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MASTER

STEAM SYSTEM AND FEEDWATER SYSTEM FAILURES

EXPERIMENTAL GAS COOLED REACTOR

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STEAM SYSTEM AND FEEDWATER SYSTEM FAILURES

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	<u>page</u>
TITLE PAGE	i
SIGNATURE PAGE	ii
TABLE OF CONTENTS	iii
I. OBJECTIVE	1
II. SUMMARY AND CONCLUSIONS	
A. Steam Generator Automatic Isolation	1
B. Steam Generators	2
C. Steam System	2
D. Blowers and Compressors	2
E. Feedwater System	3
F. Coolant System Relief	3
III. RECOMMENDATIONS	4
IV. GIVEN DATA	
A. Steam Generator Isolation System	4
B. Steam Generators	4
C. Steam System	5
D. Blowers and Compressors	5
E. Feedwater System	6
F. Coolant System Relief	6

V. ASSUMPTIONS

A. Steam Generator Isolation	7
B. Steam Generator	7
C. Steam System	7
D. Blowers and Compressors	7
E. Feedwater System	7

VI. DESCRIPTION

A. Steam Generator Isolation	8
B. Steam Generator	8
C. Steam System	9
D. Blowers and Compressors	9
E. Feedwater System	9
F. Reactor Coolant System	10

VII. DISCUSSION

A. Steam Generator Isolation	10
B. Steam Generator Failures	12
C. Steam System Failures	15
D. Blower and Compressor Reactions to Steam-Helium Mixtures	16
E. Feedwater System Failures	17
F. Coolant System Relief Valves	19

VIII. CALCULATIONS

Appendix A - Reactor Coolant Blowers

Appendix B - Steam Line Failures

Appendix C - Steam Generator Failures

Appendix D - Analysis of Steam Blowdown Cycle

Appendix E - Blower Behavior following Steam Tube Rupture

STEAM SYSTEM AND FEEDWATER SYSTEM FAILURES

I. OBJECTIVE

The purpose of this study is to assess the adequacy of the EGCR steam and feedwater systems for continued decay heat removal from the EGCR core after the following accidents:

- A. steam line failures,
- B. steam generator internal failures,
- C. feedwater system failures.

In addition, this study evaluates the reaction of the reactor coolant blowers and vessel cooling compressors to steam-helium mixtures and reviews the steam generator isolation systems. The formation of hydrogen following steam-water leakage (into the coolant system), which reacts with the graphite in the core structure and in the fuel-assembly sleeves, and the subsequent release of hydrogen are not considered. The problems associated with hydrogen formation are considered in a separate report*.

II. SUMMARY AND CONCLUSIONS

The containment system is adequate to prevent activity release to the atmosphere in the event of all credible steam line or feedwater system failures.

The design of the drum water level automatic isolation system does not prevent activity release during certain credible steam generator failures, however this activity is released at the top of the plant stack and does not result in a dose which exceeds the acceptable yearly exposure.

A. Steam Generator Automatic Isolation

A simplified analysis of the steam generator drum water level, during accident conditions wherein the steam and water leakage into the coolant system does not exceed 163,000 lb/hr, indicates that the drum level does not decrease to the isolation level; therefore no automatic isolation occurs.

For large steam generator failures (leakage greater than 163,000 steam-water/hr) that may occur due to a rapid coolant system depressurization, the isolation system effectively isolates the defective steam generator. In addition, any steam generator failure that results in water accumulation at the bottom of either steam generator will result in automatic isolation of that steam generator by the action of the flood level isolation system.

*Analysis of Possible Hydrogen Hazards in EGCR due to Overpressurization or Depressurization Accidents, Kaiser Engineers, February 1, 1963.

Feedwater piping system failures, which result in loss of feedwater to a steam generator, result in isolation of that generator by the drum water level isolation system.

B. Steam Generators

Credible failures within a steam generator are limited to tube failures and cracking of tube sheets. The length of tube sheet cracks will be limited to the ligament between tubes, however the depth of the cracks cannot be defined. Gross failure of internal components such as the downcomer, steam and water drums, steam piping and feedwater piping are considered incredible.

C. Steam System

1. The release of steam from a failed steam line is limited, by excess flow valves and a flow limiting venturi in parallel with the excess flow valve in each 6-inch steam line. This combination limits exhaust steam flow to a steaming rate of approximately 110 per cent of design flow. Failure of one 6-inch steam line or the 8-inch steam main does not result in a hazard to the general public.

2. The drum water low level automatic steam system blowdown to 135 psig allows reactor coolant to escape directly to the atmosphere if a tube failure is present since the drum isolation level is not reached. In the event that flood level isolation occurs before steam pressure in the generator containing the failure is reduced to coolant system pressure, reactor coolant will not escape through the failure. The feedwater systems are adequate to maintain drum level above that required to cause drum level isolation, even in the event of a rupture which results in an initial release of 163,000 lb/hr. The maximum dose to the public, in the event helium system pressure is reduced to 135 psig through the failure, is approximately 1.3 rem to the thyroid.

D. Blowers and Compressors

1. Reactor Coolant Blowers

The reactor coolant blower blades would be over-stressed at coolant system operating pressure and temperature if 100 per cent steam were admitted to the blower while operating at 100 per cent speed. However, there is no credible mechanism by which 100 per cent steam can be admitted instantaneously to the blower. Based upon the introduction of 163,000 lb/hr of steam into the coolant system, the partial steam pressure increases approximately 3 psi/sec. A partial steam pressure of 50 psi will initiate a reactor scram and blower rampdown; the blower blades will not be overstressed.

At the fully ramped-down speed of 23 per cent, the blowers will not be overloaded when handling 100 per cent steam. However, two blowers operating simultaneously will be in surge; one blower operating separately will not surge. At this loading, the blowers may not be damaged since the blade stresses are below the yield point of the blade material. If the blowers surge, mechanical damage to the blower and drive train components could result in complete loss of forced cooling to the reactor core by these blowers.

Blower motor overload trips should be set at 400 to 500 per cent of normal operating current to prevent tripping of the blowers following steam-water admission to the coolant system. Thermal protective devices should not be used; however, the high motor winding temperature alarm will be of value to the operator.

2. Vessel Cooling Compressors

The vessel cooling compressors cannot handle steam-helium mixtures with a molecular weight of approximately 8.8 at coolant system relief pressure due to motor horsepower limitation.

E. Feedwater System

Failures in the normal feedwater system do not result in a hazard to the general public but may result in loss of main feedwater to one or both steam generators. If the failure results in a steam drum low water level, the reactor is scrammed and the steam pressure is automatically reduced to 135 psig through the electromatic relief valves. The shutdown feedwater system assures a heat sink for reactor core decay heat removal.

F. Coolant System Relief

The coolant system relief valves are each sized to relieve 161,000 lb/hr steam.

The opening of a coolant system relief valve may result in some core coolant flow disturbance. In addition, the higher steam content of the fluid passing through the blower in the loop containing the failure will cause a higher pressure differential across that blower and will eventually cause both blowers to surge. This surging does not occur before approximately 25 seconds has elapsed assuming 100 per cent power level and maximum credible steaming rate. Since a scram on high coolant pressure occurs within 10 seconds, fuel element temperatures will have decreased sufficiently before surge occurs and, consequently, no fuel elements will exceed the normal operational temperature limitations.

III. RECOMMENDATIONS

Steam Generators

The steam generators should be inspected at regular intervals during scheduled plant shutdown to determine the condition of the steam side. Special attention should be given to the evaporator tubes which should be checked to determine the degree of erosion or pitting. The inspection should include a hydrostatic test of the steam-water side at 150 per cent design pressures to assure that pressure containing components have not deteriorated in service.

IV. GIVEN DATA

A. Steam Generator Isolation System

1. The steam-generator drum-water level isolation system is completely automatic, and does not require operator action to perform isolation function.
2. Drum-water level scram is 9 in. below normal drum level and corresponds to 30.2 ft³ of water between the normal and scram levels.
3. Isolation level is 15-1/2 in. below scram level and corresponds to 40.5 ft³ of water between the scram and isolation levels.

B. Steam Generators

1. Process Calculations for EGCR Steam Generators, C. F. Braun Company.
2. Steam Generator Water and Steam Volumes, C. F. Braun Calculations, March 10, 1960.
3. C. F. Braun Company shop drawings.
4. Radiographs - Steam Generator, on file at C. F. Braun Company, Alhambra, California.
5. Steam Generator Technical Manual - August 4, 1961, C. F. Braun Company.
6. Steaming capacity of each steam generator must be limited to 140,000 lb/hr to avoid water carryover into the superheater and to prevent possible internal damage.
7. Letter, Mr. L. H. Jackson to Mr. P. D. Bush, dated September 1, 1961, Creep Rupture Properties of A-212 Plate, w/ORNL attachment dated August 29, 1961.
8. Letter, Mr. P. D. Bush to Mr. L. H. Jackson, dated December 1, 1961, Steam Generator Tube Rupture.

C. Steam System

1. Title II drawings of main and auxiliary steam, feedwater, and condensate piping and instrument diagrams:

Drawing No. 5927-EGCR-P-105, Heat Balances Turbine Cycle - Rev. 2, dated February 8, 1962

Drawing No. 5927-EGCR-P-112, Main and Auxiliary Steam Piping and Instrument Diagram - Rev. 15, dated September 14, 1962

Drawing No. 5927-EGCR-P-113, Condensate Piping and Instrument Diagram - Rev. 14, dated September 14, 1962

Drawing No. 5927-EGCR-P-114, Steam Generator and Feedwater Piping and Instrument Diagram - Rev. 18, dated December 28, 1962.

2. Study II-650, "Plant Control Analysis - Experimental Gas Cooled Reactor", Approved January 26, 1961.

3. Study II-601, "Reactor Safety System, Design and Analysis", Approved February 15, 1961.

4. Study IV-316, "Hazards Analysis - Effects of Steam Generator Tube Rupture", Rev. 1, dated October 25, 1961.

5. Study IV-317, "Safety and Control System Reaction to Steam System Failures", Rev. 1, dated September 20, 1961.

6. Letter dated November 22, 1961, Mr. P. D. Bush to Mr. L. H. Jackson, Main Steam Line Excess Flow Valves.

D. Blowers and Compressors

1. Reactor Coolant Blowers

(a) Each reactor coolant blower is designed to compress helium at a normal inlet of 298 psia, 480 F at a rate of 215,000 lb/hr with a pressure rise of 16.75 psi corresponding to 100 per cent reactor power.

(b) Each reactor coolant blower requires 3597 bhp at 110 per cent design helium flow.

(c) Continuous maximum blower drive motor overload corresponds to 125 per cent motor nameplate rating of 3100 hp.

(d) Fluid coupling slip is 3 per cent at 110 per cent design reactor power; 12 per cent at 100 per cent design reactor power.

(e) Reactor coolant blower characteristics are obtained from Joy Company proposal.

(f) Maximum blower motor horsepower is 6944 hp at time of maximum motor torque. (Kaiser Engineers' Inter-office Memorandum dated November 6, 1961, included as Appendix A-2).

2. Vessel Cooling Compressors

(a) Kaiser Engineers' Specification PK-15, Compressors, Vessel Cooling, Certified for Construction June 9, 1960.

(b) Motor Nameplate rating - 250 hp.

(c) Breakdown motor torque - 250 per cent full nameplate rating.

E. Feedwater System

1. Drawing 5927-EGCR-P-114, Steam Generator and Feedwater - Piping and Instrument Diagram, Rev. 18, dated December 28, 1962.

2. Drawing 5927-EGCR-P-108, Condensate and Feedwater Flow Diagram, Rev. 2, dated July 19, 1961.

3. Feedwater pump capacity is 282,000 lb/hr (610 gpm) @ 1440 psia (3600 TDH) with inlet feedwater at 290 F - specific gravity of 0.924.

4. Feedwater pump characteristic curve. Test performance curve 21700-B dated December 14, 1960, Pacific Pumps, Inc., Huntington Park, California.

5. The flow through a feedwater control valve is 2700 gpm with a pressure differential of 1400 psi across the valve.

6. Feedwater flow to the steam generator containing a failure continues until the feedwater system is isolated by operator action or by the action of the steam generator isolation system.

F. Coolant System Relief

1. The maximum credible steam-water leakage into the coolant system as the result of steam generator tube failure(s) is 163,000 lb/hr.

2. Reactor coolant system design pressure is 350 psig.

3. The design basis is that any one of the three relief valves on either coolant circuit and on the reactor vessel is capable of relieving coolant system over-pressure resulting from the maximum steam-water leakage rate.

V. ASSUMPTIONS

A. Steam Generator Isolation

The drum water level isolation system is operative at all reactor power levels.

B. Steam Generator

1. The discharge from the steam drum into failed evaporator or economizer tubes is saturated water.

2. The leakage from the tube failure(s) is at sonic velocity.

3. The helium-steam mixture in the reactor coolant system due to tube failure(s) is of uniform density.

C. Steam System

1. Piping failures occur instantaneously.

2. Maximum allowable steam flow leaving each generator outlet is 140,000 lb/hr (110 per cent of design).

D. Blowers and Compressors

1. Reactor Coolant Blowers

(a) The reactor coolant blowers are operating at 100 per cent design at the time of the postulated failures.

(b) A reactor scram initiates rampdown of the coolant blowers to 23 per cent speed.

2. Vessel Cooling Compressors

Efficiencies:	Compressor	80 per cent
	Motor	90 per cent
	Speed Increasing Gear	95 per cent.

E. Feedwater System

1. The feedwater system is supplying feedwater to the steam generators at a rate corresponding to 100 per cent reactor power.

2. Piping failures occur instantly.

VI. DESCRIPTION

A. Steam Generator Isolation

The steam generator automatic isolation system for the EGCR isolates the steam and helium sides of a defective steam generator by a water level signal taken from the steam drum of each steam generator.

Each isolation system performs the following functions in the corresponding coolant circuit:

1. announces loop isolation,
2. trips operating reactor coolant blower,
3. closes coolant circuit isolation valves,
4. closes valve in vessel cooling compressor suction line from that coolant circuit,
5. closes feedwater system isolation valves,
6. closes steam system isolation valves.

The above actions are based upon the following:

1. Blower trip is a prerequisite to closing coolant circuit isolation valves.
2. Feedwater isolation valve closure limits water and steam introduction into the coolant system, vessel cooling system, and subsequent release into the containment building in the event the stack activity monitor set points are exceeded and containment isolation is effected.
3. Steam isolation valve closure prevents release of radioactive helium coolant to the atmosphere through the steam system during steam system blowdown to 135 psig through the electromatic relief valves.
4. Coolant system block valve closure prevents heat transport to the defective steam generator.

B. Steam Generator

Each steam generator consists of an economizer section, evaporator section, and a superheater section. Normal feedwater inlet temperature is 290 F, at a pressure of 1390 psig (Drawing No. 5927-EGCR-P-105). The helium enters the generator through a gas side distribution baffle and traverses the superheater, evaporator and economizer in series. The gas is then directed around the interior of the shell, and leaves through a 22-in. diameter opening.

C. Steam System (Drawings No. 5927-EGCR-P-112 and P-114)

One 6-in. schedule 120 pipe conveys steam from the superheater outlet of each steam generator. These 6-in. lines penetrate the containment building shell and are combined into one 8-in. schedule 120 steam main which terminates at the turbine stop valve. One 6-in. stop check valve is located in each 6-in. line just upstream of the junction of the two lines and the 8-in. steam main. Each 6-in. line also contains two motor-operated isolation valves which can be closed from the fully open position in 29 seconds. Two excess flow valves in-series and one bypass/venturi are installed in each 6-in. line to prevent the steaming rate of each generator from exceeding 140,000 lb/hr following failure of either a 6-in. steam line or the 8-in. steam main.

D. Blowers and Compressors

1. Reactor Coolant

The reactor coolant blowers are 10 stage axial flow machines. Each blower is driven by 3100 hp, a-c induction motor through a variable speed fluid coupling and a speed increasing gear. Blower speed and, therefore, coolant flow is varied by adjusting the oil level within the fluid coupling. The normal operating speed of the blower is 6130 rpm.

2. Vessel Cooling Compressors

Each vessel cooling compressor is driven by a 250 hp, a-c induction motor through a speed increasing gear. The compressors are each designed to circulate 23,000 lb/hr of helium at a suction pressure of 313 psia at 508 F. The pressure rise is 8.75 psi.

E. Feedwater System

The EGCR feedwater system design is indicated on Drawing No. 5927-EGCR-P-114.

The main feedwater pumps each have a capacity of 282,000 lb/hr at 1440 psia and 290 F; either pump can supply feedwater to both steam generators (Drawing No. 5927-EGCR-P-108). In the event of failure of the operating pump, the standby pump is automatically started.

Two high-pressure surge tanks, each with a normal storage capacity of 2,000 gallons of feedwater, float on the feedwater line to each steam generator.

Four shutdown feedwater pumps, two for each steam generator, take suction from the condensate storage tank to assure meeting the shutdown feedwater

requirement of 15 gpm to each steam generator. Two of the pumps, one for each steam generator, are steam driven. Each of the four pumps is capable of delivering 30 gpm at a discharge pressure of 240 psia. The shutdown feedwater pumps are on emergency power and automatically start upon a loss-of-power scram. These pumps will also automatically start upon low steam drum water level, or low deaerator water level. No feedwater, however, is delivered to the generators by the shutdown pumps until the steam system pressure is reduced by the automatic opening of the steam system electromatic relief valves. During this blowdown period, feedwater is supplied from the pressurized surge tanks which float on the inlet lines.

F. Reactor Coolant System

The reactor coolant system consists of two parallel piping circuits. Each circuit contains a steam generator, an attemperator, an axial-flow blower, and two isolation valves. In the event of internal steam-generator failures, high-pressure water, steam, or a water-steam mixture will be introduced into the reactor coolant system through the failure. The coolant system is protected against excessive pressure by two sets of relief valves. Each set of relief valves contains three valves (two relief valves, one on each steam generator outlet; and one connected to the reactor vessel inlet piping). Although the capacity of each relief valve is 161,000 lb/hr, each valve can relieve 163,000 lb/hr within the pressure accumulation permitted by ASME Codes. Therefore, coolant system design pressure is not exceeded by the admission of 163,000 lb/hr of steam (the maximum credible leakage rate of steam and water) into the coolant system. Only one set of three relief valves is in service at one time. The normal relief valves remain effective until system pressure reduces to 285 psia. Should the system pressure fall below this value, the normal relief valves are automatically valved off from the coolant system and the emergency relief valves are connected to the system. Thus, relief valve seat leakage cannot depressurize the coolant system.

VII. DISCUSSION

A. Steam Generator Isolation

1. General

The steam generator isolation system uses both a steam drum low low water level signal and a flood level signal to initiate automatic isolation. The intended purpose of isolation of the helium and steam sides of the steam generator are:

- (a) to limit the leakage of water-steam mixtures into the coolant system, vessel cooling system, and subsequently into the containment building in the event of steam generator internal failures,

- (b) to prevent release to the atmosphere of helium or helium-steam mixtures containing fission products through the electromatic relief valves in the event of an internal steam generator failure followed by reduction in steam system pressure to less than coolant system pressure,
- (c) to prevent steam generator components from exceeding design temperatures,
- (d) to reduce the pressure rise in the containment building due to continued leakage of steam-water into the containment building.

In the event of a steam generator internal failure with leakage rates up to 163,000 lb/hr, an automatic isolation signal will not be obtained from the failed steam generator drum level. Calculations were performed which indicate that drum water content of the failed generator will decrease less than 3 ft³ from the time of failure to the time that the leakage flow has decreased (due to decreasing steam drum pressure) to the value of the feedwater flow. These calculations are based on a simplified model which considers that the feedwater flow to the failed steam generator will not increase. The reactor is assumed to continue to operate at 100 per cent power until it is scrammed by high coolant system pressure.

Blowdown of the steam system will occur either from a loss-of-power signal or from a drum water low level signal from either steam generator. If the turbine-generator is connected to the external network, an electromatic relief valve will not open until a drum water low level signal is generated. A drum water low level signal will occur when the deaerator water supply is exhausted.

However, if the plant is not connected to the external network, the turbine stop valve is tripped approximately 4 minutes after the start of the accident, resulting in a power failure and opening of the electromatic relief valves. As the steam system pressure reduction is effected, steam system pressure will approach reactor coolant system pressure (300 psia), and leakage from the failed steam generator to the reactor coolant system will approach zero. As the steam system pressure decreases from 300 psia to completion of blowdown at 135 psig, leakage will be from the reactor coolant system to the steam system. Fission products in the coolant system will then be released to the atmosphere through the open electromatic relief valves. Preliminary calculations of the resulting dose to the public show that the maximum thyroid dose will be less than 1.3 rem when the plant is not connected to the external power network and less than 0.03 rem when it is connected to the external power network.

2. Steam Line Failures

Failures in the 6-in. or 8-in. steam lines will trip the excess flow valves in the steam line(s) if the flow exceeds 110 per cent of design flow. A flow limiting venturi in parallel with these valves (in each 6-in. line) allows a bypass flow of up to 140,000 lb/hr which is required for steam drum blowdown and for operating certain auxiliary equipment.

The reactor will eventually be scrambled on drum water low level if the steam leakage is sufficiently large since condensate return is decreased. The drum water low level signal also starts the shutdown feedwater pumps. The surge tanks and shutdown feedwater pumps are adequate to assure a continued supply of feedwater. No coolant circuit isolation occurs since the shutdown feedwater supply is adequate to maintain drum water levels in both steam generators.

3. Feedwater Line Failures

Feedwater line failures result in decreasing drum water levels and reactor scram when the level reaches drum water low level. If the failure results in complete loss of feedwater to only one steam generator, the reactor is scrambled on drum low level and that generator is isolated by the drum low-low level isolation system.

B. Steam Generator Failures

Failures in pressure-containing equipment and piping can be either brittle or ductile failures, depending upon the material, temperature and stress. The materials specified for the components and piping considered in this report fall within the category of ductile materials and, therefore, if failures occur, they will be in the form of an elliptical tear with the major axis parallel to the axis of the pipe. WAPD-TM-56 presents a method verified by actual service data and destructive tests for predicting the limits of ductile failure.

1. Tube Failures

Steam generator tube failures are credible. Gradual erosion of tube walls by the high velocity steam-water mixtures flowing within the tubes may ultimately weaken the tubes. The evaporator tubes are more susceptible to this erosion.

The arrangement of tubes within the generator and the tube support baffles prevent lateral displacement of the tubes sufficiently to preclude a double-ended rupture, except for tube failures in outer rows. The space between 1-in. tubes is 1/4 in.; between 3/4-in. tubes, 3/16 in.

Tube failures are expected to be longitudinal splits as discussed in GIVEN DATA, IV-B-8, of this study.

C. F. Braun Company Drawing 54502-E701, Revision 3, dated December 1960, lists the following properties of the evaporator tubes:

- 1-in. OD x 14 gage (0.083 in. wall) ASTM A-83 Grade A
- 3/4 in. OD x 16 gage (0.065 in. wall) ASTM A-83 Grade A.

The bursting pressure of the above tube sizes based upon 20-year service are 2789 psia and 2912 psia, respectively, for the 1-in. and the 3/4-in. OD tube, based upon minimum stress to rupture of 16,800 psi for 175,000 hours. The stress level in the operating tubes is approximately 11,750 psi, based upon an internal pressure of 1400 psig at operating conditions. In operation, however, the pressure differential will be reduced 300 psi by the coolant system pressure and the tubing will be subjected to lower stresses corresponding to 1100 psig internal pressure. From these stress levels, it is concluded that a loss-of-coolant system pressure which increases the pressure stress level in the tubes does not result in tube failures. If the rate of system depressurization is high, the steam generator nearest the breach in the coolant system may experience some tube damage due to the excessive gas flow across the tube bundles. This does not occur in the sound circuit (Ref. Study No. IV-303, Rev. 1).

2. Major Failures

The components of the steam generator were reviewed to determine the credibility of failures. The following components were considered:

2a. Steam and Water Drums

Failure of the steam and water drums is not considered credible. Controlled shop fabrication, stress relieving, and rigid inspection assures quality of these components. All base materials were carefully controlled during manufacture and all welds were fully radiographed. Examination of the radiographs indicate weld quality in excess of Code requirements.

2b. Steam Generator Tube Sheets

If the steam generator tube sheets crack, water and/or steam may be introduced into the helium system. The numerous holes in the tube sheets will limit the length of such cracks to the ligament(s) between tube holes or to the tube to tube sheet seal welds. Such cracks could result in water leakage into the helium system, however the leakage is expected to be much less than the maximum credible steaming rate. The actual release into the coolant system, however, cannot be definitely determined since the width and depth of the crack in the thick (approximately 11-1/2 in.) tube sheet is not amenable to analysis.

2c. Downcomer

The downcomer is fabricated of rolled and welded plate. The plate materials were carefully controlled to assure highest quality. The welds, including the attachment welds to the tube sheets, have all been radiographed. Examination of these radiographs in the files of C. F. Braun Company indicates that all welds exceed the Code requirements for weld quality. On the basis of the radiographs and the low usage factors, the failure of the downcomer is considered incredible.

2d. Internal Feedwater Pipe

This pipe is seamless carbon steel conforming to the requirements of ASTM-A-106, Grade B. All base materials were ultrasonically tested. All welds have been radiographed and are of unquestionable quality. Closely controlled shop fabrication, stress relieving and inspection techniques, together with the low usage factors render failure of the pipe incredible.

2e. Internal Steam Piping

The internal steam piping consists of a 6-in. superheated steam pipe within a 10-in. saturated steam pipe. The inner pipe is fitted with external radiation shields to minimize heat transfer from the superheated steam to the saturated steam.

The design of this piping is such that all welds are staggered and are amenable to radiographic examination. The welds have all been radiographed. Examination of radiographs in C. F. Braun Company files show weld quality in excess of ASME Code requirements.

Ultrasonic testing of base materials, closely controlled shop fabrication, stress relieving, and inspection techniques, coupled with the low usage factors, render failure of these pipes incredible.

2f. External Saturated Steam Pipe

The external saturated steam pipe is fabricated of seamless carbon steel pipe conforming to ASTM-A-106 Grade B. All welds have been radiographed and weld quality exceeds Code requirements. The ultrasonic testing of base materials, shop fabrication techniques, coupled with the low usage factors render failure incredible.

2g. Failure of Steam Generator Shell

Failure of the steam generator shell is not credible as long as the shell is within design pressure and temperature limits. To avoid failure of the

steam generator shell due to possible overheating in the event of loss of feedwater, the helium side of the steam generator must be isolated; however, shell failure would not occur for at least four hours after heatup to 1100 F based upon the creep-rupture properties of the ASTM-A-212 shell material. Either the isolation system or the reactor operator would act in much shorter time to prevent overheating of the shell.

C. Steam System Failures

Steam system failures external to the steam generator were considered at the following three locations which are believed to result in conditions more severe than external steam line failures in other locations:

1. failure of the 8-in. steam main just downstream of the transition of the two 6-in. lines into the steam main,
2. failure of 6-in. steam line from one steam generator immediately downstream of the steam line flow limiting devices,
3. failure of 6-in. steam line from one steam generator immediately upstream of the flow limiting devices.

The size of ductile failures of the steam lines is calculated in Appendix B.

A failure of the 8-in. steam main results in complete loss of steam to the turbine generator, which is tripped by either the loss of vacuum relay or on low steam pressure by PS-1-116. Both steam generators feed the failure at a maximum initial steam rate of 280,000 lb/hr. The steam generators continue to generate steam which is relieved directly to atmosphere through the failure. Since main feedwater distribution is not affected, both steam generators continue to generate steam until the feedwater supply is exhausted and the reactor is scrammed on drum water low level. The steam drum low level signal also starts the shutdown feedwater pumps. Both steam generators are available for decay heat removal.

A failure of the one 6-in. steam line downstream of the flow limiters results in release of steam from one steam generator only. The check valve in the failed line closes to prevent reverse steam flow from the other steam generator. Consequently, the steam generator supplying the second 6-in. steam line is unaffected and continues to supply steam to the turbine. Turbine power output decreases since steam supply is reduced by loss of the one steam supply. The turbine generator continues to generate electrical power at a reduced rate until the reactor is scrammed by drum water low level signal which will occur when the deaerator is depleted.

The increased steam flow closes the excess flow valve in the line feeding the rupture. The bypass venturi limits steam flow to 140,000 lb/hr. The affected steam generator continues to generate steam which is relieved to atmosphere through the containment building ventilating system for failures within the containment building. No radiological hazards to the operator or the general public occurs. However, personnel within the containment building may be subjected to a steam environment depending on the location of the failure and the location of personnel within the containment building.

Failure of the 6-in. steam line upstream of the flow limiters will result in behavior similar to a rupture just downstream of the limiters; however, some steam generator damage may occur since the maximum steaming capacity of the steam generator is exceeded. If the steam generator tubes are damaged by excessive steam flow, a reactor coolant system partial depressurization may result. The remaining steam generator will be available for continued decay heat removal.

D. Blower and Compressor Reactions to Steam-Helium Mixtures

1. Reactor Coolant Blowers

The reactor coolant blowers are ten-stage axial flow compressors designed to handle helium. If the density of the fluid in the coolant system increases, the blowers require additional power. With the coolant system containing pure steam at 350 psig, each blower requires approximately 340 per cent of design power when operating at 100 per cent speed.

The degree of blower overload is governed by the size of steam generator failure and the rate of leakage of steam into the coolant system. Yielding of the blower blades does not occur since steam buildup in the system will be relatively slow (3 psi/sec). The blowers are ramped down to 23 per cent speed at approximately 1.5 per cent per second after all scram actions. This rampdown action limits the overload on the blowers. The developed drive motor power at maximum torque is 6944 hp.

Operation at 23 per cent speed with essentially pure steam in the system at 325 psig results in surging if both blowers are operating. Stopping one blower will bring the remaining blower out of the surge region.

2. Vessel Cooling Compressors

The vessel cooling compressor motors are overloaded and attain stall torque when the steam-helium mixture in the coolant system has a molecular weight of approximately 8.8 (Appendix A-4).

Natural circulation with steam at 135 psig or 350 psig has been shown to be adequate for core decay heat removal (Study IV-330-1). In the event that both blowers are lost, the reactor will be adequately cooled until such time as the steam within the system condenses. However, when steam starts condensing in the system, isolation of both loops will probably occur due to action of the flood level isolation systems. Even if both loops are isolated the reactor operator has at least one hour either to reverse isolation of one loop or to depressurize the system and start up the emergency coolant loop. If the service machine is connected to a top nozzle, loss of the blowers will result in loss of nozzle cooling and subsequent overheating of that nozzle. In these cases, the coolant system should be manually depressurized to permit use of the VCC or the emergency cooling system.

E. Feedwater System Failures

Credible failures in the feedwater system result in complete loss of feedwater to one steam generator.

Feedwater system failures were postulated to occur at the following locations which are believed to result in conditions more severe than failures in other locations:

- a. feedwater piping within the containment building,
- b. feedwater piping exterior to the containment building to the common discharge line from the main feedwater pump,
- c. feedwater pump common discharge line,
- d. feedwater pump suction,
- e. feedwater control malfunction.

1. Inlet Elbow - Failure

Failure of the elbow on the feedwater inlet is considered incredible. This elbow is radiographed, stress relieved and the field attachment weld made under closely controlled conditions to assure highest quality.

2. Failure within Containment Building

Failure of feedwater piping within the containment building results in complete loss of water to one steam generator only. A check valve at each steam generator prevents reverse flow of feedwater from the steam generator. The reactor is scrammed on drum water low level signal from the steam generator associated with the failure. The sound generator is available for decay heat removal. The generator associated with the failed feedwater line is isolated by the action of

the steam generator drum level isolation system. Feedwater will continue to be discharged into the containment building until the steam generator associated with the failure is isolated.

3. Feedwater Piping External to Containment Building

The consequences of piping failure external to the containment building are less severe than for failures within the containment building. The steam generator associated with the failure will lose drum level and will be isolated. The second steam generator will be supplied with feedwater from several reliable and independent sources and will be available for continued decay heat removal.

