AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

DECLASSIFIED

DOCUMENT NO.

PTI

W-82406

(CLASSIFICATION)

GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

SERIES AND COPY NO.

DATE
July 1, 1964

☒

THIS DOCUMENT CONTAINS RESTRICTED DATA
DEFINED BY THE ATOMIC ENERGY ACT
ITS DISCLOSURE WITHOUT AUTHORIZATION
IN ANY MANNER TO AN UNAUTHORIZED
PERSON IS PROHIBITED.

TITLE

TECHNICAL NOTE ON LAST-DITCH COOLING
OF THE SMALL HANFORD REACTORS

PART I - HIGH TANKS

☐

OTHER OFFICIAL CLASSIFIED INFORMATION

THIS MATERIAL CONTAINS INFORMATION AFFECTING
THE NATIONAL DEFENSE OF THE UNITED STATES
WITHIN THE MEANING OF THE ESPIONAGE LAWS,
TITLE 18, U. S. C., SECS. 793 AND 794, THE TRANS-
MISSION OR REVELATION OF WHICH IN ANY MANNER
TO AN UNAUTHORIZED PERSON IS PROHIBITED BY
LAW.

AUTHOR

Stephen S. Jones

CIRCULATING COPY
RECEIVED 100 D AREA
JUL 20 1964
RETURN TO
TECHNICAL INFORMATION FILES

THIS DOCUMENT MUST NOT BE LOANED, REPRODUCED, COPIED, OR TRANSMITTED IN ANY MANNER TO AN UNAUTHORIZED PERSON. NO ONE SHOULD HAVE ACCESS TO IT WITHOUT THE APPROVAL OF THE ISSUING OFFICE. IT IS THE RESPONSIBILITY OF THE USER TO RETURN IT TO THE ISSUING OFFICE WITHIN THE TIME FRAME SPECIFIED. IT IS THE RESPONSIBILITY OF THE USER TO KEEP IT IN THE FILE AND NOT TO BE REPRODUCED, COPIED, OR TRANSMITTED IN ANY MANNER TO AN UNAUTHORIZED PERSON. IT IS THE RESPONSIBILITY OF THE USER TO RETURN IT TO THE ISSUING OFFICE WITHIN THE TIME FRAME SPECIFIED. IT IS THE RESPONSIBILITY OF THE USER TO KEEP IT IN THE FILE AND NOT TO BE REPRODUCED, COPIED, OR TRANSMITTED IN ANY MANNER TO AN UNAUTHORIZED PERSON. IT IS THE RESPONSIBILITY OF THE USER TO RETURN IT TO THE ISSUING OFFICE WITHIN THE TIME FRAME SPECIFIED.

ROUTE TO:

PAYROLL NO.

LOCATION

FILES ROUTE
DATE

SIGNATURE AND DATE

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

(CLASSIFICATION)

DECLASSIFIED

HW-82406 PT-I

This document consists of
34 pages, No. [redacted] of
40 copies. [redacted]

Classification Canceled and Changed To

DECLASSIFIED

By Authority of DS Lewis
CG-PR-2 4-12-94
 By DK Hanson, 4-18-94
 Verified By J E Savely 4-19

This document contains restricted data as defined in the Atomic Energy Act of 1954. Its transmission or disclosure in any form, in whole or in part, to an unauthorized person is prohibited.

NOTICE

This report was prepared for use within General Electric Company in the course of work under Atomic Energy Commission Contract AT(45-1) - 1350, and any views or opinions expressed in the report are those of the author only. This report is subject to revision upon collection of additional data.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

DECLASSIFIED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

D I S T R I B U T I O N

1. T. W. Ambrose	27. O. C. Schroeder
2. J. T. Baker/R. C. Stinson	28. D. E. Sebade
3. J. W. Baker/R. J. Pyzel	29. H. G. Spencer
4. C. R. Barker/R. W. Hooper	30. R. E. Spicka
5. R. S. Bell	31. R. W. Wood
6. L. B. Brinkman	32. P. J. Zimmerman
7. P. A. Carlson	33. Records Center
8. M. A. Clinton	34. 300 Area Files
9. R. F. Corlett	35-40. Extras
10. D. M. Diediker	
11. B. Fiorelli/I. L. Huffman	
12. D. K. George	
13. S. M. Graves	
14. O. H. Greager	
15. A. K. Hardin	
16. R. C. Haynes/J. R. Pierce	
17. H. W. Heacock	
18. R. D. Hickman	
19. P. J. Hollifield	
20. R. T. Jaske	
21. R. T. Jessen	
22. S. S. Jones	
23. G. L. Madsen/R. K. Wahlen	
24. G. E. Peck	
25. R. S. Peterson	
26. R. W. Reid	

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION.	5
SUMMARY	5
DISCUSSION.	5
1. General	5
2. Measurement of Last-Ditch Reactor Flow.	6
3. Assured Reactor Flow.	8
4. Limiting Flow and the Heat Extraction Factor.	14
5. Reactor Emergency Outlet Temperatures	14
6. Power Level Adequacy.	17
7. Required Measured Flow for Given Power Level.	21
CONCLUSIONS	22
APPENDICES	
A. Nomenclature.	23
B. Coolant Flow Temperature Factors.	25
C. High Tank Limiting Flow and Heat Extraction Factors	27
D. Reactor Power Level Limitations of Emergency Tube Cooling	32
BIBLIOGRAPHY.	34

