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MASTER

~~BJ-PD-76-P-332~~

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14 June 1976

ATO 3-76SF98001

Mr. T. R. Sandke
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Subject: Contract AT(04-3)-893, Task I - Standpipe-Bubbler Pump Level-Control Study; Byron Jackson Pump Division, Transmittal of EM 0190 - Standpipe-Bubbler Pump Level-Control System Study - 1E-3862 Controlled Clearance Pump/System Model Analysis (Task A)

Reference: (1) G.E. Specification 22A3510, Rev.1, Standpipe-Bubbler Pump Level Control System Study
(2) GE-SAN-893-1-0871, J. Champagne to W. Walker, dated August 12, 1975, Standpipe-Bubbler Level Control System Study, Byron Jackson Pump Division, Transmittal of GE/BJ/WARD Model Exchange Meeting No. 3
(3) BJ-PD-76-P-310, M. Cook to F. Luffey, dated 4 June 1976, Standpipe-Bubbler Input to ARD System Model

Dear Mr. Sandke:

Enclosed is a copy of Byron Jackson Pump Division Engineering Memorandum No. 0190 Standpipe-Bubbler Pump Level Control System Study - 1E-3862, Controlled Clearance Pump/System Model Analysis (Task A). This report contains the data required for the milestone 1.d of reference (1). This report contains a revised model based on the Controlled Clearance Pump per the agreements and commitments of reference (2).

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With the concurrence of L. Manners, G.E., a draft copy of EM 0190 was transmitted to F. Luffey, WARD, under reference (3). This report provides WARD with data required to determine the compatibility of the Task A Analysis with the CRBRP system requirements (reference (1), milestone 2).

Very truly yours,

A handwritten signature in cursive script, appearing to read "A A Kerner".

A. A. Kerner
Program Manager

MEC:cyc/8

Enclosure

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BYRON JACKSON PUMP DIVISION
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BREEDER REACTOR PUMP DEPARTMENT

ENGINEERING MEMORANDUM 0190
STANDPIPE-BUBBLER PUMP LEVEL CONTROL
STUDY: - 1E-3862, CONTROLLED CLEARANCE PUMP/SYSTEM
MODEL ANALYSIS (TASK A) W.P. 7373.

June 7, 1976

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ENGINEERING MEMORANDUM 0190
STANDPIPE-BUBBLER PUMP LEVEL CONTROL
STUDY - 1E-3862, CONTROLLED CLEARANCE PUMP/SYSTEM
MODEL ANALYSIS (TASK A) W.P. 7373

ABSTRACT

Computer simulation results of the standpipe-bubbler pump level control system/controlled clearance pump configuration 1E-3862 are presented herein.

Fluid level control system behavior is presented in graphical form for normal plant loading, unloading, and trip transients, under varying conditions of cover gas mass flow rate, tank impedances, temperature, and flow rates through discharge seal and bearing leakage paths.

Satisfactory fluid level control can be attained for this configuration with a standpipe-bubbler system.

TABLE OF CONTENTS

<u>Title</u>	<u>Page No.</u>
I. Introduction	1
II. Analytic Model of Reactor	3
III. Analytic Model of Standpipe-Bubbler	9
IV. Summary of Analysis	17
V. Computer Program	18
VI. Results	28
VII. Comparison of Results with Those of Previous Analysis	38
VIII. Design Layout	39
IX. Feasibility Report and Range of Expected Gas Flow Rates	41
References	
Nomenclature	
Figures	
Appendix 1 - Pump Tank Area and Volume	
Appendix 2 - Computer Program Listing	

I. INTRODUCTION

This is the fifth in a series of reports (references 1-4) dealing with the analytic model, feasibility, and system design layout of the standpipe-bubbler pump level control system.

A. Previous Work

Reference 1 contains an analytic model of the standpipe-bubbler system. In that report, the standpipe-bubbler was treated as a component. The reactor loop was not explicitly considered; instead, the pump suction pressure (as a function of time) and the cover gas pressure above the standpipe were specified, and the response of the standpipe-bubbler to these "forced inputs" was determined. Comparison between the performance predictions of the analytic model and measurements made on a laboratory-scale physical model of the standpipe-bubbler was very good, inspiring confidence in the usage of the analytic model to predict performance of a full-scale standpipe-bubbler system. These predictions were used to develop a system design layout.

In order to assess the behavior of the standpipe-bubbler as a part of the overall reactor system, an analytic model of the rest of the reactor loop was constructed and combined with the standpipe-bubbler model of reference 1 (with some minor improvements). The results of that study are contained in reference 2. While some additional performance features were noted, the results supported the conclusions of reference 1 and did not affect the system design layout.

Following issuance of reference 2, the pump design was changed to the "controlled clearance" concept (1F-7583, Rev. 0). Since this involved changes in pump tank geometry and internal flow path impedances, the results of references 1 and 2 were no longer necessarily valid, and modification of the analytic model was made necessary. However, to obtain a rapid preliminary estimate of the impact of this change on the standpipe-bubbler performance, a partial simulation was conducted using the computer program contained in reference 2 and altering such program inputs as pump tank height and cross-section area to approximate the new system.

The results of such a study, contained in reference 3, indicated that the same standpipe-bubbler system (as that used with the original pump) could be used with the controlled clearance pump, provided the nozzle location was changed from 7'-7.5" (above pump suction) to 6'.

A complete simulation of the controlled clearance pump (1F-7583, Rev. C) was then made and reported in reference 4. This included the changes in pump tank geometry, internal flow path impedances, flow paths, and head increase across the pump. It utilized the same standpipe dimensions and nozzle location as the previous study. The results were very similar to the previous results and indicated that the standpipe-bubbler system maintains satisfactory sodium level control.

B. Present Report

The present report contains a complete simulation of the 1E-3862 configuration. This configuration differs from 1F-7583, Rev. C, in that it contains a much more complex lower pump tank geometry and many more flow paths.

The present simulation also includes a more realistic standpipe configuration than had been included in the past. Previous simulations considered a standpipe consisting of a single horizontal section and a single vertical section. The present one simulates the configuration contained in reference 5.

C. Results in Present Report

Histories of reactor tank and standpipe fluid levels, along with pump suction and pump tank cover gas pressures and pump discharge flow rate, were generated as functions of: a) cover gas mass flow rate, b) tank impedances, c) temperature, d) flow rates through discharge seal and bearing leakage paths. A nozzle location of 6.75 ft. is utilized.

The results indicate that the standpipe-bubbler system maintains satisfactory sodium level control within the pump tank.

II. ANALYTIC MODEL OF REACTOR

A. Description of Model

A schematic diagram of a simplified model of the reactor system is contained in figure 1. The model can be divided into a liquid loop and a gas loop.

Liquid sodium flows from the reactor vessel through line 1, at a flow rate Q_{r1} , to the pump. On the suction side of the pump, at pressure P_p , it communicates with the pump tank, where additional liquid can flow into (or out of) line 1 at a rate of Q_p . On the discharge side of the pump some liquid flows into the pump tank at a rate equal to the sum of Q_{IHx} , the bearing leakage flow rates, Q_{BEAR} (2 paths), and the discharge seal leakage flow rate, Q_{LEAK} . The remainder flows at a rate Q_{r2} through line 2 back to the reactor vessel.

The liquid level in the reactor vessel is controlled by an overflow valve and associated line to the overflow tank. In addition, liquid is continuously pumped back to the reactor vessel from the overflow tank so that the liquid inventory in the loop cannot decrease with time. The latter is not shown in the figure but is accounted for by adjusting the overflow rate, Q_o .

Although the schematic diagram shows only one pump (and associated loop) connected to the reactor vessel, the real system contains three pumps (and associated loops). It is assumed that all three pumps operate identically in parallel. The two not shown on the diagram are taken into account when considering the dynamics of the reactor vessel.

The gas loop, handling argon, consists of line b, from the reactor vessel to the overflow tank, line a, from the top of the standpipe to the overflow tank, gas supplies to the reactor vessel and pump tanks, and a gas discharge from the overflow tank to the RAPS. The gas supply to the pump tank, $\dot{m}_g$, is constant. The gas supply to the reactor vessel, $\dot{m}_s$, and the discharge from the overflow tank, $\dot{m}_{RAPS}$, are controlled by the gas pressure in the reactor vessel, P_{gr} .

To simplify the loop, the gas header in the real system is included in the overflow tank volume, V_o . Another simplification involves neglecting gas flow through the liquid overflow line (between the reactor vessel and the overflow tank).

Gas flow from the standpipes of the two pumps, not shown on figure 1, to the overflow tank are accounted for in the mass balance on that tank.

A further simplification of the entire reactor system involves treating the flow as isothermal.

B. Liquid Loop

1. Conservation of Mass in Reactor Vessel

A mass balance on the reactor vessel, accounting for all three pumps (and associated loops), yields:

$$A_r \frac{dY_r}{dt} = 3 Q_{r2} - 3 Q_{r1} - Q_o \quad (1)$$

The overflow rate, Q_o , is given by:

$$\begin{aligned} Q_o &= \frac{1.989}{\rho} - .2228 \text{ ft.}^3/\text{sec. for } Y_r > 16.3 \text{ ft.} \\ &= -.2228 \text{ ft.}^3/\text{sec. for } Y_r \leq 16.3 \text{ ft.} \end{aligned} \quad (1a)$$

2. Dynamic Equations for Loop

The dynamic equations for lines 1 and 2, taking account of inertia and viscous losses, are:

$$\begin{aligned} \frac{\rho l_1}{A_1} \frac{dQ_{r1}}{dt} + \frac{\rho (1 + C_1)}{2 A_1^2} Q_{r1}^2 \\ = P_{gr} - P_p + \rho g (Y_r - Y_o) \end{aligned} \quad (2)$$

$$\begin{aligned} \frac{\rho l_2}{A_2} \frac{dQ_{r2}}{dt} + \frac{\rho}{2 A_2^2} (C_2 Q_{r2}^2 - Q_d^2) \\ = P_d - P_2 + \rho g (Y_o - Y_2) \end{aligned} \quad (3)$$

The dynamic equation for flow within the reactor vessel, accounting for the two additional pumps, is:

$$\frac{3 \rho (Y_1 - Y_2)}{A_r} \frac{dQ_{r2}}{dt} + \frac{9 \rho C_3 Q_{r2}^2}{2 A_r^2} = p_2 - P_{gr} - \rho g (Y_r - Y_2) \quad (4)$$

3. Pump Characteristics

The equation governing the pressure increase across the pump, as obtained from reference 6, is:

$$P_d - P_p = \rho g H_r \bar{N}^2 \left\{ 1.229 - .18 \left(\frac{Q_d}{\bar{N} Q_{\max}} \right) + .192 \left(\frac{Q_d}{\bar{N} Q_{\max}} \right)^2 - .28 \left(\frac{Q_d}{\bar{N} Q_{\max}} \right)^3 + .039 \left(\frac{Q_d}{\bar{N} Q_{\max}} \right)^4 \right\} + .5 \rho Q_d^2 \left(1/A_1^2 - 1/A_2^2 \right) \\ \equiv f_1(Q_d) \quad (5)$$

4. Relationships Between Various Flow Rates

Conservation of mass leads to:

$$Q_{r1} = Q_d - Q_p \quad (6)$$

and:

$$Q_{r2} = Q_d - Q_{IHX} - 2Q_{BEAR} - Q_{LEAK} \quad (7)$$

Q_{IHX} , Q_{BEAR} , and Q_{LEAK} are proportional to the discharge flow from the pump, i.e.:

$$Q_{IHX} = (FQ_{IHX}) Q_d \quad (8a)$$

$$Q_{BEAR} = (FQ_{BEAR}) Q_d \quad (8b)$$

$$Q_{LEAK} = (FQ_{LEAK}) Q_d \quad (8c)$$

5. Working Equations for Q_d and P_p

It is convenient to combine equations (2), (3), (4), (6), and (7) to eliminate P_d and P_2 from the analysis, yielding an equation for Q_d :

$$f_1(Q_d) = \left[\frac{3\rho(Y_1 - Y_2)(PCT)}{A_r} + \frac{\rho\ell_2}{A_2} (PCT) + \frac{\rho\ell_1}{A_1} \right] \frac{dQ_d}{dt} - \frac{\rho\ell_1}{A_1} \frac{dQ_p}{dt} \\ + \left[\frac{9\rho C_3}{2A_r^2} (PCT)^2 + \frac{\rho C_2}{2A_2^2} (PCT)^2 - \frac{\rho}{2A_2^2} \right] Q_d^2 + \frac{\rho(1+C_1)}{2A_1^2} (Q_d - Q_p)^2 \quad (9)$$

where $PCT \equiv 1 - FQ_{IHX} - 2FQ_{BEAR} - FQ_{LEAK}$.

It is also convenient to combine equations (2) and (6) to obtain an equation for P_p :

$$P_p = P_{gr} + \rho g (Y_r - Y_o) - \rho \frac{\ell_1}{A_1} \frac{dQ_d}{dt} + \rho \frac{\ell_1}{A_1} \frac{dQ_p}{dt} \\ - \frac{\rho(1+C_1)}{2A_1^2} (Q_d - Q_p)^2 \quad (10)$$

C. Gas Loop1. Conservation of Mass, and Gas Law, in
Reactor Vessel and Overflow Tank

Considering the gas in the reactor vessel,
one can write:

$$\left(\frac{d\rho_{gr}}{dt} \right) A_r (Y_{tr} - Y_r) - \rho_{gr} A_r \frac{dY_r}{dt} = \dot{m}_s - \rho_{gr} Q_b \quad (11)$$

and:

$$P_{gr} = \rho_{gr} RT \quad (12)$$

where the mass rate of flow of gas pumped
into the reactor vessel from the supply, $\dot{m}_s$, is
given by:

$$\begin{aligned} \dot{m}_s &= 9.604 \times 10^{-5} \text{ slug/sec.} & \text{for } P_{gr} \geq 2167.999 \\ & & \text{lb/ft.}^2 \\ &= 5.585 \times 10^{-3} \text{ slug/sec.} & \text{for } P_{gr} < 2167.999 \\ & & \text{lb/ft.}^2 \end{aligned} \quad (11a)$$

Similarly, for the overflow tank:

$$V_o \left(\frac{d\rho_{go}}{dt} \right) = \frac{(\rho_{go} + \rho_{gr})}{2} Q_b + \frac{3(\rho_{go} + \rho_{ga})}{2} Q_a - \dot{m}_{RAPS} \quad (13)$$

and:

$$P_o = \rho_{go} RT \quad (14)$$

where the mass rate of flow of gas from the overflow tank to the RAPS, $\dot{m}_{RAPS}$, is given by:

$$\begin{aligned} \dot{m}_{RAPS} &= 3\dot{m}_g + 9.604 \times 10^{-5} \text{ slug/sec} \\ &\text{for } P_{gr} \leq 2168.001 \text{ lbf/ft.}^2 \\ &= 3\dot{m}_g + 5.585 \times 10^{-3} \text{ slug/sec.} \\ &\text{for } P_{gr} > 2168.001 \text{ lbf/ft.}^2 \end{aligned} \quad (13a)$$

2. Dynamic Equations for Loop

The dynamic equations for lines b and a, neglecting inertia, are, respectively:

$$P_{gr} - P_o = \frac{C_b}{2} \left(\frac{\rho_{go} + \rho_{gr}}{2} \right) \left(\frac{Q_b}{A_b} \right) \left| \frac{Q_b}{A_b} \right| \quad (15)$$

and:

$$P_a - P_o = \frac{C_a}{2} \left(\frac{\rho_{go} + \rho_{ga}}{2} \right) \left(\frac{Q_a}{A_a} \right) \left| \frac{Q_a}{A_a} \right| \quad (16)$$

ρ_{ga} is related to P_a through:

$$P_a = \rho_{ga} RT \quad (17)$$

3. Relationship Between Flow Rates

If a quasi-steady flow approximation is used, Q_a can be related to the gas flow rate into the standpipe through:

$$Q_a = \frac{P_g}{P_a} Q_g \quad (18)$$

III. ANALYTIC MODEL OF STANDPIPE-BUBBLER

A. Description of Model

The schematic diagram in figure 1 shows the relation between the standpipe-bubbler and the rest of the reactor system. More detailed schematics of the standpipe-bubbler are contained in figures 2 and 3.