4. Feedwater Pumps - Common Discharge Line

Failure of the main feedwater pump common discharge line results in failure of high pressure feedwater supply to both steam generators. The reactor is scrammed on steam drum water low level which also starts the low head shutdown feedwater pumps and opens the electromatic relief valves to reduce steam side pressure to 135 psig. The surge tanks are sized for the steam side blowdown, therefore no isolation occurs. Both steam generators are available for decay heat removal since shutdown feedwater supply is available. No hazard to the operator or to the general public occurs.

5. Feedwater Pump Suction

Failure of the main feedwater pump suction line results in a reduction or loss of the available positive suction head to the feedwater pumps, and consequently, loss of feedwater to the steam generators. The reactor is scrammed on steam generator drum water low level, which also starts the shutdown feedwater pumps and opens the electromatic relief valves to reduce steam side pressure down to 135 psig. Both steam generators are available for decay heat removal since feedwater supply is assured by the shutdown feedwater pumps.

6. Feedwater Control Malfunction

A malfunction of the steam drum level control system could result in complete stoppage of feedwater, or excess feedwater to the affected generator. If the control fails such that the feedwater control valve is closed, the operator can manually control feedwater flow by remote positioning of the bypass valve in the feedwater supply line. If the operator fails to act, drum water level will decrease; scram would occur on steam drum water low level signal and subsequently isolation will follow on the low-low level isolation signal.

If the control fails such that the feedwater control valve is open, the steam drum water level would increase at a rate dependent upon the difference in steam and feedwater flow. The operator will be alerted by the steam drum high level annunciators. If the operator fails to take corrective action, a high level point would be reached at which the two feedwater isolation valves to that steam generator are closed automatically. If there is no subsequent operator action, the drum level would then decrease and scram would occur on low drum level. Isolation would follow on the low-low drum level isolation signal. No radiological hazard occurs as a result of these malfunctions.

F. Coolant System Relief Valves

The coolant system relief valves are required to protect reactor coolant system components from pressures in excess of the design pressure of 350 psig. Pressure increases could occur as a result of the following:

1. overheating of coolant,
2. overcharging with helium,
3. steam generator failures which introduce steam into the coolant.

Of the three causes of pressure increase, the largest results from steam generator internal failures. As previously discussed (Par. VII-B-2b), failure of the tube sheet would be limited to a small crack and is, therefore, not considered further. The maximum credible leak from a steam generator has been adjudged to be less than 163,000 lb/hr*. Tube failures cannot be isolated from the coolant system, except as a part of a coolant circuit which can be isolated. Therefore, each coolant system relief valve must be capable of relieving over-pressure within the permissible pressure accumulation specified by the Code.

*Minutes of Oak Ridge Hazards Meeting of February 12-13, 1962, dated February 15, 1962.

THE CAMBER, SOLIDITY, ETC. ARE TAKEN AT THE MEAN RADIUS OF THE BLADE :

THUS:

- (1) SETTING $\phi = 42^\circ$
- (2) CHORD = 1.5 IN.
- (3) BLADE LENGTH = 2.72 IN.
- (4) SOLIDITY = $\frac{\text{CHORD}}{\text{PITCH}} = \frac{1.5 \times 35}{6.28 \times 9.52} = 0.88 \approx 1$
- (5) NO. OF BLADES PER STAGE = 35
- (6) NO. OF STAGES = 10
- (7) CAMBER = 0.7 ($\therefore$ 65-710 SECTION)
- (8) MEAN RADIUS = 9.52 IN.

A. HELIUM FLOW

FROM PAGE 7 OF SUPPLEMENTAL JOY REPORT, AT THE 110% PSEUDO OPERATING POINT:

$$V_{\text{CORR}} = 350 \text{ FT/SEC.}$$

$$\therefore \text{SINCE } V_{\text{ACTUAL}} = V_{\text{CORR}} \times \sqrt{\theta} \quad \text{AND } \sqrt{\theta} = \sqrt{T/520}$$

$$V_{\text{ACT}} = 350 \times \left(\frac{943}{520}\right)^{\frac{1}{2}} = 471 \text{ FT/SEC.}$$

GETTING AXIAL VELOCITY AT 100% OPERATING PT.

$$\frac{W_{100}}{W_{PS}} = \frac{V_{100} P_{100} A_{100}}{V_{PS} P_{PS} A_{PS}}$$

$$V_{100} = \frac{W_{100}}{W_{PS}} \times \frac{P_{PS}}{P_{100}} V_{PS} = \frac{215,000}{(236,000 \times .95)} \times \frac{0.118}{0.118} \times 471$$

$$V_{100} = \underline{452} \text{ FT/SEC.} = V_A \quad \text{AXIAL VEL.}$$

BLADE SPEED AT 100%

$$\frac{6130 \text{ RPM}}{60 \text{ SEC/M}} \times \frac{2\pi}{12 \text{ IN/FT}} \times 9.52 \text{ IN.} = \underline{509} \text{ FT/SEC.}$$

REACTOR COOLANT BLOWERS

STUDY IX-334

SIMILAR TO

DR'N R.S. 10-13-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET A-1 OF A-26

ISSUE

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APPENDIX A

A

B

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

A VELOCITY DIAGRAM CAN BE CONSTRUCTED:

$$\beta_1 - \beta_2 = \theta \text{ TURNING ANGLE}$$

THE TURNING ANGLE θ , AND LIFT COEFFICIENT C_L IS OBTAINED KNOWING α OF ATTACK AND BLADE PROPERTIES. THERE IS SOME INTERPOLATION NECESSARY OF THE DATA SUPPLIED BY THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS (NACA), TECHNICAL NOTE 3916.

$$\beta_1 = \tan^{-1} \frac{V_b}{V_a} = \tan^{-1} \frac{509}{452}$$

$$\beta_1 \approx 48^\circ$$

$$\text{SETTING } \phi = 42^\circ \text{ (JOY REPORT)} ; \alpha = 6^\circ$$

USING DATA FOR $\beta_1 = 45^\circ$ SINCE $\beta_1 = 48$, NACA GIVES:

V	TYPE-SECTION	θ	C_L
0.5	65-4-10	5	0.43
0.5	65-12-10	9	0.70
0.5	65-18-10	12	0.87
0.75	65-4-10	6	0.30
0.75	65-12-10	11	0.56
0.75	65-18-10	-	-
1.00	65-4-10	7.7	0.29
1.00	65-8-10	11	0.42
1.00	65-12-10	13.5	0.47
1.00	65-18-10	-	-

REACTOR COOLANT BLOWERS

STUDY III-334

SIMILAR TO

DR'N R.T.S. 10-13-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET A-2 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

APPENDIX A

ESTIMATE FOR 65-710 } $\theta = 9.5^\circ, C_L = 0.42$
 $\beta_1 = 45^\circ$
 $\gamma = 0.88$

ESTIMATE FOR 65-710 } $\theta = 9.5^\circ, C_L = 0.425$
 $\beta_1 = 48^\circ$
 $\gamma = 0.88$

NOW A VELOCITY DIAGRAM IS CONSTRUCTED:

THE RESULTS ARE FACTORED INTO EQUATION 155 FROM VINCENT, THEORY AND DESIGN OF GAS TURBINES AND JET ENGINES (PG. 344).

$$\frac{P_2}{P_1} = \left(1 + \frac{V_b N_{RH} C_L \gamma}{2 g J C_p T_1}\right)^\eta \frac{R}{R-1} \rightarrow \text{ONE STAGE} \leftarrow$$

$$= \left(1 + \frac{509 \times 626 \times .425 \times .88}{2 \times 32.2 \times 778 \times 1.249 \times 943}\right)^{2.52 \eta}$$

$$\eta = 0.88 \text{ (EFFICIENCY GIVEN ON JOY SUPPLEMENT)}$$

$$= (1 + .00202)^{2.22}$$

10 STAGES: $\frac{P_2}{P_1} = (1.00202)^{22.2} = 1.0458$

$$\therefore P_2 = 1.0458 \times 298 \approx 311 \text{ PSI}$$

REACTOR COOLANT BLOWERS

STUDY II-334

SIMILAR TO

DR'N R.S. 10-13-64

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET A-3 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

$$\Delta P = 311 - 298 = 13 \text{ PSI}$$

THIS RESULT ($\Delta P = 13$) COMPARES WITH THE ACTUAL ΔP OF 16.75 PSI. THIS AND OTHER PREVIOUS USES OF THE ABOVE EQUATION INDICATE THAT THE CALCULATED COMPRESSION RATIO (P_2/P_1) SHOULD BE MULTIPLIED BY A FACTOR OF 1.01, WHEN $\Delta P \gg 1$, TO GIVE BETTER RESULTS. THEREFORE THE MODIFIED EQUATION FOR THE COMPRESSION RATIO IS:

$$\text{10 STAGES} \quad \frac{P_2}{P_1} = 1.01 \left(1 + \frac{V_b N_{Rm} C_{eT}}{2g J C_p T_1} \right)^{10 \frac{A}{A-1}}$$

B. STEAM FLOW

GETTING FLOW RATE AND PRESSURE DROP (RISE)

(THE PRESSURE DROP OF THE SYSTEM MUST EQUAL RISE OF BLOWER)

① FIRST TRIAL

IF STEAM AT THE SAME VOLUME FLOW RATE WERE GOING THROUGH THE BLOWER, THE FOLLOWING WOULD BE THE PRESSURE DIFFERENTIAL CALCULATION: SAME VELOCITY TRIANGLE AS BEFORE ($V_A = 452 \text{ FT/SEC}$)

(1) 385 PSIA

(2) 428 °F

(3) $A = 1.29$

(4) $C_p = 0.78$

USE THE SAME EFFICIENCY AS BEFORE SINCE THE VOLUMETRIC FLOW IS THE SAME AND NO ADDITIONAL DATA FOR EFFICIENCIES ARE AVAILABLE:

10 STAGES

$$\frac{P_2}{P_1} = 1.01 \left(1 + \frac{509 \times 626 \times 425 \times 88}{2 \times 32.2 \times 778 \times 78 \times 888} \right)^{10 \times 88 \times \frac{1.29}{.29}}$$

$$= 1.01 (1.0034)^{39.1} = 1.16$$

① ΔP ACROSS BLOWER:

$$P_2 = 1.16 \times 385 = 423 \text{ PSI}$$

REACTOR COOLANT BLOWERS

STUDY II - 334

SIMILAR TO

DR'N R.L.S. 10-13-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 14 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT. NPD-W

APPENDIX A

$$\Delta P = 423 - 365 = 58 \text{ PSI}$$

② ΔP DROP IN SYSTEM

$$\Delta P = \frac{G^2(N_2 - N_1)}{\alpha g_c} + \frac{f_m G^2 N_m L}{2 g_c N_R}$$

NEGLECTING ACCELERATION, WE CAN WRITE :

$$\frac{\Delta P_s}{\Delta P_{He}} = \frac{f_{ms} G_s^2 N_{ms}}{f_{mHe} G_{He}^2 N_{mHe}}$$

WHERE : $G = \rho V$

$N = 1/\rho$

f = FANNING FRICTION FACTOR

$$\text{SINCE } Re = \frac{DG}{\mu} \text{ AND } f \approx \frac{0.46}{Re^2}$$

$$f \propto \frac{\mu^2}{G^2}$$

$$\therefore \frac{\Delta P_s}{\Delta P_{He}} = \frac{G_{He}^2 G_s^2 N_s^2 \mu_s^2}{G_s^2 G_{He}^2 N_{He}^2 \mu_{He}^2} = \left(\frac{G_s}{G_{He}} \right)^{1.8} \left(\frac{N_s}{N_{He}} \right) \left(\frac{\mu_s}{\mu_{He}} \right)^2$$

IN OUR CASE, SINCE VELOCITIES ARE EQUAL

$$\frac{G_s}{G_{He}} = \frac{\rho_s}{\rho_{He}} = \frac{0.78}{0.118} = 6.61$$

$$\frac{N_s}{N_{He}} = \frac{\rho_{He}}{\rho_s} = \frac{0.118}{0.73} = 0.151$$

$$\frac{\mu_s}{\mu_{He}} = \frac{1.411 \times 10^{-5} \text{ LB/FT-SEC.}}{1.94 \times 10^{-5} \text{ "}} = 0.728$$

$$\therefore \frac{\Delta P_s}{\Delta P_{He}} = (6.61)^{1.8} (.151) (.728)^2 = 4.25$$

IF WE ASSUME THAT THIS RATIO IS THE SAME THROUGHOUT THE WHOLE SYSTEM,

$$\Delta P_s = 4.25 \times 16.75 = \underline{71.2 \text{ PSI}}$$

THE INERTIA OF THE BLOWER WILL INITIALLY KEEP IT AT THE SAME BLADE SPEED OF 509 FT/SEC. HOWEVER, THE VELOCITY OF STEAM THROUGH THE BLOWER (AND THUS MASS

REACTOR COOLANT BLOWERS

STUDY IV-334

SIMILAR TO

DR'N R.P.S. 10/3/61

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET 15 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

FLOW) WILL HAVE TO CHANGE TO MAKE THE BLOWER PRESSURE RISE EQUAL THE SYSTEM PRESSURE DROP. THE AXIAL VELOCITY OF STEAM MUST THUS BE DETERMINED.

⑥ SECOND TRIAL

ASSUME $V_A = 400$ FT/SEC.

* SEE BELOW FOR DETERMINATION OF TURNING ANGLE θ , AND LIFT COEFFICIENT C_L .

$$\beta_1 = \tan^{-1} \frac{509}{400} = 52^\circ$$

θ OF ATTACK = 10°

FROM NACA:

β_1	Γ	SECTION	B	C_L
45°	0.5	65-410	7.6	0.63
45°	0.5	65-12-10	12	0.88
45°	0.5	65-18-10	15.2	1.08
45°	0.75	65-410	9.2	0.47
45°	0.75	65-12-10	15	0.70
45°	0.75	65-18-10	19	0.82
45°	1.00	65-410	11	0.40
45°	1.00	65-810	15	0.51
45°	1.00	65-12-10	17.5	0.59

CONT.

REACTOR COOLANT BLOWERS

STUDY III-334

SIMILAR TO

DR'N R.S.S. 10-13-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 16 OF 26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

β_1	∇	SECTION	θ	C_d
60°	0.5	65-410	6.4	0.69
60°	0.5	65-12-10	10	0.92
60°	0.5	65-18-10	13	1.09
60°	0.75	65-410	8	0.52
60°	0.75	65-12-10	3.7	0.76
60°	0.75	65-18-10	16.7	0.84
60°	1.00	65-410	9.7	0.46
60°	1.00	65-810	12.8	0.54
60°	1.00	65-12-10	15.2	0.60

ESTIMATE FOR $\beta_1 = 52^\circ$, 65-710, $\nabla = 0.88$ } $\theta = 12.3^\circ$, $C_d = 0.56$

$$\therefore \frac{P_2}{P_1} = 1.01^{\frac{1}{10}} \left(1 + \frac{509 \times 580 \times .56 \times .88}{2 \times 32.2 \times 778 \times .78 \times 848} \right)^{7 \frac{1.29}{.29}}$$

$$= 1.01^{\frac{1}{10}} (1.00415)^{90 \times 4.45}$$

10 STAGES: $\frac{P_2}{P_1} = 1.01 (1.00415)^{40}$

= 1.20 HAS GONE UP WITH A DECREASE IN FLOW.

THEREFORE IT IS NOT IN SURGE REGION.

① ΔP ACROSS BLOWER:

$$P_2 = 1.20 \times 385 = 462 \text{ PSI}$$

$$\Delta P = 462 - 385 = 77 \text{ PSI}$$

② ΔP DROP IN SYSTEM:

$$\frac{\Delta P_{400}}{\Delta P_{452}} = \left(\frac{G_{400}}{G_{452}} \right)^{1.8} \left(\frac{N_{400}}{N_{452}} \right) \left(\frac{X_{L_{400}}}{X_{L_{452}}} \right)^{.2}$$

$$= \left(\frac{V_{400} R_{400}}{V_{452} R_{452}} \right)^{1.8} = \left(\frac{400}{452} \right)^{1.8} = 0.803$$

$$\therefore \Delta P_{400} = .803 \times 71.2 = 57.2 \text{ PSI}$$

REACTOR COOLANT BLOWERS

STUDY II-334

SIMILAR TO

DR'N R.L.S. 10-6-61

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET 7 OF 26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

INTERPOLATION ALLOWS US TO GET AN APPROXIMATE ANSWER OF WHEN THE TWO ΔP 'S ARE EQUAL.

$$452 \text{ FT/SEC. GIVES : } \Delta P_{\text{SYSTEM}} - \Delta P_{\text{BLOWER}} = 71.2 - 58 = 13.2 \text{ PSI}$$

$$400 \text{ FT/SEC. GIVES : } \Delta P_{\text{SYSTEM}} - \Delta P_{\text{BLOWER}} = 51.2 - 73 = -158 \text{ PSI}$$

$$\Delta (\Delta P) = 29.0 \text{ PSI}$$

$$\Delta (V) = 52 \text{ FT/SEC}$$

$$\therefore \frac{52}{29.0} = \frac{\Delta V}{13.2} \quad (\text{INTERPOLATING})$$

$$\Delta V = \frac{52}{29.0} \times 13.2 = 23.6 \text{ FT/SEC}$$

$$\therefore \left\{ \begin{array}{l} V = 452 - \Delta V = \underline{428.4} \text{ FT/SEC. (AXIAL VELOCITY)} \\ \Delta P \approx \underline{60} \text{ PSI} \end{array} \right.$$

③ POWER RATIO

$$P = \frac{\Delta P \times W}{\eta \rho}$$

$$\begin{aligned} \frac{P_s}{P_{He}} &= \left(\frac{\Delta P_s \times W_s}{\rho_s \times \eta_s} \right) \left(\frac{\rho_{He} \times \eta_{He}}{\Delta P_{He} W_{He}} \right) \\ &= \left(\frac{\Delta P_s}{\Delta P_{He}} \right) \left(\frac{W_s}{W_{He}} \right) \left(\frac{\rho_{He}}{\rho_s} \right) \left(\frac{\eta_{He}}{\eta_s} \right) \\ &= \left(\frac{61}{16.75} \right) \left(\frac{V_s \rho_s A_s}{V_{He} \rho_{He} A_{He}} \right) \left(\frac{\rho_{He}}{\rho_s} \right) \left(\frac{\eta_{He}}{\eta_s} \right) \\ &= \frac{61}{16.75} \times \frac{428.4}{452} \times \frac{88}{89} = \underline{3.41} \end{aligned}$$

AFTER SCRAM NOTE: THE FOLLOWING IS BASED ON THE ORIGINAL BLOWER CONTROL SPECIFICATIONS, SEE APPENDIX A-5 FOR REVISED CALCULATIONS

AFTER SCRAM, THE FLOW OF STEAM THAT THE BLOWER PUMPS DECREASES UNTIL THE PRESSURE ACROSS THE FLOWMETER INDICATOR IS THAT WHICH IS EQUIVALENT TO THE PRESSURE CAUSED BY A 20% FLOW OF HELIUM:

$$\Delta P = \frac{KW^2}{\rho} \quad \text{ACROSS THE FLOWMETER, } K \text{ IS A CONSTANT}$$

$$\Delta P_{He-20\%} = \frac{KW_{He-20}^2}{\rho_{He-20}}$$

REACTOR COOLANT BLOWERS

STUDY IX-334

SIMILAR TO

DR'N R.S. 10-16-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET A-8 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

$$\Delta P_s = \frac{KW_s^2}{P_s} = \frac{KW_{He-20}^2}{P_{He-20}}$$

$$\therefore \frac{W_s^2}{W_{He-20}^2} = \frac{P_s}{P_{He-20}} = \left(\frac{0.78}{0.12} \right)$$

$$\frac{W_s}{W_{He-20}} = 2.55$$

① SYSTEM PRESSURE DROP

$$\begin{aligned} \frac{\Delta P_s}{\Delta P_{He-20}} &= \left(\frac{G_s}{G_{He-20}} \right)^{1.8} \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= \left(\frac{W_s}{W_{He-20}} \right)^{1.8} \left(\frac{P_{He-20}}{P_s} \right) \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= \left[\left(\frac{P_s}{P_{He-20}} \right)^{.5} \right]^{1.8} \left(\frac{P_{He-20}}{P_s} \right) \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= \left(\frac{P_{He-20}}{P_s} \right)^{.1} \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= \left(\frac{0.12}{0.78} \right)^{.1} \left(\frac{1.41 \times 10^{-5}}{1.94 \times 10^{-5}} \right)^{-2} \\ &\approx 0.780 \end{aligned}$$

$$G = Vp$$

$$= \frac{W}{A}$$

FROM JOY SUPPLEMENT, $\Delta P_{He-20} = 0.8$ PSI RISE, OR ALSO 0.8 PSI DROP THROUGH SYSTEM

$$\therefore \Delta P_s = 0.780 \times 0.8 = 0.624 \text{ PSI}$$

② VELOCITY FLOW RATE OF STEAM (AXIAL)

$$\frac{W_{He-20}}{W_{He-100}} = \frac{V_{20} P_{20} A_{20}}{V_{100} P_{100} A_{100}}$$

$$\frac{43,000}{215,000} = \frac{V_{20} \times 0.12}{452 \times 0.718}$$

$$V_{20} = 88.9 \text{ FT/SEC.}$$

REACTOR COOLANT BLOWERS

STUDY IX-334

SIMILAR TO

DR'N R.S. 10-16-61

CH'D A.H.G.

APP'D

SCALE

=12

SHEET 19 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

$$W_s = 2.55 W_{H_2} \quad (\text{SEE ABOVE})$$

$$P_s V_s A_s = 2.55 V_{20} P_{20} A_{20}$$

$$V_s = 2.55 \times 88.9 \times \frac{0.12}{0.78}$$

$$\approx 35 \text{ FT/SEC}$$

③ CONSTRUCTION OF VELOCITY TRIANGLE AND DETERMINATION OF V_b

KNOWN :

(1) AXIAL VELOCITY OF STEAM = 35 FT/SEC

(2) ΔP DROP IN SYSTEM = 0.624 PSI

(3) ΔP RISE IN BLOWER ALSO = 0.624 PSI

TRIAL AND ERROR SOLN.

④ FIRST TRIAL - TRIANGLE SIMILAR TO TRIANGLE ON SHEET 3
($\therefore V_b = 39.5$)

$$C_d = 0.425$$

$$\theta = 9.5^\circ$$

$$\frac{P_2}{P_1} = \left(1 + \frac{39.5 \times 40.5 \times 0.425 \times 88}{2 \times 32.2 \times 778 \times 0.78 \times 888} \right)^{\frac{1.29}{0.29}}$$

ASSUME EFFICIENCY OF 50% SINCE BLADE SPEED IS VERY LOW, AND FLOW RATE IS ALSO LOW - WILL CHK. EFF. LATER

$$\therefore \frac{P_2}{P_1} = (1.0000204)^{2.22}$$

NO 1.01 FACTOR SINCE RATIO IS SO SMALL - SEE SHEET 4

10 STAGES

$$\frac{P_2}{P_1} = (1.0000204)^{22.2}$$

REACTOR COOLANT BLOWERS

STUDY II-334

SIMILAR TO

DR'N R.S. 12-16-61

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET NO OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

$$\frac{P_2}{P_1} = 1.0005$$

$$P_2 = 1.0005 \times 365 = 365.183$$

$$\Delta P = 0.183 \quad \text{TOO SMALL}$$

⑥ SECOND TRIAL - $V_b = 44.6$, TRIANGLE SCALED DOWN FROM SHEET 6

$$C_d = 0.56$$

$$\theta = 12.3^\circ$$

η STILL ABOUT SAME AS ABOVE $\approx 50\%$

$$\frac{P_2}{P_1} = \left(1 + \frac{44.6 \times 50.7 \times .56 \times .88}{2 \times 32.2 \times 778 \times .78 \times 856} \right)^{2.22}$$

10 STAGES: $\frac{P_2}{P_1} = (1.0000319)^{22.2}$
 $= 1.000709$

$$P_2 = 1.000709 \times 365 = 365.258$$

$$\therefore \Delta P = 0.258 \text{ PSI} \quad \text{STILL TOO SMALL}$$

⑦ THIRD TRIAL - $V_b = 60.6$ (TO GIVE $\beta_1 = 60^\circ$)

$$C_d = 0.71$$

$$\theta = 15^\circ$$

REACTOR COOLANT BLOWERS

STUDY IV-334

SIMILAR TO

DR'N R.L.S. 10-16-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 11 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

A

B

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

$$\frac{P_2}{P_1} = \left(1 + \frac{58.5 \times 60.6 \times .71 \times .88}{2 \times 32.2 \times .778 \times .78 \times 896} \right)^{2.22}$$

10 STAGES

$$\frac{P_2}{P_1} = (1.0000635)^{22.2}$$

$$= 1.00141$$

$$P_2 = 1.00141 \times 365 = 365.515$$

$$\Delta P = .515 \text{ PSI}$$

BY EXTRAPOLATION, FOR A $\Delta P = 0.624 \text{ PSI}$, THE BLADE VELOCITY IS APPROXIMATELY:

$$39.5 + (60.6 - 39.5) \frac{(.624 - .165)}{(.515 - .165)} \approx 67 \text{ FT/SEC.}$$

$$\text{OR } \frac{67}{509} \times 6130 \approx 810 \text{ RPM}$$

→ NOTE HOWEVER THAT THE ANSWER ABOVE WOULD GIVE A $\beta = \tan^{-1} 67/35 = 62^\circ$ AND THEREFORE AN α OF ATTACK OF 20° . THIS IS CLEARLY IN THE SURGE REGION AS CAN BE SEEN FROM THE NACA REPORT.

AN EFFICIENCY OF .50 USED ABOVE IS PROBABLY TOO HIGH. A LOWER EFFICIENCY WOULD MOVE THE RESULTS FURTHER INTO THE SURGE REGION.

THE TIME REQUIRED TO REDUCE THE FLOW FROM 100% SPEED TO SCRAM SPEED IS NOT LESS THAN:

$$\frac{1}{428} \times \frac{428 - 35}{7.5 \times 10^{-2}} \approx \underline{61 \text{ SECONDS}}$$

REACTOR COOLANT BLOWERS

STUDY IX-334

SIMILAR TO

DR'N R.P.S.

10-16-61

CH'D

APP'D

SCALE

=12

SHEET A-12 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A

B

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

C. AIR FLOW

CONDITION : 14.7 PSI
70°F (530°R)
 $C_p = 0.24 \text{ BTU/LB}$
 $\rho = 0.0753 \text{ LB/FT}^3$

AGAIN THE POINT WHERE THE BLOWER PRESSURE RISE EQUALS THE SYSTEM PRESSURE DROP MUST BE OBTAINED. RIGHT AFTER THE ACCIDENT THE INERTIA OF THE BLOWER KEEPS ITS BLADE VELOCITY CONSTANT.

① FIRST TRIAL

$V_{\text{AXIAL}} = 452 \text{ FT/SEC}$ — SAME AS TRIANGLE ON SHEET 3

$C_L = 0.425$
 $\theta = 9.5^\circ$

$$\frac{P_2}{P_1} = 1.01^{\frac{1}{10}} \left(1 + \frac{509 \times 626 \times 0.425 \times 0.88}{2 \times 32.2 \times 778 \times 0.24 \times 530} \right)^{0.88 \times \frac{1.4}{1.4}}$$

10 STAGES: $\frac{P_2}{P_1} = 1.01 (1.01872)^{20.8}$
 $= 1.79$

$$P_2 = 1.79 \times 14.7 = 26.3 \text{ PSI}$$

$$\therefore \Delta P = 26.3 - 14.7 = 11.6 \text{ PSI}$$

AT THIS AXIAL VELOCITY (452 FT/SEC), THE SYSTEM PRESSURE DROP CAN BE ESTIMATED.

$$\frac{\Delta P_A}{\Delta P_{H_2O}} = \left(\frac{G_A}{G_{H_2O}} \right)^{1.8} \left(\frac{V_A}{V_{H_2O}} \right) \left(\frac{\mu_A}{\mu_{H_2O}} \right)^{-2}$$

$$\frac{G_A}{G_{H_2O}} = \frac{P_A}{P_{H_2O}} = \frac{0.0753}{0.118} = 0.638$$

REACTOR COOLANT BLOWERS

STUDY III-334

SIMILAR TO

DR'N R.I.S. 10-17-61

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET 13 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

A

B

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

$$\frac{V_A}{V_{Ne}} = \frac{.118}{.0753} = 1.57$$

$$\frac{u_A}{u_{Ne}} = \frac{.018 \times .000672}{1.94 \times 10^{-5}} = 0.624$$

$$\frac{\Delta P_A}{\Delta P_{Ne}} = (.638)^{1.8} (1.57)(.624)^2 = 0.635$$

$$\Delta P_A = .635 \times 16.75 = 10.62 \text{ PSI} \quad \text{THIS IS CLOSE}$$

② SECOND TRIAL - $V_A = 475 \text{ FT/SEC.}$

SINCE $\beta_1 = 47^\circ$, THE DATA FOR $\beta_1 = 45^\circ$ IN NACA WILL BE USED

V	SECTION	θ	C_L
0.50	65-410	4.2	0.38
0.50	65-12-10	8.2	0.65
0.50	65-18-10	10.8	0.80
0.75	65-410	5	0.26
0.75	65-12-10	10	0.52
0.75	65-18-10	-	-
1.00	65-410	7	0.27
1.00	65-810	10	0.39
1.00	65-12-10	12.3	0.44

ESTIMATED FOR $\beta_1 = 47^\circ$, 65-7-10, $V = .88$ } $\theta = 8.3^\circ$
 $C_L = 0.38$

$$\frac{P_2}{P_1} = 1.01^{\frac{1}{10}} \left(1 + \frac{509 \times 651 \times .38 \times .88}{2 \times 32.2 \times 778 \times .24 \times 530} \right)^{.84 \times \frac{1.4}{4}} \quad \text{EFF. DECREASES SLIGHTLY}$$

$$= 1.01^{\frac{1}{10}} (1.01743)^{2.94}$$

REACTOR COOLANT BLOWERS

STUDY II-334

SIMILAR TO

DR'N R.S. 10-17-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 14 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT. - NPD-W

APPENDIX A

A

B

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

10 STAGES: $\frac{P_2}{P_1} = (1.01)(1.663) = 1.68$

$P_2 = 1.68 \times 14.7 = 24.7$

$\therefore \Delta P = 24.7 - 14.7 = 10 \text{ PSI}$

SYSTEM PRESSURE DROP

$$\frac{\Delta P_R}{\Delta P_{A'}} = \left(\frac{G_R}{G_{A'}}\right)^{1.8} \left(\frac{V_{A'}}{V_R}\right)^2 \quad \text{WHERE } A' \text{ IS AIR AT } 452 \text{ FT/SEC}$$

$$= \left(\frac{V_R P_R}{V_{A'} P_{A'}}\right)^{1.8} = \left(\frac{475}{452}\right)^{1.8}$$

$$= 1.092$$

$\therefore \Delta P = 1.092 \times 10.62 = 11.6 \text{ PSI}$

THE POINT WHERE THE PRESSURES ARE EQUAL IS DETERMINED BY INTERPOLATION

$\Delta = .98 \quad [11.60 - 10.62] \rightarrow 452 \text{ FT/SEC}$

$\Delta = -1.6 \quad [10 - 11.6] \rightarrow 475 \text{ FT/SEC}$

$\Delta V = 23$

$\Delta(\Delta) = 2.58$

$\therefore V_A = 452 + \frac{.98}{2.58} \times 23 = \underline{461} \text{ FT/SEC AXIAL}$

$\Delta P \approx \underline{10.5} \text{ PSI}$

THE ABOVE CALCULATIONS ALSO SHOWED THAT OPERATION IS NOT IN SURGE REGION SINCE INCREASE IN FLOW RATE DECREASED P_2/P_1

POWER RATIO

AS ON SHEET 8

$$\frac{P_R}{P_{MC}} = \left(\frac{\Delta P_R}{\Delta P_{MC}}\right) \left(\frac{V_R}{V_{MC}}\right) \left(\frac{.88}{.86}\right)$$

$$= \left(\frac{10.5}{16.75}\right) \left(\frac{461}{452}\right) \left(\frac{.88}{.86}\right) = \underline{0.655}$$

REACTOR COOLANT BLOWERS

STUDY IV - 334

SIMILAR TO

DR'N R.P.S. 10-17-64

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 15 OF 26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

A

B

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

NOTE: THE FOLLOWING IS BASED ON THE ORIGINAL BLOWER CONTROL
AFTER SCRAM SPECIFICATIONS, SEE APPENDIX A-5 FOR REVISED RESULTS.
 AFTER SCRAM, THE CALCULATION IS SIMILAR TO THAT PREVIOUSLY
 USED FOR STEAM - SHEET B

$$\frac{W_A}{W_{He-20}} = \left(\frac{P_A}{P_{He-20}} \right)^{.5} = \left(\frac{.0753}{.12} \right)^{.5} = 0.792$$

① SYSTEM PRESSURE DROP

$$\frac{\Delta P_A}{\Delta P_{He-20}} = \left(\frac{G_A}{G_{He-20}} \right)^{1.8} \left(\frac{N_A}{N_{He-20}} \right) \left(\frac{\mu_A}{\mu_{He-20}} \right)^{.2}$$

$$\begin{aligned} \frac{\Delta P_A}{\Delta P_{He-20}} &= \left(\frac{P_{He-20}}{P_A} \right)^{.1} \left(\frac{\mu_A}{\mu_{He-20}} \right)^{.2} \\ &= \left(\frac{0.12}{0.0753} \right)^{.1} \left(\frac{.018 \times .000672 \text{ LB/FT-SEC}}{1.94 \times 10^{-5}} \right)^{.2} \\ &= 0.954, \therefore \Delta P_A = .954 \times .8 = \underline{0.762 \text{ PSI}} \end{aligned}$$

② FLOW RATE

$$\frac{W_{He-20}}{W_{He-100}} = \frac{V_{20}}{V_{100}} \frac{P_{20}}{P_{100}}$$

$$\frac{43,000}{215,000} = \frac{V_{20}}{452} \times \frac{0.12}{0.118}$$

$$V_{He-20} = \frac{43,000}{215,000} \times 452 \times \frac{.118}{.12} \approx 89 \text{ FT/SEC}$$

$$\frac{W_A}{W_{He-20}} = 0.792 = \frac{V_A P_A A_A}{V_{20} P_{20} A_{20}}$$

$$\therefore V_A = 0.792 \times 89 \times \frac{0.12}{0.0753}$$

$$= \underline{112 \text{ FT/SEC}}$$

③ CONSTRUCTION OF TRIANGLE AND V_b DETERMINATION

KNOWN:

(1) AXIAL VELOCITY OF AIR = 112 FT/SEC.