DECLASSIFIED

LIST OF FIGURES

		<u>Page</u>
1	Estimated Effect on High-Tank Line Corrosion Time	10
2	Flow Temperature Factors	12
3	Low-Flow Error Factor - Six Small Reactors	13
4	Critical Flow and Time for High-Tank Takeover	15
5	Relative Flow and Heat Extraction Values	16
6a	B, D and F Reactors Tube Outlet Temperature Limit	18
6b	C Reactor Tube Outlet Temperature Limit	18
7a	H Reactor Tube Outlet Temperature Limit	19
7b	DR Reactor Tube Outlet Temperature Limit	19
C-1	Heat Extraction Factor vs. Time After Scram	28
C-2	Process Pump Flywheel Decay Characteristics	30

LIST OF TABLES

I	Assured Flow Factors.	9
II	Reactor High Tank Cooling Constants	20
C-I	Flywheel Decay Characteristics of H Process Pumps	29
C-II	Critical Flow and Heat Factors.	31

DECLASSIFIED

TECHNICAL NOTE ON LAST-DITCH COOLING
OF THE SMALL HANFORD REACTORS
PART I - HIGH TANKS

INTRODUCTION

A number of tests have been performed and reports issued concerning the adequacy of the last-ditch cooling systems at the Hanford small production reactors. At the present time, re-evaluations are being made, both theoretical and experimental, by process engineers and others at the particular reactor sites. In the interest of uniformity and consistency, this report presents a means of determining the last-ditch cooling adequacy for all the small production reactors. This method includes both the high tanks and the export system. The latter is presented in Part II of this report.

SUMMARY

This report presents a unified method for determining the cooling adequacy of the reactor high tanks. It includes both bulk outlet and tube outlet temperature limitations. A procedure is presented for determining the maximum power level for high tank cooling adequacy of a uniform and nonuniform reactor. It is expected that this report will transfer the determination of high tank adequacy from Reactor Engineer to Process Technology. However, an appropriate review of Process Technology conclusions is anticipated.

DISCUSSION

1. General

The third or last-ditch cooling system at the small Hanford production reactors provides a very high assurance of reactor cooling under any credible emergency condition. For instance, after a failure of the BPA electric power the reactors will scram and their flow will decay along a flow-time curve determined by the speed and inertia of the pump flywheels. Normally the backup steam pumps will accelerate and provide more than adequate emergency flow in about three minutes. In the unlikely event that these steam pumps fail to provide adequate flow, the last-ditch system is designed to fulfill this purpose. At the six small reactors this is made up of two quite different components. The first consists of two 300,000 gal high tanks by each reactor that take over and provide about 12,000 gpm reactor flow at 3-6 minutes after the reactor power failure. The second component is a raw water export line that interconnects the four small reactor areas. There are four steam-powered pumps on this line, one at each 182 Building, and a minimum of two of these pumps are assumed to startup and provide export system pressurization within ten minutes following the loss of electric power. This system provides emergency flow in parallel with the high tanks and then provides the only source of emergency flow as these high tanks empty.

Thus, there are three parts to the last-ditch cooling system at the old reactors:

DECLASSIFIED

- a. process pump flywheel decay
- b. high tanks
- c. export pumping system

And a period of overlap exists between each of them. The methods of measuring the emergency high tank flow are discussed in Part I of this report.

2. Measurement of Last-Ditch Reactor Flow

This last-ditch flow is measured in two general manners. The simpler but less accurate manner is based upon the flow characteristics of the reactor. The free fall of the reactor effluent into the top of the downcomer yields a condition of barometric pressure and nearly constant effluent head. Therefore, the following relationship exists for the reactor top of front riser pressure (TORP):

$$p_T = \Delta p_s + \Delta p_f \quad (1)$$

where

p_T = reactor TORP-psig

Δp_s = the static pressure head of the water level in the cross-over above the front riser - TORP-psi

and

Δp_f = the reactor flow resistance pressure-drop from the front riser to the downcomer - psi.

The Δp_f versus flow curve for each small reactor is presented in Reference 1; and within the limits of accuracy of our calculations, other Δp_f curves for different reactor conditions will lie parallel to this one. Thus, the following procedure may be used to obtain a best estimate TORP curve for the determination of low reactor flows:

- a. During reactor shutdown, obtain accurate reactor TORP and flow values at one or more high flow conditions.
- b. Determine one or more points on the current Δp_f curve for the reactor from the relationship:

$$\Delta p_f = p_T - \Delta p_s \quad (1a)$$

where p_T is the measured value of TORP and the value of Δp_s is obtained from Figure 17 (page 39), Reference 1, for the measured value of reactor flow and coolant temperature.

- c. Draw the new reactor Δp_f curve parallel to that of Reference 1.

DECLASSIFIED

- d. Determine the reactor low flow versus TORP curve from the relationship:

$$P_T = \Delta p_s + \Delta p_f \quad (1)$$

using the modified values of Δp_f .

This method involves an extrapolation of the reactor accurate high flow and pressure conditions down to those of low flow. A more accurate method for determining reactor low flow values involves the use of the high tanks as a means of reactor flow calibration.

These tanks are cylindrical in shape with elliptical ends. Once the water level drops below the elliptical end into the straight section of the tank, the flow is given by the relation:

$$G_H = k \frac{\Delta H}{\Delta t} \quad (2)$$

where

G_H = the average high tank flow rate, 1000 gpm, over the time, Δt , in minutes

ΔH = decrease in high tank water level in straight section of tank - ft

And the value of k for the various reactors is

<u>Reactor</u>	<u>k</u>
B, D, F	9.86
C	11.36
DR, H	10.33

Thus, making use of the high tanks, a reactor low flow versus pressure (TORP) curve may be obtained in the following manner:

- Allow both high tanks to drain through the reactor providing the only source of reactor cooling.
- Accurately monitor the high tank water level or static head, the time, the reactor riser pressures, and the coolant temperature.
- Select a time period, Δt , large enough for accurate ΔH values and determine the reactor flow according to the relationship:

$$G_R = k \left(\frac{\Delta H_N + \Delta H_F}{\Delta t} \right) \quad (3)$$

where ΔH_N and ΔH_F refer to the decrease in level of the near and far high tanks, respectively.