The upper portion of the pump tank is modeled as a rigid-walled vessel with variable cross-sectional area A , top located at Y_t and bottom located at Y_{bot} .

In the side of the vessel is an orifice of square cross-section (with height h), opening into a standpipe of cross-sectional area A_s , as shown. The top of the orifice is located at $Y_s = Y_{n1}$. Liquid and gas flow out of the pump tank and into the standpipe (or vice versa), through the orifice, with volumetric flow rates Q_l and Q_g , respectively.

Gas enters the vessel through the upper port, at a constant mass flow rate $\dot{m}_g$.

The lower portion of the pump tank contains two chambers, #1 and #2, which communicate with the upper portion through ports having impedances I_{SH} and I_{AN} , and flow rates Q_{SH} and Q_{AN} , respectively. Q_{SH} represents the shaft flow, and Q_{AN} represents the annulus flow.

In addition, chambers 1 and 2 communicate with each other through a port having an impedance I_{CH} and flow rate Q_{CH} . Chamber 2 also communicates with the suction side of the pump (at pressure P_p), through a port having impedance I_p and flow rate Q_p .

There are, in addition, flows of liquid from the discharge side of the pump to chamber 1 (Q_{BEAR}), chamber 2 (Q_{BEAR} , Q_{LEAK}), and the upper portion of the tank (Q_{IHx}). These are all fixed percentages of the discharge flow rate (see equation 8).

B. Basic Equations - Conservation of Mass

Conservation of gas in the pump tank, of liquid in the pump tank, and of liquid in the standpipe, respectively, yield the following equations:

$$-\frac{AP_g}{RT} \frac{dY_i}{dt} + \frac{V}{RT} \frac{dP_g}{dt} + \frac{P_g Q_g}{RT} - \dot{m}_g = 0 \quad (19)$$

$$A \frac{dY_i}{dt} + Q_\ell + Q_{AN} + Q_{SH} - Q_{IHX} = 0 \quad (20)$$

$$A_s \frac{dY_s}{dt} - Q_\ell \sin \theta = 0 \quad (21)$$

where the cross-sectional area and gas volume of the tank are given by:

$$A = 18.6 + 1.844 Y_i + .0468 Y_i^2 \text{ ft}^2 \quad (19a)$$

$$V = 334.37 - 18.69 Y_i - .92 Y_i^2 - .0157 Y_i^3 \text{ ft}^3 \quad (19b)$$

Refer to Appendix 1 for equation (19a) & (19b).

In the above equations, the gas is treated as an isothermal perfect gas.

The mass rate of flow of gas pumped into the pump tank from supply, $\dot{m}_g$, is taken to be a constant:

$$\dot{m}_g = \text{constant} \quad \square \quad (19c)$$

For computational reasons, it is convenient to substitute two new dependent variables for Y_s and P_g :

$$P_1 \equiv P_g - P_a + \rho g (Y_i - Y_s) \quad (22)$$

$$P_2 \equiv P_g + \rho g(Y_i - Y_{bot}) - P_p \quad (23)$$

Combining equations (19) - (23) results in:

$$\frac{dY_i}{dt} = - \frac{Q_\ell + Q_{AN} + Q_{SH} - Q_{IHx}}{A} \quad (24)$$

$$\begin{aligned} \frac{dP_1}{dt} = & \frac{RT\dot{m}_g - (P_2 + P_p - \rho g(Y_i - Y_{bot}))Q_g}{V} + \left[\frac{A}{V} (P_2 + P_p - \rho g(Y_i - Y_{bot})) \right. \\ & \left. + \rho g \right] \frac{dY_i}{dt} - \frac{\rho g Q_\ell \sin \theta}{A_s} - \frac{dP_a}{dt} \end{aligned} \quad (25)$$

$$P_2 = P_1 + P_a - P_p + \rho g \left[(Y_s)_{initial} + \int_0^t \frac{Q_\ell \sin \theta}{A_s} dt - Y_{bot} \right] \quad (26)$$

Once Y_i , P_1 and P_2 are obtained, one can solve for Y_s and P_g from:

$$Y_s = \frac{1}{\rho g} \left[P_p - P_a - (P_1 - P_2) \right] + Y_{bot} \quad (27)$$

$$P_g = P_2 + P_p - \rho g(Y_i - Y_{bot}) \quad (28)$$

C. Equations for Lower Portion of Pump Tank

Consideration of the flow through the various ports of the lower portion of the pump tank leads to the following equations:

$$\frac{\rho l_{SH}}{A_{SH}} \frac{dQ_{SH}}{dt} = P_2 + P_p - P_{C1} - I_{SH} Q_{SH} |Q_{SH}| \quad (29a)$$

$$Q_{CH} = Q_{SH} + Q_{BEAR} \quad (29b)$$

$$Q_P = Q_{AN} + Q_{SH} + 2Q_{BEAR} + Q_{LEAK} \quad (29c)$$

$$P_{C2} = P_p + I_p Q_P |Q_P| - \rho g (Y_{bot} - Y_o) \quad (29d)$$

$$P_{C1} = P_{C2} + I_{CH} Q_{CH} |Q_{CH}| \quad (29e)$$

$$Q_{AN} = \pm \left[\frac{P_p + P_2 - P_{C2}}{I_{AN}} \right]^{1/2} \quad (29f)$$

In equation (29f),

$$+ \text{ for } P_p + P_2 - P_{C2} \geq 0$$

$$- \text{ for } P_p + P_2 - P_{C2} < 0.$$

D. Equations for Q_ℓ and Q_g

$$1. \quad \underline{Y_i \geq Y_n}$$

When the orifice between the tank and the standpipe is completely submerged in liquid, the flow is treated as single-phase flow through an orifice and pipe (standpipe).

Accounting for the inertia of liquid in the standpipe and the viscous losses in both the orifice and the pipe, one obtains the following equation for Q_ℓ :

$$\frac{\rho (l_s + l_{sp})}{A_s} \frac{dQ_\ell}{dt} = P_1 - \left(\frac{.5}{A_s^2} + \frac{.18783}{A_n^2} \right) \rho Q_\ell |Q_\ell| - \frac{32\mu (l_s + l_{sp})}{h_s^2 A_s} Q_\ell \quad (30a)$$

Since the orifice is submerged, there is no gas flow, i.e.:

$$Q_g = 0 \quad (31a)$$

$$2. \quad Y_n - h < Y_i < Y_n$$

When the liquid level is between the top and bottom of the orifice, and when $P_1 \geq 0$, it is assumed that the flow through the orifice and the horizontal section of the standpipe is stratified, with the liquid-gas interface located at Y_i . Under such conditions:

for $P_1 \geq 0$

$$\rho \left[\frac{\ell_s}{\left(Y_i - Y_n + \frac{h+h_s}{2} \right) \frac{A_s}{h_s}} + \frac{\left(\ell_{sp} \right)}{A_s} \right] \frac{dQ_\ell}{dt} = \left\{ P_1 - \left[\frac{.18783}{\left(\frac{Y_i - Y_n + h}{h} \right)^2 A_n^2} \right. \right. \\ \left. \left. \pm \frac{.5}{A_s^2} \right] \rho Q_\ell |Q_\ell| - \left(\frac{2 \ell_s \left[2 \left(Y_i - Y_n + \frac{h+h_s}{2} \right) + h_s \right]^2}{\left(Y_i - Y_n + \frac{h+h_s}{2} \right)^3 A_s} + \frac{32 \left(\ell_{sp} \right)}{h_s^2 A_s} \right) \mu Q_\ell \right\} \quad (30b)$$

The concurrent gas flow, neglecting inertia and pipe friction, is given by:

for $P_1 \geq 0$

$$Q_g = \frac{1.2058 \left(Y_n - Y_i \right) A_n}{\rho_g^{1/2} h} \left[P_1 + \frac{\rho_g}{2} \left(Y_n - Y_i \right) \right]^{1/2} \quad (31b)$$

where:

$$\rho_g = \frac{P_g}{RT} = \frac{P_2 + P_p - \rho g Y_i}{RT} \quad (32)$$

For the case $P_1 < 0$, it is assumed liquid will fill the standpipe, blocking the orifice and preventing any gas flow, provided the standpipe contains liquid. If the standpipe is empty, there can be no liquid flow into the pump tank, but some gas flow may occur:

For $P_1 < 0$

if $Y_s - (Y_n - h) > 0$

$$\frac{\rho (\ell_s + \ell_{sp})}{A_s} \frac{dQ_\ell}{dt} = P_1 - \left(\frac{.18783}{A_n^2} + \frac{.5}{A_s^2} \right) \rho Q_\ell |Q_\ell| \quad (30c)$$

and:

$$Q_g = 0$$

$$- \frac{32(\ell_s + \ell_{sp})}{h_s^2 A_s^2} \mu Q_\ell \quad (31c)$$

if $Y_s - (Y_n - h) \leq 0$

$$Q_\ell = 0$$

(30d)

and:

$$\text{if } P_1 + \frac{\rho g}{2} (Y_n - Y_i) < 0$$

$$Q_g = - \frac{1.2058 (Y_n - Y_i) A_n}{\rho_g^{1/2} h} \left\{ - \left[P_1 + \frac{\rho g}{2} (Y_n - Y_i) \right] \right\}^{1/2} \quad (31d.1)$$

$$\text{if } P_1 + \frac{\rho g}{2} (Y_n - Y_i) \geq 0$$

(31d.2)

$$Q_g = 0$$

3. $Y_i \leq Y_n - h$

When the liquid level in the tank is below the bottom of the orifice, if

$$P_1 + \rho g(Y_n - Y_i - h) > 0$$

there will be no liquid flow through the orifice, but gas will flow out of the tank and bubble through the standpipe,

$$\text{for } P_1 + \rho g(Y_n - Y_i - h) \geq 0 \quad (30e)$$

$$Q_\ell = 0$$

$$Q_g = \frac{1.2058 A_n}{\rho_g^{1/2}} \left[P_1 + \rho g \left(Y_n - Y_i - \frac{h}{2} \right) \right]^{1/2} \quad (31e)$$

If $P_1 + \rho g(Y_n - Y_i - h) < 0$, liquid will flow from the standpipe into the tank, filling the orifice and blocking any gas flow, provided the standpipe contains liquid. If the standpipe is empty, there will be no liquid flow, but some gas flow. Therefore:

$$\text{for } P_1 + \rho g(Y_n - Y_i - h) < 0$$

$$\text{if } Y_s - (Y_n - h) > 0$$

$$\frac{\rho(\ell_s + \ell_{sp})}{A_s} \frac{dQ_\ell}{dt} = \left\{ P_1 + \rho g(Y_n - Y_i - h) \right. \quad (30f)$$

$$\left. - \left(\frac{.18783}{A_n^2} \pm \frac{.5}{A_s^2} \right) \rho Q_\ell |Q_\ell| - \frac{32(\ell_s + \ell_{sp})}{h_s^2 A_s} \mu Q_\ell \right\}$$

$$Q_g = 0 \quad (31f)$$

$$\text{if } Y_s - (Y_n - h) \leq 0$$

$$Q_\ell = 0 \quad (30g)$$

and:

$$\text{if } P_1 + \rho g \left(Y_n - Y_i - \frac{h}{2} \right) < 0$$

$$Q_g = - \frac{1.2058 A_n}{\rho_g^{1/2}} \left\{ - \left[P_1 + \rho g \left(Y_n - Y_i - \frac{h}{2} \right) \right] \right\}^{1/2}$$

$$\text{if } P_1 + \rho g \left(Y_n - Y_i - \frac{h}{2} \right) \geq 0$$

(31 g.1)

(31 g.2)

$$Q_g = 0$$

Note that in the equations for Q_ℓ , ($\pm$) signs are interpreted as follows:

+ for $Q_\ell \geq 0$, - for $Q_\ell < 0$.

E. Standpipe Configuration

The standpipe configuration considered is shown in figure 3. It simulates that specified in reference 5.

The standpipe angle, θ , and linear length exclusive of the first horizontal section, l_{sp} , are given by:

$$\begin{aligned} \text{if } Y_{n1} < Y_S \leq Y_{nz} \\ \theta &= \theta_1 \end{aligned} \quad (33a)$$

$$l_{sp} = \frac{Y_S - Y_{n1}}{\sin \theta_1} \quad (34a)$$

$$\begin{aligned} \text{if } Y_{n2} < Y_S \leq Y_{n3} \\ \theta &= \theta_2 \end{aligned} \quad (33b)$$

$$l_{sp} = l_{s2} + \frac{Y_S - Y_{n2}}{\sin \theta_2} \quad (34b)$$

etc.

or

$$\begin{aligned} \text{if } Y_{ni} < Y_S \leq Y_{n(i+1)} \\ \theta &= \theta_i \end{aligned} \quad (33c)$$

$$l_{sp} = \sum_{j=2}^i l_{sj} + \frac{Y_S - Y_{ni}}{\sin \theta_i} \quad (34c)$$

IV. SUMMARY OF ANALYSIS

We now have a system of 38 equations which must be solved simultaneously for 38 dependent variables.