(2) ΔP DROP IN SYSTEM = 0.762 PSI

(3) ΔP RISE IN BLOWER = 0.762 PSI

REACTOR COOLANT BLOWERS

STUDY II-334

SIMILAR TO

DRN RPS. 10-17-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 16 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

① FIRST TRIAL - TRIANGLE SIMILAR TO THAT ON SHEET 13
 $(\therefore V_b = 126 \text{ FT/SEC})$

$$C_L = 0.425$$

$$\theta = 9.5^\circ$$

ASSUME EFFICIENCY OF .60 FROM BLADE SPEED AND VOLUME
 FLOW - USING JOY SUPPLEMENT

$$\frac{P_2}{P_1} = \left(1 + \frac{126 \times 155 \times .425 \times .88}{2 \times 32.2 \times 778 \times .24 \times 530} \right)^{\frac{.60 \times 1.4}{.4}}$$

10 STAGES: $\frac{P_2}{P_1} = (1.001148)^{21}$
 $= 1.0244$

$$P_2 = 1.0244 \times 14.7 = 15.059$$

$$\therefore \Delta P \approx 0.359 \quad \text{TOO SMALL}$$

② SECOND TRIAL - TRIANGLE SIMILAR TO THAT ON SHEET 6

$$C_L = 0.56$$

$$\theta = 12.3^\circ$$

$$\frac{P_2}{P_1} = \left(1 + \frac{142.2 \times 162.2 \times .56 \times .88}{2 \times 32.2 \times 778 \times .24 \times 530} \right)^{2.1}$$

$$= (1.001785)^{2.1}$$

10 STAGES: $\frac{P_2}{P_1} = (1.001785)^{21}$

REACTOR COOLANT BLOWERS

STUDY IV - 334

SIMILAR TO

SHEET 17 OF A-26

ISSUE

DR'N R.P.S. 10-12-61

CH'D A.H.G.

APP'D

SCALE

= 12

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

$$\frac{P_2}{P_1} = 1.04$$

$$P_2 = 1.04 \times 14.7 = 15.3$$

$$\therefore \Delta P = 15.3 - 14.7 = 0.6 \text{ PSI}$$

BY EXTRAPOLATION:

$$V_b = 126 + (142.2 - 126) \frac{(.762 - .359)}{(.600 - .359)} = \underline{153} \text{ FT/SEC}$$

$$\text{OR } \frac{153}{509} \times 6130 \approx \underline{1840} \text{ RPM}$$

THE TIME REQUIRED TO REDUCE THE FLOW FROM 100%
SPEED TO SCRAM SPEED IS:

$$\text{TIME} = \frac{481 - 112}{461} \times \frac{10^2}{1.5\% \text{ SEC}} \approx \underline{50} \text{ SECONDS}$$

REACTOR COOLANT BLOWERS

STUDY II - 334

SIMILAR TO

DR'N R.I.S. 10-7-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 18 OF 26

ISSUE

FALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

BLADE STRESSES

1- BLADE ROOT STRESSES

Ⓐ TENSILE STRESS DUE TO CENTRIFUGAL FORCE

CENTRIFUGAL FORCE OF ELEMENT dr AT RADIUS r IS:

$$dF = \frac{\rho}{g} A dr \omega^2 r$$

$$F = \int_{r_n}^{r_t} \frac{\rho A \omega^2}{g} r dr$$

$$= \frac{\rho A \omega^2}{g} \left(\frac{r_t^2}{2} - \frac{r_n^2}{2} \right)$$

$$= \frac{\rho A \omega^2}{g} \left(\frac{r_t + r_n}{2} \right) (r_t - r_n)$$

BUT: $r_m = \frac{r_t + r_n}{2}$, $l = r_t - r_n$ BLADE LENGTH

$$\therefore F = \frac{\rho A \omega^2}{g} \cdot l r_m$$

$$\tau_F = \frac{F}{A} = \frac{\rho \omega^2}{g} l r_m$$

$$\omega = \frac{2\pi N}{60} = \frac{6.28 \times 6130}{60} = 641 \frac{\text{RAD.}}{\text{SEC}}$$

$$r_m = \frac{8.16 + 10.88}{2} = 9.52 \text{ IN.}$$

$$l = 2.72 \text{ IN.}$$

$$g = 386 \text{ IN/SEC}^2$$

$$\rho = 0.283 \text{ LB/IN}^3$$

$$\therefore \tau_F = \frac{.283 \times 641^2}{386} \times 2.72 \times 9.52 = 7840 \text{ PSI}$$

Ⓑ BENDING DUE TO GAS LOADING

AT DESIGN SPEED OF 6750 RPM

$$\sqrt{B} = 1.347 \quad S = 20.12$$

$$(U\Delta)_{ACT} = (U \cdot \sqrt{B}) (\Delta_{CORR} \cdot \sqrt{B}) \quad (\text{FROM JOY REPORT})$$

REACTOR COOLANT BLOWERS

STUDY II-334

SIMILAR TO

DR'N R.L.S. 10-17-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 119 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

$$(U\Delta)_{\text{CORR. PER STAGE}} = 55,350$$

$$(U\Delta)_{\text{ACT. PER STAGE}} = 55,350 (1.347)^2 = 100,400 \text{ FT}^2/\text{SEC}^2$$

$U\Delta$ IS A CONSTANT FOR FREE-VORTEX FLOW

$$\Delta = \frac{100,400}{U} ; (\Delta U) = 100,400$$

$$\text{TORQUE: } T = \frac{W\Delta}{g} \text{ OR } \frac{\Delta W \Delta}{g}$$

$$\text{LOAD: } R = \frac{T}{\text{COP} \cdot Y}$$

$$\text{ANNULUS AREA} = \frac{\pi}{4} (21.76^2 - 16.32^2) = 162.2 \text{ IN}^2 \text{ (AGREES WITH JOY)}$$

IF WE DIVIDE THE ANNULUS AREA INTO INCREMENTS, WE MAY WRITE:

$$\Delta W = W_{\text{TOTAL}} \times \frac{\text{AREA OF INCREMENT}}{\text{TOTAL ANNULUS AREA}}$$

$$\Delta W = W_{\text{TOT}} \times \frac{\Delta A}{A}$$

NOW:

$$\frac{W_s}{W_{He}} = \frac{P_s V_s A_s}{P_{He} V_{He} A_{He}} = \frac{.78}{.118} \times \frac{428.4}{452} = 6.2$$

$$\therefore W_{\text{TOTAL}} (= W_s) = 6.2 \times \frac{215,000}{3600} \approx 350 \frac{\text{LB}}{\text{SEC}}$$

DIVIDING UP THE ANNULUS AREA, A TABLE IS SET UP:

STA.	RAD. IN.	MEAN R IN.	ΔA IN ²	U FT/SEC	Δ FT/SEC	ΔW LBS.	T LBS	V DEG	R LBS	R' LBS	L IN.	M IN-LBS
1	8.16	> 8.50	36.45	455	221	78.5	442	37.3	554	554	0.34	188
2	8.84	> 9.18	38.97	491	204.3	83.6	436	40.6	579	575	1.02	588
3	9.52	> 9.86	42.10	528	190.3	90.5	441	43.4	607	602	1.70	1022
4	10.20	> 10.54	45.25	564	178.4	97.4	443	45.7	632	627	2.38	1490
5	10.88											
TOTAL											3288	

* SEE NEXT SHEET

REACTOR COOLANT BLOWERS

STUDY IV-334

SIMILAR TO

DR'N R.P.S. 10-17-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 20 OF 26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

APPENDIX A

WHERE:

$$R' = R \cos. (V_n - \gamma_{\text{root}})$$

$$M = R' \times l \quad \text{WHERE } l \text{ IS DISTANCE FROM ROOT TO CENTER OF INCREMENT UNDER CONSIDERATION}$$

MAXIMUM BENDING MOMENT PER BLADE:

$$\frac{3288}{28} = 94.0 \text{ IN-LB}$$

MOMENT OF INERTIA OF THE BLADE CROSS-SECTION IS:

$$I_{xx} = 3.5 C^4 \times 10^{-5} = 3.5 \times 1.5^4 \times 10^{-5} = 17.73 \times 10^{-5} \text{ IN}^4 \text{ (FROM JOY)}$$

$$V_b = \frac{M y}{I_{xx}} = \frac{94.0 \times 0.88}{17.73 \times 10^{-5}} = 46,500 \text{ PSI}$$

∴ TENSILE STRESS AT ROOT IS;

$$7840 + 46,500 = \underline{54,500} \text{ PSI} \quad (\text{YIELD STRESS IS } 30,000 \text{ PSI})$$

2 - BLADE ATTACHMENT STRESSES

① RIM SEGMENT TENSILE STRESS

THIS IS PRODUCED BY THE CENTRIFUGAL LOAD OF THE RIM SEGMENT ITSELF AND THE CENTRIFUGAL LOAD OF THE BLADE DOVETAIL ATTACHMENT.

① FROM BEFORE, $F = T_f A$, WHERE A IS THE AREA OF THE AIRFOIL CROSS SECTION, AND, FOR AN AIRFOIL OF THICKNESS EQUAL TO 10% OF THE CHORD, IS GIVEN BY:

$$A = 0.0652 C^2 \quad \text{WHERE } C = \text{CHORD}$$

$$= 0.0652 \times 1.5^2$$

$$= 0.1466 \text{ IN}^2 \quad (\text{AGREES WITH JOY})$$

$$\therefore F = 7840 \times 0.1466 = \underline{1148} \text{ LBS}$$

② FROM DIMENSIONS GIVEN IN FIGURE 4 OF JOY, THE END AREA OF THE BLADE DOVETAIL IS:

$$A_{\text{DOVE}} = .265 (.3) + .1878 (.0663)$$

REACTOR COOLANT BLOWERS

STUDY IX - 334

SIMILAR TO

DR'N R.S.S. 10-17-61

CH'D A.H.G.

APP'D

SCALE = 12

SHEET 21 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

$$A_{\text{DOV}} = 0.0920 \text{ IN}^2 \text{ (AGREES WITH JOY)}$$

CENTRIFUGAL FORCE PRODUCED BY THE BLADE DOVETAIL IS:

$$\begin{aligned} & (W/g) r_m \omega^2 \\ & = .092 \times \frac{1.3125}{\cos. 29.18^\circ} \times \frac{.283}{386} (8.16-.15)(641)^2 \\ & = \underline{333 \text{ LBS.}} \end{aligned}$$

③ CENTRIFUGAL LOAD OF THE RIM SEGMENT

END AREA OF RIM SEGMENT = A_{RIM} :

$$A_{\text{RIM}} = 1.171 \times .3 - .1846 \times .1292 = 0.3274 \text{ IN}^2 \text{ (AGREES WITH JOY)}$$

$$\begin{aligned} \therefore F_{\text{RIM}} & = \frac{.3274 \times 1.3125}{\cos. 29.18^\circ} \times \frac{.283}{386} \times 8.01 \times 641^2 \\ & = \underline{1183 \text{ LBS}} \end{aligned}$$

TOTAL LOAD ON RIM SEGMENT IS :

$$F = 1148 + 333 + 1183 = 2664 \text{ LBS}$$

CROSS-SECTIONAL AREA OF RIM-SEGMENT IS :

$$\begin{aligned} A & = \left[\frac{2\pi(7.918)}{35} - 2(.212) \right] \times \frac{1.3125}{\cos. 29.18^\circ} \\ & = 1.502 \text{ IN}^2 \text{ (AGREES WITH JOY)} \end{aligned}$$

$\therefore$ TENSILE STRESS ON RIM SEGMENT IS :

$$T_{\text{RIM}} = \frac{2664}{1.502} = \underline{1773 \frac{\text{LBS}}{\text{IN}^2}}$$

⑥ COMPRESSIVE STRESS DUE TO BEARING LOADS ON RIM - DOVETAIL CONTACT SURFACE - (SURFACE B-C IN FIG. 4 OF JOY)

BEARING LOADS ARE MADE UP OF:

- (1) CENTRIFUGAL LOAD OF BLADE
- (2) CENTRIFUGAL LOAD OF BLADE DOVETAIL
- (3) UNBALANCE LOAD DUE TO BLADE BENDING MOMENT

REACTOR COOLANT BLOWERS

STUDY IX-334

SIMILAR TO

DR'N R.E.S. 10-17-61

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET 22 OF 26

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

APPENDIX A

FROM BEFORE:

(1) CENTRIFUGAL LOAD OF BLADE = 1148 LBS

(2) CENTRIFUGAL LOAD OF BLADE DOVETAIL = 333 LBS

(3) BLADE BENDING MOMENT = 94.0 IN-LBS

LOAD DUE TO BENDING MOMENT = $\frac{94.0}{0.33} = \underline{285}$ LBS

∴ BEARING LOAD = 1148 + 333 + 285
= 1766 LBS

← FROM JOY DIAGRAM 4

N = LOAD NORMAL TO BEARING SURFACE

= $\frac{1766}{2 \cos 55^\circ} = \frac{1766}{2 \times .5535} = 1598$ LBS

BEARING AREA PER SIDE:

= $\frac{.083 \times 1.3125}{\cos 29.18^\circ} = 0.1247$ IN² (AGREES WITH JOY)

∴ $T_{br} = \frac{1598}{.1247} = \underline{\underline{12,820}}$ PSI

© BLADE DOVETAIL SHEAR TEAR-OUT

BLADE DOVETAIL SHEAR TEAR-OUT WOULD TEND TO OCCUR ACROSS SECTION C-C IN FIGURE 4. SHEAR TEAR-OUT WOULD BE CAUSED BY THE CENTRIFUGAL LOAD OF THE BLADE AND DOVETAIL

TEAR-OUT LOAD = 1148 + 333
= 1481 LBS

SHEAR AREA = $2 \times .1878 \times \frac{1.3125}{\cos 29.18^\circ} = 0.5645$ IN² (AGREES WITH JOY)

∴ $T_{sh} = \frac{1481}{.5645} = \underline{\underline{2630}}$ PSI

© RIM SEGMENT SHEAR TEAR-OUT

THE SAME LOADS WHICH TEND TO PRODUCE BLADE DOVETAIL SHEAR TEAR-OUT WOULD TEND TO PRODUCE RIM SEGMENT SHEAR TEAR-OUT ACROSS SECT. B-D IN FIG. 4 OF JOY.

REACTOR COOLANT BLOWERS

STUDY IV-334

SIMILAR TO

DR'N R.Y.S.

10-17-61

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET 23 OF A-26

ISSUE

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APPENDIX A

A

B

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

TEAR-OUT LOAD = 1481 LBS

$$\text{SHEAR AREA} = 2(.300 - .093) \times \frac{1.3125}{\cos 29.18^\circ} \\ = 0.622 \text{ IN}^2 \text{ (AGREES WITH JOY)}$$

$$\therefore \tau_{SN} = \frac{1481}{.622} = \underline{\underline{2381 \text{ PSI}}}$$

SUMMARY OF BLADE STRESSES (STEAM AT 6130RPM)

1. BLADE ROOT STRESSES - - - - - 54,500 PSI

2. BLADE ATTACHMENT STRESSES

- Ⓐ RIM SEGMENT TENSILE STRESS - - - - - 1,773 PSI
- Ⓑ COMPRESSIVE STRESS - - - - - 12,820 PSI
- Ⓒ BLADE DOVETAIL SHEAR TEAR-OUT - - - - - 2,630 PSI
- Ⓓ RIM SEGMENT SHEAR TEAR-OUT - - - - - 2,381 PSI

REACTOR COOLANT BLOWERS

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SCALE = 12

SHEET 24 OF A-26

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT. NPD-W

APPENDIX A

NOMENCLATURE

A = CROSS SECTIONAL AREA, FT.^2 OR IN.^2
 C_L = LIFT COEFFICIENT
 C_p = SPECIFIC HEAT AT CONSTANT PRESSURE, $\text{BTU/LB.}^\circ\text{F}$
 D = DIAMETER, FT. OR IN.
 F = FORCE, LBS.
 f = FANNING FRICTION FACTOR, DIMENSIONLESS
 G = FLOW RATE, LB./SEC.-FT^2
 g = ACCELERATION DUE TO GRAVITY, FT/SEC^2 OR IN/SEC^2
 I = MOMENT OF INERTIA, IN^4
 J = MECHANICAL EQUIVALENT OF HEAT, FT.-LBS/BTU
 k = RATIO OF SPECIFIC HEATS, C_p/C_v
 L = LENGTH OF TUBE, FT OR IN
 l = BLADE LENGTH, IN — DISTANCE FROM BLADE ROOT, IN
 M = MOMENT, IN.-LBS
 N = LOAD NORMAL TO SURFACE, LBS
 P = PRESSURE — POWER
 P_1 = INLET PRESSURE TO BLOWER OR STAGE, PSI
 P_2 = OUTLET PRESSURE FROM BLOWER OR STAGE, PSI
 ΔP = PRESSURE DIFFERENTIAL, PSI
 R = LOAD, LBS
 R' = LOAD PERPENDICULAR TO BLADE ROOT, LBS
 Re = REYNOLDS NUMBER, DIMENSIONLESS
 r_h = BLADE ROOT RADIUS, INCHES
 r_t = BLADE TIP RADIUS, IN
 r = RADIUS, IN
 r_m = MEAN BLADE RADIUS, IN
 r_h = HYDRAULIC RADIUS
 T = TORQUE, LBS. — TEMPERATURE, $^\circ\text{R}$
 T_1 = INLET TEMPERATURE TO BLOWER, $^\circ\text{R}$
 U = BLADE VELOCITY, FT/SEC (ALSO V_b)
 V = VELOCITY, USUALLY AXIAL, FT/SEC

REACTOR COOLANT BLOWERS

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APP'D

SCALE = 12

SHEET **25** OF **A-26**

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT. NPD-W

APPENDIX A

V_{corr} = CORRECTED AXIAL VELOCITY, FT/SEC
 V_{act} = ACTUAL AXIAL VELOCITY, FT/SEC
 V_b = BLADE VELOCITY, FT/SEC (ALSO U)
 N = SPECIFIC VOLUME, FT³/LB
 N_{R_1} = INLET VELOCITY RELATIVE TO ROTOR BLADE, FT/SEC
 N_{R_2} = OUTLET VELOCITY RELATIVE TO ROTOR BLADE, FT/SEC
 N_{Rm} = MEAN VELOCITY RELATIVE TO ROTOR BLADE, FT/SEC
 W = MASS FLOW, LBS/HR
 y = HALF-THICKNESS OF BLADE, IN

GREEK SYMBOLS

α = ANGLE OF ATTACK, DEGREES
 β_1 = ANGLE OF APPROACH TO ROTOR - MEASURED FROM AXIS, DEGREES
 β_2 = ANGLE OF DEPARTURE FROM ROTOR, DEGREES
 γ = SETTING ANGLE - IN STRESS ANALYSIS, DEGREES
 Δ = CHANGE OF — CHANGE OF TANGENTIAL VELOCITY, FT/SEC.
 δ = $P/14.7$, DIMENSIONLESS
 η = ADIABATIC EFFICIENCY, DIMENSIONLESS
 θ = TURNING ANGLE, DEGREES
 $\sqrt{b}$ = $\sqrt{T/520}$, DIMENSIONLESS
 ρ = DENSITY, LB/FT³ OR LB/IN³
 ∇ = SOLIDITY, DIMENSIONLESS — STRESS, LB/IN²
 ω = ANGULAR FREQUENCY, RADIANS/SEC

OTHER SUBSCRIPTS

A = AIR OR AXIAL
 He = HELIUM
 S = STEAM
 $20,100$ = AT 20% FLOW, AT 100% FLOW
 400 = AT AXIAL VELOCITY OF 400 FT/SEC
 452 = AT AXIAL VELOCITY OF 452 FT/SEC
 PS = AT PSEUDO OPERATING POINT

REACTOR COOLANT BLOWERS

STUDY II-334

SIMILAR TO

DR'N R.S. 10-B-61	CH'D A.H.G.	APP'D	SCALE = 12	SHEET A-26 OF A-26	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT. NPD-W				APPENDIX A	

A

B

THE PRECEDING WAS THE ANALYSIS BASED ON THE SUPPOSITION THAT BOTH BLOWERS WOULD CONTINUE TO OPERATE WITH THE INTRODUCTION OF STEAM OR AIR INTO THE SYSTEM. THE FOLLOWING IS THE ANALYSIS WHEN ONLY ONE BLOWER CONTINUES TO OPERATE WHEN STEAM REPLACES THE HELIUM.

② OTHER THAN CORE

$$\frac{\Delta P_s}{\Delta P_{He}} = \left(\frac{G_s}{G_{He}} \right)^{1.8} \left(\frac{N_s}{N_{He}} \right) \left(\frac{\mu_s}{\mu_{He}} \right)^{.2}$$

⑥ CORE

$$\frac{\Delta P_s}{\Delta P_{He}} = \left(\frac{G_s}{2G_{He}} \right)^{1.8} \left(\frac{N_s}{N_{He}} \right) \left(\frac{\mu_s}{\mu_{He}} \right)^{.2}$$

I. BEFORE SCRAM - FIRST TRIAL (SAME VOLUME FLOW RATE AS IN ONE HELIUM LOOP)

$$\frac{G_s}{G_{He}} = \frac{P_s}{P_{He}} = 6.61$$

$$\Delta P_{He} = 10.25 \text{ PSI ACROSS CORE}$$

$$\frac{G_s}{2G_{He}} = 3.30$$

$$\Delta P_{He} = 6.50 \text{ PSI ACROSS REST OF LOOP}$$

$$\frac{N_s}{N_{He}} = 0.151$$

$$\frac{\mu_s}{\mu_{He}} = 0.728$$

② OTHER THAN CORE

$$\frac{\Delta P_s}{\Delta P_{He}} = (6.61)^{1.8} (.151) (.728)^{.2}$$

$$= 4.25$$

$$\therefore \Delta P_s = 4.25 \times 6.50 = 27.6 \text{ PSI } \checkmark$$

⑥ CORE

$$\frac{\Delta P_s}{\Delta P_{He}} = (3.3)^{1.8} (.151) (.728)^{.2}$$

$$= 8.58 \times .151 \times .9385$$

$$= 1.22 \checkmark$$

$$\Delta P_s = 1.22 \times 10.25 = 12.5$$

$$\therefore \text{TOTAL } \Delta P = \underline{40.1 \text{ PSI}}$$

REACTOR COOLANT BLOWERS

STUDY IV-334

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APP'D

SCALE

= 12

SHEET A-2-1

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A

B

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AGAIN AS ON SHEETS A-5 AND A-6 THIS IS NOT THE FINAL PRESSURE DIFFERENTIAL. AS BEFORE, THE BLADE SPEED IS ASSUMED CONSTANT (FOR A WHILE AT LEAST) AT 509 FT./SEC. AND THE STEAM VELOCITY WILL HAVE TO CHANGE TO MAKE THE BLOWER PRESSURE RISE EQUAL THE SYSTEM PRESSURE DROP.

FOR THE FIRST TRIAL ABOVE, THE PRESSURE RISE THROUGH THE BLOWER IS AGAIN 98 PSI AS ON SHEETS A-4 AND A-5 ($V_A = 452$ FT/SEC).

II SECOND TRIAL - $V_A = 475$ FT/SEC.

CONSTRUCTION OF VELOCITY TRIANGLE

$$\beta_1 = 47^\circ$$

$$\beta_2 = 47 - 8.3 = 38.7^\circ$$

β_1	η	SECTION	θ	C_d
45°	0.75	65-410	4.9	0.26
45°	0.75	65-72-10	10	0.52
45°	1.00	65-410	7	0.27
45°	1.00	65-810	10	0.39
45°	1.00	65-12-10	12.4	0.44

ESTIMATE FOR: $\beta_1 = 47^\circ$

$$\eta = .88$$

SECTION = 65-710

$$\theta = 8.3^\circ, C_d = 0.37$$

$\eta = .80$ FROM JOY GRAPH

$$\therefore \frac{P_2}{P_1} = 1.01^{\frac{1}{10} \left(1 + \frac{509 \times 651 \times .37 \times .88}{2 \times 32.2 \times 778 \times .78 \times 800} \right) \frac{1.29}{.29} \times .80}$$

10 STAGES:

$$\frac{P_2}{P_1} = 1.01 (1.00309)^{35.6}$$

REACTOR COOLANT BLOWERS

STUDY IV-334

SIMILAR TO

DR'N R.I.S.

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET A-2 OF 2

ISSUE

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$$\frac{P_2}{P_1} = 1.128$$

$$P_2 = 1.128 \times 365 = 411 \text{ PSI}$$

$$\therefore \Delta P = 411 - 365 = \underline{46 \text{ P.S.I.}}$$

DROP IN SYSTEM:

$$\frac{\Delta P_{s_2}}{\Delta P_{s_1}} = \left(\frac{V_2}{V_1} \right)^{1.8} \text{ AS ON SHEET A-7}$$

$$= \left(\frac{475}{452} \right)^{1.8} = 1.0917$$

$$\Delta P_{s_2} = 1.0917 \times 40.1 = \underline{43.7 \text{ PSI}}$$

INTERPOLATION WHEN THE ΔP 'S ARE EQUAL GIVES:

$$\Delta P = \underline{44.2 \text{ PSI}}$$

$$V_A \approx \underline{480 \text{ FT/SEC}}$$

POWER RATIO:

AS BEFORE: (SEE SHEET A-8)

$$\frac{P_s}{P_{He}} = \frac{44.2}{16.75} \times \frac{480}{452} \times \frac{.88}{.79} \approx \underline{3.40}$$

↑ NOW LESS THAN .80 SINCE $V_A > 475 \text{ FT/SEC.}$

REACTOR COOLANT BLOWERS

STUDY IV-334

SIMILAR TO

DR'N R.S.

CH'D A.H.G.

APP'D

SCALE

= 12

SHEET A-2-B

ISSUE

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A

B

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$$\Delta P_{\text{ACROSS FLOWMETER}} = \frac{KW^2}{\rho}$$

$$\Delta P_{H_2O} = \frac{KW_{H_2O}^2}{C_{H_2O}}$$

$$\Delta P_s = \frac{KW_s^2}{P_s} = \frac{KW_{He-20}^2}{P_{He-20}}$$

$$\frac{W_s}{W_{A2-10}} = 2.55 \quad \text{SEE SNEG T A-9}$$

$$\begin{aligned} \frac{\Delta P_s}{\Delta P_{He-20}} &= \left(\frac{G_s}{G_{He-20}} \right)^{1.8} \left(\frac{N_s}{N_{He-20}} \right) \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= \left(\frac{W_s}{W_{He-20}} \right)^{1.8} \left(\frac{N_s}{N_{He-20}} \right) \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= \left(\frac{\rho_{He-20}}{\rho_s} \right)^{1.8} \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= \left(\frac{0.12}{0.78} \right)^{1.8} \left(\frac{1.411 \times 10^{-5}}{1.94 \times 10^{-5}} \right)^{-2} \\ &= 0.780 \quad \checkmark \end{aligned}$$
$$\begin{aligned}\frac{\Delta P_s}{\Delta P_{He-20}} &= \left(\frac{1}{2} \frac{W_s}{W_{He-20}} \right)^{1.8} \left(\frac{V_s}{V_{He-20}} \right) \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= \left(\frac{1}{2} \frac{W_s}{W_{He-20}} \right)^{1.8} \left(\frac{\rho_{He-20}}{\rho_s} \right) \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2} \\ &= (.5)^{1.8} \times .780 \\ &\approx 0.225 \quad \checkmark\end{aligned}$$

ΔP DROP THROUGH REST OF SYSTEM $\approx .40$ PSI

STUDY IV-300

⑥ CORE: $\Delta P = .225 \times .4 = .090 \text{ PSI}$

TOTAL $\Delta P = 0.409 \text{ PSI}$

STUDY IV-334

SIMILAR TO

SCALE = 12

SHEET 1-204

ISSUE

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I ASSUMPTIONS

- ① THE STEAM ACCIDENT RESULTS IN SATURATED STEAM AT 335 PSI AND 427°F LEAKING INTO THE SYSTEM.
- ② THE AIR ACCIDENT RESULTS IN AIR AT 14.7 PSI AND 70°F LEAKING INTO THE SYSTEM.
- ③ THE STEAM OR AIR COMPLETELY REPLACES THE HELIUM AS THE COOLANT.
- ④ THE DENSITY OF FLUID VARIES AS P/T FOR COMPENSATION

II GIVEN DATA

② HELIUM AT 100% OPERATING LEVEL

- ① TEMPERATURE - 483°F
- ② PRESSURE - 298 PSI
- ③ DENSITY - 0.118 LBS/FT³
- ④ FLOW RATE - 215,000 LBS/HR.

③ HELIUM AT 20% (SCRAM) OPERATING LEVEL

- ① TEMPERATURE - 425°F
- ② PRESSURE - 288 PSI
- ③ DENSITY - 0.12 LBS/FT³
- ④ FLOW RATE - 43,000 LBS/HR.

④ STEAM

- ① TEMPERATURE - 427°F
- ② PRESSURE - 365 PSIA
- ③ DENSITY - 0.78 LBS/FT³

⑤ AIR

- ① TEMPERATURE - 70°F
- ② PRESSURE - 14.7 PSI
- ③ DENSITY - 0.0753 LBS/FT³

STUDY IV-334

SIMILAR TO

DR'N R.S.

(10-26-61)

CH'D A.H.G.

APP'D

SCALE

= 12

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A-2-5

III DISCUSSION

THE COMPENSATOR CORRECTS FOR CHANGES IN THE DENSITY OF THE FLUID, "THINKING" IN ALL CASES THAT HELIUM IS THE COOLANT. THE COMPENSATION RANGE IS FOR TEMPERATURES BETWEEN 350-550°F AND PRESSURES BETWEEN 200-350 PSIG (215 - 365 PSIA). ANY TEMPERATURE OR PRESSURE OUTSIDE OF THIS RANGE IS CONSIDERED TO BE AT THE RANGE LIMIT. FOR EXAMPLE, A TEMPERATURE OF 250°F IS TREATED AS IF IT WERE 350°F AS FAR AS THE COMPENSATING NETWORK IS CONCERNED.