- The corresponding TORP pressure is the observed TORP at time $t + \Delta t/2$, i.e., the midtime of the test period.

DECLASSIFIED

- e. With one or two low-flow versus TORP values determined in the foregoing manner, a TORP versus flow curve is obtained using the procedure described earlier for the transfer of high flow TORP data to a low flow TORP curve, i.e., from Equation (1a) determine the low flow Δp_f point. Draw a curve through this point(s) parallel to the Δp_f curve of Reference 1 and then transpose back to the modified TORP curve according to Equation (1).

This latter method is potentially more accurate than the extrapolation of high flow values to low flow conditions described in the first method. Its use is recommended on a periodic basis. At the present time the riser pressure is used as the indication of reactor emergency flow from both the high tanks and from the export system. In the latter case it is the only method of determining export flow.

3. Assured Reactor Flow

Because of the extreme importance of adequate reactor cooling, a very conservative approach is used in converting the measured emergency flow to an assured value. The recommended equation is:

$$G_{H_a} = \left(\frac{F_C F_S F_T}{1 + F_G} \right) G_{H_m} \quad (4)$$

where

G_{H_a} = assured reactor flow = 1000 gpm

F_C = line corrosion factor, i.e., fraction of clean line flow

F_S = strainer plugging factor, fraction of clean strainer flow

F_T = emergency temperature factor, fraction of cold temperature flow

and

$(1 + F_G)$ = low flow error factor, fractional increase in assured flow required to ensure that the measured flow will be adequate; i.e., approximate correction for errors in the measurement of the flow from the high tanks on the export system

Values of these factors for the high tanks and for the export system are summarized in Table I, and discussed on the following pages.

a. Line Corrosion Effects

The approximate effect of line corrosion upon high tank flow was obtained from a recent test at H-Reactor.⁽²⁾ The test results were converted to flow at a common temperature and the difference in flow at the same pressure drop was assumed caused by corrosion. This effect converted to a ratio of the corroded over the clean line flow is shown in Figure 1.

DECLASSIFIED

TABLE I

ASSURED FLOW FACTORS				
Factor	Component	Reactors	Value	Remarks
F_C (corrosion)	high tanks	B - H	See Figure 1	a. An indication of the line corrosion effect on high tank flow was obtained in a recent test conducted at H-Reactor. ⁽²⁾ The results are summarized in Figure 1. In lieu of comparable data at the other reactors, they are assumed to have a similar line-corrosion flow effect.
F_S (strainer plugging)	high tanks	B - H	1.00	a. A recent review of high tank line corrosion indicates a negligible degree of strainer plugging during repeated tests of the system. ⁽³⁾
	export	B - H	0.98	b. The export system has not been adequately checked under the simulated emergency conditions of electric pump loss, surge suppressor action, steam pump startup, and groves valve opening. Therefore, a conservative plugging allowance is required.
F_T	high tanks	B - H	See Figure 2	a. Refer also to Appendix of this report.
$1 + F_G$	high tanks	B - H	See Figure 3	a. Use lower curve following low flow calibration, and higher curve after calibration time and six months or as indicated.
	export	B - H	See Figure 3	b. Use higher error factor curve.

DECLASSIFIED

Corrosion Factor - F_c

ESTIMATED EFFECT OF HIGH-TANK LINE
CORROSION TIME ON REACTOR EMERGENCY
FLOW

FIGURE 1

b. Strainer Plugging Factors

The strainer plugging factor allows for possible accumulation of loose corrosion products, etc., and partial plugging of the high tank strainers during an emergency. At this time no prior flushing or cleaning of these strainers would be expected and some emergency flow reduction could occur. Originally, a strainer plugging factor of 0.96 was recommended for the high tank strainers.⁽³⁾ Since this time, numerous tests and strainer examinations have indicated very little strainer plugging.⁽⁴⁾ Therefore, a value of $F_S = 1$ is permissible for the high tanks provided the process of flushing the high tank lines through their strainers is continued and no strainer plugging in excess of ten percent of the free area occurs.

c. Coolant Temperature Effects

The coolant flow increases with increased temperature because of the decrease in its viscosity. The details of this effect are presented in Appendix B of this report and are summarized in Figure 2. The F_T curve in this figure represents the relative increase in flow between test and emergency conditions. When we wish to compare two different shutdown high tank and/or export flows, then curve F_T may be used to convert the test data to a common temperature. Once this is done, the modified test results may be compared to determine corrosion or other effects.

d. Low Flow Error Factor

Conservatively, a total rather than a probability error condition is assumed. Then the fractional flow change for errors in pressure measurement is given by the relationship presented in general form by Sherwood and Reed:⁽⁵⁾

$$F_G = \frac{\Delta G}{G} = .54 \frac{\Delta P_T + \Delta P_D}{P_T - \Delta P_S} \quad (5)$$

where the term not previously defined is:

P_D = the top of downcomer pressure - psig

For streamline flow which exists in the process tube active charge region for flows below 5000 gpm, the fractional error is given as:

$$\frac{\Delta G}{G} = \frac{\Delta P_T - \Delta P_D}{P_T - \Delta P_S} \quad (6)$$

The application of these equations to the reactor flow is summarized in Figure 3. The lower curve should be used whenever the emergency high tank flow is determined from a high tank calibration. In the cases where a high tank calibration has not been obtained within two years and for the export flow, then the higher flow error curve in Figure 3 should be used.