The 38 equations are: eq. (1), (1a), (6), (7), (8a), (8b), (8c), (9), (10), (11), (11a), (12), (13), (13a), (14)-(18), (19a), (19b), (19c), (24)-(28), (29a)-(29f), (30)-(34).

The 38 dependent variables are: $Y_r, Q_{r1}, Q_{r2}, Q_o, P_{gr}, P_p, Q_d, Q_p, Q_{IHx}, Q_{BEAR}, Q_{LEAK}, Q_a, Q_b, \rho_{gr}, \dot{m}_s, \rho_{go}, P_o, \rho_{ga}, \dot{m}_{RAPS}, P_a, Q_g, Q_l, \dot{m}_g, Y_i, P_g, A, V, Y_S, P_1, P_2, \rho_g, Q_{SH}, P_{C1}, Q_{CH}, P_{C2}, Q_{AN}, \theta, l_{sp}$.

V. COMPUTER PROGRAMA. General Description

A listing of the computer program used to solve the set of equations described in Sections II-IV is in the Appendix. This program computes the temporal history of the behavior of the combined reactor-standpipe-bubbler system as it responds to changes in (normalized) pump speed, $\bar{N}$.

Three conditions are considered:

1. Loading

$$\begin{aligned}\bar{N} &= .35 && \text{for } t < t_1 \\ &= .35 + .0005 (t - t_1) && \text{for } t_1 \leq t \leq t_1 + 1300 \text{ sec.} \\ &= 1.0 && \text{for } t > t_1 + 1300 \text{ sec.}\end{aligned}$$

2. Unloading

$$\begin{aligned}\bar{N} &= 1.0 && \text{for } t < t_1 \\ &= 1.0 - .0005 (t - t_1) && \text{for } t_1 \leq t \leq t_1 + 1300 \text{ sec.} \\ &= .35 && \text{for } t > t_1 + 1300 \text{ sec.}\end{aligned}$$

3. Trip

$$\bar{N} = 1.0 \quad \text{for } t \leq t_1$$

$\bar{N} =$	.84	for $t-t_1 = .95$ sec.
	.715	1.95
	.63	2.95
	.555	3.95
	.5	4.95
	.425	6.55
	.39	7.55
	.36	8.55
	.335	9.55
	.29	11.75
	.255	13.75
	.23	15.75
	.205	17.75
	.185	19.75
	.155	23.75
	.135	27.75
	.115	31.75

$\bar{N} = .1$ for $t-t_1 \geq 35.75$ sec.

For values of t between the above tabulated values, linear interpolation is used. The data used to construct the above table is contained in reference 6.

B. Inputs and Outputs

The inputs to the program, the notation used in the program, and the appropriate units are:

Data Card #1

1.	Y_1	(Y1)	ft.
2.	ℓ_1	(L1)	ft.
3.	A_1	(A1)	ft. ²
4.	C_1	(C1)	dimensionless
5.	Y_2	(Y2)	ft.
6.	ℓ_2	(L2)	ft.
7.	A_2	(A2)	ft. ²
8.	C_2	(C2)	dimensionless

Data Card #2

9.	A_r	(AR)	ft.^2
10.	C_3	(C3)	dimensionless
11.	H_r	(HR)	ft.
12.	$Q_{\max}$	(QMAX)	$\text{ft.}^3/\text{sec.}$
13.	Y_t	(YT)	ft.
14.	Y_o	(YO)	ft.
15.	Y_{tr}	(YTR)	ft.
16.	V_o	(VO)	ft.^3

Data Card #3

17.	A_b	(AB)	ft.^2
18.	C_b	(CB)	dimensionless
19.	A_a	(AA)	ft.^2
20.	C_a	(CA)	dimensionless
21.	FQBEAR	(FQBEAR)	dimensionless
22.	FQLEAK	(FQLEAK)	dimensionless
23.	FQIHX	(FQIHX)	dimensionless
24.	Y_{bot}	(YBOT)	ft.

Data Card #3A

25.	ℓ_p	(L2P)	ft.
26.	A_p	(AP)	ft.^2
27.	I_{CH}	(CHI)	$\text{lb.f. sec.}^2/\text{ft.}^8$
28.	ℓ_{CH}	(CHL)	ft.
29.	A_{CH}	(CHA)	ft.^2

Data Card #3A (cont'd)

30.	I_{AN}	(ANI)	$\text{lb} \cdot \text{sec}^2 / \text{ft}^8$
31.	ℓ_{AN}	(ANL)	ft.
32.	A_{AN}	(ANA)	ft^2

Data Card #3B

33.	I_{SH}	(SHI)	$\text{lb} \cdot \text{sec}^2 / \text{ft}^8$
34.	ℓ_{SH}	(SHL)	ft.
35.	A_{SH}	(SHA)	ft^2

Data Card #4

36.	Forty character title	(CONFIG)	
37.	T	(T)	$^{\circ}R$
38.	ρ	(RHOL)	$\text{slug} / \text{ft}^3$
39.	μ	(MU)	$\text{slug} / \text{ft} \cdot \text{sec}.$
40.	$\dot{m}_g$	(MDOTG)	$\text{slug} / \text{sec}.$

Data Card #5

41.	I_p	(IP)	$\text{lb} \cdot \text{sec}^2 / \text{ft}^8$
42.	A_n	(AN)	ft^2
43.	A_s	(AS)	ft^2
44.	h_s	(HS)	ft.
45.	h	(H)	ft.
46.	$Y_{n1} - Y_{n6}$ (6 values)	(YSEG)	ft.

Data Card #5X

47.	$\ell_s, \ell_{s2} - \ell_{s6}$ (6 values)	(SEGL)	ft.
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Data Card #5Y

48.	$\theta_1 - \theta_6$ (6 values)	(ANGL)	degrees
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Data Card #6

49.	Case Code:	(ICASE)	
	1 - loading		
	2 - unloading		
	3 - trip		
50.	t_1	(TI)	sec.
51.	total time of operation	(TSTOP)	sec.
52.	integration step size	(DT)	sec.
53.	data printout time interval	(TPRINT)	sec.
54.	initial value of Y_r	(YR)	ft.
55.	initial value of Y_i	(YI)	ft.
56.	initial value of P_o	(PO)	lbf/ft. ²
57.	initial value of P_a	(PA)	lbf/ft. ²
58.	computation sta- bilization factor	(SHLCCF)	dimensionless

In addition, the following data is internal to the program:

$$g = 32.172 \text{ ft./sec.}^2$$

$$R = 1244.7 \text{ ft.lbf/slug } ^\circ R$$

The outputs of the program, as functions of time, are:

1.	Q_d	(QD)	$\text{ft.}^3/\text{sec.}$
2.	P_p	(PP)	lbf./ft.^2
3.	Q_{IHx}	(QIHx)	$\text{ft.}^3/\text{sec.}$
4.	Q_{r1}	(QR1)	$\text{ft.}^3/\text{sec.}$
5.	Q_{r2}	(QR2)	$\text{ft.}^3/\text{sec.}$
6.	Y_r	(YR)	ft.
7.	Y_i	(YI)	ft.
8.	P_1	(P1)	lbf./ft.^2
9.	P_2	(P2)	lbf./ft.^2
10.	Y_s	(YS)	ft.
11.	P_g	(PG)	lbf./ft.^2
12.	Q_p	(QP)	$\text{ft.}^3/\text{sec.}$
13.	Q_l	(QL)	$\text{ft.}^3/\text{sec.}$
14.	Q_g	(QG)	$\text{ft.}^3/\text{sec.}$
15.	P_{gr}	(PGR)	lbf./ft.^2
16.	P_o	(PO)	lbf./ft.^2

17.	P_a	(PA)	1bf./ft. ²
18.	Q_a	(QA)	ft. ³ /sec.
19.	Q_b	(QB)	ft. ³ /sec.
20.	Q_o	(QO)	ft. ³ /sec.
21.	Q_{SH}	(QSH)	ft. ³ /sec.
22.	Q_{AN}	(QAN)	ft. ³ /sec.
23.	P_{c2}	(PC2)	1bf./ft. ²
24.	P_{c1}	(PC1)	1bf./ft. ²

C. Computational Scheme

Shown below is the order of computation and the equation used to obtain the various dependent variables. Each equation contains a number of variables in addition to the dependent variable sought. In computing the state of the system at the n^{th} point in time, these additional variables are evaluated at either the $(n-1)^{\text{th}}$ point in time or at the n^{th} point in time. The former is indicated by $n-1$, and the latter by n in the list below. (In a few cases where, strictly speaking, variables should have been evaluated at n , some were evaluated at $n-1$ to simplify the procedure.)

<u>Compute</u>	<u>From:</u>	<u>Evaluating Other Variables At:</u>
<u>Main Program</u>		
1. Q_d	(9)	$n - 1$
2. Y_r	(1)	$n - 1$
3. $\dot{m}_s$	(11a)	$n - 1$
4. $\dot{m}_{RAPS}$	(13a)	$n - 1$
5. ρ_{gr}	(11)	$n - 1$
6. ρ_{go}	(13)	$n - 1$

7.	A	(19a)	$n - 1$
8.	Y_i	(24)	$n - 1$
9.	V	(19b)	$n - 1$
10.	P_1	(25)	$n - 1$
11.	P_{gr}	(12)	n
12.	P_p	(10)	n
13.	P_2	(26)	n
14.	Q_{SH}	(29a)	$n - 1$
15.	Q_{IHX}	(8a)	n
16.	Q_{LEAK}	(8c)	n
17.	Q_{BEAR}	(8b)	n
18.	Q_{CH}	(29b)	n
19.	Q_p	(29c)	n
20.	P_{c2}	(29d)	n
21.	P_{c1}	(29e)	n
22.	Q_{AN}	(29f)	n
23.	Q_ℓ	(30)	$n - 1$
24.	Q_{r1}	(6)	n
25.	Q_{r2}	(7)	n
26.	Q_o	(1a)	n
27.	P_o	(14)	n
28.	P_g	(28)	n
29.	ρ_g	(32)	n
30.	Q_g	(31)	n

31.	P_a	(16)	n
32.	ρ_{ga}	(17)	n
33.	Q_b	(15)	n
34.	Q_a	(18)	n
35.	Y_s	(27)	n

Subroutine SP:SEG (YS, SPL, THETA)

36.	ℓ_{sp}	(34c)	n - 1
37.	θ	(33c)	n - 1

Subroutine Function FNBAR (ICASE, TNOW, T1)

38.	$\bar{N}$	(see V.A.)	n
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Subroutine Function SNBAR (IC, TNOW, TPS, TSPIKE, WIDTH, HEIGHT)

Not used in this study.

D. Initial Conditions

In general, initial conditions for the dependent variables are obtained from the steady-state versions of the differential equations, the algebraic equations, and the program inputs.

However, to simplify the procedure, the initial value of Q_d is obtained, approximately, by multiplying Q_{max} by the initial value of $\bar{N}$, and the initial values of Y_r , Y_i , P_o and P_a are treated as inputs. Except for Y_i , the latter are taken to be the static values. The initial value of Y_i is chosen to equal Y_{n1} . Q_ℓ , Q_g , Q_a , Q_b , and P_1 are taken as zero. P_{gr} is taken to be the static value. Q_{SH} is chosen to equal Q_{IHx} .

E. Averaging

For reasons of numerical stability, it is necessary to use a very small step size in the computations (.01 sec.). Over such a time scale there are small fluctuations in a number of the flow rates which are solely due to the numerical computation and have no physical significance. Therefore, the final values of these flow rates, Q_d , Q_p , Q_l , Q_g and Q_a , are taken to be the averages over the preceding ten steps. Such averages are also used in calculating dQ_d/dt and dQ_p/dt during the computation of P_p .

F. Computation Stabilization Factor

In order to stabilize the computation, it has been found necessary to multiply the left-hand side of equation (29a) by a "stabilization factor," (SHLCCF), typically 10. This effectively increases the value of ℓ_{SH} . By varying the value of the stabilization factor from 5 to 50, it has been shown that the introduction of this factor does not significantly affect the results of the analysis (sec. VI G). Alternatively, such a factor could be omitted if the step size is reduced.

VI. RESULTS

A. Procedure

The computer program described in Section V was used to obtain predictions of the behavior of the full-scale, sodium-argon standpipe-bubbler coupled to the reactor system.

First, a reference case was defined. This consists of the proposed standpipe-bubbler and reactor configuration, together with mean operating parameters. The parameters (both configurational and operating) of the reference case are:

1. Y_1 = -.75 ft.
2. ℓ_1 = 116.1 ft.
3. A_1 = 6.681 ft.²
4. C_1 = 2.284
5. Y_2 = -28.75 ft.
6. ℓ_2 = 425.3 ft.
7. A_2 = 2.885 ft.²
8. C_2 = 11.262
9. A_r = 290 ft.²
10. C_3 = 30287.7
11. H_r = 458 ft.
12. $Q_{\max}$ = 75.0836 ft.³/sec.
13. Y_t = 10.25 ft.
14. Y_o = 0 ft.
15. Y_{tr} = 18.39 ft.
16. V_o = 2429 ft.³
17. A_b = .0513 ft.²
18. C_b = 24.39
19. A_a = .0233 ft.²
20. C_a = 5.03
21. FQBEAR = .0101
22. FQLEAK = .025
23. FQIHX = .00658
24. Y_{bot} = 3.31 ft.