THE PRESSURE DROP ACROSS THE FLOWMETER IS GIVEN BY:

$$\Delta P = \frac{KW^2}{P}$$

WHERE: K IS A CONSTANT

W = MASS FLOW RATE

P = DENSITY (CORRECTED BY COMPENSATOR)

THE CONTROL IS SUCH THAT THE ΔP IS ONLY CHANGED BY A CHANGE IN DENSITY FOR A GIVEN MASS FLOW OPERATING LEVEL (SET). THE FLOWMETER THINKS HELIUM IS THE FLUID IN ALL CASES.

THE POWER TO THE BLOWER IS GIVEN APPROXIMATELY BY:

$$P = KW^3 \quad (\text{IF DENSITY STAYS CONSTANT})$$

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ISSUE

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A-2-6

IV CALCULATIONS (STEAM REPLACING HELIUM)

1. 100% FLOW - BEFORE SCRAM

THE COMPENSATOR DETECTS THE STEAM TEMPERATURE OF 427°F AND PRESSURE OF 335 PSI AND "THINKS" IT IS HELIUM AT A DENSITY OF:

$$\rho = (\text{ORIGINAL } \rho) \times \frac{365}{298} \times \frac{483+460}{438+460} = 1.29 \times \text{ORIGINAL } \rho$$

AT THE FLOWMETER:

$$\Delta P = \frac{KW^2}{\rho}$$

FOR HELIUM CASE:

$$\Delta P = \frac{KW_{He}^2}{\rho_{He}} \quad \text{BUT COMPENSATOR "THINKS" HELIUM DENSITY}$$

IS NOW 1.29 × ORIGINAL ρ_{He} AND THEREFORE THE ΔP ACROSS THE FLOWMETER BECOMES:

$$\Delta P = \frac{KW_{He}^2}{\rho_{He} \times 1.29}$$

THIS IS THE ΔP THAT THE STEAM GIVES SINCE THE FLOWMETER DOES NOT KNOW WHAT THE FLOWING FLUID IS.

$$\therefore \frac{KW_{He}^2}{1.29 \rho_{He}} = \frac{KW_s^2}{\rho_s}$$

$$\frac{W_s}{W_{He}} = \left(\frac{\rho_s}{1.29 \rho_{He}} \right)^{\frac{1}{2}} = \left(\frac{.73}{1.29 \times .118} \right)^{\frac{1}{2}} \approx 2.26$$

$$W_s = 2.26 \times 215,000 = \underline{490,000} \text{ LBS/HR.}$$

2. 20% FLOW - SCRAM CONDITION

THE COMPENSATOR DETECTS A DENSITY OF:

$$\rho = (\text{ORIGINAL } \rho_{He-20}) \times \frac{285}{288} \times \frac{425+460}{438+460}$$

$$= 1.26 \times \text{ORIGINAL } \rho_{He-20}$$

AS ABOVE:

$$\frac{W_s}{W_{He}} = \left(\frac{\rho_s}{1.26 \rho_{He-20}} \right)^{\frac{1}{2}} = \left(\frac{.78}{1.26 \times .12} \right)^{\frac{1}{2}} = 2.27$$

$$W_s = 2.27 \times 43,000 = \underline{98,000} \text{ LBS/HR.}$$

* SEE NEXT PAGE FOR POWER REQUIREMENT

STUDY IV-334

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ISSUE

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A-2-7

AIR REPLACING HELIUM

1. 20% FLOW-SCRAM CONDITION

THE COMPENSATOR DETECTS A DENSITY OF:

$$P = (\text{ORIGINAL } P_{He-20}) \times \frac{215}{288} \times \frac{425+460}{350+460}$$

$$= .815 \times \text{ORIGINAL } P_{He-20}$$

AS ABOVE:

$$\frac{W_A}{W_{He}} = \left(\frac{P_A}{P_{He} \times .815} \right)^{\frac{1}{2}} = \left(\frac{.0753}{.118 \times .815} \right)^{\frac{1}{2}}$$

$$= .885$$

$$W_A = .885 \times 43,000 = \underline{38,000 \text{ LB/HR}}$$

POWER REQUIREMENT OF STEAM IN SCRAM

FROM APPENDIX A OF IX-334, THE FOLLOWING CAN BE CALCULATED:

AT 100%:

$$\frac{W_s}{W_{He}} = \frac{V_s P_s A_s}{V_{He} P_{He} A_{He}} = \frac{428.4 \times .78}{452 \times .118} = 6.25$$

$$W_s = 6.25 \times 215,000 = 1,340,000 \text{ LB/HR}$$

FROM SHEET A-1-4, AT FLOW CORRESPONDING TO 20% HELIUM FLOW:

$$W_s = 98,000 \text{ LB/HR}$$

∴ SINCE $H.P. = K, W^3$, FOR STEAM:

$$\frac{H.P._{20}}{H.P._{100}} = \left(\frac{98,000}{1,340,000} \right)^3 = .0004$$

$$\text{OR } .0004 \times 341\% = \underline{.136\% \text{ OF FULL POWER}}$$

FOR STEAM AT 1,340,000 LB/HR

STUDY IX-334

SIMILAR TO

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APP'D

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= 12

SHEET A-2-8 OF

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FLOW VELOCITIES (SHEETS A-9, A-10)

$$V_{20} = 88.9 \text{ FT/SEC}$$

$$V_3 = 35 \text{ FT/SEC}$$

KNOWN:

(1) AXIAL VELOCITY OF STEAM = 35 FT/SEC

(2) ΔP DROP IN SYSTEM = 0.404 PSI

(3) ΔP RISE ACROSS BLOWER = 0.404 PSI

FROM SHEETS A-11 AND A-12 WE OBTAINED:

V_b	ΔP RISE (PSI)
39.5	0.165
44.6	0.258
60.6	0.515

BY INTERPOLATION FOR A $\Delta P = 0.404$:

$$V_b = 53.7 \text{ FT/SEC}$$

$$53.7 \text{ FT/SEC} \rightarrow \frac{53.7}{50.9} \times 6130 \approx 647 \text{ RPM}$$

FROM THE ABOVE, β , CAN BE CALCULATED:

$$\beta_1 = \tan^{-1} \frac{53.7}{35} = 57^\circ \text{ GIVING AN } \angle \text{ OF ATTACK} = 15^\circ$$

FROM THE NACA REPORT, THIS IS CLOSE TO THE SURGE REGION. ANOTHER WAY TO CHECK IF THE BLOWER IS OPERATING IN THE SURGE REGION IS TO DECREASE THE AXIAL VELOCITY AND CALCULATE THE NEW ΔP . IF IT DECREASES, THEN WE ARE OPERATING IN THE SURGE REGION.

LET US PICK $V_a = 32 \text{ FT/SEC}$

$$\beta_1 = \tan^{-1} \frac{53.7}{32} = 59^\circ$$

β_1	∇	SECTION	θ	C_d
60	0.75	65-4-10	11°	0.64
60	0.75	65-12-10	18.8°	0.92
60	1.00	65-4-10	12.6°	0.54
60	1.00	65-8-10	16.3°	0.63
60	1.00	65-12-10	21.2°	0.73

REACTOR COOLANT BLOWERS

STUDY II-334

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SHEET 2 OF 9

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ESTIMATED FOR $\beta_1 = 59^\circ$

$\tau = .88$

SECTION 65-710

$\theta = 14.8^\circ$, $C_e = 0.68$

$$\frac{P_2}{P_1} = \left(1 + \frac{53.8 \times 53.1 \times .68 \times .88}{2 \times 32.2 \times .778 \times .78 \times 896} \right)^{.50 \times \frac{1.29}{.29}}$$

$$\frac{P_2}{P_1} = (1.0000490)^{2.22}$$

10 STAGES:

$$\frac{P_2}{P_1} = (1.0000490)^{22.2}$$

$$= 1.00109$$

$$\therefore P_2 = 1.00109 \times 365 = 365.398$$

$$\Delta P = 0.398$$

HAS DECREASED SLIGHTLY - MAYBE IN SURGE ?

REACTOR COOLANT BLOWERS

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FROM K.E. ENGINEERING REPORT 621-20-R APPENDIX B, THE TOTAL MASS OF HELIUM IN CIRCUIT IS

HELIUM IN REACTOR	792.8	x 1	= 792.8
HELIUM IN STEAM GENERATOR	165.6	x 2	= 331.2
HELIUM IN HOT LEG	32.4	x 2	= 64.8
HELIUM IN COLD LEG	41.0	x 2	= 82.0

TOTAL 1270.8 LB.

HELIUM TEMPERATURE	PRESSURE	SPEC. VOLUME
REACTOR IN 507	310	8.26
OUT 1003	203	13.31
STEAM GEN. IN 1043	303	13.31
OUT 483	298	8.49

$$\text{AV. SPEC. VOLUME REACTOR} = \frac{8.26 + 13.31}{2} = 10.79 \text{ FT}^3/\text{LB}$$

$$\text{AV. SPEC. VOLUME ST. GEN} = \frac{13.31 + 8.49}{2} = 10.90 \text{ FT}^3/\text{LB}$$

$$\text{SPEC. VOLUME HOT LEG} = 13.31$$

$$\text{SPEC. VOLUME COLD LEG} = \frac{8.49 + 8.26}{2} = 8.36 \text{ FT}^3/\text{LB}$$

$$\begin{aligned} \text{TOTAL VOLUME: } & 792.8 \times 10.79 + 331.2 \times 10.90 + 64.8 \times 13.31 + 82.0 \times 8.36 \\ & = 8554.3 + 3610.1 + 862.5 + 685.5 = 13712.4 \text{ FT}^3 \end{aligned}$$

REACTOR COOLANT BLOWERS

IV-334

SIMILAR TO

DR'N A.H.G

CH'D DAL 12-18.61

APP'D

SCALE

= 12

SHEET 2-1 OF A-3-7

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

MOLECULAR WEIGHT OF HELIUM-STEAM MIXTURE TO REACH 325 PSIG
PRESSURE IN HELIUM COOLANT SYSTEM

$$\text{PRESSURE INCREASE } (325 + 14.7) - 298 = 41.7 \text{ PSI}$$

THE MASS OF STEAM TO BE INTRODUCED INTO THE HELIUM COOLANT SYSTEM IS EQUAL TO:

$$W = \frac{\Delta p \cdot V \cdot M_s}{R \cdot T}$$

$$\Delta p = 41.7 \text{ PSI}$$

$$V = 13712.4 \text{ FT}^3$$

$$M_s = 18$$

$$R = 10.73$$

$$T = 480 + 460 = 940$$

$$W = \frac{41.7 \times 13712.4 \times 18}{10.73 \times 940} = 1020.5$$

$$M_{AV} = \frac{\frac{1270.8 \times 4}{4} + \frac{1020.5 \times 18}{18}}{\frac{1270.8}{4} + \frac{1020.5}{18}} = \frac{2291.3}{317.7 + 56.7} = \frac{2291.3}{374.4} = 6.12$$

$$\text{MOISTURE CONTENT } \frac{1020.5}{2291.3} = 44.5\% \approx 45\%$$

REACTOR COOLANT BLOWERS

IV-334

SIMILAR TO

SHEET 2 OF A-5-7

ISSUE

DRN A.H.6

CHD 12-18-61

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SCALE = 12

ALLIS-CHALMERS MFG. CO. DEPT.

CALCULATION OF BLOWER PRESSURE RATIO FOR HELIUM-STEAM MIXTURE
@ 325 PSIG PRESSURE

$$(C_p)_{\text{STEAM}} = .75$$

$$(C_v)_{\text{STEAM}} = .581$$

$$\frac{p}{s} = 1.29 \quad \left(\frac{h}{h-1}\right)_s = 4.45$$

$$(C_p)_{\text{HELIUM}} = 1.25$$

$$(C_v)_{\text{HELIUM}} = .753$$

$$\frac{p}{h} = 1.66 \quad \left(\frac{h}{h-1}\right)_h = 2.52$$

FOR A MIXTURE OF 1270.8 LB HELIUM
1020.5 LB STEAM.

$$(C_p)_m = (.75 \times 1020.5 + 1.25 \times 1270.8) \times \frac{1}{2291.3} = 1.027 \text{ BTU/LB } ^\circ\text{F}$$

$$(C_v)_m = (.581 \times 1020.5 + .753 \times 1270.8) \times \frac{1}{2291.3} = .676$$

$$\frac{h}{h-1} = \left(\frac{C_p}{C_v}\right)_m = \frac{1.02}{.67} = 1.519$$

$$\frac{h}{h-1} = \frac{1.519}{.519} = 2.927$$

APPENDIX A p. 4.

$$\frac{p_2}{p_1} = 1.01 \left[1 + \frac{V_1^2 U_{RM} C_p}{2g J C_p T_1} \right]^{\frac{h}{h-1} - 1}$$

WE HAVE

$$\frac{p_2}{p_1} = 1.01 \left[1 + \frac{509 \times 626 \times .425 \times .00}{2 \times 32.2 \times 778 \times 1.027 \times 940} \right]^{10 \times .88 \times 2.927}$$

$$= 1.01 \left[1 + .002464 \right]^{25.76}$$

$$= 1.01 \times 1.06525 = 1.0759$$

$$p_2 = 339.7 \times 1.0759 = 365.5 \text{ PSIA}$$

REACTOR COOLANT BLOWERS

IV-334

SIMILAR TO

DR'N A.H.G.

CH'D DAC 12-18-61

APP'D

SCALE

= 12

SHEET 33 OF A-3-7

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

$$\Delta p_{\text{COMP}} = 339.7 \times 0.759 = 25.8 \text{ PSI}$$

PRESSURE DROP IN SYSTEM.

MEAN DENSITY

$$\left(\frac{V}{AV} \right)_M = \frac{13712.4}{2291.3} = 5.985$$

$$\left(\frac{P}{AV} \right)_M = \frac{1}{5.985} = .167$$

FOR MIXTURE

$$\text{FOR HELIUM } \left(\frac{V}{AV} \right)_{HE} = \frac{13712.4}{1270.8} = 10.79$$

$$\left(\frac{P}{AV} \right)_{HE} = \frac{1}{10.79} = .0927$$

MEAN VISCOSITY

$$\mu_S = 1.411 \times 10^{-5}$$

$$\mu_{HE} = 1.94 \times 10^{-5}$$

$$2291.3 \mu_M = [1270.8 \times 1.94 + 1020.5 \times 1.411] \times 10^{-5}$$

$$\mu_M = 1.704 \times 10^{-5}$$

$$\frac{G_M}{G_{HE}} = \frac{P_M}{P_{HE}} = \frac{.167}{.0927} = 1.802$$

$$\frac{V_M}{V_{HE}} = \frac{5.985}{10.79} = .555$$

$$\frac{\mu_M}{\mu_{HE}} = \frac{1.704}{1.94} = .878$$

$$\frac{\Delta p_M}{\Delta p_{HE}} = \left(\frac{G_M}{G_{HE}} \right)^{1.8} \times \frac{V_M}{V_{HE}} \times \left(\frac{\mu_M}{\mu_{HE}} \right)^2 \quad (\text{APP. A p. 5})$$

REACTOR COOLANT BLOWERS

IV-334

SIMILAR TO

DR'N A.H.G.

CH'D 12-14-61

APP'D

SCALE

= 12

SHEET 3 OF A-3-7

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

$$\frac{\Delta P_M}{\Delta P_{HE}} = (1.802)^{1.8} \times .555 \times (.878)^{.2}$$

$$= 2.8863 \times .555 \times .9743 = 1.5607$$

$$(\Delta P_M)_{\text{SYST}} = 16.75 \times 1.5607 = 26.1 \text{ PSI}$$

$$\Delta P \text{ THRU BLOWER} = 25.8 \text{ PSI}$$

} V. 26 PSI

POWER RATIO

$$\frac{P_M}{P_{HE}} = \left(\frac{\Delta P_M}{\Delta P_{HE}} \right) \times \frac{W_M}{W_{HE}} \times \frac{\rho_{HE}}{\rho_M}$$

$$= \frac{26}{16.75} \times \frac{2291.3}{1270.8} \times \frac{.0927}{.167} = \underline{\underline{1.554}}$$

REACTOR COOLANT BLOWERS

IV - 334

SIMILAR TO

DR'N A.H.G.

CH'D DBC 12-19-61

APP'D

SCALE

= 12

SHEET ~~A-3-5~~ OF A-3-7

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A

B

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

A, MOLECULAR WEIGHT OF HELIUM-STEAM MIXTURE TO REACH 330 PSIG
PRESSURE IN HELIUM COOLANT SYSTEM.

PRESSURE INCREASE $(330 + 14.7) - 298 = 46.7 \text{ PSI}$

THE MASS OF STEAM TO BE INTRODUCED INTO THE HELIUM COOLANT SYSTEM IS EQUAL TO:

$$W = \frac{46.7 \times 13712.4 \times 18}{10.73 \times 940} = 1142.9 \text{ LB}$$

$$M_{AV} = \frac{1270.8 + 1142.9}{\frac{1270.8}{4} + \frac{1142.9}{18}} = \frac{2413.7}{317.7 + 63.5} = \frac{2413.7}{381.2} = 6.33$$

B, POWER RATIO

$$(C_p)_{MIXT} = (.75 \times 1142.9 + 1.25 \times 1270.8) \times \frac{1}{2413.7} = 1.013 \frac{\text{Btu}}{\text{LB}^\circ\text{F}}$$

$$(C_v)_{MIXT} = (.581 \times 1142.9 + .753 \times 1270.8) \times \frac{1}{2413.7} = .672$$

$$k_{MIXT} = \frac{1.013}{.672} = 1.507 \quad \frac{k}{k-1} = \frac{1.507}{.507} = 2.972$$

$$\frac{p_2}{p_1} = 1.01 \left[1 + \frac{509 \times 626 \times .425 \times .88}{2 \times 32.2 \times 778 \times 1.013 \times 940} \right]^{10 \times .88 \times 2.972}$$

$$= 1.01 \left[1 + .002498 \right]^{26.15}$$

$$= 1.01 \times 1.0671275 = 1.0778$$

$$p_2 = 344.7 \times 1.0778 = 371.5 \text{ PSIA}$$

$$\Delta p_{COMP} = 344.7 \times .0778 = 26.8 \text{ PSI}$$

REACTOR COOLANT BLOWERS

IV-334

SIMILAR TO.

DR'N A.H.G.

CH'D *AK* 12-19-61

APP'D

SCALE

= 12

SHEET *A-3-6* OF *A-3-7*

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

MEAN DENSITY

$$(\rho_M)_H = \frac{2413.7}{13712.4} = .176$$

MEAN VISCOSITY.

$$\mu_M = (1270.8 \times 1.94 + 1142.9 \times 1.41) \times 10^{-5} \frac{1}{2413.7} = 1.690 \times 10^{-5}$$

PRESSURE DROP IN SYSTEM.

$$\begin{aligned} \frac{\Delta p_M}{\Delta p_{He}} &= \left(\frac{G_M}{G_{He}} \right)^{1.8} \times \frac{\mu_M}{\mu_{He}} \times \left(\frac{\rho_M}{\rho_{He}} \right)^{.2} \\ &= \left(\frac{.176}{.0927} \right)^{1.8} \times \frac{.0927}{.176} \times \left(\frac{1.690}{1.94} \right)^{.2} \\ &= (1.899)^{1.8} \times .527 \times (.871)^{.2} \\ &= 3.17207 \times .527 \times .97275 \\ &= 1.6261 \end{aligned}$$

$$\Delta p_M = 1.6261 \times 16.75 = 27.2 \text{ PSI}$$

$$\Delta p_{con} =$$

26.0

say 27

POWER RATIO

$$\frac{P_M}{P_{He}} = \frac{27}{16.75} \times \frac{2413.7}{1270.8} \times \frac{.0927}{.176} = 1.61$$

$$\text{CHECK WITH } 1.554 \times \frac{6.33}{6.12} = 1.607$$

REACTOR COOLANT BLOWERS

IV-334

SIMILAR TO

DR'N A.H.G.

CH'D DAK 12-19-61

APP'D

SCALE

= 12

SHEET A-3-7 OF A-3-7

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 5833-3

VESSEL COOLING COMPRESSORS

VESSEL COOLING COMPRESSORS OPERATING CONDITIONS ARE:

MAXIMUM DESIGN FLOW	23,000 LB/HR
PRESSURE RISE	8.75 PSI
SUCTION PRESSURE	313 PSIA
SUCTION TEMPERATURE	508 F

THE SPECIFIC VOLUME @ SUCTION CONDITIONS IS:

$$84 \times \frac{968}{460} \times \frac{14.7}{313} = 8.30 \text{ FT}^3/\text{LB}$$

THE COMPRESSOR "WATER" HORSEPOWER IS:

$$8.75 \times 144 \times 8.30 \times \frac{23,000}{60} \times \frac{1}{33,000} = 121.5 \text{ HP}$$

ASSUMING

80%	COMPRESSOR EFFICIENCY
90%	MOTOR EFFICIENCY
95%	INCREASER EFFICIENCY
95%	MECHANICAL EFFICIENCY (BEARINGS, LUBRICATION OIL PUMPS...)

MOTOR HORSE POWER

$$\frac{121.5}{.80 \times .90 \times .95 \times .95} = \frac{121.5}{.65} = 187 \text{ HP}$$

RATIO

$$\frac{\text{MOTOR NAMEPLATE RATING}}{\text{OPERATING HP}} = \frac{250}{187} = 1.34$$

VESSEL COOLING COMPRESSORS

IV-334

SIMILAR TO

DR'N AUG

CH'D *Jan* 12-19-61

APP'D

SCALE = 12

SHEET OF

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A-4-1 of A-4-3

$$\frac{\text{BREAKDOWN MOTOR TORQUE}}{\text{NAME PLATE TORQUE}} = \frac{\text{COMPRESSOR MAX. SHAFT HP}}{\text{COMP. SHAFT HP CORRESPONDING TO 250 HP} \rightarrow 151.9 \times 1.32} = 250\%$$

(FROM SPEC. PK-15 p.6)

$$(H)_{\text{MIXT}} = (H)_{\text{HE}} = (\Delta p)_{\text{MIXT}} \times 144 \times v_{\text{MIXT}} = (\Delta p)_{\text{HE}} \times 144 \times v_{\text{HE}}$$

$$\text{VOLUME FLOW} = W_{\text{MIXT}} \times V_{\text{MIXT}} = W_{\text{HE}} \times V_{\text{HE}}$$

THE POWER RATIO IS EQUAL TO

$$\frac{P_{\text{MIXT}}}{P_{\text{HE}}} = \frac{W_M}{W_{\text{HE}}} \times \frac{\Delta p_M}{\Delta p_{\text{HE}}} \times \frac{v_M}{v_{\text{HE}}} \times \frac{\cancel{\eta_{\text{HE}}}}{\cancel{\eta_M}}$$

$$= \frac{v_{\text{HE}}}{v_M} \times \frac{v_{\text{HE}}}{v_M} \times \frac{v_M}{v_{\text{HE}}} = \frac{v_{\text{HE}}}{v_M}$$

$$\text{WE HAVE } \frac{P_{\text{MIXT}}}{P_{\text{HE}}} = \frac{250 \times 151.9 \times 1.34}{100 \times 151.9} = 2.50 \times 1.34 = 3.35 = \frac{v_{\text{HE}}}{v_{\text{M}}}$$

WE HAVE $p_m = \frac{3.35}{8.30} = .4036 \text{ LB/FI}^3$

IN A VOLUME OF 1 FT³ THERE IS:

$$\frac{.12054 \times 2}{1} = .4036 \text{ LB OF MIXTURE}$$

$$x = 4086 - 1205 = 2831$$

THE PERCENT OF HELIUM $\frac{.125}{.4036} = .2986$ or 29.86%

VESSEL COOLING COMPRESSORS

IV - 334

SIMILAR TO

DR'N **ALG**

CH'D

APP'D

SCALE **=12**

SHEET **OF**

ISSUE

ALLIS-CHALMERS MFG. CO.	DEPT.
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A-4-2 ✓ A-4-3

MOLECULAR WEIGHT OF THE MIXTURE :

$$\frac{.2986 + .7014}{\frac{.2986}{4} + \frac{.7014}{18}} = \frac{1}{.0747 + .0390} = \frac{1}{1137} = 8.8 \text{ LB/MOLES}$$

VESSEL COOLING COMPRESSORS

IV - 334

SIMILAR TO

DR'N AUG

CH'D

APP'D

SCALE

= 12

SHEET

OF

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A-4-3 / A-4-3

ALLIS-CHALMERS MANUFACTURING COMPANY

INTER-OFFICE CORRESPONDENCE

To: Mr. A. De Agazio

From: R. Schlegel

Subject: Reactor Coolant Blowers
Control System
Hazards Analysis
EGCR File No. 149

Date: July 2, 1962

The attached calculations were performed to determine the action of the EGCR reactor coolant blower control system (Revised Scram Specification), if the helium in the coolant system were replaced with either steam or air and a reactor scram followed.

CONCLUSIONS

(1) A reactor scram following steam admission to the system results in blower control action to reset speed to 23.3 per cent. If both blowers continue to operate, each will circulate steam at the rate of 212,000 lb/hr. If one blower is isolated, the rate of steam circulation by the remaining blower will be 290,000 lb/hr.

(2) A reactor scram following air admission to the system results in blower control action to reset speed to 23.3 per cent. If both blowers continue to operate, each will circulate air at the rate of 25,300 lb/hr.

(3) If the controller reduces blower speed to 23.3 per cent speed, the blower motors would not be overloaded but the blowers would be operating in surge region. If one blower is isolated, the other would come out of the surge region.

AFTER SCRAM, THE FLOW OF GAS THAT THE BLOWER PUMPS DECREASES AS THE BLOWERS SLOW DOWN TO 23.3% SPEED. THE PRESSURE RISE THROUGH THE BLOWERS EQUALS THE PRESSURE DROP IN THE SYSTEM.

A. SCRAM CONDITION - 2 BLOWERS OPERATING

I STEAM FLOWING

(a) FIRST TRIAL

1. PRESSURE RISE THROUGH BLOWER

BLADE SPEED = 23%

$$= 23.3 \times 509 = 118.6 \text{ FT/SEC}$$

VELOCITY TRIANGLE SIMILAR TO THAT ON SHEET A-11, $\therefore C_2 = .71$, $\theta = 15^\circ$

THE VOLUME FLOW RATE IS APPROXIMATELY $68.5/452 = 15.1\%$ AT THE BLOWER SPEED OF 23.3%. THE EFFICIENCY FROM THE JOY REPORT IS THEN ABOUT 58%.

$$\frac{P_2}{P_1} = \left(1 + \frac{118.6 \times 114.2 \times .71 \times .88}{2 \times 32.2 \times 778 \times .78 \times 896} \right)^{\frac{1.29}{.29} \times .58 \times 10}$$

$$= (1.000242)^{25.8} = 1.00625$$

$$P_2 = 1.00625 \times 365 = 367.28$$

$$\Delta P = \underline{2.28 \text{ PSI}}$$

2. PRESSURE DROP THROUGH SYSTEM

$$\frac{\Delta P_s}{\Delta P_{He-20}} = \left(\frac{G_s}{G_{He-20}} \right)^{1.8} \left(\frac{V_s}{V_{He-20}} \right) \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2}$$

$$= \left(\frac{V_s P_s}{V_{He-20} P_{He-20}} \right)^{1.8} \left(\frac{P_{He-20}}{P_s} \right) \left(\frac{\mu_s}{\mu_{He-20}} \right)^{-2}$$

$$= \left(\frac{68.5 \times .78}{88.9 \times .12} \right)^{1.8} \left(\frac{.12}{.78} \right) \left(\frac{1.41 \times 10^{-5}}{1.94 \times 10^{-5}} \right)^{-2}$$

REACTOR COOLANT BLOWERS

SIMILAR TO

DR'N R.P.S. 4-262

CH'D *Will Miller*

APP'D

SCALE

= 12

SHEET A-5-2 OF A-5-6

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A

B

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

$$\frac{\Delta P_s}{\Delta P_{He-20}} = 2.62$$

$$\Delta P_s = 2.62 \times .8 = \underline{2.10 \text{ PSI}}$$

∴ APPROXIMATELY,

$$\Delta P_s = \underline{2.2 \text{ PSI}} \quad (\text{RISE} = \text{DROP})$$

FROM NACA REPORT, THIS IS IN SURGE

3. POWER REQUIREMENT

$$P = K_1 W^3$$

$$\text{OR } P = K_2 V^3 \quad \text{SINCE } W = V \rho A$$

$$\frac{P_{\text{SCRAM}}}{P_{100\%}} = \left(\frac{V_{\text{SCRAM}}}{V_{100\%}} \right)^3 \cong \left(\frac{68.5}{428.4} \right)^3 = .0041$$

$$P_{\text{SCRAM}} = .0041 \times 341\% = \underline{1.4\%} \text{ OF } 100\% \text{ POWER}$$

$$\rightarrow W_s = W_{He-20} \frac{V_s P_s}{V_{He-20} P_{He-20}} \cong 43,000 \times \frac{68.5 \times .78}{2 \times 452 \times .12} = \underline{212,000 \text{ LB/HR}} \quad (\text{EACH BLOWER})$$

II AIR FLOWING - 2 BLOWERS

② FIRST TRIAL

1. PRESSURE RISE THROUGH BLOWER

SIMILAR TO TRIANGLE ON A-6

$$C_2 = .56$$

$$\theta = 12.3$$

$$\frac{93.3}{452} = 20.6\% \text{ VOL. FLOW}$$

∴ 62% EFFICIENCY

$$\frac{P_2}{P_1} = \left(1 + \frac{118.6 \times 135 \times .56 \times .88}{2 \times 32.2 \times 778 \times .24 \times 530} \right)^{.62 \times \frac{1.4}{.7} \times 10}$$

$$= (1.00124)^{21.7} = 1.0273$$

$$P_2 = 1.0273 \times 14.7 = 15.10$$

$$\Delta P = 15.10 - 14.70 = \underline{.4 \text{ PSI}}$$

REACTOR COOLANT BLOWERS

SIMILAR TO

DR'N R.Y.S. 4-2-62 CH'D Mettall CMG

APP'D

SCALE = 12

SHEET A-5-3 OF A-5-6

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

2. PRESSURE DROP THROUGH SYSTEM

$$\frac{\Delta P_A}{\Delta P_{He-20}} = \left(\frac{G_A}{G_{He-20}} \right)^{1.8} \left(\frac{V_A}{V_{He-20}} \right) \left(\frac{\mu_A}{\mu_{He-20}} \right)^{-2}$$

$$= \left(\frac{V_A P_A}{V_{He-20} P_{He-20}} \right)^{1.8} \left(\frac{P_{He-20}}{P_A} \right) \left(\frac{\mu_A}{\mu_{He-20}} \right)^{-2}$$

$$= \left(\frac{93.3}{88.9} \times \frac{.0753}{.12} \right)^{1.8} \left(\frac{.12}{.0753} \right) \left(\frac{.018 \times 10^{-5}}{1.94 \times 10^{-5}} \right)^{-2}$$

$$= .685$$

$$\Delta P_A = .685 \times .8 = .55 \text{ PSI}$$

$$V_{A-45} = V_{A-55} \times \left(\frac{\Delta P_{45}}{\Delta P_{55}} \right)^{\frac{1}{1.8}} = 933 \times \left(\frac{.45}{.55} \right)^{\frac{1}{1.8}} = 834$$

$$\therefore W_A = \frac{V_A P_A}{V_{He-20} P_{He-20}} \times W_{He} = \frac{834 \times .0753}{88.9 \times .12} \times 43,000 = 25,300 \text{ LB/HR}$$

(EACH BLOWER)

∴ APPROXIMATELY,

$$\Delta P_A = \underline{.45 \text{ PSI}} \quad (\text{RISE} = \text{DROP})$$

NOT IN SURGE

B. SCRAM CONDITION - 1 BLOWER OPERATING

I STEAM FLOWING

② FIRST TRIAL

1. PRESSURE RISE THROUGH BLOWER

THIS GAVE $\Delta P = 2.28 \text{ PSI}$
(SEE 2 SHEETS BEFORE)

2. PRESSURE DROP THROUGH SYSTEM

$$\frac{\Delta P_S}{\Delta P_{He}} = \left(\frac{G_S}{G_{He-20}} \right)^{1.8} \left(\frac{V_S}{V_{He-20}} \right) \left(\frac{\mu_S}{\mu_{He-20}} \right)^{-2}$$

OTHER THAN CORE

$$= 2.62 \text{ AS BEFORE}$$

$$\frac{\Delta P_S}{\Delta P_{He}} = \left(\frac{1}{2} G_S / G_{He-20} \right)^{1.8} \left(\frac{V_S}{V_{He-20}} \right) \left(\frac{\mu_S}{\mu_{He-20}} \right)^{-2}$$

THROUGH CORE

REACTOR COOLANT BLOWERS

SIMILAR TO

DR'N R.L.S. 4-1-62

CH'D *Mellor CMA*

APP'D

SCALE

= 12

SHEET A-5-4 OF A-5-6

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

$$\frac{\Delta P_s}{\Delta P_{He}} = (.5)^{1.8} \times 2.62 = .755$$

$$\therefore \Delta P_{total} = 2.62 \times .4 + .755 \times .4$$

$$= \underline{1.35 \text{ PSI}}$$

(ΔP DROP THROUGH CORE, THROUGH
REST OF SYSTEM = .4 PSI
STUDY III-300)

⑥ SECOND TRIAL

1. PRESSURE RISE THROUGH BLOWER

TRIANGLE SIMILAR TO THAT ON A-6

$$\therefore C_d = .56$$

$$\theta = 12.3^\circ$$

$$\frac{P_2}{P_1} = \left(1 + \frac{118.6 \times 135 \times .56 \times .88}{2 \times 32.2 \times 778 \times .78 \times 896} \right)^{\eta \times \frac{1.29}{.29} \times 10}$$

AGAIN $\eta = 62\%$

$$\frac{P_2}{P_1} = (1.000225)^{27.6} = 1.00621$$

$$P_2 = 1.00621 \times 365 = 367.27$$

$$\Delta P = \underline{2.27 \text{ PSI}}$$

2. PRESSURE DROP THROUGH SYSTEM

$$\frac{\Delta P_s}{\Delta P_{He-20}} = 2.62 \times \left(\frac{93.3}{68.5} \right)^{1.8} = 4.56 \text{ PSI} \quad \text{OTHER THAN CORE}$$

$$\frac{\Delta P_s}{\Delta P_{He-20}} = (.5)^{1.8} \times 4.56 = 1.31 \text{ PSI} \quad \text{THROUGH CORE}$$

$$\therefore \Delta P_{total} = 4.56 \times .4 + 1.31 \times .4$$

$$= \underline{2.34 \text{ PSI}}$$

$\therefore$ APPROXIMATELY,

$$\Delta P_s = \underline{2.3 \text{ PSI}} \quad (\text{RISE} = \text{DROP})$$

NOT IN SURGE

REACTOR COOLANT BLOWERS

SIMILAR TO

DR'N R.F.S. 4-1-62

CH'D

Michael Allen

APP'D

SCALE

= 12

SHEET A-5-5 OF A-5-6

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A

B

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

3. POWER REQUIREMENT

$$\frac{P_{\text{SCRAM}}}{P_{100\%}} = \left(\frac{V_{\text{SCRAM}}}{V_{100\%}} \right)^3 \approx \left(\frac{93.3}{428.4} \right)^3 \approx .01$$

$$P_{\text{SCRAM}} = .01 \times 341\% = \underline{3.41\%} \text{ OF } 100\% \text{ POWER}$$

$$\rightarrow W_s \approx 43,000 \times \frac{93.3}{.2 \times 452} \times \frac{.78}{.12} \approx \underline{290,000 \text{ LB/HR}} \quad (\text{FOR THE ONE BLOWER})$$

REACTOR COOLANT BLOWERS

SIMILAR TO

DR'N R.E.S., 4-262

CH'D *Metha ALMA*

APP'D

SCALE

= 12

SHEET A-5-6 OF A-5-6

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

A

B

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

6" SUPERHEATED STEAM LINE

PIPE DESIGNATION SM-32-6" 1A & 1B
KE SPEC. PA-1 4" 10" SCH. 120 SEAMLESS PIPE SA-335

6" PIPE

6.625" O.D.; 5.501" ID 0.562" WALL
INTERNAL (FLOW) AREA 23.77 SQ IN.
METAL AREA 10.70 SQ IN.
EXTERNAL AREA 34.47 SQ IN.