DECLASSIFIED

FRACTIONAL FLOW CHANGE F_T OR F_T'

FIGURE 2 - FLOW TEMPERATURE FACTORS

COOLANT INLET TEMPERATURE - °C

FIGURE 3

LOW-FLOW ERROR FACTOR - SIX
SMALL HANFORD PRODUCTION REACTORS

UNCLASSIFIED

4. Limiting Flow and the Heat Extraction Factor

The limiting emergency flow is the flow that occurs during the period of maximum reactor outlet temperatures as the flow changes from a steady full level value to a stable emergency value. After the first 20 seconds this peak temperature occurs:

- a. at the earliest time of achieving stable high tank flow
- b. at the earliest time of achieving stable export flow as the high tanks empty

There is marked difference between the high tanks and the export system in the factors determining this limiting flow. Consequently, they are discussed in two separate reports.

The manner in which the effluent temperature changes as the emergency flow source changes from the pump flywheel decay to that of high tank flow is illustrated in Figure 4. This shows that the peak effluent temperature occurs just at the point where stable high tank flow is achieved. This means that the limiting high tank flow can be determined independently of the pump flywheel decay and even without any through reactor flow. This procedure is described in detail in a recent report.⁽⁷⁾

The problem that remains is the determination of the heat extraction factor, i.e., the fraction of the original reactor heat output that must be removed to maintain the effluent temperature $\leq 90^{\circ}\text{C}$. An empirical simplified relationship exists between the relative flow factor, f_G , and the heat extraction factor, f_T . This is presented for H-Reactor in Figure 5. This curve should also apply to B, D, DR, and F Reactors, provided the higher low flow error factor is used.

The details of the determination of this f_G versus f_T relationship are presented in Appendix C of this report.

5. Reactor Emergency Outlet Temperatures

a. Bulk Temperature Limit

During emergency flow, bulk boiling may occur in the reactor effluent system at the top of the downcomer at temperatures as low as 98°C . At these low emergency flows there is very little pressure driving force and bulk boiling with the accompanying pressurization could readily lead to fuel burnout and serious reactor damage. Therefore, the maximum allowable bulk outlet temperature at 20 or more seconds following a reactor scram is established as 90°C .⁽⁸⁾

b. Tube Outlet Temperature Limit

Laboratory studies of individual tubes have indicated that fuel burnout can occur at shutdown power level conditions and that cooling by boiling cannot be depended upon to ensure adequate fuel cooling under the low driving force pressures associated with emergency flow conditions.^(9,10) Therefore, it is important to limit tube outlet temperatures, under

DECLASSIFIED

FIGURE 4

CRITICAL FLOW & TIME FOR HIGH-TANK TAKEOVER FROM PUMP DECAY
(Example - H Reactor 1/17/64, PT-651)

Time After Effective Scram - Minutes

DECLASSIFIED

FIGURE 5

RELATIVE FLOW AND HEAT EXTRACTION VALUES
AT CRITICAL CONDITIONS

UNCLASSIFIED

emergency conditions, to values below the saturation point. Conservatively, the tube outlet temperature limit is arbitrarily assumed equal to the saturation temperature corresponding to this crossheader pressure, minus 5°C. Where this value of 5° allows for a cumulative error of 4 feet in the location of the highest temperature crossheader, 1 foot in the level of water in the downcomer approach section, 1 psi error in the frictional pressure drop in this section of the effluent system and 0.4 psi depression of the top of downcomer pressure below 14.7 psia. This latter effect being a combination of small suction pressure effects created by the downcomer system, and changes in the local barometric pressure. Although there is a negligible increase in frictional pressure drop as one proceeds down the rear face from the top to the bottom crossheader, there is an increase of psi or °C in saturation pressure and temperature. Therefore, the limiting tube outlet conditions almost always occur near the top of the reactor. The tube outlet temperature limits for the highest crossheaders containing high-powered tubes are presented in Figures 6 and 7.

6. Power Level Adequacy

As noted in the prior section, there are two limits to adequate high tank cooling. The bulk temperature limit of 90° and the tube temperature limit of crossheader saturation temperature minus 5°. Initially, it is desirable to determine both limits and then take the more restrictive value. In general, the bulk temperature is controlling. However, for special high power charges placed near the top of the reactor, it is not unlikely that these tubes will be most demanding with respect to emergency last-ditch flow.

a. Bulk Temperature Limit

The maximum allowable reactor operating power level, P_B , for adequate emergency bulk cooling is given by the equation:

$$P_B = \frac{0.264}{f_t} (G_{H_a}) (90 - T_{i_H}) \quad (5)$$

where

G_{H_a} = assured high tank flow at critical time of high tank take-over from the pump flywheel decay - 1000 gpm

f_t = the fraction of full level heat extraction requirements at the critical time

and

T_{i_H} = the high tank coolant temperature - °C

DECLASSIFIED

FIGURE 6a

B, D, & F REACTORS EMERGENCY FLOW
TUBE OUTLET TEMPERATURE LIMIT, C

FIGURE 6b

C REACTOR EMERGENCY FLOW
TUBE OUTLET TEMPERATURE LIMIT, C

DECLASSIFIED

-12-
FIGURE 7a

HW-82406 PT 1

Tube Outlet
Temperature
 T_L , C

H REACTOR EMERGENCY FLOW
TUBE OUTLET TEMPERATURE LIMIT

FIGURE 7b
DR REACTOR EMERGENCY FLOW
TUBE OUTLET TEMPERATURE LIMIT

Tube Outlet
Temperature, T_L , C

DECLASSIFIED

b. Tube Temperature Limit

The maximum allowable reactor operating power level, P_T , for adequate emergency tube cooling is obtained from the equation:

$$P_T = \frac{.264}{f_r} (G_{H_2O}) (T_L - T_{H_2O}) F_e \quad (6)$$

where the undefined terms are:

T_L = the tube emergency outlet temperature limit, i.e., cross-header saturation temperature minus 3°C

and

F_e = the reactor flattening efficiency. Values of F_e are presented in Table for the various small Hanford production reactors

This equation has only limited application. The basic assumptions made in its derivation are that the reactor contains a fairly uniform fuel charge with respect to tube flows and heat output. The flattening efficiency is defined as:

$$F_e = \left(\frac{P_G / P_{T_0}}{G_G / G_{T_0}} \right) = \frac{N_P}{N_G} \quad (7)$$

and

N_P = number of effective power tubes

N_G = number of effective flow tubes

Values of N_P , N_G , and F_e are presented in Table II for the condition of the reactors at the end of 1963. The derivation of Equation (6) along with its limitations and a method to handle nonhomogeneous conditions is presented in Appendix D.

TABLE II

REACTOR HIGH TANK COOLING CONSTANTS

Reactor	High Tank* Draining Constant 1000 gals/ft of Level	Reactor Constants		
		No. of Effective Power Tubes N_P	No. of Effective Flow Tubes N_G	Flattening Efficiency F_e
B	9.86	1490	1840	.81
C	11.36	1630	1920	.86
D	9.86	1525	1862	.82
DR	10.33	1500	1900	.79
F	9.86	1530	1915	.90
H	10.33	1865	1950	.83

DECLASSIFIED

7. Required Measured Flow for Given Power Level

This same procedure may be applied in reverse to determine the required high tank flow that should be measured to ensure adequate emergency cooling following the loss of primary and secondary pumping power when operating at a selected power level.

This procedure involves certain trial and error solutions but is a direct inverse of that in section 6. The method is briefly outlined as follows:

a. Assured High Tank Flow

(1) Bulk Limit

$$G_{H_a} = \frac{f_r P_B}{.264 (90 - T_{H_i})} \quad (5a)$$

(2) Tube Limit

$$G_{H_a} = \frac{f_r P_B}{.264 (T_L - T_{H_i}) F_\epsilon} \quad (7)$$

Where the two equations will not necessarily yield the same required value of assured reactor flow. The process should be continued with which ever of the assured flow values is higher. It should be noted that the restrictions on Equation (6) noted earlier also apply to Equation (7), see Appendix D.

In solving Equations (5a) and (7), f_r is a function of the G_{H_a} value that is to be determined. Therefore, these are solved either by trial and error or by substituting in the actual relationship between f_G and f_r . Assuming a linear F_G vs. f_r relationship as noted at the KE, KW, and H Reactors, we obtain the equations:

Bulk Limit

$$G_{H_a} = \frac{b P_B}{.264 (90 - T_{H_i}) - (a P_B / G_o)} \quad (8)$$

Tube Limit

$$G_{H_a} = \frac{b P_B}{.264 (T_L - T_{H_i}) F_\epsilon - (a P_B / G_o)} \quad (9)$$

where a and b are constant in the linear relationship between f_G and f_r .

DECLASSIFIED

b. Measured High Tank Flow at Full Level Conditions

$$G_{H_m} = \frac{(1 + F_G)}{(F_C F_T)} G_{H_a}^* \quad (4a)$$

Here G_{H_m} is the high tank flow that must be measured to ensure adequate reactor emergency cooling from the selected operating power level, P_B .

CONCLUSIONS

A procedure and certain factual data are presented for the determination of cooling adequacy of the small reactor high tanks. This should serve as a starting point for obtaining specific data, as needed, for each reactor and evaluating its emergency cooling adequacy under present and any proposed operating conditions.

Stephen S. Jones

Stephen S. Jones, Senior Engineer
Reactor Engineering
Process and Reactor Development
Research and Engineering Section
Irradiation Processing Department

SSJ:sp

* Use G_{H_A} or $G_{H_A}^0$, whichever is larger.

DECLASSIFIED

APPENDIX A

NOMENCLATURE

- F_C - Fraction of clean line flow to stricken reactor because of corrosion.
- F_ϵ - Flattening efficiency, ratio of temperature rise in ten hottest standard tubes to the bulk effluent temperature rise.
- $1 + F_G$ - Low flow error factor, fractional increase in measured flow to allow for flow measurement errors.
- F_P - Relative effect of fluid temperature upon line frictional Δp_F .
- F_S - Fraction of measured flow that can be counted on during an emergency because of possible crossheader strainer plugging.
- F_T - A flow temperature correction factor.
- f_G - Fraction of full level flow at τ seconds after a loss of pumping power.
- f_τ - Fraction of original heat output, or heat extraction requirements at τ seconds after a loss of pumping power and reactor scram.
- G_{H_a} - Assured flow to stricken reactor - 1000 gpm. (from high tanks)
- G_H - Single high tank flow rate in straight section of tank - 1000 gpm.
- G_{H_m} - Measured flow to stricken reactor - 1000 gpm. (from high tanks)
- G_O - Original full-level reactor flow - 1000 gpm.
- ΔH - Decrease in high tank water level - ft.
- k - High tank flow factor.
- N_G - Number of effective flow tubes.
- N_P - Number of effective power tubes.
- P_B - Reactor power level with adequate bulk effluent cooling after a BPA loss down to last-ditch backup - Mw.
- P_O - A reactor power level for which adequate last-ditch flow should be determined - Mw.
- P_{t_o} - Maximum power level of ten hottest tubes - Kw.
- P_t - Reactor power level with adequate process tube cooling after a BPA loss down to last-ditch backup - Mw.
- P_D - Top of downcomer pressure - psig.