- 25. $\ell_p = .125 \text{ ft.}$
- 26. $A_p = .392 \text{ ft.}^2$
- 27. $I_{CH} = 17.41 \text{ lbf. sec.}^2/\text{ft.}^8$
- 28. $\ell_{CH} = .25 \text{ ft.}$
- 29. $A_{CH} = .26 \text{ ft.}^2$
- 30. $I_{AN} = 11,000 \text{ lbf. sec.}^2/\text{ft.}^8$
- 31. $\ell_{AN} = .5 \text{ ft.}$
- 32. $A_{AN} = .01414 \text{ ft.}^2$
- 33. $I_{SH} = 79.5 \text{ lbf. sec.}^2/\text{ft.}^8$
- 34. $\ell_{SH} = .104 \text{ ft.}$
- 35. $A_{SH} = .112 \text{ ft.}^2$
- 36. ----
- 37. $T = 1160^\circ\text{R}$
- 38. $\rho = 1.672 \text{ slub/ft.}^3$
- 39. $\mu = 6.3715 \times 10^{-6} \text{ slug/ft. sec.}$
- 40. $\dot{m}_g = 1.3127 \times 10^{-5} \text{ slug/sec.}$
- 41. $I_p = 6.38 \text{ lbf. sec.}^2/\text{ft.}^8$
- 42. $A_n = .111 \text{ ft.}^2$
- 43. $A_s = .196 \text{ ft.}^2$
- 44. $h_s = .5 \text{ ft.}$
- 45. $h = .3333 \text{ ft.}$
- 46. $Y_{n1} = 6.75 \text{ ft.}$
 - $Y_{n2} = 11.25 \text{ ft.}$
 - $Y_{n3} = 12.75 \text{ ft.}$
 - $Y_{n4} = 17.75 \text{ ft.}$
 - $Y_{n5} = 18.25 \text{ ft.}$
 - $Y_{n6} = 18.75 \text{ ft.}$

47. $l_s = 2 \text{ ft.}$
 $l_{s2} = 4.5 \text{ ft.}$
 $l_{s3} = 13 \text{ ft.}$
 $l_{s4} = 5 \text{ ft.}$
 $l_{s5} = 13.5 \text{ ft.}$
 $l_{s6} = 13.5 \text{ ft.}$
48. $\theta_1 = 90^\circ$
 $\theta_2 = 6.63^\circ$
 $\theta_3 = 90^\circ$
 $\theta_4 = 2.12^\circ$
 $\theta_5 = 2.12^\circ$
 $\theta_6 = 90^\circ$
49. ----
50. $t_1 = 200 \text{ sec.}$
51. ----
52. $DT = .01 \text{ sec.}$
53. ----
54. $YR = 16.3 \text{ ft.}$
55. $YI = 6.75 \text{ ft.}$
56. $PO = 2168 \text{ lbf./ft.}^2$
57. $PA = 2168 \text{ lbf./ft.}^2$
58. $SHLCCF = 10$

Note that A_s corresponds to a 6-inch diameter standpipe and $\dot{m}_g$ to .25 scfm.

The operation of the system for the reference case was first computed. Then the effects of individually changing $\dot{m}_g$; I_{SH} , I_{CH} , I_p ; T ; and FQBEAR and FQLEAK were investigated, holding all other parameters constant.

Finally, to verify the computation scheme, SHLCCF was varied, and its effects noted.

Three conditions were considered: loading, trip, and unloading. For each condition, time-history plots of Y_i , Y_s , Y_r , P_g , P_p and Q_d were obtained. These are contained in figures 4 through 21. Both loading and unloading start at $t = 200$ seconds and end at $t = 1500$ seconds on these curves. Trip starts at $t = 50$ seconds and ends at $t = 85.75$ seconds.

B. Reference Case

The behavior of the reference case can be seen from figures 4-6.

1. Loading

Liquid level in the pump tank (Y_i) remains constant (fig. 4d) while the standpipe level (Y_s) drops smoothly from 15.8 ft. to 12.4 ft. (fig. 4e). Concurrently, the reactor level (Y_r) remains constant (fig. 4f) while the pump tank^r gas pressure (P_g) and pump suction pressure (P_p) both decrease smoothly (figures 4b and 4c). The pump discharge flow rate (Q_d) increases as noted in fig. 4a.

2. Trip

Fig. 5d shows that following the start of trip, Y_i increases from 6.75 ft. to a peak of 7.1 ft. within 13.0 seconds and then very slowly decreases.

Y_s increases rapidly from 12.4 ft. to 17.5 ft. within 15 seconds (fig. 5e). It exhibits a damped oscillation and decays to its post trip steady state value of 16.3 ft.

The reactor level, Y_r , decreases by approximately .12 feet (see fig. 5f). However, within 160 seconds subsequent to trip start, Y_r returns to its original value.

Both P_g and P_p exhibit a rapid rise during the trip transient (figs. 5b and 5c).

The decrease in Q_d during trip is shown in fig. 5a. The bump in the curve, towards the end of trip, is due to the fact that the tabulation of $\bar{N}$ (Sec. V) does not represent a perfectly smooth function.

3. Unloading

During unloading, Y_i increases by .07 feet, as shown in figure 6d. Following unloading it slowly decreases, eventually reaching its original steady-state value. Y_s increases from 12.4 feet to 15.8 feet (figure 6e), the reverse of its behavior during loading (though slightly less regular). As in the case of loading, Y_r remains constant during the process (figure 6f). Figures 6b and 6c show that both P_g and P_p increase smoothly. Q_d , of course, decreases as shown in figure 6a.

C. Effect of $\dot{m}_g$

Figures 7-9 show that within the range investigated $\dot{m}_g$ has very little effect on the behavior of the standpipe bubbler system.

During loading it has no effect. For trip it has no significant effect (figure 8). During unloading it does affect somewhat the maximum value reached by Y_i (the higher the $\dot{m}_g$, the lower the maximum Y_i). Increasing $\dot{m}_g$ from .1 scfm to .4 scfm results in a decrease in the maximum Y_i of approximately .25 feet (figure 9).

D. Effect of Impedance

Two cases are considered: the reference case, and a "low impedance" case in which I_{SH} , I_{CH} , and I_p are simultaneously reduced.

Figures 10-12 reveal the following effects:

1. Loading

- a) Y_i (figure 10d), Y_r (10f), P_p (10b), Q_d (10a)

No significant effect.

- b) Y_s (figure 10e)

The higher the values of the impedances, the higher the value of Y_s , but the smaller the change in Y_s during loading.

- c) P_g (figure 10c)

Similar to effect on Y_s .

2. Trip

- a) Y_i (figure 11d)

The low impedance case results in a rise in Y_i greater than that for the reference case by approximately .1 feet.

- b) Y_s (figure 11e)

The low impedance case curve of Y_s is very similar to the reference case curve, with three exceptions. The initial value of Y_s is lower by 1.4 ft.; there are small fluctuations in the initial state; the peak value of Y_s is greater by approximately .25 ft.

- c) Y_r (figure 11f)

Higher values of impedance are found to reduce the drop in reactor level slightly.

- d) P_g (figure 11c)

Very little effect except the initial value is lower by approximately 75 lbf./ft.² for the low impedance case.

- e) P_p (figure 11b) & Q_d (figure 11a)

No significant effect.

3. Unloading

- a) Y_i (figure 12d)

The low impedance case results in a maximum Y_i greater than the equivalent reference value by approximately .12 ft.

- b) Y_s (figure 12e)

The larger the value of impedance, the larger Y_s , but the smaller the change in Y_s during unloading. The low impedance case also exhibits fluctuations in the initial state.

- c) Y_r (figure 12f), P_p (12b), Q_d (12a)

No significant effect.

- d) P_g (figure 12c)

Similar to effect on Y_s , but no fluctuations are present in the initial state.

E. Effect of T

The effects of T are displayed in figures 13-15.

1. Loading

- a) Y_i (figure 13d), Y_s (13e), Y_r (13f), Q_d (13a)

No significant effect.

- b) P_g (figure 13c)

Increasing T results in slightly lower values of P_g . This is related to the temperature effects on P_p .

- c) P_p (figure 13b)

Increasing T results in slightly lower values of P_p . This is due to a reduction in ρ (see equation 10).

2. Trip

- a) Y_i (figure 14d)

Increasing T from 400°F to 1015°F results in a slight decrease in Y_i (approximately .05 ft.) following trip.

- b) Y_s (figure 14e), Y_r (14f), P_g (14c),
 P_p (14b), Q_d (14a)

The same effects as during loading.

3. Unloading

- a) Y_i (figure 15d)

Increasing T from 400°F to 1015°F results in a decrease in the maximum value of Y_i of approximately .15 feet.

- b) $\frac{Y_s \text{ (figure 15e), } Y_r \text{ (15f), } P_g \text{ (15c), } P_p \text{ (15b), } Q_d \text{ (15a)}}{}$

The same effects as during loading.

F. Effect of FQBEAR and FQLEAK

The effects of the flow rates through the discharge seal and the bearing leakage paths are studied by considering two cases: the reference case and the "low leakage flow" case in which FQBEAR and FQLEAK are simultaneously reduced. These effects are contained in figures 16-18.

1. Loading

- a) $\frac{Q_d \text{ (figure 16a), } P_p \text{ (16b), } Y_i \text{ (16d), } Y_r \text{ (16f)}}{}$

No effect.

- b) $\frac{P_g \text{ (figure 16c), } Y_s \text{ (16e)}}{}$

Reduced leakage flow rates increase the amount these quantities drop during loading by decreasing their final values.

2. Trip

- a) $\frac{Q_d \text{ (figure 17a), } P_p \text{ (17b), } Y_r \text{ (17f)}}{}$

No significant effect.

- b) $\frac{Y_i \text{ (figure 17d)}}{}$

The low flow rate case displays an increase in Y_i greater than that in the reference case by approximately .1 ft.

- c) $\frac{Y_s \text{ (figure 17e)}}{}$

The only significant effect involves the initial value: it is approximately 1.3 ft. lower for the low flow rate case.

- d) P_g (figure 17c)

The initial value is approximately 75 lbf./ft.² for the low flow rate case.

3. Unloading

- a) Q_d (figure 18a), P_p (18b), Y_r (18f)

No effect.

- b) Y_i (figure 18d)

A reduction in leakage flow results in an increase in the maximum value of Y_i of approximately .1 ft.

- c) Y_s (figure 18e), P_g (18c)

A reduction in leakage flow rate increases the amount by which these quantities rise during unloading, by decreasing their initial values.

G. Effect of SHLCCF

In section Vf the introduction of a computation stabilization factor (SHLCCF) was described. For the computation scheme to be valid, it is necessary to demonstrate that the results are substantially independent of the value of such a factor (within the limits 1-10).

Figures 19 to 21 show the effects of SHLCCF (values of 5, 10, 50) on the results. It is seen that there are no significant effects. The only measurable effect is a small decrease in the rate at which oscillations in Y_s are damped out following trip, for the case SHLCCF = 50 (an extreme case).

VII. COMPARISON OF RESULTS WITH THOSE OF PREVIOUS ANALYSIS

The results of this study are very similar to those reported in reference 4. The only significant difference is: at 100% speed Y_s is 2.4' higher in the present study than in the previous study.

It should be noted that a nozzle location of 6.75 ft. was utilized in the present study, while 6 ft. was used in the previous study.

VIII. DESIGN LAYOUT

The CRBRP standpipe bubbler system design layout SK 0295 (figure 22) shows the configuration and details of the standpipe bubbler system. This configuration is based on the results of the study to date but will not be finalized until the Task C tests are completed.

The standpipe bubbler installation is shown on figure 22a. This configuration results from the various design constraints. First, two additional elbows are required to avoid penetration or altering the configuration of the guard vessel. Second, the standpipe must clear the motor pit structure while encased in the required trace heaters and thermal insulation. Third, an expansion loop is required to accommodate the dimensional changes due to the large temperature range. Fourth, the standpipe must interface with the cover gas return line at an elevation high enough to prevent overflow.

The Pump Cover Gas Model, figure 22b, is a generalized cross-section of the 1E-3862 pump gas spaces. The interface numbers used on this figure are those used in ICD CG 52004 and will be used in the subsequent discussions.

The cover gas from the recycle argon supply enters the pump at interface 10. This flow divides at the labyrinth seal with one-half going up through the labyrinth and the other half going down the shaft annulus. The half which flows up expands into the cover gas plenum. From the plenum, it passes over the top of seal standpipe and passes the lower shaft seal faces. Some oil is leaking through the seal, and therefore the line which connects the seal standpipe to the leakage tank contains both oil and gas. The function of this gas flow is to sweep any oil vapor out of the pump.

The gas leaves the oil leakage collection tank through interface 12 to the RAPS. The other half of the cover gas which flows down the shaft annulus enters the pump tank ullage. The gas is metered out of the pump tank ullage by bubbling up through the sodium in the standpipe. This gas enters the gas equalization line at interface 5, flows to the overflow tank and then to the RAPS.

Cover gas may be admitted into the cover gas plenum by manual control at interface 11. The function of this cover gas inlet is to provide a purge flow during seal maintenance. A purge flow is needed to prevent the inflow of air into the pump tank. Any air which enters the upper pump tank is a contaminant which may result in sodium frost. This gas source may also be used to recover from an off-level condition. Also shown is an additional interface designated 11a. The function of this cover gas source is to provide flow into the pump tank ullage in the event of an off-level condition plugging the shaft annulus. When this gas source is considered, it is apparent that a higher pressure must be supplied to the cover gas plenum (interface 11) than to the pump tank ullage; otherwise when the sodium melts, it will be forced up the annulus to the plenum. Based on this consideration, it appears doubtful if this gas source should be used.

Cover gas may also be admitted to the cover gas plenum through interface E. This is the emergency supply inlet and is only used when the recycle argon supply fails. This interface has not been identified on the ICD at this time.

A backup flow controlled cover gas supply is shown at interface 18 which could be used in the event of the main cover gas supply into the pump at interface 10 being cut off.

The Cover Gas Diagram, figure 22c, shows a simplified cover gas network for the System 82 connections to the pump. This network represents the present understanding of the gas control logic. The uncontrolled gas input to the pump tank from the IHX return (interface 3) is also shown. The IHX return path accommodates the gas which comes out of the solution when the sodium cools in the IHX.

IX. FEASIBILITY REPORT & RANGE OF EXPECTED GAS FLOW

The results of this preliminary study indicate that the standpipe-bubbler system is a feasible level control system for the CRBRP pump tank in conjunction with the controlled clearance pump configuration as defined by Byron Jackson Drawing 1E3862.

With proper design, level fluctuations in the pump tank can be contained within the specified limits and excessive oscillations can be avoided.

The results also indicate that the specified gas flow rate of .25 scfm is sufficient for good performance of the standpipe-bubbler system. Furthermore, any flow rate within the range investigated, .1 scfm - .4 scfm, should result in acceptable performance with proper design.