SA-335 MATERIAL

σ_y = YIELD STRENGTH = 30,000 PSI

σ_u = ULTIMATE STRENGTH 60,000 PSI

STRESSES (PRESSURE)

$$\sigma_t = \frac{a^2 p_i (1 + \frac{b^2}{a^2})}{b^2 - a^2} = \frac{(2.75)^2 (1400)}{(3.313)^2 - (2.75)^2} \left(1 + \frac{3.313^2}{2.75^2}\right) = 7600 \text{ PSI}$$

$$\sigma_a = \frac{p_i a}{2t} = \frac{(1400)(5.501)}{(2)(0.562)(2)} = 3400 \text{ PSI}$$

$$\sigma = (\sigma_t^2 - \sigma_t \sigma_a + \sigma_a^2)^{1/2} = 7600^2 - (7600)(3400) + 3400^2 \approx 6600$$

LENGTH OF FAILURE

$$L' = 0.743 \left(\frac{\sigma_u^2 - 1}{\sigma_y^2} \right)^{1/2} \approx 6.7" \text{ (MAXIMUM LENGTH)}$$

$$L = 0.743 \left(\frac{\sigma_t^2 - 1}{\sigma_y^2} \right)^{1/2} \approx 3.3" \text{ (MINIMUM LENGTH)}$$

EQUIVALENT DIAMETER OF OPENING

$$D_u = \frac{2L'}{\pi} = 4.27" \quad A_u = 14.31 \text{ SQ. IN.}$$

$$D_y = \frac{2L}{\pi} = 2.1" \quad A_y = 3.46 \text{ SQ. IN.}$$

STEAM LINE FAILURES
(6" SUPERHEATED STEAM)
DUCTILE FAILURE

STUDY IV-334

SIMILAR TO

DR'N SM

CH'D ANG.

APP'D

SCALE = 12

SHEET B-1 OF B-3

ISSUE

-Property of ALLIS-CHALMERS MFG. CO. DEPT. NPD-W

APPENDIX B

8" SUPERHEATED STEAM MAIN

PIPE DESIGNATION SM-1-8"1B KE DWG P114
KE SPEC. PA-1. 4". 10" SCH. 120 SEAMLESS PIPE. SA. 335

8" PIPE

8.625" O.D. ; 7.189" I.D. ; 0.718" WALL
INTERNAL (FLOW) AREA 40.59 SQ. IN.
METAL AREA 17.84 SQ. IN.
EXTERNAL AREA 58.43 SQ. IN.

SA-335 MATERIAL

σ_y = YIELD STRENGTH = 30,000 PSI

σ_u = ULTIMATE STRENGTH = 60,000 PSI

STRESSES (PRESSURE)

$$\sigma_t = \frac{a^2 p_i}{b^2 - a^2} \left(1 + \frac{b^2}{a^2} \right) = 7750 \text{ PSI}$$

$$\sigma_a = \frac{p_i a}{2t} = 3500 \text{ PSI}$$

$$\sigma = \left(\sigma_t^2 - \sigma_t \sigma_a + \sigma_a^2 \right)^{1/2} = 6700 \text{ PSI}$$

LENGTH OF FAILURE

$$L' = 0.743 \left(\frac{\sigma_u^2}{\sigma^2} - 1 \right)^{1/2} \approx 6.6" \text{ (MAXIMUM LENGTH)}$$

$$L' = 0.743 \left(\frac{\sigma_y^2}{\sigma^2} - 1 \right)^{1/2} \approx 3.2" \text{ (MINIMUM LENGTH)}$$

EQUIVALENT DIAMETER OF OPENING

$$D_u = \frac{2L'}{\pi} = 4.2" \quad A_u = 13.85 \text{ SQ. IN.}$$

$$D_y = \frac{2L}{\pi} = 2.04" \quad A_y = 3.27 \text{ SQ. IN.}$$

STEAM LINE FAILURES
(8" SUPERHEATED STEAM MAIN)
DUCTILE FAILURE

STUDY IV-334

SIMILAR TO

DR'N SM

CH'D AHG

APP'D

SCALE = 12

SHEET B-2 OF B-8

ISSUE

-Property of ALLIS-CHALMERS MFG. CO. DEPT. NPD-W

APPENDIX B

STEAM LINE FAILURES

INITIAL EXHAUST FLOW CAN BE CALCULATED
USING GOUDIE FORMULA (MARKS-5TH ED. PP 1150)

$$W = 0.3155 A \left(\frac{P_1}{V_1} \right)^{1/2}$$

WHERE:

W = FLOW - LB/SEC.

A = FLOW AREA - SQ. IN.

P₁ = ABSOLUTE PRESSURE - PSIA

V = SPECIFIC VOLUME - CU. FT. / LB

6" STEAM LINE

$$P_1 = 1265 \text{ PSIA}$$

$$V_1 = 0.59 \text{ CU. FT. / LB}$$

$$A = 14.31 \text{ SQ. IN.}$$

$$W = (0.3155)(14.31) \left(\frac{1265}{0.59} \right)^{1/2} = 208.5 \text{ lb/SEC}$$

8" STEAM MAIN

ASSUME 20 PSI LINE LOSS - SG. TO POINT
OF FAILURE.

$$P_1 = 1245 \text{ PSIA}$$

$$V_1 = 0.59 \text{ CU. FT. / LB}$$

$$A = 13.85 \text{ SQ. IN.}$$

$$W = (0.3155)(13.85) \left(\frac{1245}{0.59} \right)^{1/2} = 200 \text{ lb/SEC}$$

STEAM LINE FAILURES
INITIAL EXHAUST FLOWS

STUDY IV-334

SIMILAR TO

DR'N SM

CH'D JAL 3-8-63

APP'D

SCALE = 12

SHEET 8-5 OF 8-1

ISSUE

-Property of ALLIS-CHALMERS MFG. CO. DEPT. NPD-W

APPENDIX B

APPENDIX. C

Steam Generator Calculations

The behavior of the steam drum water level following a failure of steam tubes was analyzed. The calculations are based on a simplified model, however it is believed that they are adequate to justify the conclusions of this study.

The magnitude of the failure selected in the analysis allows a total mass flow leaving the steam generator at the time of rupture of 163,000 lb/hr, or 2,140 lb/min. The failure was assumed to occur at the top of the evaporator section.

A failure which allows a leakage flow in excess of feedwater flow will result in a lower water level in the steam drum. The change in volume in the steam space of the drum increases the specific volume of the steam and tends to reduce the steam pressure. The reduced steam pressure must be accompanied by some increased vaporization of water with a lowering of water temperature. The reduction of water temperature, consequently, is accompanied by a reduction in saturation pressure.

Both the steam flow and leakage flow from the steam drum are pressure dependent and, consequently, a reduction in steam pressure causes a reduction in both steam and leakage flow. Simultaneously, a decrease in steam drum pressure will allow an increase in feedwater flow. This process continues until the total of the steam to the turbine and the leakage flow equals the feedwater flow. At this point, the level will stop dropping.

The equations describing the behavior of drum level were programmed for a Bendix G-15 digital computer. The calculated steam drum pressure is shown in Figure I; the weight of water in the steam drum is shown in Figure II. Exhibit I is the output from the computer.

It should be noted that the failed generator steam flow to the turbine will stop when the drum pressure decreases to 1265 psia due to the action of the steam line check valves and initial pressure regulator. The nature of the process is such that drum pressure will decrease more rapidly while steam is leaving the drum than when just liquid is leaving. This is due to the greater specific volume of steam. Figure III shows the equilibrium feedwater flow. This value is the sum of the flows to both steam generators. If the flow to the sound generator is subtracted from the total, the difference obtained is the feedwater flow to the failed generator. At equilibrium, this must equal the steam and leakage flow from the drum of the failed steam generator. It is found that equilibrium is reached when 3352 pounds of water remain in the drum. This corresponds to a decrease of approximately 2.7 ft³ of water from normal level. Consequently, neither a scram nor steam generator isolation will occur.

A scram will be caused by high pressure in the reactor coolant system. Eventually, because of the loss of inventory from the steam system, a low level in one of the steam generators will be reached. However, neither steam generator will reach the isolation level.

Problem: Determine the drum water level behavior in the failed steam generator in the event of the maximum credible tube rupture

Assumptions:

1. Assume total leakage flow is 163,000 lb/hr
2. Assume ruptures are at upper ends of the evaporator tubes
3. Assume drum level is initially normal i.e. 79.9 ft³ of water in drum
- + Assume constant heat input to unit at 100%
5. Assume constant feedwater flow of 124,000 lb/hr
6. Assume helium release to atmosphere is maximum possible
7. Assume minimum pressure at the junction of the two 6-in steam lines is 1265 psia

1 OF 10

Steam Generator Drum Level Following
Maximum Credible Tube Rupture

Appendix C

SIMILAR TO

DR'N *ALLC 6/27/62*

CH'D *JRK 6-28-62*

APP'D

SCALE = 12

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT. *NPD-W*

Study IX 334

A

B

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

The steam flow leaving the superheater outlet can be expressed by

$$W_s = \sqrt{\frac{\Delta P}{k}}$$

When $\Delta P = P_D - 1265$
 $k = \text{a constant}$

$$k = \frac{1378 - 1265}{\left(\frac{125,000}{60}\right)^2} = \frac{113}{46 \times 10^5} = 2.46 \times 10^{-5}$$

$$\therefore W_s = \sqrt{\frac{P_D - 1265}{2.46 \times 10^{-5}}} \quad \text{where } P_D \text{ is the steam drum pressure}$$

Since the ratio of helium to steam pressure is less than 0.5 critical flow exists at the leak(s), thus

$$W_L = C \frac{P_D}{\sqrt{T_D}}$$

P_D = Drum pressure (PSIA)

T_D = Absolute drum temp ($^{\circ}R$)

$$C = \frac{163,000}{60} (32.3) \frac{1}{1378}$$

$$C = 63.6$$

$$\therefore W_L = 63.6 \sqrt{\frac{P_D}{T_D}}$$

2 OF 10

APPENDIX C

SIMILAR TO

DR'N *ALLC 6/27/62*

CH'D *DRH 6/27/62*

APP'D

SCALE

= 12

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. *NPD-W*

Study II 334

A

B

The mass rate of change in the steam drum
can be expressed now as follows:

$$\frac{dM}{dt} = 2140 - 63.6 \frac{P_D}{\sqrt{T_D}} - \sqrt{\frac{P_D - 1265}{2.46 \times 10^{-5}}}$$

which reduces to (and dropping subscripts)

$$\frac{dM}{dt} = 2140 - 63.6 \frac{P}{\sqrt{T}} - 202 \sqrt{P - 1265} \quad (1)$$

3 OF 10

APPENDIX C

SIMILAR TO

DATE *ALLA 6/27/62*

CH'D *DAL 6/27/62*

APP'D

SCALE = 12

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. *NPD-W*

Study II 334

Drum pressure is expressed by the
Clapeyron equation

$$\frac{dP}{dT} = \frac{L}{T \Delta V} \left(\frac{1}{144} \right) \text{ where } L \text{ is the molar heat of vaporization}$$

ΔV is the change in
volume upon vaporization = v_g

Thus, from the steam tables

$$L = 579 \frac{\text{BTU}}{\text{lb}} \cdot \frac{18 \text{ lb}}{\text{mol}} = 10,400 \frac{\text{BTU}}{\text{mol}}$$

$$\Delta V = v_g = \frac{2841 \text{ ft}^3}{\text{lb}} \cdot \frac{18 \text{ lb}}{\text{mol}} = 5.14 \text{ ft}^3/\text{mol}$$

$$\frac{dP}{dT} = \frac{10,400 (778)}{144 (5.14) T} = \frac{10,920}{T} \frac{\text{PSI}}{^\circ\text{R}}$$

Actually a better estimate from the steam tables
can be obtained over range of 1350 psi to 1400 psi

$$\Delta P = 50 \text{ psi}$$

$$\Delta T = 5^\circ\text{R}$$

$$\bar{T} = \frac{557 + 582}{2} + 460 = 1044.5 \approx 1045$$

$$C = \frac{50}{5} (1045) = 10,450 \frac{\text{PSI}}{^\circ\text{R}}$$

$$\frac{dP}{dT} = \frac{10,450}{T}$$

(2)

4 of 10

Drum head following max credible
rupture

APPENDIX C

SIMILAR TO

DATE 6/3/5

CH'D BY 6/28/62

APP'D

SCALE = 12

ALLIS-CHALMERS MFG. CO.

DEPT. UPDW

Sheet 224

If the water level drops, the change in volume must be compensated for by the evaporation of some water

The ^{rate of} volume change due to removing liquid from the drum is:

$$\left(2140 - 63.6 \frac{P}{\sqrt{T}}\right) V_L$$

The ^{rate of change} mass of water that must evaporate to compensate for this change is

$$- \left(2140 - 63.6 \frac{P}{\sqrt{T}}\right) \frac{V_L}{V_{fg}}$$

and the energy required to evaporate this amount of water is then

$$- \left(2140 - 63.6 \frac{P}{\sqrt{T}}\right) \frac{V_L}{V_{fg}} (h_{fg}) \quad (3a)$$

Similarly, any steam leaving the drum must also require the vaporization of water then an equation similar to 3a is

$$+ 202 \sqrt{P - 1265} \left(\frac{V_L}{V_{fg}}\right) h_{fg} \quad (3b)$$

5 OF 10

APPENDIX C

SIMILAR TO

DR'N AHA 6/27/62

CH'D BRL 6-28-62

APP'D

SCALE = 12

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

Study II 334

Combining equations 3a and 3b the rate of energy loss due to steam and leakage flows is

$$\frac{dQ}{dt} = \left[\left(2140 - 63.6 \frac{P}{\sqrt{T}} \right) (V_L) - 202 \sqrt{P-1265} (V_g) \right] \frac{h_{fg}}{V_{fg}} \quad (3c)$$

Since

$$\Delta T = \frac{Q}{m c_p} \text{ then}$$

$$\frac{dT}{dt} = \frac{h_{fg}}{m c_p V_{fg}} \left[\left(2140 - 63.6 \frac{P}{\sqrt{T}} \right) V_L - 202 V_g \sqrt{P-1265} \right] \quad (3)$$

From the steam tables for the press & temp^{range} of interest

$$\bar{h}_{fg} \approx 590 \text{ BTU/lb}$$

$$\bar{V}_L \approx 0.023 \text{ ft}^3/\text{lb}$$

$$\bar{V}_{fg} \approx 0.300 \text{ ft}^3/\text{lb}$$

$$\bar{V}_g \approx 0.315 \text{ ft}^3/\text{lb}$$

$$\bar{c}_p \approx 1.4 \text{ BTU/lb}^\circ\text{R}$$

$$\therefore \frac{dT}{dt} = \frac{1}{M} \left[6.91 \times 10^4 - 2060 \frac{P}{\sqrt{T}} - 8.95 \times 10^4 \sqrt{P-1265} \right]$$

6 OF 10

APPENDIX C

SIMILAR TO

DR'N *ALL 6/27/62*

CH'D *DA 6-28-62*

APP'D

SCALE

= 12

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. *NPD-W*

Study II 334

$$\frac{dM}{dt} = 2140 - 63.6 \frac{P}{\sqrt{T}} - 202 \sqrt{P-1265} \quad \text{I}$$

$$\frac{dP}{dT} = \frac{10450}{T} \quad \text{II}$$

$$\frac{dT}{dt} = \frac{1}{M} \left[6.91 \times 10^4 - 2060 \frac{P}{\sqrt{T}} - 8.98 \times 10^4 \sqrt{P-1265} \right] \quad \text{III}$$

$$M' = M_0 + \frac{dM}{dt} \Delta t \quad \text{IV}$$

$$P' = \frac{dP}{dT} \frac{dT}{dt} \Delta t + P_0 \quad \text{V}$$

$$T' = \frac{dT}{dt} \Delta t + T_0 \quad \text{VI}$$

Equations I to VI were programmed for a Bendix G-15 digital computer. The initial values of M , P , and T were:

$$M_0 = 3470 \text{ lb}$$

$$P_0 = 1374 \text{ psia}$$

$$T_0 = 585 + 460 = 1045^\circ \text{R}$$

Isolation bulb - 2160 lb water in drum

7 of 10

APPENDIX C

SIMILAR TO

DR'N *ARR* 6/27/62

CH'D *DDL* 6/28/62

APP'D

SCALE

= 12

ISSUE

ALLIS-CHALMERS MFG. CO.

REPT *NPD-W*

Study IX-334

A

B

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

Problem: Calculate the equilibrium drum inventory following a 163,000 lb/hr leak

The pressure drop from the pump discharge to the steam drum is normally

$$1505 + 14.4 = 1378 = 141 \text{ psi}$$

(Value of 1505 is obtained from feedwater pump curve for flow of 4280 lb/min)

$$\Delta P = kW^2 \quad \text{where } W \text{ is flow to one steam generator}$$

$$k = \frac{141}{(2140)^2} = 30.8 \times 10^{-6}$$

$$\Delta P = P_p - P_D = 30.8 \times 10^{-6} W^2 + P_D$$

where P_p = Pump discharge pressure

P_D = Pump drum pressure

W = feedwater flow or leakage plus steam flow

The value of pump discharge pressure required to supply the failed steam generator with water equal to the leakage plus steam flow can be determined by using the values of W_s , W_L , P_D from the computer output sheets.

N.B. Note: Computer output gives flows at end of time increment, pressure at start of time increment

3 OF 10

APPENDIX C

SIMILAR TO

DR'N ALG 6/29/62

CH'D DPC 6/29/62

APP'D

SCALE = 12

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

NPD-W

Study IX-334

A

B

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

then

$$P_p = 30.8 \times 10^{-6} (W_s + W_L)^2 + P_D$$

Drum Pressure	$W_s + W_L$	P_p	W_{Total}
1163	2.31×10^3	1327	4450
1246	2.46×10^3	1434	4601
1260	2.487×10^3	1451	4627
1265.8	2.681×10^3	1482	4821
1277	3.229×10^3	1598	5369

The results are superimposed on the feedwater pump head curve. The intersection of the two curves is the flow that can be delivered at the equilibrium level. The value of $W_s + W_L$ can be determined and from the computer output the equilibrium level can be found.

W_s = Steam flow from drum

W_L = Leakage flow from drum

$W_f = W_s + W_L + 2140$

2140 = feedwater flow (lb/min) to sound steam generator

9 OF 10

APPENDIX C

SIMILAR TO

DR'N ADA 6/29/62

CH'D DAL 6/29/62

APP'D

SCALE = 12

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

Study II 334

A

B

At equilibrium, the mass lost is

$$3470 - 3352 = 118 \text{ lb}$$

$$118 \text{ lb} (.023 \text{ ft}^3/\text{lb}) = 2.72 \text{ ft}^3$$

This change in volume is not sufficient to
even cause a scream

100 F 10

APPENDIX C

SIMILAR TO

DR'N *area 6/25/64* CH'D *DRL 6/29/64* APP'D

SCALE = 12

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT. *NPD-W*

Study Dc 334

ALLIS-CHALMERS MANUFACTURING COMPANY
INTER-OFFICE CORRESPONDENCE

To: S. Matovich

From: E. F. Wilson

Attention:

Date: September 12, 1961

Refer to:

Subject: Bursting Strength of Seamless Steel Boiler Tubing, A-83, Grade A

Cust. P. O. #

D. O. Reg. #

S. O. #

The subject material is a rimming or semi-killed, open-hearth steel with a nominal minimum tensile strength of 45,000 psi. The tube material was identified as 1.0 in. OD by 0.083 in. wall and 0.75 in. OD by 0.065 in. wall.

Service conditions specified were 1400 psi saturated steam corresponding to 587.1 F. Creep movement is not significant in service performance but stress to rupture on prolonged loading is a consideration. Basic stress rupture data used for purposes of design are as follows for a 600 F temperature:

<u>Time</u>	<u>Average Stress to Rupture</u>	<u>Variation Range, Stress to Rupture</u>
1,000	32,000 psi	26,000 psi min - 37,000 psi max
10,000	28,000 psi	22,000 psi min - 32,000 psi max
100,000	--	18,000 psi min
175,200	--	16,800 psi min

Minimum obtainable stress rupture values for 100,000 hours and 175,200 hours (20 years) were obtained by extrapolation of test data on a logarithmic attenuation. The value of 16,800 psi for 20 years can be compared with a conservative ASME Code figure of 11,750 psi for up to 650 F, -- unspecified service time.

Fiber stress values in the tubing corresponding to the 1400 pressure can be calculated as 8400 psi for the 1 in. tube and 8080 psi for the 0.75 in. tube. Therefore the available strength is one hundred per cent in excess of exerted load.

In other terms, the bursting pressure of the 1 in. tube is 2789 psi and 2912 psi for the 0.75 in. tube for 20 years at 600 F. Exerted pressure is 1400 psi.

E.F.W.
E. F. Wilson

cc: W. F. Banks
W. M. Hawkins

STEAM GENERATOR
- TUBING -

STUDY IV-334
APPENDIX C

C-1A of 10

FIG I

MASS OF WATER IN STEAM
DRUM AFTER ACCIDENT

ADA 6/20/62

FIGURE II

STUDY II 334

FIGURE III

EXHIBIT I

62662
 Steam Drum level
 Initial steam flow 128,000 lb/h
 Feedwater flow 128,000 lb/h constant
 Steam flow stops at drum pressure
 of 1265 psia

ALLA 6/27/62

.0009 @.2009 @.2071 @
 207 543470 @ 54.34700
 208 .2131 @
 213 542160 @ 54.21600
 214 .u @0000071 @.u @2000213 @.0490 @
 49 19050 @190 50
 50 .x @.000z @

54.27111 54.21473 54.34564
 -54.27184 54.13639 54.10436
 -53.28067 48.50000 .00000

54.26853 54.20093 54.34436
 -54.25546 54.13507 54.10423
 -53.26372 49.10000 .00000

54.26609 54.18703 54.34317
 -54.23912 54.13384 54.10410
 -53.24646 49.15000 .00000

54.26381 54.17301 54.34205
 -54.22282 54.13269 54.10399
 -53.22888 49.20000 .00000

54.26169 54.15887 54.34102
 -54.20656 54.13162 54.10388
 -53.21101 49.25000 .00000

54.25073 54.14460 54.34007
 -54.19033 54.13065 54.10379
 -53.19282 49.30000 .00000

54.25793 54.13019 54.33920
 -54.17412 54.12978 54.10370
 -53.17431 49.35000 .00000

54.25631 54.11561 54.33841
 -54.15791 54.12899 54.10362
 -53.15547 49.40000 .00000

54.25485 54.10083 54.33770
 -54.14168 54.12830 54.10356
 -53.13627 49.45000 .00000

54.25358 53.85794 54.33707
 -54.12537 54.12772 54.10350

Output Format

W_L	W_S	M
$\frac{dM}{dt}$	P_D	T
$\frac{dT}{dt}$	t	-

Number form

$K.ABCDE \equiv 0.ABCDE \times 10^{K-50}$

where K is a 2 digit number

A,B,C,D,E are digits

12.00000 $\equiv$ zero

-53.11664 49.50000 .00000

54.25249 53.70412 54.33653
-54.10890 54.12723 54.10345
-52.96471 49.55000 .00000

54.25158 53.54493 54.33607
-53.92073 54.12685 54.10341
-52.75528 49.60000 .00000

54.25087 53.37579 54.33570
-53.74451 54.12658 54.10338
-52.53221 49.65000 .00000

54.25037 53.17743 54.33543
-53.54114 54.12644 54.10337
-52.27012 49.70000 .00000

.xxxxx

•x \$0100 \$

10 19015 \$190 15

11 .0150 \$

15 4v301 \$4v0 301

16 .3021 \$

302 \$ 12.00000

303 .0230 \$

23 19028 \$190 28

24 .3041 \$

304 \$ 12.00000

305 •x \$0686 \$4 \$000z \$

54.25012 12.00000 54.33525
-53.36118 54.12642 54.10337
-51.35535 49.75000 .00000

} Equilibrium values if feedwater flow increase is considered

54.25008 12.00000 54.33506
-53.36084 54.12640 54.10337
-51.35522 49.80000 .00000

54.25005 12.00000 54.33488
-53.36051 54.12639 54.10337
-51.35509 49.85000 .00000

54.25002 12.00000 54.33470
-53.36018 54.12637 54.10336
-51.35496 49.90000 .00000

54.24998 12.00000 54.33452
-53.35984 54.12635 54.10336
-51.35482 49.95000 .00000

54.24995 12.00000 54.33434
-53.35950 54.12633 54.10336
-51.35469 50.10000 .00000

•0687 \$x \$2061 \$

206 492 \$ 49.20000

207 .0020 \$

2

110011 0111

3 .0490 ⑤
 49 650031 ⑤651 3
 50 .x ⑤.000z ⑤

54.24938 12.00000 54.33078
 -53.35384 54.12597 54.10333
 -51.35296 50.20000 .00000

54.24872 12.00000 54.32728
 -53.34722 54.12562 54.10329
 -51.35019 50.30000 .00000

54.24807 12.00000 54.32385
 -53.34066 54.12527 54.10325
 -51.34733 50.40000 .00000

54.24741 12.00000 54.32048
 -53.33413 54.12492 54.10322
 -51.34439 50.50000 .00000

54.24677 12.00000 54.31718
 -53.32766 54.12457 54.10319
 -51.34137 50.60000 .00000

54.24613 12.00000 54.31394
 -53.32125 54.12423 54.10315
 -51.33827 50.70000 .00000

54.24549 12.00000 54.31077
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 -51.33510 50.80001 .00000

54.24486 12.00000 54.30766
 -53.30858 54.12355 54.10309
 -51.33185 50.90001 .00000

54.24423 12.00000 54.30461
 -53.30234 54.12321 54.10305
 -51.32853 51.10000 .00000

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 -53.29616 54.12288 54.10302
 -51.32514 51.11000 .00000

54.24300 12.00000 54.29870
 -53.29003 54.12255 54.10299
 -51.32169 51.12000 .00000

54.24240 12.00000 54.29583
 -53.28397 54.12223 54.10296
 -51.31816 51.13000 .00000

54.24180 12.00000 54.29303

-53.27130	51.12131	54.29292
-51.31457	51.14000	.00000

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-53.27203	54.12159	54.10289
-51.31092	51.15000	.00000

54.24062	12.00000	54.28760
-53.26616	54.12128	54.10286
-51.30722	51.16000	.00000

54.24004	12.00000	54.28497
-53.26035	54.12097	54.10283
-51.30344	51.17000	.00000

54.23946	12.00000	54.28240
-53.25462	54.12066	54.10280
-51.29963	51.18000	.00000

54.23890	12.00000	54.27989
-53.24895	54.12036	54.10277
-51.29576	51.19000	.00000

54.23834	12.00000	54.27744
-53.24336	54.12006	54.10274
-51.29185	51.20000	.00000

54.23778	12.00000	54.27504
-53.23784	54.11977	54.10271
-51.28789	51.21000	.00000

54.23724	12.00000	54.27269
-53.23239	54.11948	54.10268
-51.28389	51.22000	.00000

54.23670	12.00000	54.27040
-53.22701	54.11919	54.10266
-51.27986	51.23000	.00000

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-53.22171	54.11891	54.10263
-51.27579	51.24000	.00000

54.23565	12.00000	54.26597
-53.21648	54.11863	54.10260
-51.27168	51.25000	.00000

54.23513	12.00000	54.26384
-53.21133	54.11836	54.10257
-51.26756	51.26000	.00000

54.23462	12.00000	54.26176
-53.20625	54.11809	54.10255

-51.26341 51.27001 .00000

54.23413 12.00000 54.25973
-53.20125 54.11782 54.10252
-51.25924 51.28001 .00000

54.23363 12.00000 54.25774
-53.19633 54.11756 54.10250
-51.25505 51.29001 .00000

54.23315 12.00000 54.25581
-53.19148 54.11730 54.10247
-51.25084 51.30001 .00000

54.23267 12.00000 54.25392
-53.18672 54.11705 54.10245
-51.24662 51.31001 .00000

54.23220 12.00000 54.25208
-53.18203 54.11680 54.10242
-51.24239 51.32001 .00000

54.23174 12.00000 54.25029
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-51.23817 51.33001 .00000

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-51.23394 51.34001 .00000

54.23084 12.00000 54.24684
-53.16844 54.11608 54.10235
-51.22971 51.35001 .00000

54.23041 12.00000 54.24519
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-51.22549 51.36001 .00000

54.22998 12.00000 54.24357
-53.15978 54.11562 54.10231
-51.22128 51.37001 .00000

54.22956 12.00000 54.24200
-53.15556 54.11539 54.10228
-51.21707 51.38001 .00000

54.22914 12.00000 54.24047
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-51.21289 51.39001 .00000

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-51.20872 51.40001 .00000

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-51.20457	51.41001	.00000

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-53.13949	54.11454	54.10220
-51.20044	51.42000	.00000

54.22757	12.00000	54.23475
-53.13568	54.11434	54.10218
-51.19634	51.43000	.00000

54.22719	12.00000	54.23341
-53.13193	54.11414	54.10216
-51.19226	51.44000	.00000

54.22683	12.00000	54.23211
-53.12826	54.11395	54.10214
-51.18822	51.45000	.00000

54.22647	12.00000	54.23085
-53.12466	54.11376	54.10212
-51.18420	51.46000	.00000

54.22611	12.00000	54.22963
-53.12114	54.11357	54.10211
-51.18022	51.47000	.00000

54.22577	12.00000	54.22844
-53.11770	54.11339	54.10209
-51.17628	51.47999	.00000

54.22543	12.00000	54.22728
-53.11434	54.11321	54.10207
-51.17238	51.48999	.00000

54.22510	12.00000	54.22616
-53.11104	54.11304	54.10205
-51.16852	51.49999	.00000

54.22478	12.00000	54.22507
-53.10782	54.11287	54.10204
-51.16470	51.50999	.00000

54.22447	12.00000	54.22401
-53.10468	54.11270	54.10202
-51.16093	51.51999	.00000

54.22416	12.00000	54.22298
-53.10160	54.11254	54.10201
-51.15720	51.52999	.00000

54.22386	12.00000	54.22198
-52.98594	54.11238	54.10199
-51.15352	51.53998	.00000

54.22357	12.00000	54.22101
-52.95652	54.11222	54.10197
-51.14989	51.54998	.00000

54.22328	12.00000	54.22007
-52.92785	54.11207	54.10196
-51.14630	51.55998	.00000

54.22300	12.00000	54.21916
-52.89980	54.11192	54.10195
-51.14277	51.56998	.00000

54.22273	12.00000	54.21828
-52.87254	54.11178	54.10193
-51.13930	51.57998	.00000

54.22246	12.00000	54.21742
-52.84582	54.11164	54.10192
-51.13587	51.58998	.00000

54.22220	12.00000	54.21659
-52.81980	54.11150	54.10190
-51.13250	51.59997	.00000

54.22194	12.00000	54.21579
-52.79445	54.11137	54.10189
-51.12919	51.60997	.00000

STOP

47

APPENDIX D

The calculations of Appendix C showed that an equilibrium level will be reached in the steam drum even for the maximum credible steam tube failure leakage flow. The following calculations show that isolation will not occur due to steam drum low level signal even once the deaerator is depleted of water. The radiological analysis included considers two cases, namely with the reactor connected and also disconnected from the external network. The radiological calculations are also based (1) on a release at electromatic relief valve elevation, and (2) on a release from the plant stack. The latter case is considered. A line to the stack from the electromatic relief valves was added to the design subsequent to the original calculations.