DECLASSIFIED

- P_T - Reactor front top of riser pressure (TORP) - psig.
- Δp_s - Static pressure of water in cross-over line above TORP - psi
- Δp_f - Line frictional pressure drop - psi.
- T_i - Process water inlet temperature - °C.
- T_{iH} - High tank water temperature - °C.
- T_L - Tube outlet emergency temperature limit - °C.
- Δt - Time duration of high tank flow calibration - minutes.
- X - Years since line cleaning
- α - Lumped flywheel decay parameter.
- τ - Time after reactor safety rod scram - seconds.
- μ - Viscosity of coolant.
- ρ - Density of coolant.

DECLASSIFIED

APPENDIX B

COOLANT FLOW TEMPERATURE FACTORS

The general equation for the effect of temperature of turbulent water flow through a pipe was developed in an earlier document (11) to give:

$$F_P = \left(\frac{\Delta p_T}{\Delta p_O} \right)_G = \left(\frac{\mu_T}{\mu_O} \right)^{0.2} \left(\frac{\rho_O}{\rho_T} \right) \quad (B-1)$$

This line friction pressure change can be related to a flow change by the equation:

$$G = k \Delta p^{0.54} \quad (B-2)$$

and based upon Equation (B-2), the system flow change at constant pressure for a given change in temperature is:

$$F'_T = \frac{G_T}{G_O} = \left(\frac{\mu_T}{\mu_O} \right)^{0.108} \left(\frac{\rho_O}{\rho_T} \right)^{0.54} \quad (B-3)$$

This flow effect can be related to the pressure drop factor F_P by the expression:

$$F'_T = \left(\frac{1}{F_P} \right)^{0.54} \quad (B-4)$$

and the values of F_P can then be used directly from Figure 3 of Reference 11. The curve representing this condition is presented as line F'_T in Figure 3. This applies to the conditions of:

1. High tank flushing flows made at different high tank temperatures, i.e., conversion of flushing flows to a common temperature of 20°C for comparison of line corrosion effects.
2. High tank through reactor flows under reactor shutdown test condition, i.e., conversion to a common test temperature of 20°C for the determination of corrosion effects.

There is a second type of temperature correction that only involves a part of the flow resistance system. This is the increase in emergency over testing flow because of the increased reactor effluent temperature under emergency conditions. This means that the coolant temperature between test and emergency conditions changes as follows:

1. High Tank System

No change.

DECLASSIFIED

2. Reactor System

An increase in flow because of the coolant temperature increase from test to an emergency value of close to 55°C., average temperature between reactor inlet and outlet conditions.

The effect of this temperature change upon the overall flow resistance is equal to the combined effect of the unchanged high tank and the changed reactor resistance. This is given by the equation:

$$F_{P_c} = \left(\frac{\Delta p_H + F_P \Delta p_R}{\Delta p_H + \Delta p_R} \right)_G \quad (B-5)$$

The flow resistance of the cleaned high tank lines is very nearly equal to that of the reactor at all the old reactors. (12,13) Therefore, Equation (B-5) can be simplified to:

$$F_{P_c} = \left(\frac{1 + F_P}{2} \right)_G \quad (B-6)$$

and the flow change for this temperature increase from test to emergency conditions is:

$$F_T = \left(\frac{2}{1 + F_P} \right)^{.54} \quad (B-7)$$

Values of F_T for various high tank temperatures are presented in Figure 3.

DECLASSIFIED

APPENDIX C

HIGH TANK LIMITING FLOW AND HEAT EXTRACTION FACTORS

The high tank limiting flow is the stable full high tank flow to the reactor. The reactor heat extraction factor associated with this limiting flow depends upon the time after reactor scram when this limiting flow is first attained. The change in this heat extraction factor with time after reactor scram is shown in Figure C-1. This was obtained directly from Figure 1 of Reference 14.

The time of achieving stable high tank flow depends upon the pump speed, flywheel inertia, and flow characteristics, and upon the value of the high tank flow. A simplified relationship for the flywheel decay flow is:

$$f_G = \frac{G_M}{G_O} = \frac{1}{1 + \alpha \tau} \quad (C-1)$$

The α term includes flywheel inertia and speed, the water flow inertia, and the pumping characteristics of the system. Values of α can be determined from an experimental pump trip-out test according to the relationship:

$$\alpha = \frac{1 - f_G}{\tau f_G} \quad (C-1a)$$

For the recent H-Reactor trip-out test values of α are presented in Table C-I. The high tanks opened to the reactor at 125 seconds and beyond this time the flywheel flow was augmented by the high tanks. During this period of flywheel flow only the term $1 + \alpha \tau$ was calculated from the value of α obtained from Equation (C-1a) and values of f_G versus the reciprocal of $1 + \alpha \tau$ are plotted in Figure C-2. It is apparent in this figure that the experimental results agree very closely with the empirical Equation (C-1). The measured stable high tank flow was 12,400 gpm, yielding a flow factor (f_G) of 0.14. From Figure C-2, $1 + \alpha \tau = 0.14$ and the theoretical critical time for $\alpha = 0.0275$ is 224 seconds. The experimental critical time, from Figure 7 of Reference 2, for reaching this critical flow was 295 seconds. This difference results from the high tank contribution to the flywheel decay flow as the high tank flow increases from zero to the stable flow value. Making use of the development presented on pages 16 - 19 of Reference 6, the critical flow times for different values of last-ditch flow are given by the equation:

$$\tau_{c_x} = \tau_{c_o} \left(\frac{\tau_x}{\tau_o} \right) \quad (C-2)$$

where

τ_{c_o} = the measured critical or limiting high tank flow time obtained from a pump trip-out test - seconds