REFERENCES

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2. Byron Jackson Pump Division of Borg-Warner Corporation, Breeder Reactor Pump Department Engineering Memorandum 0160, "Standpipe-Bubbler Pump Level Control Study System Design Layout (Task A)" - W.P. 4413, dated June 6, 1975.
3. Byron Jackson Pump Division of Borg-Warner Corporation, Breeder Reactor Pump Department Engineering Memorandum 0164, "Standpipe-Bubbler Pump Level Control Study Controlled Clearance Concept Feasibility Analysis (Task A)" - W.P. 7373, dated August 13, 1975.
4. Byron Jackson Pump Division of Borg-Warner Corporation, Breeder Reactor Pump Department Engineering Memorandum 0178, "Standpipe-Bubbler Pump Level Control Study - 1F-7583, Rev. C, Controlled Clearance Pump/System Model Analysis (Task A)" - W.P. 7373, dated December 24, 1975.
5. WARD Drawing No. 1184E43, "PHTS Stand Pipe Bubbler Preliminary Arrangement," 11/5/75.
6. Champagne, J. H., Letter #GE-BJ-893-1-0870, to J. B. Whaley, dated August 5, 1975.
7. Byron Jackson Pump Division of Borg-Warner Corporation, Breeder Reactor Pump Department Engineering Memorandum 0170, Addendum No. 1, "Internal Fluid Management Analysis, 1E3862," dated March 8, 1976.

NOMENCLATURE

A	-	cross-sectional area of pump tank
A_1	-	cross-sectional area of line 1
A_2	-	cross-sectional area of line 2
A_a	-	cross-sectional area of line a
A_b	-	cross-sectional area of line b
A_n	-	cross-sectional area of orifice
A_p	-	effective cross-sectional area of leakage path between pump tank and pump suction
A_r	-	cross-sectional area of reactor vessel
A_s	-	cross-sectional area of standpipe
A_{sh}	-	cross-sectional area of shaft flow path
C_1	-	viscous loss coefficient of line 1
C_2	-	viscous loss coefficient of line 2
C_3	-	viscous loss coefficient of reactor vessel
C_a	-	viscous loss coefficient of line a
C_b	-	viscous loss coefficient of line b
$f_1(Q_d)$	-	function defined by eq. (5)
FQBEAR	-	defined by eq. (8b)
FQIHX	-	defined by eq. (8a)
FQLEAK	-	defined by eq. (8c)
g	-	acceleration of gravity
H_r	-	rated pump head
h	-	orifice dimension
h_s	-	standpipe dimension (diameter for circular cross-section)

I_{AN}	-	impedance of annulus flow path
I_{CH}	-	impedance of flow path between chambers 1 and 2
I_P	-	impedance of leakage path between pump tank and pump suction
I_{SH}	-	impedance of shaft flow path
ℓ_1	-	length of line 1
ℓ_2	-	length of line 2
ℓ_P	-	effective length of leakage path between pump tank and pump suction
ℓ_s	-	length of first horizontal section of standpipe
ℓ_{sh}	-	length of shaft flow path
ℓ_{si}	-	length of i^{th} section of standpipe
ℓ_{sp}	-	linear length of filled section of standpipe, exclusive of ℓ_s
$\dot{m}_g$	-	mass rate of flow of gas pumped into pump tank from supply
$\dot{m}_{RAPS}$	-	mass rate of flow of gas from overflow tank to RAPS
$\dot{m}_s$	-	mass rate of flow of gas pumped into reactor vessel from supply
$\bar{N}$	-	normalized pump speed
P_1	-	defined by eq. (22)
P_2	-	defined by eq. (23)
P_a	-	gas pressure above liquid in standpipe
P_d	-	discharge pressure at pump
P_{c1}	-	pressure in chamber 1
P_{c2}	-	pressure in chamber 2
P_g	-	gas pressure in pump tank

P_{gr}	-	gas pressure in reactor vessel
P_o	-	gas pressure in overflow tank
P_p	-	suction pressure at pump
PCT	-	1. - FQIHX - 2FQBEAR - FQLEAK
p_2	-	pressure in reactor vessel at $Y = Y_2$
Q_{AN}	-	volumetric annulus flow rate
Q_a	-	volumetric gas flow rate through line a
Q_b	-	volumetric gas flow rate through line b
Q_{BEAR}	-	volumetric flow rate through bearing leakage path
Q_{CH}	-	volumetric flow rate between chambers 1 and 2
Q_d	-	volumetric discharge flow rate from pump
Q_g	-	volumetric gas flow rate from pump tank to standpipe
Q_{IHX}	-	volumetric IHX liquid flow rate into pump tank
Q_l	-	volumetric liquid flow rate from pump tank to standpipe
Q_{LEAK}	-	volumetric leakage flow rate through discharge seal
Q_{max}	-	rated maximum volumetric flow rate through pump
Q_o	-	volumetric liquid flow rate from reactor vessel, through overflow valve
Q_p	-	volumetric liquid flow rate from pump tank to pump suction
Q_{r1}	-	volumetric liquid flow rate through line 1
Q_{r2}	-	volumetric liquid flow rate through line 2
Q_{SH}	-	volumetric shaft flow rate

R	-	gas constant
$SHLCCF$	-	computation stabilization factor
T	-	temperature
t	-	time
t_1	-	time at which operation (loading, unloading, trip) starts
V	-	gas volume in pump tank
V_o	-	volume of overflow tank
Y	-	vertical coordinate, measured with respect to centerline of pump suction
Y_o	-	level of pump suction
Y_1	-	level at which line 1 joins reactor vessel
Y_2	-	level at which line 2 joins reactor vessel
Y_{bot}	-	level of bottom of upper portion of pump tank
Y_i	-	level of liquid-gas interface in pump tank
Y_{nl}	-	level of top of orifice
Y_{ni}	-	level of i^{th} bend in standpipe
Y_r	-	level of liquid-gas interface in reactor vessel
Y_s	-	level of liquid-gas interface in standpipe
Y_t	-	level of top of pump tank (bottom of thermal shield)
Y_{tr}	-	level of top of reactor vessel
μ	-	viscosity of liquid
ρ	-	density of liquid
ρ_g	-	density of gas in pump tank
ρ_{ga}	-	density of gas above liquid in standpipe

- ρ_{go} - density of gas in overflow tank
- ρ_{gr} - density of gas in reactor vessel
- θ - standpipe angle
- θ_i - angle of i^{th} section of standpipe

FIGURE 1

FIGURE 2

SCHEMATIC DIAGRAM OF STANDPIPE

FIGURE 3

LOADING

STANDARD REFERENCE

FIGURE 4

TRIP

STANDARD REFERENCE

FIGURE 5

UNLOADING

STANDARD REFERENCE

FIGURE 6

LOADING

GASS MASS FLOW

FIGURE 7 $R_g = .1, .25, .4$ scfm

TRIP

GAS MASS FLOW

FIGURE 8 $\dot{M}_g = .1, .25, .4$ scfm

UNLOADING

GAS MASS FLOW

FIGURE 9 $\dot{m}_g = .1, .25, .4 \text{ scfm}$

LOADING

IMPEDANCE EFFECT

FIGURE 10

	I_{SH}	I_{CH}	I_p (psi/gpm ²)	
#1	3×10^{-7}	1.25×10^{-7}	1.45×10^{-7}	MINIMUM
#2	2.74×10^{-6}	6×10^{-7}	2.2×10^{-7}	MAXIMUM (REFERENCE CASE)

*RIP

IMPEDANCE EFFECT

FIGURE 11

	I_{SH}	I_{CH}	I_p (psi/gpm ²)	
#1	3×10^{-7}	1.25×10^{-7}	1.45×10^{-7}	- MINIMUM
#2	2.74×10^{-6}	6×10^{-7}	2.2×10^{-7}	- MAXIMUM (REFERENCE CASE)

UNLOADING

IMPEDANCE EFFECT

FIGURE 12

	I_{SH}	I_{CH}	I_P (psi/gpm ²)
#1	3×10^{-7}	1.25×10^{-7}	1.45×10^{-7} -MINIMUM
#2	2.74×10^{-6}	6×10^{-7}	2.2×10^{-7} - MAXIMUM (REFERENCE CASE)

LOADING

TEMPERATURE EFFECT

FIGURE 13 T= 400, 700, 1015°F

TRIP

TEMPERATURE EFFECT

FIGURE 14 T = 400, 700, 1015°F

UNLOADING

TEMPERATURE EFFECT

FIGURE 15 T = 400, 700, 1015°F

LOADING

FQBEAR/FQLEAK

FIGURE 16

#1 - FQ BEAR = .0086	MIN
FQ LEAK = .0136	
#2 - FQ BEAR = .0101	MAX (Reference case)
FQ LEAK = .025

TRIP

FDBEAR/FQLEAK

FIGURE 17

#1 - FQ BEAR = .0086
FQ LEAK = .0136 MIN#2 - FQ BEAR = .0101
FQ LEAK = .025 MAX (Reference case)

UNLOADING

FOBEAR/FOLEAK

FIGURE 18

#1 - FQ BEAR = .0086
FQ LEAK = .0136 MIN

#2 - FQ BEAR = .0101
FQ LEAK = .025 MAX (Reference case)