A B C

PROBLEM: DETERMINE IF ISOLATION OF A DEFECTIVE
STEAM GENERATOR WILL OCCUR DUE TO STEAM
DRUM LEVEL IN THE EVENT OF A LARGE
TUBE(S) RUPTURE

FROM THE ANALYSIS PRESENTED IN APPC, IT IS SEEN
THAT AN EQUILIBRIUM DRUM LEVEL CAN BE
ESTABLISHED WITH A LEAKAGE OF APPROXIMATELY
2500 lb/min THIS CORRESPONDS TO AN INITIAL
LEAKAGE

FOR THIS ANALYSIS ASSUME AN ECONOMIZER
FAILURE OF 2140 lb/min (128,000 lb/hr)

THE LOWEST RELIEF VALVE SETTING IS 345 psia
BLOWER SUCTION PRESSURE IS ABOUT 298 psia
THUS THE PARTIAL PRESSURE OF STEAM TO LIFT
VALVES IS

$$345 - 298 = 47 \text{ psia}$$

USING A SYSTEM VOLUME OF 12000 ft³ AND A
TEMP OF (510 + 1050) .5 + 460 = 1240 °R

$$m = \frac{PV/M}{RT} = \frac{47(144)(12000)(18)}{1545(1240)} = 746 \text{ lb STEAM}$$

APPENDIX D

SIMILAR TO

DR'N ADA

CH'D

APP'D

SCALE

= 12

SHEET 1 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

A

B

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

CALCULATE FRACTION OF 290 F FEEDWATER ENTERING REACTOR COOLANT SYSTEM THROUGH LEAKAGE IN THE ECONOMIZER SECTION WHICH WILL FLASH DUE TO ITS OWN HEAT CONTANT:

ASSUME FLASHING TAKES PLACE AS A CONSTANT PRESSURE PROCESS SO THAT AN ENTHALPY BALANCE HOLDS.

FEEDWATER AT 290 F, ~ 1300 PSIA

h_f FOR SAT'D WATER = 259.31 BTU/LB
 $h - h_f$ FOR COMPRESSED LIQUID = 2.40 BTU/LB
 $\frac{261.71}{261.71}$

FROM KEENAN & KEYES STEAM TABLES.

$h_1 = 261.7$ BTU/LB.

APPENDIX D

SIMILAR TO

DR'N HUMPHREYS

CH'D

APP'D

SCALE

= 12

SHEET 2 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

A

B

A-C MFG. CO., MILWAUKEE, WIS.

FORM NO. 6833-3

ENTHALPY BALANCE -

$$(1) \quad h_1 = X h_{g_2} + (1-X) h_{f_2}$$

X = FRACTION FLASHED TO STEAM

LOWEST RELIEF VALVE SETTING = 330 PSIG
OR 345 PSIA

NORMAL OPERATING PRESSURE AT BLOWER
SUCTION $\approx$ 298 PSIA

WHEN RELIEF VALVE LIFTS $P_s = 345 - 298 = 47$ PSI
SINCE SATURATION PRESSURE = 57.56 PSIA AT 290 F
YOU CAN BUILD UP TO 345 PSIA JUST DUE TO FLASHING;

FOR P_s = PARTIAL PRESSURE OF STEAM = 47 PSIA

$$t_2 = 277.13 \text{ F}$$

$$h_{f_2} = 246.12 \text{ BTU/LB} : h_{g_2} = 1172.9 \text{ BTU/LB.}$$

SUBST. INTO EG'N(1)

$$261.7 = X(1172.9) + (1-X) 246.1$$

$$261.7 = 1172.9 X - 246.1 X + 246.1$$

$$15.6 = 926.8 X$$

$$X = \frac{15.6}{926.8} = 1.69 \times 10^{-2} \text{ OR } \boxed{1.69\%}$$

THEREFORE, WHEN THE FIRST RELIEF VALVE SETTING IS
REACHED $\sim 1.7\%$ OF INCOMING 290 F FEEDWATER FLASHES
DUE TO ITS OWN HEAT.

APPENDIX D

SIMILAR TO

DR'G HUMPHREYS

CH'D ADA

APP'D

SCALE = 12

SHEET 3 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY W-334

FRACTION FLASHING AS A FUNCTION OF PARTIAL PRESSURE OF STEAM

$$P_s \cong \quad t = 79 F$$

$$h_{g_2} = 1096.3 \frac{\text{BTU}}{\text{LB}} ; h_{f_2} = 47.05 \frac{\text{BTU}}{\text{LB}}$$

$$261.7 = X (1096.3) + (1-X) 47.05$$

$$261.7 = 1096.3 X - 47.0\% + 47.0$$

APPENDIX D

SIMILAR TO

DR'M HUMPHREYS

CH'D ADA

APP'D

SCALE = 12

SHEET 4 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

FOR 290 F
FEEDWATER

PARTIAL PRESSURE OF STEAM
IN REACTOR COOLANT, PSIA

APPENDIX D

SIMILAR TO

DR'N	CH'D	APP'D	SCALE = 12	SHEET 5 OF 48	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.				STUDY IV-334	

A

B

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

USING AN AVERAGE VALUE FOR THE FRACTION OF WATER FLASHING - FROM GBH'S CURVE-SAY 0.07

THE RATE OF STEAM PRODUCTION DUE TO FLASHING THEN IS
 $2140 (0.07) \frac{\text{LB}}{\text{MIN}} = 150 \text{ LB/MIN}$

THE WATER REMAINING BEHIND, THEN, IS AT AN AVERAGE TEMPERATURE OF 227°F.

THE DEAERATOR CAN LOOSE FROM THE NORMAL LEVEL TO THE FEEDWATER PUMP TRIP LEVEL.

$$5000 \left(\frac{1}{0.01736} \right) \left(\frac{1}{7.48} \right) = 38,500 \text{ LB.}$$

FROM PAGE 1 A LEAK OF 2500 LB/MIN DOES NOT EXCEED CAPACITY OF FEEDWATER PUMP TO MAINTAIN DRUM LEVEL. FEEDWATER PUMP TRIPED AT

$$\frac{38,000 \text{ LB}}{2140 \frac{\text{LB}}{\text{MIN}}} = 18.0 \text{ MIN}$$

THE TIME TO READ THE LOW DRUM LEVEL (JUST DUE TO LEAK AND STEAMING) IS

$$30.2 \text{ ft}^3 \left(\frac{43.5 \text{ LB}}{\text{ft}^3} \right) \left(\frac{\text{MIN}}{4280 \text{ LB}} \right) = .307 \text{ MIN}$$

$$t = 18.0 + .307 \approx 18.3 \text{ MIN}$$

VOLUME BELOW TUBE SHEET

MUD DRUM $\approx 113 \text{ ft}^3$

STRAIGHT SIDE $\approx \frac{5\pi 81}{4} = 318 \text{ ft}^3$

HEAD $\approx \frac{1}{4} \pi 81 = 63 \text{ ft}^3$

↑
ASSUME 9' Ø x 1' CYLINDER

APPENDIX D

SIMILAR TO

DR'N ADA

CH'D LCC

APP'D

SCALE = 12

SHEET 6 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

$$V = 318 + 63 - 113 = 268 \text{ Ft}^3$$

$$\frac{268 \text{ Ft}^3 \left(\frac{1}{0.01736} \frac{\text{LB}}{\text{Ft}^3} \right)}{(2140 - 150) \frac{\text{LB}}{\text{MIN}}} = 7.75 \text{ MIN}$$

THE MUD DRUM IS AT 585°F AND THE SHELL IS 510°F. A METAL TO FEEDWATER COEFFICIENT OF HEAT TRANSFER OF 1000 $\frac{\text{BTU}}{\text{hr}^2 \cdot \text{F}}$ IS ASSUMED. THIS IS COMPARABLE TO EVAPORATOR COEFFICIENTS.

THE STRAIGHT SIDE AREA IS $5 \pi 9 = 141 \text{ ft}^2$
 HEAD SURFACE AREA $\sim \frac{\pi 81}{4} \approx 63$
 ASSUME DRUM 6' DIA $\sim \pi 36 \approx 113 \text{ ft}^2$
 TOTAL SURFACE $\approx 317 \text{ ft}^2$

APPENDIX D

SIMILAR TO

DR'N ADA

CH'D

APP'D

SCALE = 12

SHEET 7 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

USING HOTTEL CHART P 37 Mc ADAMS

$$Y_s = \frac{t_a - t_s}{t_a - t_b} = \frac{227 - t_s}{227 - 585} = \frac{t_s - 227}{358}$$

$$X = \frac{k\theta}{\rho c_p r_m^2} \quad \text{SHELL } 1\frac{1}{2}'' \text{ TK } \approx .0936'$$

$$\text{DRUM } 1\frac{1}{16}'' \text{ TK } \approx .014'$$

DRUM WOULD CHANGE TEMP SLOWER

$$r_m^2 = \frac{25.2}{.14(1000)} = 0.18$$

$$X = \frac{25.2\theta}{500(.14)(.0049)} = 73.5\theta \quad (\theta \text{ IN HOURS})$$

$$\theta = 1 \text{ MIN} \quad X = 1.225$$

$$Y_s = 0.035 \quad t_s = .035(358) + 227 = 239^\circ \text{F}$$

$$\theta = 2 \text{ MIN}$$

$$Y_s < 0.01 \quad t_s < 230^\circ \text{F}$$

USE A Δt of 5°F

$$Q = 1000(317)(5) = 1.58 \times 10^6 \frac{\text{BTU}}{\text{hr}}$$

$$\frac{Q}{A} = 5000 \text{ WARM IS CORRECT ORDER OF MAGNITUDE}$$

APPENDIX D

SIMILAR TO

DR'N *ARC*

CH'D

APP'D

SCALE

= 12

SHEET *8* OF *48*

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY 1V-334

ASSUME HEAT TRANSFER DUE TO CONTACT WITH METAL
VARIES LINEARLY WITH LEVEL

$$t = 0 \quad Q = 0 \frac{\text{BTU}}{\text{hr.}}$$

$$t = 7.8 \text{ min. } Q = 158 \times 10^6 \frac{\text{BTU}}{\text{hr.}} \text{ OR } 2.64 \times 10^4 \frac{\text{BTU}}{\text{MIN}}$$

$$\text{TIME} = 7.8 \text{ MIN.}$$

$$\frac{dq}{dt} = Q = 3.38 \times 10^3 \frac{\text{BTU}}{\text{MIN}^2} t$$

$$dq = 3.38 \times 10^3 t dt$$

$$q = 3.38 \times 10^3 \frac{t^2}{2} = 1.69 \times 10^3 t^2$$

$$\text{AT } 227^\circ\text{F } h_{fg} = 960.1 \frac{\text{BTU}}{\text{LB}}$$

APPENDIX D

SIMILAR TO

DR'N <i>all</i>	CH'D <i>LCC</i>	APP'D	SCALE = 12	SHEET <i>9</i> OF <i>48</i>	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.				STUDY IV-334	

THE AMOUNT OF STEAM PRODUCED BY HEAT TRANSFER FROM THE METAL THAN IS

$$M = 1.76 t^2$$

THE RATE DUE TO FLASHING IS 150 LB/MIN. THUS THE TOTAL STEAM PRODUCED IS

$$M_t = 1.76 t^2 + 150 t$$

TIME TO LIFT RELIEF VALVE THAN IS

$$764 = 1.76 t^2 + 150 t$$

$$1.76 t^2 + 150 t - 764 = 0$$

$$t = \frac{-150 \pm \sqrt{2.25 \times 10^4 + .537 \times 10^4}}{3.52} = \frac{-150 \pm 167}{3.52}$$

$$t = \frac{-150 + 167}{3.52} = 4.82 \text{ MIN.}$$

THE RATE OF STEAM PRODUCTION AT 7.8 MIN. IS

$$\frac{dM}{dt} = W = 3.52 t + 150 = 177.4 \text{ LB/MIN}$$

CALCULATE TIME TO SCRAM

SCRAM PRESSURE IS 325 PSIG OR 340 PSIA

PLENUM PRESSURE IS 313 PSIA

STEAM PRESSURE TO SCRAM IS 340 - 313 = 27 PSIA

$$M_{st} = \frac{27(144)(12,000)(18)}{1545(1240)} = 438 \text{ LB STEAM}$$

$$\text{THUS } 1.76 t^2 + 150 t - 438 = 0$$

$$t = \frac{-150 + \sqrt{2.25 \times 10^4 + .308 \times 10^4}}{3.52} = \frac{-150 + 160}{3.52} = 2.84 \text{ MIN}$$

APPENDIX D

SIMILAR TO

DR'N *amc*

CH'D *JCC*

APP'D

SCALE = 12

SHEET *10* OF *48*

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

FROM CALCULATIONS TRANSMITTED WITH LETTER
BUSH - JACKSON JANUARY 26, 1962 APPROXIMATELY
6.2 MINUTES WILL BE REQUIRED TO BRING STEAM
PRESSURE TO 330 PSIG

$$t = 18.3 + 6.2 = 24.5 \text{ MIN.}$$

THE TIME SEQUENCE SO FAR IS AS FOLLOWS

TIME (MIN)	EVENT
0	RUPTURE - 2140 ^{LB} /MIN ECONOMIZER
2.8	SCRAM DUE TO HIGH PRESSURE
4.8	LIFT RELIEF VALVE IN PRIMARY SYSTEM
18.0	DEAERATOR REACHES LOW LEVEL - FEEDWATER PUMP TRIPPED.
18.3	ELECTROMATIC STEAM SIDE BLOWDOWN STARTS
24.5	STEAM SIDE REACHES PRIMARY SYSTEM PRESSURE (345 PSIA)

ABOVE THE TUBE SHEET HEAT WILL ALSO BE
TRANSFERRED BY THE TUBES. ABOUT $\frac{2.75}{20} = 0.1375$
OF THE SURFACE WILL BE EFFECTIVE.

SUPERHEATER	1420 ft ²
EVAPORATOR	6400
ECONOMIZER	5100

APPENDIX D

SIMILAR TO

DR'N

CH'D

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APP'D

SCALE

= 12

SHEET 11 OF 45

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-534

A

B

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

USING THE UNTEMMEYER CURVES BETWEEN $t = 7.8$ MIN. AND 24.5 MIN. OR 466 SEC AND 1470 SEC. THE FRACTIONAL POWER VARIES FROM 2.7×10^{-2} TO 2.0×10^{-2}

USING A CONSTANT POWER FRACTION OF 2.7×10^{-2}

$$\frac{P}{2} = 2.7 \times 10^{-2} \left(\frac{85 \times 10^6}{2} \text{ WATT} \right) \left(3.413 \frac{\text{BTU}}{\text{hr WATT}} \right) \left(\frac{\text{hr.}}{60 \text{ MIN}} \right) = 6.55 \times 10^4 \frac{\text{BTU}}{\text{MIN}}$$

THE RATE OF STEAM PRODUCTION THEN IS

$$\frac{P}{2(960)} = \frac{6.55 \times 10^4 \frac{\text{BTU}}{\text{min}}}{960 \times 10^3 \frac{\text{BTU}}{\text{LB}}} = 68.2 \text{ LB/MIN}$$

THE TOTAL RATE OF STEAM PRODUCTION THEN BETWEEN 7.8 MIN AND 24.5 MIN IS

$$177 + 68 = 245 \text{ LB/MIN.}$$

$$\frac{dN}{N} = -\frac{1}{18N_0} (245) dt$$

$$\ln N = -\frac{1}{6300} 245t + C = C - .0388t$$

$$\ln N = C - .0388t$$

$$\text{AT } 7.8 \text{ MIN } N = 250 \quad \ln N = 5.51$$

$$C = 5.51 - 0.303 = 5.81$$

AT 24.5 MIN.

$$\ln N = 5.81 - 0.0388 (24.5) = 4.86$$

$$N = 130$$

$$\frac{N}{N_0} = .372$$

APPENDIX D

SIMILAR TO

DR'N

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APP'D

SCALE

= 12

SHEET

12

OF

43

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

A

B

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

TIME TO OVERFLOW INTO COLD LEG IS

$$\frac{150 \cdot \frac{1}{0.01736}}{2140 - 245} + 7.8 = 4.5 + 7.8 = 12.3 \text{ MIN}$$

THUS THE COMPLETE SEQUENCE IS

<u>TIME (MIN)</u>	<u>EVENT</u>
0	RUPTURE - 2140 LB/MIN
2.8	SCRAM ON HIGH PRESSURE
4.8	LIFT PRIMARY SYSTEM RELIEF VALVES
12.3	OVERFLOW STEAM GENERATOR INTO COLD LEG PIPE
18.0	DEAERATOR REACHES TRIP LEVEL MAIN FEEDWATER PUMP TRIPPED OFF
18.3	ELECTROMATIC RELIEF VALVES OPEN START STEAM SIDE BLOWDOWN
→ 24.5	STEAM SYSTEM REACHES 330 PSIG. START TO RELIEVE ACTIVITY TO ATMOSPHERE 37% AVAILABLE

NOTE: 21.2 COMPUTED LATER

IF THE PLANT IS NOT CONNECTED TO THE EXTERNAL NETWORK, THE SEQUENCE IS DIFFERENT.

ONE MINUTE AFTER THE SCRAM, THE TURBINE STOP VALVE IS TRIPPED AND A POWER FAILURE RESULTS. THE ELECTROMATIC RELIEF VALVE WILL OPEN ON POWER FAILURE. THUS,

TIME 0 MIN.	RUPTURE
2.8	SCRAM
3.8	TURBINE TRIP - OPEN EMR & START BLOWDOWN.
4.8	LIFT PRIMARY SYSTEM RELIEF VALVES
9.0	STEAM SYSTEM REACHES 330 PSIG
NOTE 2.2 COMPUTED LATER	START RELIEF OF ACTIVITY TO ATMOSPHERE

APPENDIX D

SIMILAR TO

SHEET 13 OF 48

STUDY IV-334

DR'N *ama*

CH'D *CC*

APP'D

SCALE = 12

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

RELIEF (PRIMARY) VALVES DISCHARGE $t=7.8 \text{ MIN}$ To $t=9 \text{ MIN}$

$$\ln N = 5.81 - 0.0388 t$$

$$\ln N = 5.81 - 0.350 = 5.46$$

$$N = 238$$

$$\frac{N}{N_0} = 0.68$$

NOTE $t=0$ REFERS TO START OF BLOWDOWN

IT IS NOW NECESSARY TO DETERMINE IF THE LOW LEVEL ISOLATION FUNCTIONS

USING CURVE IIA FROM LETTER BUSH - JACKSON FEBRUARY 9, 1962 FIT THE CURVES TO STRAIGHT LINE EQUATIONS AS FOLLOWS

FROM $t=0$ To $t=0.4$ $P=1365 \text{ PSIA}$

FROM $t=0.4$ To $t=3.6 \text{ MIN}$
 $P=1460 - 238 t$

FROM $t=3.6$ To $t=6.2 \text{ MIN}$
 $P=965 - 100 t$

TWO PHASE FLOW, LIKE SONIC FLOW IS DEPENDANT ONLY UPON UPSTREAM PRESSURE. ASSUME CRITICAL FLOW OCCURS UNTIL $t=3.6 \text{ MIN}$.

APPENDIX D

SIMILAR TO

DR'N *all*

CH'D *dcc*

APP'D

SCALE = 12

SHEET 14 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

DETERMINE WATER LOST DUE TO LEAKAGE ^{UP TO} ~~BETWEEN~~
3.6 MIN.

FROM $t=0$ TO $t=0.4$ MIN.

$$M = 2140 (0.4) = 855 \text{ LB.}$$

FROM $t=0.4$ TO $t=3.6$ MIN

$$\frac{dM}{dt} = W = CP = C (855 - 238t)$$

$$C = \frac{2140}{1365} = 1.568$$

$$\frac{dM}{dt} = 1.568 (1460 - 238t) = 2285 - 373t$$

$$M = 2285t - \frac{373}{2} t^2 \quad \left]_{0.4}^{3.6}\right.$$

$$M = (8226 - 2417) - (914 - 29.8) = 4925 \text{ LB.}$$

BETWEEN 3.6 AND 6.2 MIN.

$$W^2 R = (P - 345)$$

$$R = \frac{P - 345}{W^2} = \frac{605 - 345}{[1.568(605)]^2} = \frac{260}{89.9 \times 10^4} = 2.89 \times 10^{-4}$$

$$\frac{dM}{dt} = W = \sqrt{\frac{P - 345}{R}} = \sqrt{\frac{965 - 100t - 345}{R}}$$

$$\frac{dM}{dt} = \sqrt{\frac{620 - 100t}{3.05 \times 10^{-4}}} = 1424 - 573t^{.5}$$

$$M = 1420t - \frac{573}{1.5} t^{1.5} \quad \left]_{3.6}^{6.2}\right.$$

$$M = (8804 - 5920) - (5112 - 2600) = 370 \text{ LB.}$$

$$\text{TOTAL LEAKAGE FLOW} = 4949 + 370 + 855 = 6174 \text{ LB.}$$

APPENDIX D

SIMILAR TO

DR'N

Adla

CH'D

L.C.C.

APP'D

SCALE

= 12

SHEET

15

OF

45

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

CALCULATE LEAKAGE AT 1 MINUTE

$$M = 2285t - \frac{373}{2}t^2 - 884 + 855$$

$$M = 2285 - 186.5 - 884 + 855 = 1215 \text{ LBS} + 855 \text{ LB.}$$

AT 2 MINUTES

$$M = 2285(2) - 186.5(4) - 884 + 855 = 2941 + 855$$

AT 3 MINUTES

$$M = 2285(3) - 186.5(9) - 884 + 855 = 5148 \text{ LB.}$$

FIGURE 1 SHOWS THAT ISOLATION *WOULD* OCCUR. THE RATE OF PRESSURE DECREASE AND FEEDWATER ADDITION AND STEAM BLOWDOWN CAN BE CONSIDERABLY LOWER; THEN WE MUST CALCULATE THE RATE OF PRESSURE CHANGE.

IT WILL BE NECESSARY TO DETERMINE THE RATE OF PRESSURE CHANGE IN THE STEAM SYSTEM. BOTH STEAM GENERATORS MUST BE CONSIDERED.

ASSUME THE BLOWDOWN STARTS AT 18 MINUTES AFTER THE START OF THE ACCIDENT OR ABOUT 16 MINUTES AFTER SCRAM. THE RATE OF POWER INPUT TO EACH STEAM GENERATOR THEN IS $6.55 \times 10^4 \text{ BTU/MIN.}$

THE STORED HEAT IN THE DRUMS AND TUBES WILL ALSO BE CONSIDERED AS HEAT INPUT WITH NO REGARD TO THE POSSIBLE RATE OF TRANSFER

APPENDIX D

SIMILAR TO

DR'N *ada*

CH'D *lec*

APP'D

SCALE = 12

SHEET 17 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

FROM CALCULATIONS WITH LETTER BUSH - BANKS 6/22/60

ECONOMIZER TUBES	6,500 LB
EVAPORATOR TUBES	14,000
SUPERHEATER TUBES	7,000
DOWNCOVER	6,000
MUD DRUM & TUBE SHEET	13,000
STEAM DRUM & TUBE SHEET	31,000

EVAPORATOR, STEAM DRUM, MUD DRUM AND TUBE SHEETS, SUPERHEATER TUBES, AND DOWNCOVER

$$MC_p = 71,000 \text{ LB} \cdot 0.13 \frac{\text{BTU}}{\text{LB} \cdot \text{F}} = 9,230 \frac{\text{BTU}}{\text{F}}$$

UPON COOLING, THE ENTIRE VALUE OF MC_p FOR THE ~~EVAPORATOR~~ TUBES IS NOT AVAILABLE, THE TUBE HEAT CAPACITY OF THE ~~EVAPORATOR~~ ^{PERMANENT} WILL BE NEGLECTED. THIS IS LESS THAN 10% OF THE ABOVE VALUE.

THE DIVISION OF DUTY IN THE GENERATOR IS AS FOLLOWS

	100 %	50 %	20 %
ECONOMIZER	26.7	29.3	29.6
EVAPORATOR	50.5	49.7	49.5
SUPERHEATER	22.5	21.0	20.8

ASSUME THE DIVISION OF LOAD FROM THE ECONOMIZER TO THE SUPERHEATER IS 31 - 49 - 20 %

APPENDIX D

SIMILAR TO

DR'N

add

CH'D

LCC

APP'D

SCALE

= 12

SHEET 18 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

THUS, THE HEAT INPUT TO THE ~~SECOND~~ ^{SOUND} STEAM GENERATOR IS

ECONOMIZER

$$6.55 \times 10^4 \text{ BTU/MIN} (0.31) = 2.06 \times 10^4 \text{ BTU/MIN}$$

EVAPORATOR

$$6.55 \times 10^4 (0.49) - \overset{\text{STORED HEAT}}{64,500 (0.13) \frac{\text{BTU}}{^\circ\text{F}} \frac{dT}{dt}} = 3.21 \times 10^4 - 0.83 \times 10^4 \frac{dT}{dt} + W_{fw} h_{l, fw}$$

SUPERHEATER

$$6.55 \times 10^4 (0.20) - 6,500 (-.13) \frac{dT}{dt} = 1.31 \times 10^4 - .084 \times 10^4 \frac{dT}{dt}$$

THE HEAT INPUT TO THE FAILED UNIT IS

ECONOMIZER - 0

$$\text{EVAPORATOR } 0.83 \times 10^4 \frac{dT}{dt} \text{ BTU/MIN}$$

$$\text{SUPERHEATER } 0.84 \times 10^4 \frac{dT}{dt} \text{ BTU/MIN}$$

ASSUME A FICTICIOUS STEAM GENERATOR UNIT TWICE THE NORMAL WEIGHTS AND VOLUMES. THE HEAT INPUT WILL BE

$$\text{ECONOMIZER } 2.06 \times 10^4 \text{ BTU/MIN}$$

$$\text{EVAPORATOR } 3.21 \times 10^4 - 0.168 \times 10^4 \frac{dT}{dt}$$

$$\text{SUPERHEATER } 1.31 \times 10^4 - 0.168 \times 10^4 \frac{dT}{dt}$$

APPENDIX D

SIMILAR TO

DR'N

CH'D

APP'D

SCALE

= 12

SHEET

OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

FOR THESE CALCULATIONS, ASSUME NO CHANGE IN LEVEL. THIS ASSUMPTION WILL MAKE PRESSURE CHANGE SLOWER THAN IT SHOULD IF THE LEVEL TENDED TO DROP. ASSUME LEVEL IS AT THE SCRAM LEVEL WHICH CORRESPONDS TO 49.7 ft³ WATER IN EACH DRUM.

$$(2) 49.7 \text{ ft}^3 (43.6) \frac{\text{LB}}{\text{ft}^3} = 4340 \text{ LB} \quad \text{TOTAL WATER} \quad 4340$$

3600 -	2 x 1800
4360 -	2 x 2180
6560 -	2 x 3280
<hr/>	
18,860	LB

TUBES 1800 LB, DOWNCOVER 2180,
BOTTOM DRUM 3280

ASSUME INITIAL DRUM PRESSURE IS 1280 PSIA

THE FLOW FROM THE UNIT IS

$$W = C \frac{P_0}{\sqrt{T_0}} \quad C = \frac{200,000}{60} \frac{\sqrt{1363}}{1265} = 97.5$$

$$P_0 = P_D - k \frac{W_s^2}{4} \quad k = \frac{26.5}{(2140)^2} = 5.79 \times 10^{-6}$$

THE HEAT REMOVED FROM THE DRUM IS

$$97.5 \frac{P_0}{\sqrt{T_0}} (h_g) \text{ STEAM}$$

THE HEAT ADDED TO THE DRUM IS

$$3.21 \times 10^4 - 1.66 \times 10^4 \frac{dT_D}{dt} + 2.06 \times 10^4 + 97.5 \frac{P_0}{\sqrt{T_0}} (h_l) \text{ FEEDWATER}$$

THE NET CHANGE IN HEAT IS

$$3.21 \times 10^4 - 1.66 \times 10^4 \frac{dT_D}{dt} - 2.06 \times 10^4 - 97.5 \frac{P_0}{\sqrt{T_0}} (h_g - 260)$$

APPENDIX D

SIMILAR TO

DR'N

data

CH'D

LCC

APP'D

SCALE

=12

SHEET

20

OF

48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

$$P_D + 31.8 = C \left(400 - \frac{M_L}{P} \right)^{-1.4}$$

EVALUATE C

$$C = P V^k = 1450 (125)^{1.4} = 1.23 \times 10^6$$

$$P_D + 31.8 = 1.23 \times 10^6 \left(400 - \frac{M_L}{P} \right)^{-1.4}$$

$$400 - \frac{M_L}{P} = \left(\frac{1.23 \times 10^6}{P_D + 32} \right)^{\frac{1}{1.4}}$$

$$\text{AT } t = 0 \quad P_D = 1280 \text{ PSIA}$$

$$400 - \frac{M_L}{57.6} = \left(\frac{1.23 \times 10^6}{1.28 \times 10^3} \right)^{\frac{1}{1.4}}$$

$$400 - \frac{M_L}{57.6} = 132$$

$$M_L = (400 - 132) 57.6 = 15,437 \text{ LB}$$

$$\text{AT } t = 0.4 \quad P_D = 1012$$

$$400 - \frac{M_L}{57.6} = \left(\frac{1.23 \times 10^6}{1.044 \times 10^3} \right)^{\frac{1}{1.4}} = 155$$

$$M_L = (400 - 155) 57.6 = 14,112 \quad \Delta M = 1,325 \text{ LB}$$

$$\text{AT } t = 1.0 \quad P_D = 744 \text{ PSIA}$$

$$400 - \frac{M_L}{57.6} = \left(\frac{1.23 \times 10^6}{776 \times 10^3} \right)^{\frac{1}{1.4}} = 191$$

$$M_L = (400 - 191) 57.6 = 12,038 \text{ LB} \quad \Delta M = 3399 \text{ LB}$$

APPENDIX D

SIMILAR TO

DR'N

Chla

CH'D

APP'D

SCALE

= 12

SHEET 33 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

STEAM FLOW FROM ONE STEAM GENERATOR

STUDY 11-33A
APPENDIX D

30145

THE RATE OF CHANGE IN TEMPERATURE IS

$$\frac{dT_D}{dt} = \frac{5.26 \times 10^4 - 1.66 \times 10^4 \frac{dT_D}{dt} - 97.5 \frac{P_0}{\sqrt{T_0}} (h_g - 260)}{18,800 (1.4)} \quad \frac{\text{BTU}}{\text{MIN}} \quad \frac{\text{LB}^\circ\text{F}}{\text{LB} \cdot \text{BTU}}$$

$$\frac{dT_D}{dt} = 1.99 - .629 \frac{dT_D}{dt} - 3.69 \times 10^{-3} \frac{P_0}{\sqrt{T_0}} (h_g - 260)$$

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{P_0}{\sqrt{T_0}} (h_g - 260)$$

FROM STUDY 334

$$\frac{dP_D}{dT_D} = \frac{10,450}{T} \quad \text{OR USE STEAM TABLES}$$

$$T_0 = T_D + \frac{1.31 \times 10^4 - .168 \frac{dT_D}{dt}}{97.5 \frac{P_0}{\sqrt{T_0}} (1.4)} = T_D + \frac{\sqrt{T_0}}{P_0} (134.5 - 1.72 \times 10^{-3} \frac{dT_D}{dt})$$

SUMMARY OF EQUATIONS

$$(1) \quad W = 97.5 \frac{P_0}{\sqrt{T_0}}$$

$$(2) \quad P_0 = P_D - 5.79 \times 10^{-6} \frac{W^2}{4}$$

$$(3) \quad \frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{P_0}{\sqrt{T_0}} (h_g - 260)$$

$$(4) \quad \frac{dP_D}{dT_D} = \frac{C}{T_D} \quad \text{OR USE STEAM TABLES}$$

$$(5) \quad T_0' = T_D + \frac{\sqrt{T_0}}{P_0} [134.5 - 1.72 \times 10^{-3} \frac{dT_D}{dt}]$$

APPENDIX D

SIMILAR TO

DR'N <i>Alb</i>	CH'D <i>LCC</i>	APP'D	SCALE = 12	SHEET <i>23</i> OF <i>48</i>	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.				STUDY IV-334	

0 - 0.1 MIN.