τ_{c_x} = the limiting flow time for a different high tank limiting flow value - seconds

τ_o = the theoretical limiting flow time for the conditions of the trip-out test obtained from the equation:

DECLASSIFIED

FIGURE C-1

HEAT EXTRACTION FACTOR VERSUS TIME AFTER SCRAM-Seconds

DECLASSIFIED

TABLE C-1

FLYWHEEL DECAY CHARACTERISTICS OF H PROCESS PUMPS

Date	Test	Time After Reactor Scram Sec. τ	Reactor Flow			Pump Flywheel Decay Char.		Flow Source Flywheel High Tank			Total High Tank Flow $2G_H$ 1000 gpm	Accum. High Tank Flow		Decrease in High Tank Level ft
			Pres. TORP	Flow 1000 gpm G_M	f_G	α	$\bar{\alpha}$	$\frac{G_F^*}{G_T}$	$\frac{2G_H}{G_T}$	τ		$\frac{G_H}{1000}$ $\frac{\Sigma G_H}{\text{gals.}}$		
1-17-64	PT-IP-651**	0	561	88.2	1.0	--	.0275	--	0	0				
		25	209	52	.59	.0279		.59	0	25	0			
		50	112	37.2	.42	.0276		.42	0	50	0			
		75	72	28.8	.326	.0276		.325	0	7	0			
		100	52	23.5	.266	.0276		.266	0	100	0			
		125	41.5	20.4	.231	.0266		.232	0	12	0			
		150	35	18.2	.206	--	.0275	.195	.011		1.0	.21	.21	
		200	27.7	15.7	.178	--	.0275	.154	.024		1.8	.75	.96	
		250	23.5	13.4	.152	--	.0275	.127	.025		2.2	.91	1.87	
		295***	21.4	12.4	.140	--	.0275	.11	.030	224	2.7	1.0	2.9	0.4
		350****	21.4	12.4	.140	--	.0275	.09	.050					

$$* \quad \frac{G_F}{G_T} = \frac{1}{1 + \bar{\alpha}\tau}$$

** See Reference 2, pages 7 and 13.

*** From Figure 13, of Reference 2, earliest point of stable high tank flow.

**** The theoretical Equation (C-1) indicates flywheel flow beyond the point of stable high tank flow. However, the pump pressure drop changes according to the relationship:

$$\frac{\Delta p_T}{\Delta p_0} = \left(\frac{1}{1 + \bar{\alpha}\tau} \right)^2$$

and beyond this critical time of 295 seconds the pump discharge pressure at the risers (TORP) becomes less than the high tank TORP, and therefore there is negligible additional flywheel flow.

DECLASSIFIED

FIGURE C-2

PROCESS PUMP FLYWHEEL DECAY CHARACTERISTICS

UNCLASSIFIED

DECLASSIFIED

$$\tau_o = \frac{1 - f_{G_o}}{\bar{a} f_{G_o}} \quad (C-3)$$

and

τ_x = the theoretical limiting flow time for this different limiting flow value based upon the equation:

$$\tau_x = \frac{1 - f_{G_x}}{\bar{a} f_{G_x}} \quad (C-4)$$

Actually, a direct empirical relationship exists between the limiting flow fraction f_G and this heat extraction factor f_T . This is shown for the H-Reactor in Figure 5. The data for Figure 5 is presented in Table C-II. This merely involves determining the critical flow times from Equations (C-3) and (C-2), obtaining the corresponding heat extraction factors from Figure C-1, and making a direct comparison of f_G and f_T as shown in Figure 5.

TABLE C-II

CRITICAL FLOW AND HEAT FACTORS

Reactor Test	Stable High Tank Flow			Theo. Flow Times Seconds			Act. Flow Times		Heat Extraction Factor f_T
	Orig. Reactor Flow G_T	High Tank Flow G_H	Fract. of Orig. f_G						
				$\bar{a}$	τ_o	τ_x	τ_{co}	τ_{cx}	
H PT-I6-651	88.2	12.4	.14	.0275	224	--	295	--	
		9	.102		--	321	--	422	.087
		11	.113		--	286	--	377	.089
		13	.147		--	211	--	278	.095
	94	12	.128	.0275	--	248	--	327	.092

$$\tau_o = \frac{1 - f_G}{\bar{a} f_G}$$

$$\tau_{cx} = \tau_{co} \left(\frac{\tau_x}{\tau_o} \right)$$

DECLASSIFIED

APPENDIX D

REACTOR POWER LEVEL LIMITATIONS OF EMERGENCY TUBE COOLING

1. Uniform Reactor Flux and Flow

An equation similar to (5) in the body of the report can be applied to every reactor tube, i.e.,

$$P_t = \frac{0.264}{f_T} (G_{t_a}) (T_L - T_{H_i}) \quad (D-1)$$

where

P_t = the maximum tube power for adequate emergency cooling - Kw

and

G_{t_a} = the critical tube flow at the time of high tank takeover - gpm

The difficulty of applying such an equation is obvious, and for a reactor with a fairly homogeneous charge a considerable simplification can be effected. The assured tube flow is directly proportional to the assured total flow, according to the equation:

$$G_{t_a} = G_{t_o} \left(\frac{G_{H_a}}{G_o} \right) \quad (D-2)$$

In the same manner the tube maximum allowable power level is proportional to the total maximum allowable power level.