LOADING

STABILIZATION FACTOR

FIGURE 19

SHLCCF = 5, 10, 50

TRIP

STABILIZATION FACTOR

FIGURE 20

SHLCCF = 5, 10, 50

UNLOADING

STABILIZATION FACTOR

FIGURE 21

SHLCCF = 5, 10, 50

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

FIGURE 22a

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		BY ORDER NO.	REF NO.	Byron Jackson Pump Division BIRMINGHAM CORPORATION 1000 1/2 AVENUE
TOLERANCES ON FRACTIONS DECIMALS 1/16" ± .005 1/32" ± .005 1/64" ± .005 1/8" ± .005 3/16" ± .005 1/4" ± .005 3/8" ± .005 1/2" ± .005 5/8" ± .005 3/4" ± .005 1" ± .005 1 1/4" ± .005 1 1/2" ± .005 2" ± .005 2 1/2" ± .005 3" ± .005 4" ± .005 6" ± .005 8" ± .005 10" ± .005 12" ± .005 14" ± .005 16" ± .005 18" ± .005 20" ± .005 24" ± .005 30" ± .005 36" ± .005 42" ± .005 48" ± .005 54" ± .005 60" ± .005 72" ± .005 84" ± .005 96" ± .005 108" ± .005 120" ± .005 144" ± .005 168" ± .005 192" ± .005 216" ± .005 240" ± .005 270" ± .005 300" ± .005 324" ± .005 360" ± .005 400" ± .005 432" ± .005 480" ± .005 540" ± .005 600" ± .005 648" ± .005 720" ± .005 792" ± .005 864" ± .005 936" ± .005 1008" ± .005 1080" ± .005 1152" ± .005 1224" ± .005 1296" ± .005 1368" ± .005 1440" ± .005 1512" ± .005 1620" ± .005 1728" ± .005 1848" ± .005 1944" ± .005 2052" ± .005 2160" ± .005 2268" ± .005 2376" ± .005 2484" ± .005 2592" ± .005 2700" ± .005 2808" ± .005 2916" ± .005 3024" ± .005 3132" ± .005 3240" ± .005 3348" ± .005 3456" ± .005 3564" ± .005 3672" ± .005 3780" ± .005 3888" ± .005 3996" ± .005 4104" ± .005 4212" ± .005 4320" ± .005 4428" ± .005 4536" ± .005 4644" ± .005 4752" ± .005 4860" ± .005 4968" ± .005 5076" ± .005 5184" ± .005 5292" ± .005 5400" ± .005 5508" ± .005 5616" ± .005 5724" ± .005 5832" ± .005 5940" ± .005 6048" ± .005 6156" ± .005 6264" ± .005 6372" ± .005 6480" ± .005 6588" ± .005 6696" ± .005 6804" ± .005 6912" ± .005 7020" ± .005 7128" ± .005 7236" ± .005 7344" ± .005 7452" ± .005 7560" ± .005 7668" ± .005 7776" ± .005 7884" ± .005 7992" ± .005 8100" ± .005 8208" ± .005 8316" ± .005 8424" ± .005 8532" ± .005 8640" ± .005 8748" ± .005 8856" ± .005 8964" ± .005 9072" ± .005 9180" ± .005 9288" ± .005 9396" ± .005 9504" ± .005 9612" ± .005 9720" ± .005 9828" ± .005 9936" ± .005 10044" ± .005 10152" ± .005 10260" ± .005 10368" ± .005 10476" ± .005 10584" ± .005 10692" ± .005 10800" ± .005 10908" ± .005 11016" ± .005 11124" ± .005 11232" ± .005 11340" ± .005 11448" ± .005 11556" ± .005 11664" ± .005 11772" ± .005 11880" ± .005 11988" ± .005 12104" ± .005 12216" ± .005 12324" ± .005 12432" ± .005 12540" ± .005 12648" ± .005 12756" ± .005 12864" ± .005 12972" ± .005 13080" ± .005 13188" ± .005 13296" ± .005 13404" ± .005 13512" ± .005 13620" ± .005 13728" ± .005 13836" ± .005 13944" ± .005 14052" ± .005 14160" ± .005 14268" ± .005 14376" ± .005 14484" ± .005 14592" ± .005 14700" ± .005 14808" ± .005 14916" ± .005 15024" ± .005 15132" ± .005 15240" ± .005 15348" ± .005 15456" ± .005 15564" ± .005 15672" ± .005 15780" ± .005 15888" ± .005 15996" ± .005 16104" ± .005 16212" ± .005 16320" ± .005 16428" ± .005 16536" ± .005 16644" ± .005 16752" ± .005 16860" ± .005 16968" ± .005 17076" ± .005 17184" ± .005 17292" ± .005 17400" ± .005 17508" ± .005 17616" ± .005 17724" ± .005 17832" ± .005 17940" ± .005 18048" ± .005 18156" ± .005 18264" ± .005 18372" ± .005 18480" ± .005 18588" ± .005 18696" ± .005 18804" ± .005 18912" ± .005 19020" ± .005 19128" ± .005 19236" ± .005 19344" ± .005 19452" ± .005 19560" ± .005 19668" ± .005 19776" ± .005 19884" ± .005 19992" ± .005 20100" ± .005 20208" ± .005 20316" ± .005 20424" ± .005 20532" ± .005 20640" ± .005 20748" ± .005 20856" ± .005 20964" ± .005 21072" ± .005 21180" ± .005 21288" ± .005 21396" ± .005 21504" ± .005 21612" ± .005 21720" ± .005 21828" ± .005 21936" ± .005 22044" ± .005 22152" ± .005 22260" ± .005 22368" ± .005 22476" ± .005 22584" ± .005 22692" ± .005 22800" ± .005 22908" ± .005 23016" ± .005 23124" ± .005 23232" ± .005 23340" ± .005 23448" ± .005 23556" ± .005 23664" ± .005 23772" ± .005 23880" ± .005 23988" ± .005 24096" ± .005 24204" ± .005 24312" ± .005 24420" ± .005 24528" ± .005 24636" ± .005 24744" ± .005 24852" ± .005 24960" ± .005 25068" ± .005 25176" ± .005 25284" ± .005 25392" ± .005 25500" ± .005 25608" ± .005 25716" ± .005 25824" ± .005 25932" ± .005 26040" ± .005 26148" ± .005 26256" ± .005 26364" ± .005 26472" ± .005 26580" ± .005 26688" ± .005 26796" ± .005 26904" ± .005 27012" ± .005 27120" ± .005 27228" ± .005 27336" ± .005 27444" ± .005 27552" ± .005 27660" ± .005 27768" ± .005 27876" ± .005 27984" ± .005 28092" ± .005 28200" ± .005 28308" ± .005 28416" ± .005 28524" ± .005 28632" ± .005 28740" ± .005 28848" ± .005 28956" ± .005 29064" ± .005 29172" ± .005 29280" ± .005 29388" ± .005 29496" ± .005 29604" ± .005 29712" ± .005 29820" ± .005 29928" ± .005 30036" ± .005 30144" ± .005 30252" ± .005 30360" ± .005 30468" ± .005 30576" ± .005 30684" ± .005 30792" ± .005 30900" ± .005 31008" ± .005 31116" ± .005 31224" ± .005 31332" ± .005 31440" ± .005 31548" ± .005 31656" ± .005 31764" ± .005 31872" ± .005 31980" ± .005 32088" ± .005 32196" ± .005 32304" ± .005 32412" ± .005 32520" ± .005 32628" ± .005 32736" ± .005 32844" ± .005 32952" ± .005 33060" ± .005 33168" ± .005 33276" ± .005 33384" ± .005 33492" ± .005 33600" ± .005 33708" ± .005 33816" ± .005 33924" ± .005 34032" ± .005 34140" ± .005 34248" ± .005 34356" ± .005 34464" ± .005 34572" ± .005 34680" ± .005 34788" ± .005 34896" ± .005 35004" ± .005 35112" ± .005 35220" ± .005 35328" ± .005 35436" ± .005 35544" ± .005 35652" ± .005 35760" ± .005 35868" ± .005 35976" ± .005 36084" ± .005 36192" ± .005 36300" ± .005 36408" ± .005 36516" ± .005 36624" ± .005 36732" ± .005 36840" ± .005 36948" ± .005 37056" ± .005 37164" ± .005 37272" ± .005 37380" ± .005 37488" ± .005 37596" ± .005 37704" ± .005 37812" ± .005 37920" ± .005 38028" ± .005 38136" ± .005 38244" ± .005 38352" ± .005 38460" ± .005 38568" ± .005 38676" ± .005 38784" ± .005 38892" ± .005 39000" ± .005 39108" ± .005 39216" ± .005 39324" ± .005 39432" ± .005 39540" ± .005 39648" ± .005 39756" ± .005 39864" ± .005 39972" ± .005 40080" ± .005 40188" ± .005 40296" ± .005 40404" ± .005 40512" ± .005 40620" ± .005 40728" ± .005 40836" ± .005 40944" ± .005 41052" ± .005 41160" ± .005 41268" ± .005 41376" ± .005 41484" ± .005 41592" ± .005 41700" ± .005 41808" ± .005 41916" ± .005 42024" ± .005 42132" ± .005 42240" ± .005 42348" ± .005 42456" ± .005 42564" ± .005 42672" ± .005 42780" ± .005 42888" ± .005 42996" ± .005 43104" ± .005 43212" ± .005 43320" ± .005 43428" ± .005 43536" ± .005 43644" ± .005 43752" ± .005 43860" ± .005 43968" ± .005 44076" ± .005 44184" ± .005 44292" ± .005 44400" ± .005 44508" ± .005 44616" ± .005 44724" ± .005 44832" ± .005 44940" ± .005 45048" ± .005 45156" ± .005 45264" ± .005 45372" ± .005 45480" ± .005 45588" ± .005 45696" ± .005 45804" ± .005 45912" ± .005 46020" ± .005 46128" ± .005 46236" ± .005 46344" ± .005 46452" ± .005 46560" ± .005 46668" ± .005 46776" ± .005 46884" ± .005 46992" ± .005 47100" ± .005 47208" ± .005 47316" ± .005 47424" ± .005 47532" ± .005 47640" ± .005 47748" ± .005 47856" ± .005 47964" ± .005 48072" ± .005 48180" ± .005 48288" ± .005 48396" ± .005 48504" ± .005 48612" ± .005 48720" ± .005 48828" ± .005 48936" ± .005 49044" ± .005 49152" ± .005 49260" ± .005 49368" ± .005 49476" ± .005 49584" ± .005 49692" ± .005 49800" ± .005 49908" ± .005 50016" ± .005 50124" ± .005 50232" ± .005 50340" ± .005 50448" ± .005 50556" ± .005 50664" ± .005 50772" ± .005 50880" ± .005 50988" ± .005 51096" ± .005 51204" ± .005 51312" ± .005 51420" ± .005 51528" ± .005 51636" ± .005 51744" ± .005 51852" ± .005 51960" ± .005 52068" ± .005 52176" ± .005 52284" ± .005 52392" ± .005 52500" ± .005 52608" ± .005 52716" ± .005 52824" ± .005 52932" ± .005 53040" ± .005 53148" ± .005 53256" ± .005 53364" ± .005 53472" ± .005 53580" ± .005 53688" ± .005 53796" ± .005 53904" ± .005 54012" ± .005 54120" ± .005 54228" ± .005 54336" ± .005 54444" ± .005 54552" ± .005 54660" ± .005 54768" ± .005 54876" ± .005 54984" ± .005 55092" ± .005 55200" ± .005 55308" ± .005 55416" ± .005 55524" ± .005 55632" ± .005 55740" ± .005 55848" ± .005 55956" ± .005 56064" ± .005 56172" ± .005 56280" ± .005 56388" ± .005 56496" ± .005 56604" ± .005 56712" ± .005 56820" ± .005 56928" ± .005 57036" ± .005 57144" ± .005 57252" ± .005 57360" ± .005 57468" ± .005 57576" ± .005 57684" ± .005 57792" 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65568" ± .005 65676" ± .005 65784" ± .005 65892" ± .005 66000" ± .005 66108" ± .005 66216" ± .005 66324" ± .005 66432" ± .005 66540" ± .005 66648" ± .005 66756" ± .005 66864" ± .005 66972" ± .005 67080" ± .005 67188" ± .005 67296" ± .005 67404" ± .005 67512" ± .005 67620" ± .005 67728" ± .005 67836" ± .005 67944" ± .005 68052" ± .005 68160" ± .005 68268" ± .005 68376" ± .005 68484" ± .005 68592" ± .005 68700" ± .005 68808" ± .005 68916" ± .005 69024" ± .005 69132" ± .005 69240" ± .005 69348" ± .005 69456" ± .005 69564" ± .005 69672" ± .005 69780" ± .005 69888" ± .005 69996" ± .005 70104" ± .005 70212" ± .005 70320" ± .005 70428" ± .005 70536" ± .005 70644" ± .005 70752" ± .005 70860" ± .005 70968" ± .005 71076" ± .005 71184" ± .005 71292" ± .005 71400" ± .005 71508" ± .005 71616" ± .005 71724" ± .005 71832" ± .005 71940" ± .005 72048" ± .005 72156" ± .005 72264" ± .005 72372" ± .005 72480" ± .005 72588" ± .005 72696" ± .005 72804" ± .005 72912" ± .005 73020" ± .005 73128" ± .005 73236" ± .005 73344" ± .005 73452" ± .005 73560" ± .005 73668" ± .005 73776" ± .005 73884" ± .005 73992" ± .005 74100" ± .005 74208" ± .005 74316" ± .005 74424" ± .005 74532" ± .005 74640" ± .005 74748" ± .005 74856" ± .005 74964" ± .005 75072" ± .005 75180" ± .005 75288" ± .005 75396" ± .005 75504" ± .005 75612" ± .005 75720" ± .005 75828" ± .005 75936" ± .005 76044" ± .005 76152" ± .005 76260" ± .005 76368" ± .005 76476" ± .005 76584" ± .005 76692" ± .005 76800" ± .005 76908" ± .005 77016" ± .005 77124" ± .005 77232" ± .005 77340" ± .005 77448" ± .005 77556" ± .005 77664" ± .005 77772" ± .005 77880" ± .005 77988" ± .005 78096" ± .005 78204" ± .005 78312" ± .005 78420" ± .005 78528" ± .005 78636" ± .005 78744" ± .005 78852" ± .005 78960" ± .005 79068" ± .005 79176" ± .005 79284" ± .005 79392" ± .005 79500" ± .005 79608" ± .005 79716" ± .005 79824" ± .005 79932" ± .005 80040" ± .005 80148" ± .005 80256" ± .005 80364" ± .005 80472" ± .005 80580" ± .005 80688" ± .005 80796" ± .005 80904" ± .005 81012" ± .005 81120" ± .005 81228" ± .005 81336" ± .005 81444" ± .005 81552" ± .005 81660" ± .005 81768" ± .005 81876" ± .005 81984" ± .005 82092" ± .005 82200" ± .005 82308" ± .005 82416" ± .005 82524" ± .005 82632" ± .005 82740" ± .005 82848" ± .005 82956" ± .005 83064" ± .005 83172" ± .005 83280" ± .005 83388" ± .005 83496" ± .005 83604" ± .005 83712" ± .005 83820" ± .005 83928" ± .005 84036" ± .005 84144" ± .005 84252" ± .005 84360" ± .005 84468" ± .005 84576" ± .005 84684" ± .005 84792" ± .005 84900" ± .005 85008" ± .005 85116" ± .005 85224" ± .005 85332" ± .005 85440" ± .005 85548" ± .005 85656" ± .005 85764" ± .005 85872" ± .005 85980" ± .005 86088" ± .005 86196" ± .005 86304" ± .005 86412" ± .005 86520" ± .005 86628" ± .005 86736" ± .005 86844" ± .005 86952" ± .005 87060" ± .005 87168" ± .005 87276" ± .005 87384" ± .005 87492" ± .005 87600" ± .005 87708" ± .005 87816" ± .005 87924" ± .005 88032" ± .005 88140" ± .005 88248" ± .005 88356" ± .005 88464" ± .005 88572" ± .005 88680" 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96456" ± .005 9656				

REVISIONS			
LT#	DESCRIPTION	DATE	APPROV

NOTES:

1. DENOTES INTERFACE DEFINED ON ICD CG 52004 AS FOLLOWS:

⑤ STANDPIPE VENT TO COVER GAS EQUALIZATION LINE.

⑩ PURGE SUPPLY.

⑪ MAINTENANCE PURGE SUPPLY.

⑫ VENT TO RAPS.

⑩ AUXILIARY SUPPLY.

① EMERGENCY SUPPLY

FIGURE 22b

ALL DIMENSIONS AND TOLERANCES UNLESS OTHERWISE SPECIFIED ARE IN INCHES DECIMALS FRACTIONS ANGLES SURFACE ROUGHNESS PER MIL STD 10	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS FRACTIONS ANGLES SURFACE ROUGHNESS PER MIL STD 10	SJ ORDER NO.	REF. NO.	Bryce Jackson Pump Division BORG-MARTIN CORPORATION 145 HUNTER DRIVE
		DRAWN BY <i>BOYES</i>	DATE <i>5/7/70</i>	
ALL DIMENSIONS AND TOLERANCES UNLESS OTHERWISE SPECIFIED ARE IN INCHES DECIMALS FRACTIONS ANGLES SURFACE ROUGHNESS PER MIL STD 10	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS FRACTIONS ANGLES SURFACE ROUGHNESS PER MIL STD 10	CHECKED BY <i>HE KNE</i>	DATE <i>5-7-70</i>	DRAWING TITLE <i>STAINLESS STEEL BUBBLER SYSTEM DESIGN LAYOUT CR22 PROTOTYPE PUMP</i>
		CONTRACT NO.	DATE	
ALL DIMENSIONS AND TOLERANCES UNLESS OTHERWISE SPECIFIED ARE IN INCHES DECIMALS FRACTIONS ANGLES SURFACE ROUGHNESS PER MIL STD 10	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS FRACTIONS ANGLES SURFACE ROUGHNESS PER MIL STD 10	PERMANENT IDENTIFICATION <i>CR22</i>	DATE	COORD. SHEET NO.
		CUSTOMER APPROVE	DATE	
ALL DIMENSIONS AND TOLERANCES UNLESS OTHERWISE SPECIFIED ARE IN INCHES DECIMALS FRACTIONS ANGLES SURFACE ROUGHNESS PER MIL STD 10	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS FRACTIONS ANGLES SURFACE ROUGHNESS PER MIL STD 10	DO NOT SCALE DRAWING. REMOVE ALL BURRS AND SHARP EDGES EQUIVALENT TO GDS 1/16 ALL MACHINED CORNERS OR RADIUS GDS 1/16		
		DO NOT SCALE DRAWING. REMOVE ALL BURRS AND SHARP EDGES EQUIVALENT TO GDS 1/16 ALL MACHINED CORNERS OR RADIUS GDS 1/16		
SCALE NAME	WEIGHT	SHEET 2 OF 2

COVER GAS DIAGRAM

FIGURE 22c

REVISIONS		DATE	APPROVED
1	INITIAL	6-2-76	
2	REWORK	6-2-76	
3	REWORK	6-2-76	
4	REWORK	6-2-76	
5	REWORK	6-2-76	
6	REWORK	6-2-76	
7	REWORK	6-2-76	
8	REWORK	6-2-76	
9	REWORK	6-2-76	
10	REWORK	6-2-76	
11	REWORK	6-2-76	
12	REWORK	6-2-76	
13	REWORK	6-2-76	
14	REWORK	6-2-76	
15	REWORK	6-2-76	
16	REWORK	6-2-76	
17	REWORK	6-2-76	
18	REWORK	6-2-76	
19	REWORK	6-2-76	
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31	REWORK	6-2-76	
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37	REWORK	6-2-76	
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42	REWORK	6-2-76	
43	REWORK	6-2-76	
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45	REWORK	6-2-76	
46	REWORK	6-2-76	
47	REWORK	6-2-76	
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49	REWORK	6-2-76	
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64	REWORK	6-2-76	
65	REWORK	6-2-76	
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67	REWORK	6-2-76	
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69	REWORK	6-2-76	
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71	REWORK	6-2-76	
72	REWORK	6-2-76	
73	REWORK	6-2-76	
74	REWORK	6-2-76	
75	REWORK	6-2-76	
76	REWORK	6-2-76	
77	REWORK	6-2-76	
78	REWORK	6-2-76	
79	REWORK	6-2-76	
80	REWORK	6-2-76	
81	REWORK	6-2-76	
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90	REWORK	6-2-76	
91	REWORK	6-2-76	
92	REWORK	6-2-76	
93	REWORK	6-2-76	
94	REWORK	6-2-76	
95	REWORK	6-2-76	
96	REWORK	6-2-76	
97	REWORK	6-2-76	
98	REWORK	6-2-76	
99	REWORK	6-2-76	
100	REWORK	6-2-76	

