto |\Delta p_{sno}| \quad (2)$$

Thus $\frac{p_{sxx} - p_s}{p_{sxx} - p_{sx}} = \frac{1}{2}$

during normal operating conditions because the mass flow keeps as constant.

and $\frac{p_{sxx} - p_s}{p_{sxx} - p_{sx}} = \left(\frac{1}{2}\right)^3 = \frac{1}{8}$

during transient state because $L = \frac{L_s}{2}$ at S .

During the transient state, the differential pressures can be written proportional to $W^2 L$, so

a. Steam Generator: By using (1) and (2)

$$p_{sxx} - p_s \propto \frac{1}{3} \cdot \frac{1}{2^3} |\Delta p_{sno}| W_{H_1}^2$$

$$p_{sxx} - p_{sx} \propto \frac{1}{3} |\Delta p_{sno}| W_{H_1}^2$$

$$p_s - p_{sx} \propto \frac{1}{3} \left(1 - \frac{1}{2^3}\right) |\Delta p_{sno}| W_{H_1}^2$$

b. Fluid flow resistance between S and A : Neglecting the variation in the mass flow along the attemperator's fluid flow resistance

$$p_s - p_A \propto \left\{ |p_A - p_s|_{No} - \frac{1}{2} |\Delta p_{sno}| \right\} W_{H_1}^2$$

$$p_s - p_A \propto \left\{ |p_A - p_s|_{No} - \frac{1}{2} |\Delta p_{sno}| \right\} W_{H_1}^2 + \frac{7}{24} |\Delta p_{sno}| W_{H_1}^2$$

$$\propto |p_A - p_s|_{No} W_{H_1}^2 - \frac{5}{24} |\Delta p_{sno}| W_{H_1}^2$$

Expressing the differential pressures $p_{sxx} - p_s$ and $p_{sxx} - p_{sx} = \Delta p_s$ on function of $p_s - p_A$ which is obtained from equations (1) to (XX), we get the following constant ratios:

$$\frac{p_{sxx} - p_s}{p_s - p_A} = \frac{\frac{1}{24} |\Delta p_{sno}|}{|p_A - p_s|_{No} - \frac{5}{24} |\Delta p_{sno}|} = f_o \quad (XXI)$$

$$\frac{\Delta p_s}{p_s - p_A} = \frac{\frac{1}{3} |\Delta p_{sno}|}{|p_A - p_s|_{No} - \frac{5}{24} |\Delta p_{sno}|} = f_s$$

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By equation (XXI) the pressure on one side of the blower in the sound loop is evaluated. The pressure on the other side is given by backing down the fluid flow resistance in the by-pass line for the same loop; i. e. :

$$p_{sxx} = p_s + f_o (p_s - p_A) \quad (XXI)$$

$$\Delta p_p = p_{sxx} - \frac{k_{L2}}{k_v + \Delta k_v} (p_A - p_B) \quad (XXII)$$

where k_{L2} refers to the portion of cold leg duct between the by pass line and the bottom plenum.

The final equation in 1. together with the expression for p_s render the relationship wanted for determining the differential pressures across the different items of the steam generator, i. e.

$$\Delta p_i = f_s (p_s - p_A) \frac{\Delta p_{iNo} (L_i^2 + L_{i-1}^2 + L_i L_{i-1})}{\sum_j \Delta p_{jNo} (L_j^2 + L_{j-1}^2 + L_j L_{j-1})} \quad (XXIII)$$

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NOMENCLATURE

A	cross-sectional area, ft^2
g	gravity acceleration, ft/sec^2
k	constant, characteristic for pressure drop ($\Delta p = k W^2 v$), sec^2/ft^5
L	length, ft
m	weight, lb
p	absolute pressure, lb/ft^2
R	universal gas constant, $\frac{\text{lb ft}}{\text{mole } ^\circ\text{R}}$
T	absolute temperature, $^\circ\text{R}$
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
μ	molecular weight, lb/mole .
ρ	ratio of differential pressures, dimensionless.

Super- and sub-scripts

- refers to average value

A	Attenuator in the Unruptured Loop.
A'	Ruptured Loop.
B	Bottom Plenum
C	Reactor Core
H	1050°F Piping of the Hot Leg in the Unruptured Loop
H'	Ruptured Loop
H_2	1200°F Piping of the Hot Leg in the Unruptured Loop
H_2'	Ruptured Loop
i	specific item in the Steam Generator.
j	arbitrary item in the Steam Generator.
L	Cold Leg Piping between Steam Generator and Bypass (Unruptured Loop)
L'	(Ruptured Loop)

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<i>L₂</i>	<i>refers to Cold Leg Piping between Bottom Plenum and By-pass (Unruptured Loop)</i>
<i>L₂</i>	<i>(Ruptured Loop)</i>
<i>N</i>	<i>Nozzle in the Reactor Side</i>
<i>N'</i>	<i>Steam Generator Side</i>
<i>NO</i>	<i>Normal Operation</i>
<i>P</i>	<i>Blower in the Unruptured Loop.</i>
<i>P'</i>	<i>Ruptured Loop.</i>
<i>S</i>	<i>Steam Generator in the Unruptured Loop</i>
<i>S'</i>	<i>Ruptured Loop</i>
<i>T</i>	<i>Top Plenum</i>
<i>V</i>	<i>By-pass Line in the Unruptured Loop</i>
<i>V'</i>	<i>Ruptured Loop</i>

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TRANSIENT STATE OF PRESSURES PRODUCED BY COLD LEG RUPTURE

(NO PROTECTIVE DEVICES)

IV-303-3

FIG I

BEGINNING OF VALVES OPENING: 50 msec.

FIG II

BEGINNING OF VALVES OPENING: 20 msec.

FIG III

EXHAUST MASS FLOW PRODUCED BY
COLD LEG PIPING RUPTURE

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FIG IV