$$P_t = P_{t_o} \frac{P_T}{P_o} \quad (D-3)$$

When these relationships are substituted for the critical tube power and flow in Equation (D-1) and rearranged, we obtain the equation:

$$P_T = \frac{0.264}{f_T} (G_{H_a}) (T_L - T_{H_i}) \left(\frac{P_o/P_{t_o}}{G_o/G_{t_o}} \right) \quad (D-4)$$

This gives us the reactor total power level limit as a function of the assured total high tank limiting flow, the saturation temperature of the cross header that contains the high power level tube, the ratio of the original reactor power level over the given tube power, and the corresponding flow ratio.

For a reactor with a fairly homogeneous fuel charge, and flux peaking, Equation (9) may be simplified to yield the equation shown in the body of the report; namely:

DECLASSIFIED

$$P_T = \frac{.264}{F_\tau} (G_{H_a}) (T_{L_i} - T_{H_i}) F_\epsilon \quad (D-5)$$

where F_ϵ the flattening efficiency is equal to:

$$F_\epsilon = \frac{(P_o/P_{t_o})}{(G_o/G_{t_o})} = \frac{N_P}{N_G} \quad (D-6)$$

where N_P and N_G are the number of effective power tubes and the number of effective flow tubes, respectively. Recent values of these terms are presented in Table II in the body of the report.

2. Nonuniform Reactor Flow or Flux

For the case of a reactor with considerable differences in tube flow or heat generation in a nonsymmetric manner, i.e., any unusual peaking conditions of tube outlet temperatures or power level. Then Equation (D-5) must be modified to:

$$P_T = \frac{.264}{F_\tau} (G_{H_a}) (T_{L_C} - T_{H_i}) \left(\frac{F_{P_C}}{F_{G_C}} \right)$$

where

F_{P_C} = the ratio of the total reactor power level to the power level of the four hottest tubes on the limiting cross header

T_{L_C} = the tube emergency temperature limit on this header. Obtain from Figures 6 and 7 or the equation:

$$T_{L_C} \cong T_{L_o} + .39 (C_o - C)$$

where C is the cross header number containing the tubes in question.

F_{G_C} = the ratio of the total reactor flow to the average flow through these four tubes

and values of T_{L_o} and C_o are listed below:

Reactor	Reference Cross Header C_o	Basic Tube Temperature Limit T_{L_o}
B, D, F	37	110
C, DR, & H	41	$T_{L_{41}}$ from Figures 6 and 7

The values of F_{P_C} and F_{G_C} must be determined for each questionable configuration in the reactor. As we go down the reactor the increase in T_L because of static pressure reduces the significance of the F_{P_C}/F_{G_C} ratio. The easy solution to this problem depends upon the intuitive determination of the worst case condition. This, of course, controls and once determined, no other cases need be considered.

DECLASSIFIED

BIBLIOGRAPHY

1. Jones, S. S., J. E. Morrissey, and J. L. Manuel, "Reactor Process Flow Technical Data," HW-72699, February 15, 1962.
2. Morrissey, J. E., "Technical Results of Production Test IP-651-AI, Trip-out Test, H-Reactor," HW-80774, March 12, 1964.
3. Staff of IPD, "Hazards Summary Report," Vol. II, page 259, HW-74094, May 15, 1963.
4. Morrissey, J. E. to S. S. Jones, "High Tank Screen Plugging," May 4, 1964.
5. Sherwood and Reed, Applied Mathematics in Chemical Engineering, McGraw-Hill Book Co., N. Y., page 368 (1939).
6. Jones, S. S., "Technical Note on the Determination of K-Reactor Last-Ditch Cooling Adequacy," HW-81028, February 28, 1964.
7. Morrissey, J. E., "Technical Note on Calculating Reactor Flow from High Tank High Velocity Flush Data, HW-82914, May 22, 1964.
8. Technical Bases for Standards, Basis D-1, HW-55500 RD.
9. Waters, E. D. and D. E. Fitzsimmons, "Pressure Required to Overcome Tube Burnout During Transient Conditions," HW-66274, August 5, 1960 (SECRET).
10. Carlson, P. A. and S. S. Jones, "Potential for Process Tube Burnout During Transient Conditions, HW-61760, April 22, 1960 (SECRET).
11. Jones, S. S. and J. E. Hammond, "Flow and Heat Transfer Analysis of the KER Loops," HW-55900 REV, June 3, 1959.
12. Jones, S. S. and J. A. Stoddard, "High Tank Flow Calculations for DR-Reactors with Various Valving Conditions," HW-70452, July 20, 1961.
13. Champagne, F. H. and S. S. Jones, "Theoretical High Tank Flow at the B, D, and F Reactors," HW-65610, June 21, 1960.
14. Jones, S. S. and J. L. Manuel, "Numerical Results of PT-IP-338A and Supplement A DR-Reactor Heat Decay Test at High Outlet Water Temperatures," HW-75727, December 3, 1962.

DECLASSIFIED

**DATE
FILMED**

10 / 31 / 94

END