EM 0190

APPENDIX I

Pump Tank Area & Volume

Simplified Pump Tank Cross Sectional View

$$r = R - \Delta r$$

$$\Delta r = y \tan \alpha$$

$$r^2 = (R - y \tan \alpha)^2 = R^2 - 2 R y \tan \alpha + y^2 \tan^2 \alpha$$

$$A(y) = \pi(R^2 - 2 R y \tan \alpha + y^2 \tan^2 \alpha)$$

$$A_T(y) = A_1 - A_2 + A_3 - A_4$$

for $Y_b < Y_i < Y_t$

$$y = (10.25 - Y_i)$$

$$A_1 = \pi \left\{ 3.81^2 - 2(3.81)(.1219)(10.25 - Y_i) + (10.25 - Y_i)^2 (.1219)^2 \right\}$$

$$A_2 = \pi \left\{ 3.33^2 - 2(3.33)(.1508)(10.25 - Y_i) + (10.25 - Y_i)^2 (.1508)^2 \right\}$$

$$A_3 = \pi \left\{ 3.21^2 - 2(3.21)(.1508)(10.25 - Y_i) + (10.25 - Y_i)^2 (.1508)^2 \right\}$$

$$A_4 = .2\pi$$

$$A_T(y) = \pi(5.92 + .587Y_i + .0149Y_i^2)$$

$$= 18.60 + 1.844Y_i + .0468Y_i^2 \text{ ft}^2$$

Similarly, tank gas variable volume

$$V_V(y) = \frac{\pi}{3} Y (R^2 + Rr + r^2)$$

for frustrum of right circular cone.

$$V_V(y) = \pi Y \left\{ R^2 - (R \tan \alpha)Y + \left(\frac{\tan^2 \alpha}{3} \right) Y^2 \right\}$$

$V_V(y)$ for geometry shown in previous cross-sectional figure and specific 1E3862 layout.

$$V_V(y) = 305.18 - 18.69Y_i - .92Y_i^2 - .0157Y_i^3 \text{ ft}^3$$

and total tank gas volume as a function of fluid level $V_T(y)$.

$$V_T(y) = V_K + V_V(y)$$

where V_K = fixed gas volume due to tank design 1E3862 (includes voids, shaft clearance spaces, etc.).

$$V_K = 29.19 \text{ ft}^3$$

$$V_T(y) = 334.37 - 18.69Y_i - .92Y_i^2 - .0157Y_i^3$$

EM 0190

APPENDIX 2

Program Listing

PROJECT 3836-010: STANDPIPE BUBBLER SYSTEM
 BORG-WARNER RESEARCH CENTER
 MARCH 1976 (PUMP DESIGN #4)

ROY C. INGERSOLL RESEARCH CENTER

SPB:0002	1
SPB:0004	2
SPB:0006	3
SPB:0008	4
SPB:0010	5
SPB:0012	6
SPB:0014	7
SPB:0016	8
SPB:0018	9
SPB:0020	10
SPB:0022	11
SPB:0024	12
SPB:0026	13
SPB:0028	14
SPB:0030	15
SPB:0032	16
SPB:0034	17
SPB:0036	18
SPB:0038	19
SPB:0040	20
SPB:0042	21
SPB:0044	22
SPB:0046	23
SPB:0048	24
SPB:0050	25
SPB:0052	26
SPB:0054	27
SPB:0056	28
SPB:0058	29
SPB:0060	30
SPB:0062	31
SPB:0064	32
SPB:0066	33
SPB:0068	34
SPB:0070	35
SPB:0072	36
SPB:0074	37
SPB:0076	38
SPB:0078	39
SPB:0080	40
SPB:0082	41
SPB:0084	42
SPB:0086	43
SPB:0088	44
SPB:0090	45
SPB:0092	46
SPB:0094	47
SPB:0096	48
SPB:0098	49
SPB:0100	50
SPB:0102	51
SPB:0104	52
SPB:0106	53
SPB:0108	54
SPB:0110	55
SPB:0112	56
SPB:0114	57
SPB:0116	58
SPB:0118	59
SPB:0120	60

ROY C. INGERSOLL RESEARCH CENTER

REQUIRED INPUT DATA (CARD: COLUMN)

1:01	Y1 = LEVEL AT WHICH LINE #1 JOINS REACTOR VESSEL	SPB:0122	61
1:11	L1 = LENGTH OF LINE #1	SPB:0124	62
1:21	A1 = CROSS-SECTIONAL AREA OF LINE #1	SPB:0126	63
1:31	C1 = VISCOUS LOSS COEFFICIENT OF LINE #1	SPB:0128	64
1:41	Y2 = LEVEL AT WHICH LINE #2 JOINS REACTOR VESSEL	SPB:0130	65
1:51	L2 = LENGTH OF LINE #2	SPB:0132	66
1:61	A2 = CROSS-SECTIONAL AREA OF LINE #2	SPB:0134	67
1:71	C2 = VISCOUS LOSS COEFFICIENT OF LINE #2	SPB:0136	68
2:01	AR = CROSS-SECTIONAL AREA OF REACTOR VESSEL	SPB:0138	69
2:11	C3 = VISCOUS LOSS COEFFICIENT OF REACTOR VESSEL	SPB:0140	70
2:21	HR = RATED PUMP HEAD	SPB:0142	71
2:31	QMAX = RATED MAXIMUM VOLUMETRIC FLOW RATE THRU PUMP	SPB:0144	72
2:41	Y1 = LEVEL OF TOP OF PUMP TANK (BOTTOM OF THERMAL SHIELD)	SPB:0146	73
2:51	Y0 = LEVEL OF PUMP SUCTION	SPB:0148	74
2:61	YTR = LEVEL OF TOP OF REACTOR VESSEL	SPB:0150	75
2:71	V0 = VOLUME OF OVERFLOW TANK	SPB:0152	76
3:01	AB = CROSS-SECTIONAL AREA OF LINE "B"	SPB:0154	77
3:11	CB = VISCOUS LOSS COEFFICIENT OF LINE "B"	SPB:0156	78
3:21	AA = CROSS-SECTIONAL AREA OF LINE "A"	SPB:0158	79
3:31	CA = VISCOUS LOSS COEFFICIENT OF LINE "A"	SPB:0160	80
3:41	FQBEAK = BEARING FLOW RATE FACTOR	SPB:0162	81
3:51	FQLEAK = LEAKAGE FLOWRATE FACTOR	SPB:0164	82
3:61	FQIHx = PUMP DISCHARGE RECIRCULATION FLOWRATE FACTOR	SPB:0166	83
3:71	YBOT = LEVEL OF BOTTOM OF PUMP TANK	SPB:0168	84
3:01A	L2P = LENGTH OF PATH BTWN CHAMBER 2 & PUMP SUCTION	SPB:0170	85
3:11A	AP = AREA OF PATH BTWN CHAMBER 2 & PUMP SUCTION	SPB:0172	86
3:21A	CHI = IMPEDENCE OF PATH BTWN CHAMBERS 1 & 2	SPB:0174	87
3:31A	CHL = LENGTH OF PATH BTWN CHAMBERS 1 & 2	SPB:0176	88
3:41A	CHx = AREA OF PATH BTWN CHAMBERS 1 & 2	SPB:0178	89
3:51A	ANI = IMPEDENCE OF PATH BTWN CHAMBER 2 & PUMP TANK	SPB:0180	90
3:61A	ANL = LENGTH OF PATH BTWN CHAMBER 2 & PUMP TANK	SPB:0182	91
3:71A	ANA = AREA OF PATH BTWN CHAMBER 2 & PUMP TANK	SPB:0184	92
3:01B	SHI = IMPEDENCE OF PATH BTWN CHAMBER 1 & PUMP TANK	SPB:0186	93
3:11B	SHL = LENGTH OF PATH BTWN CHAMBER 1 & PUMP TANK	SPB:0188	94
3:21B	SHA = AREA OF PATH BTWN CHAMBER 1 & PUMP TANK	SPB:0190	95
4:01	CONFIG = BRIEF DESCRIPTION OF CASE BEING RUN	SPB:0192	96
4:11	T = LIQUID TEMPERATURE	SPB:0194	97
4:51	RHOL = DENSITY OF LIQUID	SPB:0196	98
4:61	MU = VISCOSITY OF LIQUID	SPB:0198	99
4:71	ADDTG = MASS FLOW OF GAS FROM SUPPLY TO PUMP TANK	SPB:0200	100
5:01	IP = IMPEDANCE OF PATH BTWN CHAMBER 2 & PUMP SUCTION	SPB:0202	101
5:11	AN = CROSS SECTIONAL AREA OF ORIFICE	SPB:0204	102
5:21	AS = CROSS SECTIONAL AREA OF STANDPIPE	SPB:0206	103
5:31	HS = STANDPIPE DIAMETER FOR CIRCULAR X-SECTION	SPB:0208	104
5:41	H = STANDPIPE ORIFICE DIMENSION	SPB:0210	105
5:51	YSEG = LOCATION OF STANDPIPE BENDS (6 VALUES)	SPB:0212	106
X:51	YFGL = LENGTH BETWEEN STANDPIPE BENDS (6 VALUES)	SPB:0214	107
Y:51	ANGL = ANGLE AT EACH STANDPIPE BEND (6 VALUES)	SPB:0216	108
6:01	ICASE = OPERATION TO BE SIMULATED	SPB:0218	109
6:02	T1 = TIME AT WHICH OPERATION STARTS	SPB:0220	110
6:09	TSTOP = TOTAL ELAPSED TIME FOR THE OPERATION	SPB:0222	111
6:17	DT = TIME STEP INCREMENT (CALCULATION INTERVAL)	SPB:0224	112
6:25	TPRNT = TIME STEP INCREMENT (PRINTING INTERVAL)	SPB:0226	113
6:33	YR = INITIAL LEVEL OF LIQUID-GAS INTERFACE IN REACTOR VESSEL	SPB:0228	114
6:41	YI = INITIAL LEVEL OF LIQUID-GAS INTERFACE IN PUMP TANK	SPB:0230	115
6:49	PO = INITIAL GAS PRESSURE IN OVERFLOW TANK	SPB:0232	116
6:57	PA = INITIAL GAS PRESSURE ABOVE LIQUID IN STANDPIPE	SPB:0234	117
		SPB:0236	118
		SPB:0238	119
		SPB:0240	120
		SPB:0242	121

```

REAL WPAR,L2,L1,MDOTG,IP,L2P,LS,MU,LABEL(25),MDOTS,MRAPS
LOGICAL SWITCH
INTEGER CONFIG(20), CASE(15)
DIMENSION RESULT(25,9), QDSVD(10), QPSVD(10), QLSVD(10), QGSVD(10),
& NASVD(10), ITIME(7), IADRL(2), IULIST(2), IOSTAT(3)
COMMON /BLOCK17YSFG(6),SEGL(6),ANGL(6)

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SPB:0246 123
SPB:0248 124
SPB:0250 125
SPB:0252 126
SPB:0254 127
SPB:0256 128
SPB:0258 129

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BORG WARNER

ROY C. INGERSOLL RESEARCH CENTER

COMMON MAP

COMMON BLOCK /BLOCK1/ LENGTH 0036

YSEG 0000 SEGL 0012 ANGL 0024

```

DATA KR,LP/2,5/, G/32.172/, R/1244.7/
DATA MAXLIN/2/, MAXIOH/9/, IC000/ZC000/
DATA LABEL / 'TIME', 'QD', 'PP', 'QIHX', 'QR1',
& 'QR2', 'YR', 'YI', 'PI', 'PP',
& 'YS', 'PG', 'QP', 'UL', 'QG',
& 'PGR', 'PD', 'PA', 'QA', 'QB',
& 'QD', 'QSH', 'QAN', 'PC2', 'PC1'
DATA IULIST/Z3000,5/, MT/MT/, IOD0/Z0000/, KP/1/
DATA CASE / 'LO', 'AD', 'IN', 'G', 'UN', 'LO', 'AD', 'IN', 'G',
& 'TR', 'IP', ' '

```

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SPB:0260 130
SPB:0262 131
SPB:0264 132
SPB:0266 133
SPB:0268 134
SPB:0270 135
SPB:0272 136
SPB:0274 137
SPB:0276 138
SPB:0278 139
SPB:0280 140
SPB:0282 141
SPB:0284 142
SPB:0286 143
SPB:0288 144