0.1 - 0.2 MIN.

$$P_D = 1280 \quad T_D = 1035 \text{ R} \quad T_o = 1360 \quad \sqrt{T_o} = 36.8 \quad h_g = 1179$$

ASSUME $W = 3350$

$$P_o = 1280 - 5.79 \times 10^{-6} (2.8 \times 10^6) = 1263$$

$$W = 97.5 \frac{1263}{36.8} = 3350$$

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{1263}{36.8} (1179 - 260) = -70.05 \text{ } ^\circ\text{R}/\text{MIN.}$$

$$T_D = 1035 - 70.05 (.1) = 1025 \text{ R}$$

$$P_D = 1208 \text{ PSIA} \quad h_g = 1183$$

$$T_o = 1028 + \frac{36.8}{1263} (134.5) = 1032 \text{ R}$$

$$P_D = 1208 \quad T_D = 1028 \text{ R} \quad T_o = 1032 \quad \sqrt{T_o} = 32.13 \quad h_g \quad 260 = 923$$

Try $W = 3200$

$$P_o = 1193$$

$$W = 97.5 \frac{1193}{32.13} = 3620$$

Try 3600

$$P_o = 1189 \text{ PSIA}$$

$$W = 97.5 \frac{1189}{32.13} = 3608 \text{ LB/min}$$

				APPENDIX D	
				SIMILAR TO	
DR'N <i>ama</i>	CH'D <i>JCC</i>	APP'D	SCALE = 12	SHEET <i>22</i> OF <i>40</i>	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.				STUDY IV-334	

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{1189}{32.13} (923) = 75.96 \frac{R}{MIN}$$

$$T_D = 1028 - 75.96 (.1) = 1020 R$$

$$P_D = 1133 PSIA \quad h_g = 1186$$

$$T_0 = 1020 + \frac{32.13}{1189} (134.5) = 1024 R$$

$$P_D = 1133 PSIA \quad T_D = 1020 R \quad T_0 = 1024 \quad \sqrt{T_0} = 32.0 \quad h_g - 260 = 926$$

$$Thy W = 3400$$

$$P_0 = 1116$$

$$W = 97.5 \frac{1116}{32} = 3400 LB/MIN$$

$$\frac{dT_D}{dt} = 1.255 - 2.26 \times 10^{-3} \frac{1116}{32} (926) = -71.75 \frac{R}{MIN}$$

$$T_D = 1020 - 71.75 (.1) = 1013 R$$

$$P_D = 1070 PSIA \quad h_g = 1189$$

$$T_0 = 1013 + \frac{32}{1116} (134.5) = 1017 R$$

$$P_D = 1070 \quad T_D = 1013 R \quad T_0 = 1017 R \quad \sqrt{T_0} = 31.9 \quad h_g - 260 = 929$$

$$Thy W = 3200$$

$$P_0 = 1055$$

$$W = 97.5 \frac{1055}{31.9} = 3224$$

$$\frac{dT_D}{dt} = 1.224 - 2.26 \times 10^{-3} \frac{1055}{31.9} (929) = -68.20 \frac{R}{MIN}$$

$$T_D = 1013 - 68.2 (.1) = 1006 R$$

$$P_D = 1012 PSIA \quad h_g = 1191$$

$$T_0 = 1006 + \frac{31.9}{1055} (134.5) = 1010 R$$

APPENDIX D

SIMILAR TO

SHEET 23 OF 48

STUDY IV-334

DR'N *WMA*

CH'D *JCC*

APP'D

SCALE = 12

ALLIS-CHALMERS MFG. CO.

DEPT.

0.4 - 0.6 MIN

$$P_D = 1012 \quad T_D = 1006 \quad T_o = 1010 \quad \sqrt{T_o} = 31.77 \quad h_g - 260 = 931$$

$$Try \quad W = 3000$$

$$P_o = 998$$

$$W = 97.5 \frac{998}{31.77} = 3060$$

$$Try \quad W = 3050$$

$$P_o = 998$$

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{998}{31.77} (931) = -64.86 \quad \frac{R}{MIN.}$$

$$T_D = 1006 - 64.86 (-2) = 993 \quad R$$

$$P_D = 907 \quad h_g = 1195$$

$$T_o = 993 + \frac{31.77}{998} (134.5) = 997$$

0.6 - 0.8 MIN.

$$P_D = 907 \text{ PSIA} \quad T_D = 993 \text{ R} \quad T_o = 997 \text{ R} \quad \sqrt{T_o} = 31.57 \quad h_g - 260 = 935$$

$$Try \quad W = 2700$$

$$P_o = 896$$

$$W = 97.5 \frac{896}{31.57} = 2767$$

$$Try \quad W = 2767$$

$$P_o = 896$$

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{896}{31.57} (935) = -58.74 \quad \frac{R}{MIN.}$$

$$T_D = 993 - 58.74 (-2) = 981 \quad R$$

$$P_D = 819 \text{ PSIA} \quad h_g = 1197$$

$$T_o = 981 + \frac{31.57}{896} (134.5) = 986 \text{ R}$$

APPENDIX D

SIMILAR TO

DR'N

ALL

CH'D

JCC

APP'D

SCALE

= 12

SHEET

24 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

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0.8 - 1.0 MIN

$$P_D = 819 \text{ PSIA } T_D = 981 \text{ R } T_0 = 986 \quad \sqrt{T_0} = 31.40 \quad h_g - 260 = 937$$

$$\text{Try } W = 2300$$

$$P_0 = 811$$

$$W = 97.5 \frac{811}{31.4} = 2518 \text{ LB/MIN}$$

$$\text{Try } W = 2500$$

$$P_0 = 810$$

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{810}{31.4} (937) = -53.39 \text{ R/MIN}$$

$$T_D = 981 - 53.39 (.2) = 970 \text{ R}$$

$$P_D = 744 \text{ PSIA } h_g = 1200$$

$$T_0 = 970 + \frac{31.4}{810} (134.5) = 975 \text{ R.}$$

1 - 1.5 MIN

$$P_D = 744 \text{ R } T_D = 970 \text{ R } T_0 = 975 \text{ R } \sqrt{T_0} = 31.24 \quad h_g - 260 = 940$$

$$\text{Try } W = 2000$$

$$P_0 = 738$$

$$W = 97.5 \frac{738}{31.24} = 2303$$

$$\text{Try } W = 2300$$

$$P_0 = 736 \text{ PSIA}$$

$$\frac{dT_D}{dt} = 1.225 - \frac{736}{31.24} (940) (2.26 \times 10^{-3}) = -48.81 \text{ R/MIN}$$

$$T_D = 970 - 48.81 (.5) = 946.0 \text{ R}$$

$$P_D = 599 \text{ PSIA } h_g = 1203$$

$$T_0 = 946 + \frac{31.24}{736} (134.5) = 952 \text{ R.}$$

APPENDIX D

SIMILAR TO

DR'N *arc*

CH'D *JCC*

APP'D

SCALE

= 12

SHEET 25 OF 45

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

$$P_D = 599 \text{ PSIA} \quad T_D = 946 \text{ R} \quad T_0 = 952 \text{ R} \quad \sqrt{T_0} = 30.85 \quad h_g - 260 = 943$$

$$T_{\text{avg}} W = 2000$$

$$P_0 = 593$$

$$W = 97.5 \frac{593}{30.85} = 1874$$

$$T_{\text{avg}} W = 1900$$

$$P_0 = 594 \text{ PSIA}$$

1.5-2

$$\frac{dT_D}{dt} = 1.225 - 2.76 \times 10^{-3} \frac{594}{30.85} (943) = -48.88 \frac{\text{R}}{\text{MIN}} \quad (39.80)$$

$$T_D = 946 - \frac{39.80}{(495)} (0.5) = 922 \text{ R} \quad (926)$$

$$P_D = 472 \text{ PSIA} \quad h_g = 1204$$

$$T_0 = 922 + \frac{30.85}{594} (134.5) = 929 \text{ R} \quad (933)$$

$$P_D = 472 \text{ PSIA} \quad T_D = 922 \text{ R} \quad T_0 = 929 \text{ R} \quad \sqrt{T_0} = 30.48 \quad h_g - 260 = 944$$

$$T_{\text{avg}} W = 1800$$

$$P_0 = 467$$

$$W = 97.5 \frac{467}{30.48} = 1493$$

$$T_{\text{avg}} W = 1500$$

$$P_0 = 469$$

2-3 MIN

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{469}{30.48} (944) = -31.59 \frac{\text{R}}{\text{MIN}}$$

$$T_D = 922 - 31.59(1) = 890 \text{ R}$$

$$P_D = 344 \text{ PSIA} \quad h_g = 1203$$

$$T_0 = 890 + \frac{30.48}{469} (134.5) = 899 \text{ R}$$

APPENDIX D

SIMILAR TO

SHEET 25 OF 45

ISSUE

STUDY IV-334

DR'N

allo

CH'D

JCC

APP'D

SCALE

=12

ALLIS-CHALMERS MFG. CO.

DEPT.

3-5 MIN

$$P_D = 334 \text{ PSIA} \quad T_D = 890 \quad T_0 = 899 \quad \sqrt{T_0} = 30 \quad h_g - 260 = 943$$

$$\text{Try } W = 1700$$

$$P_0 = 330$$

$$W = 97.5 \frac{330}{30} = 1072$$

$$\text{Try } W = 1100$$

$$P_0 = 332 \text{ PSI}$$

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{332}{30} (943) = -22.35 \text{ } ^\circ\text{R}/\text{MIN}$$

$$T_D = 890 - 22.35 (2) = 845 \text{ } ^\circ\text{R}$$

$$P_D = 207 \text{ PSIA} \quad h_g = 1199$$

$$T_0 = 845 + \frac{30}{332} (134.5) = 857 \text{ } ^\circ\text{R}$$

$$P_D = 207 \quad T_D = 845 \quad T_0 = 857 \quad \sqrt{T_0} = 29.27 \quad h_g - 260 = 939$$

$$\text{Try } W = 800 \text{ LB}/\text{MIN}$$

$$P_0 = 206$$

$$W = 97.5 \frac{206}{29.27} = 686 \text{ LB}/\text{MIN}$$

$$\text{Try } W = 700$$

$$P_0 = 206$$

$$\frac{dT_D}{dt} = 1.225 - 2.26 \times 10^{-3} \frac{206}{29.27} (939) = 13.70 \text{ } ^\circ\text{R}/\text{MIN}$$

$$T_D = 845 - 13.70 (2) = 818 \text{ } ^\circ\text{R}$$

$$P_D = 149 \text{ PSI} \quad h_g = 1194$$

APPENDIX D

SIMILAR TO

DR'N *all*

CH'D JCC

APP'D

SCALE = 12

SHEET 15 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

TIME (MIN)

PRESSURE (PSIA)

0	1280
0.1	1208
0.2	1133
0.3	1070
0.4	1012
0.6	907
0.8	819
1.0	744
1.5	599
2.0	472
3.0	334
5.0	207
7.0	149

$$P_0 = 207$$

$$T_0 = 818 + \frac{29.27}{206} (134.5) = 837^\circ R$$

$$P_0 = 149 \quad T_D = 818 \quad T_0 = 837 \quad \sqrt{T_0} = 28.92$$

$$Thg \quad W = 600$$

$$P_0 = 148.5$$

$$W = 97.5 \frac{148.5}{28.92} = 500$$

$$P_0 = 148.6$$

APPENDIX D

SIMILAR TO

DR'N

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CH'D

JCC

APP'D

SCALE

= 12

SHEET *28* OF *48*

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

A

B

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DRUM PRESSURE DURING
BLOWDOWN

DRUM PRESSURE PSIA

10
9
8
7
6
5
4
3
2000
1000
900
800
700
600
500
400
300
200
100

TIME - MINUTES

STUDY IV-334
APPENDIX D

29148

THE PRESSURE DECAY CAN BE REPRESENTED BY FINE EQUATIONS OF THE FORM $p = ce^{-kt}$

FROM	0 - 0.8 MIN	$p = 1280e^{-.5575t}$
	0.8 - 2 MIN	$p = 1190e^{-.465t}$
	2 - 3 MIN	$p = 950e^{-.326t}$
	3 - 5 MIN	$p = 690e^{-.24t}$
	5 - 7 MIN	$p = 475e^{-.166t}$

INHERENT IN THE EQUATION

$P_0 = P_D - k\left(\frac{W}{2}\right)^2$ IS THE ASSUMPTION THAT THE ACTUAL STEAM FLOWS FROM EACH UNIT ARE EQUAL. ACTUALLY, THE FAILED UNIT WOULD STEAM AT A LESSER RATE.

DETERMINE THE INTEGRATED FLOW OF STEAM FROM ONE UNIT. DO THIS GRAPHICALLY.

NEXT THE INTEGRATED LEAKAGE FLOW CAN BE CALCULATED. SINCE THE LEAKAGE FLOW IS TWO PHASE FLOW, CRITICAL FLOW IS ASSUMED UNTIL $\frac{P}{P_0} = 0.5$ OR UNTIL $P = 2 \times 345 = 690$ PSIA.

$$P = 1190e^{-.465t} = 690$$

$$e^{-.465t} = \frac{690}{1190} = 0.579$$

$$-.465t = 0.55$$

$$t = 1.18 \text{ MIN.}$$

APPENDIX D

SIMILAR TO

DR'W *CRW*

CH'D

APP'D

SCALE

= 12

SHEET 30 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

$$\text{SINCE } W = CP \quad C = \frac{2140}{1365} = 1.567$$

THEN BETWEEN 0 AND 0.8 MIN

$$\frac{dM}{dt} = W = 1.57 (1280 e^{-.5575t}) = 2009 e^{-.5575t}$$

$$dM = 2009 e^{-.5575t} dt$$

$$M = 3602 e^{-.5575t} \Big|_0^{0.8}$$

$$M = -3602 (e^{-.446} - 1) = 1117 \text{ LB.}$$

BETWEEN 0.8 AND 1.18 MIN

$$\frac{dM}{dt} = 1.57 (1190 e^{-.465t})$$

$$M = 4017 e^{-.465t} \Big|_{0.8}^{1.18}$$

$$M = 4017 (e^{-.5487} - e^{-.372}) = 442 \text{ LB.}$$

$$\text{TOTAL LEAKAGE TO 1.18 MIN.} = 1117 + 442 = 1559 \text{ LB.}$$

AT 1.18 MIN

$$W = 1868 e^{-.5487} = 1083 \text{ LB/MIN.}$$

FROM 1.18 MIN ON

$$\Delta P = R W^2$$

$$R = \frac{690 - 345}{(1.083 \times 10^3)^2} = 2.94 \times 10^{-4}$$

$$\text{AT 1.18 MIN } W_L = 1083 \text{ LB/MIN}$$

AT 1.5 MIN

$$W_L = 58.32 \sqrt{1190 e^{-.465t} - 345} = 1083 \text{ LB/MIN}$$

$$\text{TOTAL LEAKAGE TO 1.5 MIN} = 1565 + (1083)(1.5 - 1.18) = 1911$$

APPENDIX D

SIMILAR TO

DR'N *Calo*

CH'D

APP'D

SCALE

= 12

SHEET 31 OF 43

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

BETWEEN 1.5 AND 2 MIN

$$W_{L2\text{ MIN}} = 58.32 \sqrt{1190 e^{-.93}} - 345 = 652$$

$$W_{\text{AVE.}} = \frac{1083 + 652}{2} = 867$$

$$ML = 1911 + 867 (.5) = 2344 \text{ LB}$$

BETWEEN 2 AND 2.5 MIN

$$W_L = 58.32 \sqrt{1190 e^{-1.16}} - 345 = 311 \text{ LB/MIN.}$$

$$W_{\text{AVE.}} = \frac{311 + 652}{2} = 481 \text{ LB/MIN}$$

$$ML = 2344 + 481 (.5) = 2584 \text{ LB.}$$

DETERMINE WATER ADDED BY SURGE TANK

THE EXPANSION OF GAS IN THE SURGE TANK IS ASSUMED TO BE ADIABATIC THUS

$$p V^k = C$$

$$p = C V^{-k}$$

BUT THE VOLUME OF GAS IS ALSO

$$400 - V_{\text{LIQUID}} \text{ OR } 400 - \frac{ML}{\rho_L}$$

THUS,

$$p = C \left(400 - \frac{ML}{C} \right)^{-k}$$

$$\text{BUT } p = P_D + 31.8$$

(P_D = DRUM PRESSURE)

31.8 PRESSURE LOSS - SEE

LETTER BUSH-JACKSON

1/26/62

APPENDIX D

SIMILAR TO

DR'M

amo

CH'D

APP'D

SCALE

= 12

SHEET 32 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

A

B

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

AT $t = 1.5$ $P_D = 599$

$$400 - \frac{M}{57.6} = \left(\frac{1.23 \times 10^6}{631 \times 10^3} \right)^{\frac{1}{1.4}} = 223$$

$$M = (400 - 223) 57.6 = 10,195 \text{ LB} \quad \Delta M = 5242 \text{ LB}$$

AT $t = 2.0$ $P_D = 472$

$$400 - \frac{M}{57.6} = \left(\frac{1.23 \times 10^6}{504 \times 10^3} \right)^{\frac{1}{1.4}} = 268$$

$$M = (400 - 268) 57.6 = 7603 \text{ LB} \quad \Delta M = 7834 \text{ LB}$$

AT $t = 3 \text{ MIN}$ $P_D = 334 \text{ PSIA}$

$$400 - \frac{M}{57.6} = \left(\frac{1.23 \times 10^6}{336 \times 10^3} \right)^{\frac{1}{1.4}} = 360$$

$$M = (400 - 360) 57.6 = 2304 \text{ LB} \quad \Delta M = 13,133 \text{ LB}$$

THE WATER LEVEL DOES NOT DECREASE ONCE BLOWDOWN OCCURS. LEVEL ISOLATION DOES NOT OCCUR AND WOULD NOT OCCUR

FOR EVEN LARGER LEAKS THAN ASSUMED IN THIS STUDY.

THE BLOWDOWN TO HELIUM PRESSURE IS REACHED IN APPROX. 3 MIN AFTER START OF BLOWDOWN OR 21.6 MIN

$$h_1 N = 5.81 - .0388 t$$

AT 21.6 MIN.

$$h_1 N = 5.81 - .838 = 4.97$$

$$N = 145 \text{ MOL}$$

$$\frac{N}{N_0} = \frac{145}{350} = .414$$

APPENDIX D

SIMILAR TO

DR'N

adell

CH'D

APP'D

SCALE

= 12

SHEET 55 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

A

B

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$$P_{15} \quad t_1 = 4.8 \quad t_2 = 6.8 \text{ MIN}$$

$$h_1 N = -\frac{1}{6300} (3.52 t^2 + 150 t) + 5.98$$

$$h_1 N = 5.793$$

$$N = 325$$

$$\frac{N}{N_0} = 0.928$$

ESTIMATE THE DOSE DUE TO RELEASE OF ACTIVITY,
FRACTION OF HELIUM IN SYSTEM THAT CAN NOT BE
RELEASED TO ATMOSPHERE IS:

$$\frac{P_1}{P_0} = \frac{150 \text{ PSIA}}{345 \text{ PSIA}} = 0.435$$

RELEASED IS $1 - 0.435 = 0.565$

THUS, THE MAXIMUM ACTIVITY THAT CAN BE RELEASED IS

$$I^{131} = \frac{13 \text{ CURIE}}{101.5} (1000) (0.565) = 72.36 \text{ CURIE}$$

$$I^{133} = \frac{10 \text{ CURIE}}{101.5 \text{ CURIE}} (1000) (0.565) = 55.66 \text{ CURIE}$$

$$I^{135} = \frac{5}{101.5} (1000) (0.565) = 27.83 \text{ CURIE}$$

$$D^{131} = 1.484 \text{ REM}/\mu\text{C}$$

$$D^{133} = 0.399 \text{ REM}/\mu\text{C}$$

$$D^{135} = 0.124 \text{ REM}/\mu\text{C}$$

APPENDIX D

SIMILAR TO

DR'N

CHM

CH'D

APP'D

SCALE

=12

SHEET 37 OF 40

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

FROM AECU 3066 p 50

$$TID = \frac{2Q}{\pi C^2 \bar{\mu} (\bar{\mu} t)^{2-\eta}} \exp \left[-\frac{h^2}{C^2 (\bar{\mu} t)^{2-\eta}} \right]$$

FROM MEMO COPE TO JACKSON 2/27/61

$$\mu = 1.5$$

$$\eta = 0.35$$

$$C_y = 0.3$$

$$C_z = 0.33$$

AT 200 METER - INVERSION CONDITIONS

$$TID_{200} = 6.8 \times 10^{-3} Q \exp \left[-\frac{h^2}{6.86} \right]$$

USING HOLLANDS METHOD OF CALCULATING PLUME
RISE BUT NEGLECTING THE VELOCITY EFFECT

$$\Delta h = 1.5 V_s d + 3 \times 10^{-4} Q_H \quad (P155 \quad 3066)$$

$$Q_H = W (h_g - h_g) = 1100 \text{ LB/MIN } (1211 - 1092) = 130,900 \text{ BTU/MIN.}$$

$$130,900 \text{ BTU/MIN} \times 252 \frac{\text{CAL}}{\text{BTU}} \times \frac{\text{MIN}}{\text{SEC}} = 5.49 \times 10^4 \frac{\text{CAL}}{\text{SEC}}$$

$$\Delta h = 3 \times 10^{-4} (5.49 \times 10^4) = 16.47 \text{ ft.}$$

$$16.47 \text{ ft} \times \frac{\text{METER}}{3.28 \text{ ft}} = 5.02 \text{ METER}$$

$$\text{USE } h = h + \Delta h = 20 + 5 = 25 \text{ METER}$$

APPENDIX D

SIMILAR TO

DR'N

AKC

CH'D

APP'D

SCALE

= 12

SHEET 38 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-534

A

B

$$TID_{200} = 6.8 \times 10^{-3} Q \exp \left[-\frac{625}{6.86} \right]$$

$$TID_{200} = 6.8 \times 10^{-3} Q e^{-91} \approx 0$$

AT 1060 METER

$$TID_{1060} = \frac{2Q}{\pi (.3)(.033)(1.5)(1060)^{2-.35}} \exp \left[-\frac{625}{(.033)^2 (1060)^{2-.35}} \right]$$

$$TID_{1060} = 4.32 \times 10^{-4} Q e^{-5.79} = 1.31 \times 10^{-6} Q$$

$$d_{max} = \left(\frac{1}{C_3^2} \right)^{\frac{1}{2-n}} \left[\frac{25^2}{(.033)^2} \right]^{\frac{1}{1.65}} = 3092 \text{ METER}$$

$$TID_{3092} = \frac{2Q}{\pi .3(.033)(1.5)(3092)^{1.65}} \exp \left[-\frac{625}{(.033)^2 (3092)^{1.65}} \right]$$

$$TID_{3092} = 7.4 \times 10^{-5} Q e^{-1} =$$

DOSE AT 200 METER IS NEGLIGIBLE
1060 METER

$$DOSE_{131} = 1.31 \times 10^{-6} (72.36) \frac{C-SEC}{m^2} \times \frac{350 CC}{SEC} \times \frac{m^3}{10^6 CC} \times \frac{1484}{10^{-6} C} = .049 \text{ REM}$$

$$DOSE_{133} = 1.31 \times 10^{-6} (55.66) (350) (0.399) = 0.0101 \text{ REM}$$

$$DOSE_{135} = 1.31 \times 10^{-6} (27.83) (350) (0.124) = 0.0016 \text{ REM}$$

THYROID DOSE AT 1060 METER

$$DOSE_{TOTAL} = .049 + .0101 + .0016 = .0609 \text{ REM}$$

APPENDIX D

SIMILAR TO

DR'N

ant

CH'D

APP'D

SCALE

= 12

SHEET 39 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

A

B

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

DOSE AT 3092 METER

$$\text{DOSE}_{131} = .0492 \left(\frac{2.72 \times 10^{-5}}{1.31 \times 10^{-6}} \right) = 1.02 \text{ REM}$$

$$\text{DOSE}_{133} = .0101 () = 0.209 \text{ REM}$$

$$\text{DOSE}_{135} = .0016 () = 0.033 \text{ REM}$$

$$\text{TOTAL DOSE}_{3092} = 1.262 \text{ REM}$$

FOR THE LAPSE CONDITIONS

$$\mu = 2.3$$

$$\eta = 0.23$$

$$\left. \begin{array}{l} C_y = 0.3 \\ C_z = 0.3 \end{array} \right\} C^2 = .09$$

$$d_{\text{MAX}} = \left(\frac{h^2}{C^2} \right)^{\frac{1}{2} - \eta} = \left(\frac{25^2}{0.09} \right)^{\frac{1}{1.77}} = 6950^{\frac{1}{1.77}} = 150 \text{ METERS}$$

$$TID = \frac{2Q}{\pi (.09)(2.3)(150)^{1.77}} \exp \left[-\frac{625}{.09(150)} \right]^{1.77}$$

$$TID_{150} = 4.44 \times 10^{-4} Q e^{-1} = 1.63 \times 10^{-4} Q$$

APPENDIX D

SIMILAR TO

DR'N

all

CH'D

APP'D

SCALE

=12

SHEET 40 OF 95

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

AT 200 METER

$$TID = \frac{2Q}{\pi (.09)(2.3)(200)^{1.77}} \exp \left[-\frac{625}{.09(200)^{1.77}} \right]$$

$$TID = 2.64 \times 10^{-4} Q e^{-.595} = 1458 \times 10^{-4} Q$$

AT 1060 METER

$$TID = \frac{2Q}{\pi (.09)(2.3)(1060)^{1.77}} \exp \left[-\frac{625}{.09(1060)^{1.77}} \right]$$

$$TID = 1.39 \times 10^{-5} Q e^{-.0312} = 1.35 \times 10^{-5} Q$$

THE DOSES UNDER A LAPSE CONDITION ARE :

AT MAXIMUM GROUND CONCENTRATION

$$d_{\max} = 150 \text{ METER}$$

$$\text{DOSE} = \frac{163 \times 10^{-4}}{1.31 \times 10^{-6}} (.0609) = 7.58 \text{ REM}$$

AT 200 METER

$$\text{DOSE} = \frac{1.46 \times 10^{-4}}{1.31 \times 10^{-6}} (.0609) = 6.79 \text{ REM}$$

AT 1060 METER

$$\text{DOSE} = \frac{1.35 \times 10^{-5}}{1.31 \times 10^{-6}} (.0609) = 0.63 \text{ REM}$$

APPENDIX D

SIMILAR TO

DR'N

add

CH'D

APP'D

SCALE

= 12

SHEET 41 OF 43

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

STUDY IV-334

A

B

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DOSE SUMMARY (ASSUMING NO GAS LOSS THROUGH HELIUM RELIEF VALVES)

<u>DISTANCE</u> (METER)	<u>DOSE REM</u>	
	<u>LAPSE</u>	<u>IMMERSION</u>
150	7.58	-
200	6.79	NEG.
1060	0.63	0.06
3092	-	1.26

SINCE APPROXIMATELY 41.4% OF THE HELIUM WILL BE IN THE SYSTEM WHEN 345 PSIA IS REACHED WHILE CONNECTED TO THE NETWORK AND APPROXIMATELY 92.8% WILL BE IN THE SYSTEM WHEN OPERATING DISCONNECTED THAN THE DOSE AT POINT OF MAXIMUM GROUND CONCENTRATION WILL BE (DURING LAPSE)

WHEN CONNECTED TO NETWORK

$$7.58 \text{ REM} (.414) = \underline{\underline{3.1 \text{ REM}}}$$

WHEN NOT CONNECTED

$$7.58 \text{ REM} (.928) = \underline{\underline{7.0 \text{ REM}}}$$

AT THE EXCLUSION RADIUS (200 METER)

$$\text{WHEN CONNECTED } 6.79 \text{ REM} (.414) = 2.8 \text{ REM}$$

$$\text{WHEN DISCONNECTED } 6.79 \text{ REM} (.928) = 6.3 \text{ REM}$$

APPENDIX D

SIMILAR TO

DR'N *Adg*

CH'D

APP'D

SCALE

=12

SHEET 42 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

CALCULATE ACTIVITY RELEASE IF NO WATER IF.
PRODUCED TO CAUSE FLOOD LEVEL ISOLATION

WHEN CONNECTED TO NETWORK

THE ACTIVITY RELEASED DEPENDS STRONGLY UPON
THE STEAMING RATE HIGH STEAMING RATES FAVORING
LESS RELEASE OF ACTIVITY TO THE ATMOSPHERE
DIRECTLY AND MORE TO THE CONTAINMENT
SNELL

THE DEAERATOR MUST LOOSE 38,500 LB OF WATER
BEFORE DRUM LEVEL WILL DECREASE TO THE
LEVEL REQUIRED TO LIFT RELIEF VALVES. DURING
THIS PERIOD REGARDLESS OF THE STEAMING RATE THE
FRACTION OF ACTIVITY REMAINING IN THE COOLANT
SYSTEM IS

$$\frac{N}{N_0} = e^{-\frac{38,500}{17} \left(\frac{1}{350} \right)} = e^{-6.1} = 0.023 \quad \text{THUS, THIS REP.}$$

RESENTS A MAXIMUM POSSIBLE RELEASE DIRECTLY
TO THE ATMOSPHERE VIA THE ELECTRO MATH RELIEF
VALVES. DUE TO FLOW RATE OF STEAM FROM SECONDARY
SYSTEM, THE ACTUAL RELEASE CAN BE MUCH LESS.

THE MINIMUM RELEASE WILL OCCUR AT MAXIMUM
STEAMING RATE (163,000 LB/HY)

APPROXIMATELY 746 LB STEAM WILL LIFT RELIEF
VALVES

$$\frac{746 \frac{\text{LB}}{\text{H}}}{163,000 \frac{\text{LB}}{\text{H}} \frac{1}{60 \text{ MIN}}} = 0.275 \text{ MIN}$$

STEAM PRESSURE BLOWDOWN REQUIRES APROX

APPENDIX D

SIMILAR TO

DR'N ADA

CH'D

APP'D

SCALE

=12

SHEET 43 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

STUDY 334

3 MIN TO REACH HELIUM PRESSURE AND APPROX
0.3 MIN IS REQUIRED TO REACH LEVEL TO OPEN
RELIEF (ELECTROMATICS) VALVES THUS PURGE
WILL CONTINUE FOR

$$\frac{38,500 \text{ lb}}{163,000 \frac{\text{lb}}{\text{hr}} \div 60 \frac{\text{min}}{\text{hr}}} + 0.0275 + 3.0 + 0.3 \approx 17.2 \text{ MIN}$$

$$\frac{N}{N_0} = e^{-\frac{163,000}{16,600} \left(\frac{1}{350} \right) (17.2)} = e^{-7.4} = 0.00061$$

THE MAXIMUM OFF SITE ^{THYROID} DOSE (WHEN CONNECTED TO NETWORK)
DURING LAPSE IS THEN

$$0.023 (6.79 \text{ REM}) = 0.156 \text{ REM} \approx 156 \text{ mrem}$$

AND OCCURS AT 200 METERS

$$\text{THE MINIMUM DOSE FOR THE SAME CONDITIONS IS } 0.00061 (6.79 \text{ REM}) = 0.0041 \text{ REM} \approx 4.1 \text{ mrem}$$

WHEN NOT CONNECTED TO NETWORK

STEAM CAN BE ADDED SLOWLY SUCH THAT THERE
IS NO PURGE OF SYSTEM THROUGH RELIEF VALVES

ONE MINUTE AFTER SCRAM THE BLOWDOWN STARTS
WHICH REQUIRES 3 MINUTES. THUS, IF NO ~~STEAM~~ HELIUM
IS RELIEVED DURING THIS TIME THE ACTIVITY
RELEASE WILL BE MAXIMUM POSSIBLE

438 lb STEAM CAUSE A SCRAM (AT 100% POWER)

THUS

$$\frac{746 - 438}{4} = 77 \text{ lb/min}$$

$$\text{TIME TO CAUSE SCRAM IS } \frac{438 \text{ lb}}{77 \text{ lb/min}} = 5.68 \text{ MIN}$$

APPENDIX D

SIMILAR TO

DR'N ADA

CH'D

APP'D

SCALE

= 12

SHEET 44 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

STUDY 334

THUS, TIME TO START ACTIVITY RELEASE IS

$5.68 + 1 + 3 = 9.68$ min. THE MAXIMUM THYROID
DOSE (AT 200 METERS DURING LAPSE) IS 6.79 REM.
THE MINIMUM DOSE OCCURS AT MAXIMUM STEAMING

$$\frac{N}{N_0} = e^{-\frac{163,000}{14(60)}\left(\frac{1}{360}\right)4} = e^{-1.72} = 0.18$$

THYROID DOSE (MINIMUM) AT 200 METER DURING
LAPSE IS $0.18(6.79 \text{ REM}) = 1.22 \text{ REM}$

APPENDIX D

SIMILAR TO

DR'N ADA

CH'D

APP'D

SCALE

=12

SHEET 45 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

STUDY 334

A

B

CALCULATE DILUTION FACTOR AT 200 m, 1060 m,
AND AT POINT OF MAX GROUND CONC FOR LAPSE,
AND INVERSION CONDITIONS FOR A 61 METER STACK
RELEASE

FIRSTLY, FROM PREVIOUS CALCS, FOR A 25 METER RELEASE
DIST.

	LAPSE	INVERSION
150 m	$1.63 \times 10^{-4} Q$	-
200 m	$1.46 \times 10^{-4} Q$	-
1060 m	$1.35 \times 10^{-5} Q$	$1.31 \times 10^{-6} Q$
3092 m	-	$2.72 \times 10^{-5} Q$

$$TID = \frac{2Q}{\pi C_y C_z \mu d^{2-n}} \exp \left[-\frac{h^2}{C_z^2 d^{2-n}} \right]$$

$$d = \left[\frac{h^2}{C_z^2} \right]^{\frac{1}{2-n}}$$

FOR INVERSION $\mu = 1.5 \text{ m/sec}$ $n = 0.35$ $C_y = 0.3$ $C_z = 0.033$

$$d_{max} = \left[\frac{61^2}{(0.033)^2} \right]^{\frac{1}{1.65}} = \left[\frac{3721}{0.001089} \right]^{0.606} = 3.417 \times 10^6$$

$$d_{max} = 9090 \text{ meter}$$

$$TID_{d_{max}} = \frac{2Q}{\pi (.3)(0.033)(1.5)(3.417 \times 10^6)} e^{-1} = 4.62 \times 10^{-6} Q$$

APPENDIX D

SIMILAR TO

DR'N A.D.A. 1/11/63

CH'D

APP'D

SCALE

=12

SHEET 46 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

STUDY 334

A

B

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

FOR THE LAPSE CONDITION $\mu = 2.3 \text{ m/sec}$ $\eta = 0.23$ $C_y = C_z = 0.3$

$$d_{\text{max}} = \left[\frac{61^2}{0.09} \right]^{0.564} = 41,334^{.564} = 401 \text{ METER}$$

$$TID_{\text{max}} = \frac{2Q}{\pi(0.09)(2.3)(41,334)} (.368) = 2.74 \times 10^{-5} Q$$

FOR THE 61 meter RELEASE AT POINT OF MAXIMUM CONC.

	DISTANCE FOR MAX CONC	CONC
LAPSE	401 METER	$2.74 \times 10^{-5} Q$
INVERSION	9090 METER	$4.62 \times 10^{-6} Q$

TOTAL AVAILABLE FOR RELEASE TO ATMOSPHERE

I 131	76.36 curie $\times 1.484 \times 10^6 \frac{\text{rem}}{\text{curie}}$	$= 1.13 \times 10^6 \text{ rem}$
I 133	55.66 curie $\times 0.399 \times 10^6$	$= 22.2 \times 10^6 \text{ rem}$
I 135	27.83 curie $\times 0.124 \times 10^6$	$= 3.46 \times 10^6 \text{ rem}$
TOTAL		$138.6 \times 10^6 \text{ rem}$

THYROID DOSE DURING LAPSE

$$\text{DOSE} = \left(2.74 \times 10^{-5} \frac{\text{sec}}{\text{meter}^3} \right) \left(\frac{350 \text{ Cg}}{\text{sec}} \right) \left(\frac{\text{meter}^3}{10^6 \text{ cc}} \right) (138.6 \times 10^6 \text{ rem}) (F) = 1.33 F$$

WHERE F IS THE FRACTION OF HELIUM RELEASED TO ATMOSPHERE

	CONNECTED	DISCONNECTED
MAX	.023	1.00
MIN	.00061	0.18

APPENDIX D

SIMILAR TO

DR'N A.D.A. 1/11/63

CH'D

APP'D

SCALE

=12

SHEET 47 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT. NPD-W

STUDY 334

DURING INVERSION CONDITIONS THE DOSE IS GIVEN BY

$$\text{DOSE} = 4.62 \times 10^{-6} \frac{\text{sec}}{\text{meter}^3} \frac{360 \text{ cc}}{\text{sec}} \frac{\text{meter}^3}{10^6 \text{ cc}} 138.6 \times 10^6 \text{ rem f} = 0.224 \text{ f}$$

THYROID DOSE AT MAXIMUM GROUND CONC.
(REM)

CONNECTED TO NETWORK		DISCONNECTED FROM NETWORK	
<u>LAPSE</u>	<u>INU</u>	<u>LAPSE</u>	<u>INU</u>
MAX 0.0306	0.005	1.33	0.224
MIN NIL	NIL	0.24	0.040
DISTANCE 401 meter	9090 meter	401 m	9090 m

APPENDIX D

SIMILAR TO

DR'N *alla*

CH'D

APP'D

SCALE

= 12

SHEET 48 OF 48

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

STUDY IV-334

A

B

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APPENDIX E

The following calculations are the results of a brief investigation to determine if the reactor coolant blowers will or will not surge prior to a reactor scram. The calculations show that the blowers will not surge before a reactor scram occurs. A previous Kaiser Engineers study determined that the blowers would surge about 24 seconds following admission of steam at the maximum rate credible. If this basis is used and considering that the reactor is scrammed at about 14 seconds, it can be concluded that the fuel clad temperature will not exceed normal operating limitations. This is derived as follows:

(a) From Study IV-311, the fuel temperature following a loss-of-power scram increases 24 degrees within the first five seconds and then decreases at the rate of 2.3 F/sec.

(b) From Study IV-312, with a total loss of coolant, fuel clad temperature is at 1600 F at 3 minutes. Temperature decreases to 1450 F at 18 minutes and then increases and reaches 1580 F at one hour.

The fuel clad temperature 10 seconds after a steam tube rupture might be

$$1466 \text{ F} + 24 \text{ F} - 2.3 (10) \text{ F} = 1467 \text{ F}$$

Thus, it may be expected that the maximum cladding temperature will be less than 1580 F.

354 C 1

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8/2/62

APPENDIX E

Blower Behaviour Following Steam Tee Rupture

Scram pressure 325 psig or 340 psia
Plenum pressure unknown at this time

Plenum approximately 12000 cf of gas volume.
the maximum amount of steam to scram
is

$$M_{st} = \frac{(340-313)(144)(12000)(16)}{1545(1240)} = 438 \text{ lb}$$

$$\frac{438(3600)}{163,000} = 9.65 \text{ sec max (+ 3 sec delay = 12.65 sec)}$$

The system cycle time is approximately

$$\frac{1350 \text{ lb } 3600 \text{ sec}}{43,000 \frac{\text{lb}}{\text{hr}}} = 11.3 \text{ seconds}$$

Say that the worst condition of the
system is just prior to one cycle
time

scram normal flows and calculate
steam concentration in various parts of
the system. System effective volumes
are as follows:

Top Plenum	5630 CF	(105.4 mol)
Bottom Plenum	3245	(97.5 mol)
Steam Generator	1767	(39.8 mol)

These volumes include piping volumes

Steam leak rate is

$$\frac{163000}{18(3600)} = 2.51 \text{ mol/sec}$$

Loop helium flow is

$$\frac{215,000}{4(3600)} = 14.93 \text{ mol/sec}$$

Steam core leaving failed steam generator (entering bottom plenum) is

$$\frac{2.51}{14.93} = 0.168 \quad (\text{by volume})$$

He core then is $1 - 0.168 = 0.832$

Plenum (bottom) core then is given by

$$\frac{dN_{He}}{dt} = -\frac{N}{N_0}(2Q) + .832 Q + Q$$

$$= -\frac{N_{He}}{N_0}2Q + 1.832 Q$$

$$\frac{dN_{He}}{dt} + \frac{2Q}{N_0} N = 1.832 Q$$

$$e^{\frac{2Q}{N_0} t} = e^{\frac{2Q}{N_0} t}$$

$$N e^{\frac{2Q}{N_0} t} = \int 1.832 Q e^{\frac{2Q}{N_0} t} dt + C$$

$$N e^{\frac{2Q}{N_0} t} = \frac{1.832}{2} N_0 e^{\frac{2Q}{N_0} t} + C$$

$$N = 0.916 N_0 + C e^{-\frac{2Q}{N_0} t}$$

When $t = 0$ $N = N_0$

$$N_0 = 0.916 N_0 + C \quad \text{or} \quad C = N_0 - 0.916 N_0 = 0.084 N_0$$

$$N = 0.916 N_0 + 0.084 N_0 e^{-\frac{2Q}{N_0} t}$$

$$\frac{N}{N_0} = 0.916 + 0.084 e^{-\frac{2Q}{N_0} t}$$

at 11.3 sec

$$\frac{N}{N_0} = 0.916 + 0.084 e^{-\frac{2(14.93)(11.3)}{97.5}}$$

$$\frac{N}{N_0} = 0.916 + 0.084 e^{-3.46} = 0.918$$

The top plenum concentration is

$$\frac{dN}{dt} = -\frac{N}{N_0} 2Q + (0.916 + 0.084 e^{-\frac{2Q}{97.5} t}) 2Q$$

$$\frac{dN}{dt} = -0.283 N + 27.34 - 2.50 e^{-3.06 t}$$

at 1 sec

$$\frac{dN}{dt} = -0.283(105.4) + 27.34 + 2.50 e^{-3.06} = -0.683 \text{ mol/sec}$$

374 C4

$$N = 105.4 - 0.683 = 104.7 \text{ mol} \quad \frac{N}{N_0} = 0.993$$

at 3 sec

$$\frac{dN}{dt} = -0.283(104.7) + 27.34 + 2.5e^{-.306(3)}$$

$$\frac{dN}{dt} = -29.63 + 27.34 + 1.00 = -1.29 \text{ mol/sec}$$

$$N = 104.7 - 1.29(2) = 102.12 \text{ mol} \quad \frac{N}{N_0} = 0.968$$

at 5 sec

$$\frac{dN}{dt} = -0.283(102.12) + 27.34 + 2.5e^{-.306(5)}$$

$$\frac{dN}{dt} = -28.59 + 27.34 + 0.54 = -1.01 \text{ mol/sec}$$

$$N = 102.12 - 1.01(2) = 100.1 \text{ mol} \quad \frac{N}{N_0} = 0.949$$

at 7 sec

$$\frac{dN}{dt} = -0.283(100.1) + 27.34 + 2.5e^{-.306(7)}$$

$$\frac{dN}{dt} = -28.32 + 27.34 + 0.294 = -0.686 \text{ mol/sec}$$

$$N = 100.1 - 0.686(2) = 98.73 \text{ mol} \quad \frac{N}{N_0} = 0.936$$

at 9 sec

$$\frac{dN}{dt} = -0.283(98.73) + 27.34 + 2.5e^{-.306(9)}$$

$$\frac{dN}{dt} = -27.94 + 27.34 + .166$$

$$\frac{dN}{dt} = -0.434 \text{ mol/sec}$$

$$N = 98.73 - 0.434(2) = 97.86 \text{ mol}$$

$$\frac{N}{N_0} = 0.928$$

334 c 5

at 11.3 sec

$$\frac{dN}{dt} = -2.83(97.86) + 27.34 + 2.5e^{-3.45}$$

$$\frac{dN}{dt} = -0.27 \text{ mol/sec}$$

$$N = 97.86 - 0.27(2.3) = 97.24 \text{ mol}$$

$$\frac{N}{N_0} = \frac{97.24}{105.4} = 0.922$$

conc at good steam generator

$$\frac{dN}{dt} = -14.93\left(\frac{N_{sg}}{N_0}\right) + 14.93 \frac{N_{TP}}{N_0}$$

$$\frac{dN}{dt} = 14.93\left[\left(\frac{N_{TP}}{N_0}\right) - \left(\frac{N_{sg}}{N_0}\right)\right]$$

at 1 sec

$$\frac{N_{TP}}{N_0} = 0.993$$

$$\frac{dN}{dt} = 14.93[0.993 - 1] = -0.104 \text{ mol/sec}$$

$$N_{sg} = 39.8 - (0.104)(1) = 39.696$$

$$\frac{N_{sg}}{N_0} = \frac{39.696}{39.8} = 0.9973$$

at 3 sec

$$\frac{dN}{dt} = 14.93[.968 - .9973] = -.437$$

$$N = 39.696 - .437(2) = 38.82$$

$$\frac{N}{N_0} = 0.9754$$

at 5 sec

$$\frac{dN}{dt} = 14.93 [.949 - .975] = -0.388$$

$$N = 38.82 - .388(2) = 38.04$$

$$\frac{N}{N_0} = 0.955$$

at 7 sec

$$\frac{dN}{dt} = 14.93 [.936 - .955] = -0.283$$

$$N = 38.04 - .283(2) = 37.47$$

$$\frac{N}{N_0} = 0.941$$

at 9 sec

$$\frac{dN}{dt} = 14.93 [.928 - .941] = -0.194$$

$$N = 37.47 - .194(2) = 37.08$$

$$\frac{N}{N_0} = 0.931$$

at 11.3 sec

$$\frac{dN}{dt} = 14.93 [.922 - .931] = -0.134$$

$$N = 37.08 - .134(2.3) = 36.77$$

$$\frac{N}{N_0} = 0.924$$

Thus the Helium concentrations around the system are

at blower in failed loop	83.2%
" Bottom plenum	91.8%
" Top plenum	92.2%
" good steam generator	92.4%
blower in sound loop	92.4%

For 100% Blower speed construct several velocity triangles for blower operation with 83.2% and 92.4% Helium mixtures

Molecular weight of 92.4% mixture

$$\frac{0.924(4) + 0.076(16)}{1} = 5.06$$

and for 83.2% mixture

$$832(4) + 168(16) = 6.35$$

Assume section pressure of 300 psi and 943°R

$$V = \frac{1545(943)}{300(144)(6.35)} = 5.31 \frac{\text{ft}^3}{\text{lb}} \quad (\text{failed loop})$$

$$V = \frac{1545(943)}{300(144)(5.06)} = 6.66 \frac{\text{ft}^3}{\text{lb}} \quad (\text{sound loop})$$

From Jay curve

127.35

51.13 lb/sec	$\gamma_c = 1.071$	433 cfs
57.15	1.062	484.6
60.16	1.055	510.15
63.16	1.045	535.3

For $M = 6.35$ $N = 5.31$; and $M = 5.06$, $N = 6.66$ Since $P_r = \frac{P_1 + \Delta P}{P_1}$ and since $\Delta P = K \frac{1}{2} \rho V^2$

then correcting for higher densities

Flow	$M = 6.35$	$M = 5.06$
433	1.1134	1.0891
484.6	1.0990	1.0789
510.15	1.0878	1.0700
535.3	1.0719	1.0573

334 C.3

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8/1/62

from $pV = \frac{RT}{\mu}$

$$V = \frac{1545(950)}{6.01(144)(300)} = 5.65 \frac{\text{ft}^3}{\text{lb}}$$

The specific volume at the blower section in the sound loop is

$$V = \frac{1545(950)}{4(144)(300)} = 8.48 \frac{\text{ft}^3}{\text{lb}}$$

Assume steam has only entered the one steam generator and the cold leg up to the blower section.

The normal pressure drop from the (and one) the steam generator to the blower is 2.56 psi. Assuming that this is all due to friction effects

From 330-1

$$\frac{\Delta P_s}{\Delta P_{He}} = \frac{G_s^{1.8} \nu_s \mu_s^{0.2}}{G_{He}^{1.8} \nu_{He} \mu_{He}^{0.2}}$$

For a mixture of steam and helium assume that the viscosity does not change significantly then

$$\frac{\Delta P_s}{\Delta P_{He}} = \frac{G_s^{1.8}}{G_{He}^{1.8}} \frac{\nu_s}{\nu_{He}}$$

$$G = VC = \left(\frac{V}{V}\right)^{1.8}$$

334 C.Y

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8/11/62

then

$$\frac{\Delta P_3}{\Delta P_{He}} = \left(\frac{V_{St}}{V_{He}} \right)^{1.8} \left(\frac{V_{He}}{V_{St}} \right)^{1.8} \frac{V_{St}}{V_{He}} = \left(\frac{V_{St}}{V_{He}} \right)^{1.8} \left(\frac{V_{He}}{V_{St}} \right)^{0.8}$$

For constant velocity then

$$\Delta P_3 = \Delta P_{He} \left(\frac{V_{He}}{V_{St}} \right)^{0.8} = 2.56 \left(\frac{8.4K}{5.65} \right)^{0.8} = 3.54$$

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For a mixture of steam and helium and assuming that the viscosity does not significantly change the pressure drop is given by

$$\frac{\Delta P_{ST}}{\Delta P_{He}} = \frac{G_{ST}^{1.8}}{G_{He}^{1.8}} \frac{N_{ST}}{N_{He}}$$

$$G^{1.8} = \left(\frac{Q}{AN} \right)^{1.8}$$

$$\frac{\Delta P_{ST}}{\Delta P_{He}} = \left(\frac{Q_{ST}}{Q_{He}} \right)^{1.8} \left(\frac{N_{He}}{N_{ST}} \right)^{1.8} \left(\frac{A}{A} \right)^{1.8} \frac{N_{ST}}{N_{He}}$$

$$\frac{\Delta P_{ST}}{\Delta P_{He}} = \left(\frac{Q_{ST}}{Q_{He}} \right)^{1.8} \left(\frac{N_{He}}{N_{ST}} \right)^{0.8}$$

Assuming constant temp and pressure for the first trial then

$$\frac{\Delta P_{ST}}{\Delta P_{He}} = \left(\frac{Q_{ST}}{Q_{He}} \right)^{1.8} \left(\frac{M_{ST}}{M_{He}} \right)^{0.8}$$

failed loop cold leg $M = 6.35$
 Bottom plenum 5.14
 Top plenum 5.09
 Hot legs good steam generator 5.06
 failed steam generator 6.35

The pressure drops for normal operation are

core	10.25 psi	@	430,000 lb/hr
Hot legs	1.33 psi	@	215,000 lb/hr
Steam generator	2 psi	@	215,000 lb/hr
Cold legs	1.43 psi		215,000 lb/hr

$$V_{BPR} = \frac{970(1545)}{4(313.7)(144)} = 8.293$$

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$$430,000 \frac{\text{lb}}{\text{hr}} \times \frac{\text{hr}}{3600 \text{ sec}} \times \frac{8.293 \text{ ft}^3}{\text{lb}} = 990.5 \text{ CFS (core)}$$

$$V_{HL} = \frac{1503(1545)}{303.4(144)(4)} = 13.24$$

$$215,000 \text{ lb/hr} \times \frac{13.24}{3600} = 793.1 \text{ CFS (Hot legs)}$$

$$V_{CL} = \frac{943(1545)}{4(298)(144)} = 8.487$$

$$215,000 \frac{8.487}{3600} = 506.8 \text{ CFS (Cold legs)}$$

Steam generator

$$V = \frac{1223(1545)}{4(299)(144)} = 10.97$$

(5 steam generators)

$$215,000 \frac{10.97}{3600} = 655.1 \text{ CFS}$$

Thus for the cold leg

$$\Delta P_{ST} = (Q)^{1.8} M^{0.8} \left(\frac{1}{506.4} \right)^{1.8} (.25)^{0.8} (1.43) f$$

$$\Delta P_{ST} = 5.99 \times 10^{-6} Q^{1.8} M^{0.8} f$$

For the core

$$\Delta P_{core} = Q^{1.8} M^{0.8} \left(\frac{1}{990.5} \right)^{1.8} (.25)^{0.8} (10.25) f$$

$$\Delta P_{core} = 1.35 \times 10^{-5} Q^{1.8} M^{0.8} f$$

For the hot leg

$$\Delta P_{HL} = Q^{1.8} M^{0.8} \left(\frac{1}{793.1} \right)^{1.8} (.25)^{0.8} (1.33) f$$

$$\Delta P_{HL} = 2.65 \times 10^{-6} Q^{1.8} M^{0.8} f$$

For steam generator

$$\Delta P_{SG} = Q^{1.8} M^{0.8} \left(\frac{1}{655.1} \right)^{1.8} (.25)^{0.8} (2) f$$

$$\Delta P_{SG} = 5.577 \times 10^{-6} Q^{1.8} M^{0.8} f$$

After 11.3 sec the system pressures have increased approximately

$$\frac{\frac{2.51 \text{ mol}}{\text{sec}} \times 11.3 \text{ sec}}{337.5 \text{ mol}} = .084 \quad \text{or } 8.4 \%$$

Blower suction pressure was originally about 298 psia thus it has increased at end of 11.3 sec to

$$298 (1.084) = 323 \text{ psia}$$

The pressure drops should be corrected by a factor of $(\frac{1}{1.084})^{1.4}$ or $f = .8645$

Assume failed loop flow through blower is 505 CFS ; through good loop blower 475 CFS

Calculate pressures & pressure drops around the system.

$$\begin{aligned} &\text{Blower discharge pressure (Bottom plenum)} \\ &323 (1.075) = 347 \text{ psia} \end{aligned}$$

Core pressure drop

Core pressure drop

Corrected flow

$$(525 + 475) \frac{970}{943} \frac{323}{347} = 957 \text{ CFS}$$

$$\Delta P_{\text{core}} = 1.35 \times 10^{-5} (957)^{1.8} (5.14)^{0.8} (.8645)$$

$$\Delta P_{\text{core}} = 1.35 \times 10^{-5} (2.32 \times 10^5) (3.7) (.8645) = 10.02 \text{ psi}$$

$$\text{Top plenum pressure } 347 - 10.02 = 337 \text{ psi}$$

Hot leg pressure drop (failed loop)

corrected flow

$$525 \left(\frac{1503}{943} \right) \left(\frac{323}{337} \right) = 802 \text{ CFS}$$

$$\Delta P = 2.65 \times 10^{-6} (802)^{1.8} (5.09)^{0.8} (.8645)$$

$$\Delta P = 2.65 \times 10^{-6} (.356 \times 10^6) (3.67) (.8645) = 2.99 \text{ psi}$$

$$\text{Pressure at steam generator } 347 - 13.01 = 334 \text{ psi}$$

failed steam generator drop

corrected flow

$$525 \left(\frac{1223}{943} \right) \left(\frac{323}{334} \right) = 658.4 \text{ CFS}$$

$$\Delta P = 5.577 \times 10^{-6} (658.4)^{1.8} (4.35)^{0.8} (.8645)$$

$$\Delta P = 5.577 \times 10^{-6} (.1140 \times 10^6) (4.35) (.8645) = 2.497 \text{ psi}$$

$$\text{Press at S.G. exit} = 347 - 15.5 = 331.5 \text{ psi}$$

Cold leg pressure drop (failed loop)

$$525 \left(\frac{323}{331.5} \right) = 511.5 \text{ cfs}$$

$$\Delta P = 5.99 \times 10^{-6} (511.5)^{1.8} (6.35)^{0.8} (.8645)$$

$$\Delta P = 5.99 \times 10^{-6} (.075 \times 10^6) (4.35) (.8645) = 1.705 \text{ psi}$$

$$\text{Suction pressure } 347 - 17.2 = 329.8 \text{ psi}$$

Hot leg pressure drop (good loop)

Corrected flow

$$475 \left(\frac{802}{525} \right) = 725.61$$

$$\Delta P = 2.45 (10^6) (725.61)^{1.8} (5.09)^{0.8} (.8645)$$

$$\Delta P = 2.45 \times 10^{-6} (.141 \times 10^6) (3.67) (.8645) = 1.18 \text{ psi}$$

$$\text{Steam generator inlet pressure } 347 - 11.19 = 336 \text{ psi}$$

Good generator drop

Corrected flow

$$475 \left(\frac{1223}{943} \right) \left(\frac{323}{336} \right) = 592 \text{ cfs}$$

$$\Delta P = 5.577 \times 10^{-6} (592)^{1.8} (5.06)^{0.8} (.8645)$$

$$\Delta P = 5.577 \times 10^{-6} (.0975 \times 10^6) (3.66) (.8645) = 1.72 \text{ psi}$$

Press 54 exit

$$347 - 12.9 = 334.1 \text{ psi}$$

Cold leg pressure drop

Corrected flow

$$525 \left(\frac{323}{334.1} \right) = 507.5 \text{ CFS}$$

$$\Delta p = 5.99 \times 10^{-6} (507.5)^{1.4} (3.66) (-8645)$$

$$\Delta p = 5.99 \times 10^{-6} (0.75 \times 10^6) (3.66) (-8645) = 1.42 \text{ psi}$$

$$\text{Suction pressure } 347 - 14.3 = 332.7 \text{ psi}$$

$$\text{Press ratio required } \frac{347}{332.7} = 1.042$$

$$\text{Actual press ratio } 1.082$$

For the assumed flows the system pressure drops are lower than the pressure rise through the respective blowers, consequently the actual flows would be higher and it can be concluded that the blowers will not be in surge at the end of one cycle time

It should be noted that at the assumed

loop flows the failed loop blowdown pressure ratio required is

$$\frac{347}{329.8} = 1.052 \text{ and would actually be greater}$$

Since suction pressure is 323 then the

discharge pressure is at least $323(1.052) = 339.79 \text{ psia}$
 Scram pressure is set at 340, thus, scram
 occurs within about one cycle time on
 high pressure (for 100% operation).

Determination of 20% temp distribution

Inlet temp 508 °F

From Study N 320 the normal 100% temp distribution and coolant temperature rise can be obtained

$\Delta T_{cl_{100\%}}$	$\Delta T_{coolant}$	$\Delta T_{cl_{20\%}} = \left(\frac{1}{0.2}\right)^{0.8} \frac{1}{5} \Delta T_{cl_{100}}$	$T_{cl_{20}}$
178.5	10.8	129.7	648.5
399.7	70.3	290.6	868.9
550.3	169.7	400.0	1077.7
611.4	285.5	444.5	1238.0
568.6	403.2	413.4	1324.6
421.2	505.9	306.2	1320.1
203	572.9	147.6	1228.5
75.7	596.7	55.0	1159.7
27.2	605.4	19.7	1131.1
9.15	610.8	6.6	1125.4

Revised.

Calculate rate of heat up at 20% power

From figure 6 ORNL 62-4.32, the rate of heating at 100% with no cooling is

$$\frac{(1200 - 1466)^{\circ}\text{F}}{1.7 \text{ sec}} = 197^{\circ}\text{F/sec}$$

At 20% power, this rate of heating with no cooling would be $\frac{1}{5}$ of this or 40°F/sec

The worst discrepancy that can exist without causing a flux-flow scream is 20% power - 10% flow.

$$\frac{dT}{dt} = K(Q_{in} - Q_{out})$$

during normal operation $Q_{out} = Q_{in} = 20\%$
with 10% flow the rate of heat removal at time zero is

$$\frac{h_{10\%}}{h_{20\%}} Q_{20\%} = \left(\frac{W_{10\%}}{W_{20\%}} \right)^{.8} Q_{20\%} = .575 Q_{20\%}$$

when the flow is zero

$$\frac{dT}{dt} = K(Q_{20\%} - 0) = 40^{\circ}\text{F/sec}$$

when flow is 10%.

$$\left(\frac{dT}{dL}\right)_{T=0} = K(Q_{20\%} - .575 Q_{20\%})$$

$$\left(\frac{dT}{dL}\right)_{T=0} = \frac{K(Q_{20\%} - .575 Q_{20\%})}{K(Q_{20\%})} (40^\circ \text{F}/\text{min})$$

$$\left(\frac{dT}{dL}\right)_{T=0} = (1 - .575) 40^\circ \text{F}/\text{min} = 17^\circ \text{F}/\text{min}$$

The high pressure scram might be delayed as long as

$$T_{SK} = 3 \text{ sec} + T_{SP} = \frac{(340 - 298)(144)(12000)(14)(3600)}{1545(1240)(163000)}$$

$$T_{SK} = 3 \text{ sec} + 15.07 \approx 18 \text{ sec}$$

where T_{SP} is the time to reach the trip set point on high pressure.

The maximum cladding temperature then is less than

$$T_{cl, \text{max}} = 1325^\circ \text{F} + (17^\circ \text{F}/\text{sec})(18 \text{ sec}) = 1630^\circ \text{F}$$