```

```

2000 FORMAT(8F10.0)
2005 FORMAT(20A2,4F10.0)
2010 FORMAT(11,F7.0,9F8.0)
5000 FORMAT('1STANOPIPE RUHDLER SYSTEM',T105,7A2,I4,'/',I2,
& T31,20A2,T81,5A2)

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```

SPB:0290 145
SPB:0292 146
SPB:0294 147
SPB:0296 148
SPB:0298 149
SPB:0300 150
SPB:0302 151
SPB:0304 152
SPB:0306 153
SPB:0308 154
SPB:0310 155
SPB:0312 156
SPB:0314 157
SPB:0316 158
SPB:0318 159
SPB:0320 160
SPB:0322 161
SPB:0324 162
SPB:0326 163
SPB:0328 164
SPB:0330 165
SPB:0332 166
SPB:0334 167
SPB:0336 168
SPB:0338 169
SPB:0340 170
SPB:0342 171
SPB:0344 172
SPB:0346 173
SPB:0348 174
SPB:0350 175
SPB:0352 176

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1005 FORMAT(E15.6, ' SEC ',5A2,2X,20A2)
5005 FORMAT('OASIC INPUT PARAMETERS ',100(' '),1P,/,
& T02,E12.5, ' FT    Y1    LOCATION OF LINE #1
& T65,E12.5, ' R    T    OPERATING TEMPERATURE
& T02,E12.5, ' FT    L1    LENGTH OF LINE #1
& T65,E12.5, '    RHOL    DENSITY OF LIQUID
& T02,E12.5, ' SQFT   A1    X-SECTIONAL AREA OF LINE #1
& T65,E12.5, '    MU    VISCOSITY OF LIQUID
& T02,E12.5, '    C1    LOSS COEFFICIENT OF LINE #1
& T65,E12.5, '    MDOTG    GAS MASS FLOW INTO PUMP TANK
& T02,E12.5, ' FT    Y2    LOCATION OF LINE #2
& T65,E12.5, '    IP    PATH IMPEDANCE - CHMBR 2 & SUCTION
& T02,E12.5, ' FT    L2    LENGTH OF LINE #2
& T65,E12.5, ' FT    L2P    PATH LENGTH: CHMBR 2 & PUMP SUCTION
& T02,E12.5, ' SQFT   A2    X-SECTIONAL AREA OF LINE #2
& T65,E12.5, ' SQFT   A2    PATH X-SECT AREA: CHMBR 2 & SUCTION
& T02,E12.5, '    C2    LOSS COEFFICIENT OF LINE #2
& T65,E12.5, '    CHI    PATH IMPEDANCE: CHAMBERS 1 & 2
& T02,E12.5, ' SQFT   A2    X-SECTIONAL AREA OF LINE A
& T65,E12.5, ' FT    CHL    PATH LENGTH: CHAMBERS 1 & 2
& T02,E12.5, '    CA    LOSS COEFFICIENT OF LINE A
& T65,E12.5, ' SQFT   CHA    PATH X-SECT AREA: CHAMBERS 1 & 2
& T02,E12.5, ' SQFT   AB    X-SECTIONAL AREA OF LINE B
& T65,E12.5, '    ANI    PATH IMPEDANCE: CHMBR 2 & PUMP TANK
& T02,E12.5, '    CB    LOSS COEFFICIENT OF LINE B
& T65,E12.5, ' FT    ANL    PATH LENGTH: CHMBR 2 & PUMP TANK
& T02,E12.5, ' SQFT   AR    X-SECTIONAL AREA OF REACTOR VESSEL
& T65,E12.5, ' SQFT   ANA    PATH X-SECT AREA: CHMBR 2 & TANK
& T02,E12.5, '    C3    LOSS COEFFICIENT OF REACTOR VESSEL
& T65,E12.5, '    SHI    PATH IMPEDANCE: CHMBR 1 & PUMP TANK
& T02,E12.5, ' FT    YT    LOCATION OF PUMP TANK TOP

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& T02,E12.5,' FT SHL PATH LENGTH: CHMBR 1 & PUMP TANK',,,SPB:0354 177
& T02,E12.5,' FT YHOT LOCATION OF PUMP TANK BOTTOM',,,SPB:0356 178
& T65,E12.5,' SFT SHA PATH X-SECT AREA: CHMBR 1 & TANK',,,SPB:0358 179
& T02,E12.5,' FT YTR LOCATION OF REACTOR VESSEL TOP',,,SPB:0360 180
& T65,E12.5,' R GAS CONSTANT',,,SPB:0362 181
& T02,E12.5,' CUFT VO VOLUME OF OVERFLOW TANK',,,SPB:0364 182
& T65,E12.5,' G ACCELERATION OF GRAVITY',,,SPB:0366 183
& T02,E12.5,' FI YO LOCATION OF PUMP SUCTION',,,SPB:0368 184
& T65,E12.5,' X FQHFAR HEARING FLOW RATE FACTOR',,,SPB:0370 185
& T02,E12.5,' FT HR PUMP HEAD AT 100% FLOW',,,SPB:0372 186
& T65,E12.5,' X FQLEAK LEAKAGE FLOW RATE FACTOR',,,SPB:0374 187
& T02,E12.5,' CFPS QMAX FLOW RATE THRU PUMP @ 100% FLOW',,,SPB:0376 188
& T65,E12.5,' X FQIHX PUMP DISCHARGE RECIRCULATION FACTOR',,,SPB:0378 189
& T02,E12.5,' SFT AN X-SECTIONAL AREA: STANDPIPE ORIFICE',,,SPB:0380 190
& T65,E12.5,' SFT AS X-SECTIONAL AREA OF STANDPIPE',,,SPB:0382 191
& T02,E12.5,' FT HS STANDPIPE X-SECTN CIRCULAR DIAMETER',,,SPB:0384 192
& T65,E12.5,' FI H STANDPIPE ORIFICE DIMENSION',,,SPB:0386 193
& 3(T02,E12.5,' FT YN',,,II,' LOCATION OF STANDPIPE BEND',,,SPB:0388 194
& T65,E12.5,' FT YN',,,II,' LOCATION OF STANDPIPE BEND',,,SPB:0390 195
& T02,E12.5,' FT LS',,,II,' LENGTH UPTO STANDPIPE BEND',,,SPB:0392 196
& T65,E12.5,' FT LS',,,II,' LENGTH UPTO STANDPIPE BEND',,,SPB:0394 197
& T02,E12.5,' DEG THETA',,,II,' ANGLE AT STANDPIPE BEND',,,SPB:0396 198
& T65,E12.5,' DEG THETA',,,II,' ANGLE AT STANDPIPE BEND',,,SPB:0398 199
5006 FORMAT(1P,T02,E12.5,' SEC DT: TIME STEP INCREMENT',,,SPB:0400 200
& T65,E12.5,' SHLCCF: COMPUTATION CORRECTION FACTOR',,,SPB:0402 201
& T02,E12.5,' SEC TSTOP: TOTAL RUN TIME',,,SPB:0404 202
& T02,E12.5,' SEC TPRNT: PRINTOUT TIME INTERVAL',,,SPB:0406 203
& T02,E12.5,' SEC T1: START TIME FOR NORMALIZED PUMP SPEED',,,SPB:0408 204
5008 FORMAT(' PUMP SPEED SPIKED AT',1P,E13.5,' SEC -',E11.3,' WIDTH',,,SPB:0410 205
& E11.3,' HEIGHT',,,SPB:0412 206
5007 FORMAT('SYMBOL DEFINITIONS FOR DATA PRINTOUT',,,IX,36(' '),,,SPB:0414 207
& ' QD PUMP DISCHARGE FLOW RATE (FT3/SEC)',T60,,SPB:0416 208
& ' P1 = PG - PA + RHOL*G*(YI-YS)',,,SPB:0418 209
& ' PP PUMP SUCTION PRESSURE (LBF/FT2)',T60,,SPB:0420 210
& ' P2 = PG - PC1 + RHOL*G*(YI-YBOT)',,,SPB:0422 211
& ' QIHX FLOW BTWN PUMP TANK & HEAT XCHNGR (FT3/SEC)',T60,,SPB:0424 212
& ' YS STANDPIPE LIQUID LEVEL (FEET)',,,SPB:0426 213
& ' QR1 FLOW RATE IN LINE #1 (FT3/SEC)',T60,,SPB:0428 214
& ' PG GAS PRESSURE IN PUMP TANK (LBF/FT2)',,,SPB:0430 215
& ' QR2 FLOW RATE IN LINE #2 (FT3/SEC)',T60,,SPB:0432 216
& ' QP FLOW BTWN CHAMBER 2 & PUMP SUCTION (FT3/SEC)',,,SPB:0434 217
& ' YR REACTOR VESSEL LIQUID LEVEL (FEET)',T60,,SPB:0436 218
& ' QL FLOW BTWN PUMP TANK & STANDPIPE (FT3/SEC)',,,SPB:0438 219
& ' YI PUMP TANK LIQUID LEVEL (FEET)',T60,,SPB:0440 220
& ' QG GAS FLOW BTWN PUMP TANK & STANDPIPE (FT3/SEC)',,,SPB:0442 221
& ' PGR GAS PRESSURE IN REACTOR VESSEL (PSF)',T60,,SPB:0444 222
& ' PO GAS PRESSURE IN OVERFLOW TANK (PSF)',,,SPB:0446 223
& ' PA GAS PRESSURE IN STANDPIPE BUBBLER (PSF)',T60,,SPB:0448 224
& ' QA FLOW RATE IN LINE A (FT3/SEC)',,,SPB:0450 225
& ' QB FLOW RATE IN LINE B (FT3/SEC)',T60,,SPB:0452 226
& ' QO REACTOR VESSEL OVERFLOW RATE (FT3/SEC)',,,SPB:0454 227
5009 FORMAT(1,IX,131(' '),,,SPB:0456 228
5010 FORMAT(' ',A4,1P,9E14.5),,,SPB:0458 229
,,SPB:0460 230
C *** READ INPUT DATA ***,,SPB:0462 231
,,SPB:0464 232
CALL F:READ (IOLIST),,,SPB:0466 233
CALL F:STATUS (IOSTAT),,,SPB:0468 234
ISW14=2,,SPB:0470 235
IF (IOSTAT(1).EQ.MT .AND. IOSTAT(2).EQ.IOD0) ISW14=1,,SPB:0472 236
READ(KR,2000,END=999) Y1,L1,A1,C1,Y2,L2,A2,C2,,SPB:0474 237
1 AR,C3,HR,QMAX,YT,YO,YTR,VO,,SPB:0476 238

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2  AR,CH,AA,CA,FQBEAR,FQLEAK,FQIH,YRO
3  LPP,AP,CHI,CHL,CHA,ANI,ANL,ANA,
4  SHI,SHL,SHA
20  READ(KR,2005,END=999) CONFIG,T,RHOL,MU,MOOTG
    READ(KR,2000,END=900) IP,AN,AS,HS,H,YSEG,SEGL,ANGL
    YN = YSEG(1)
    LS = SEGL(1)
30  READ(KR,2010,END=20) ICASE, T1,TSTOP,DT,TPRNT, YR,YI,PO,PA,SHLCCF
    PCT=1.0-FQIH*2.0*FQBEAR-FQLEAK
    DPAOT = 0.0
    TSPIKE=0.
    WIDTH=0.
    HEIGHT=0.
    IF (T1.LT.0.) READ(KR,2000) TSPIKE,WIDTH,HEIGHT
    T1=ANS(T1)
    IC1 = 5*(ICASE-1)+1
    IC2 = IC1+4
    IPAGE = 1
    LPAGE = ((TSTOP+1.0)/TPRNT)/18.0 + 1.55
    IADRL(1) = 1(000)
    IADRL(2) = MIN(1,TIME(1))
    CALL FIDAIME (IADRL)
    WRITE(LP,5000) ITIME, IPAGE,LPAGE, CONFIG, (CASE(I),I=IC1,IC2)
    WRITE(LP,5005) Y1,I,L1,RHOL,A1,MU,C1,MOOTG,Y2,IP,L2,L2P,A2,AP,C2,
& CHI,AA,CHL,CA,CHA,AR,ANI,CH,ANL,AR,ANA,C3,SHI,YI,
& SHL,YBOT,SHA,YTR,R,VU,G,YO,FQBEAR,HR,FQLEAK,
& QMAX,FQIH,AN,AS,HS,H,
& (YSEG(I),I,YSEG(I+3),I+3,SEGL(I),I,SEGL(I+3),I+3,ANGL(I),I,
& ANGL(I+3),I+3, I=1,3)
    WRITE(LP,5006) DT, SHLCCF, TSTOP,TPRNT,T1
    IF (TSPIKE.GT.0.) WRITE(LP,5008) TSPIKE,WIDTH,HEIGHT
    WRITE(LP,5007)
C *** INITIAL CONDITIONS ***
    ITIME = 0.0
    NBAR = FNBAR(ICASE, ITIME, T1)
    IF ((TIME.GT.TSPIKE) .AND. (TIME.LT.(TSPIKE+WIDTH)))
& NBAR = SNBAR(ICASE, ITIME, T1, TSPIKE,WIDTH,HEIGHT)
C --- SOLVE FOR INITIAL VALUE OF QD (EQUATION IS QUARTIC)
    QD = QMAX
    IF (ICASE.EQ.1) QD=0.35*QD
C --- COMPUTE INITIAL VALUES OF REMAINING PARAMETERS
80  QL = 0.0
    QG = 0.0
    QA = 0.0
    QB = 0.0
    QO = -0.2228
    IF (YR.GT.16.3) QO = QO+1.989/RHOL
    PGR = 2168.
    A = R*T
    RHUGR = PGR/A
    RHUGO = PO/A
    RHUGA = PA/A
    QIH = FQIH*QD
    QBEAR = FQBEAR*QD
    QLEAK = FQLEAK*QD
    QP = QIH+2.0*QBEAR+QLEAK
    A = RHOL*G*(YR-YO)
    B = RHOL*(1.+C1)/(2.*A1*A1)
    C = QD-QP
    PP = PGR+A-B*C*C
    SPB:0478 239
    SPB:0480 240
    SPB:0482 241
    SPB:0484 242
    SPB:0486 243
    SPB:0488 244
    SPB:0490 245
    SPB:0492 246
    SPB:0494 247
    SPB:0496 248
    SPB:0498 249
    SPB:0500 250
    SPB:0502 251
    SPB:0504 252
    SPB:0506 253
    SPB:0508 254
    SPB:0510 255
    SPB:0512 256
    SPB:0514 257
    SPB:0516 258
    SPB:0518 259
    SPB:0520 260
    SPB:0522 261
    SPB:0524 262
    SPB:0526 263
    SPB:0528 264
    SPB:0530 265
    SPB:0532 266
    SPB:0534 267
    SPB:0536 268
    SPB:0538 269
    SPB:0540 270
    SPB:0542 271
    SPB:0544 272
    SPB:0546 273
    SPB:0548 274
    SPB:0550 275
    SPB:0552 276
    SPB:0554 277
    SPB:0556 278
    SPB:0558 279
    SPB:0560 280
    SPB:0562 281
    SPB:0564 282
    SPB:0566 283
    SPB:0568 284
    SPB:0570 285
    SPB:0572 286
    SPB:0574 287
    SPB:0576 288
    SPB:0578 289
    SPB:0580 290
    SPB:0582 291
    SPB:0584 292
    SPB:0586 293
    SPB:0588 294
    SPB:0590 295
    SPB:0592 296
    SPB:0594 297
    SPB:0596 298
    SPB:0598 299
    SPB:0600 300
```



```

QR1 = QD-QP
QR2 = QD-QHX-2.0*QREAR-QLEAK
P1 = 0.0
QSH = QHX
QCH = QSH*QREAR
PC2 = PP+IP*QP*ABS(QP)-RHOL*G*(YBOT-YO)
PC1 = PC2+CHT*QCH*ABS(QCH)
P2 = SHI*QSH*ABS(QSH)+PC1-PP
QAN = SORT((P2+PP-PC2)/ANI)
PG = P2+PP- RHOL*G*(YI-YBOT)
YS = YI+(PG-PA)/(RHOL*G)
CALL SP:SEG (YS,SPL,THETA)
DPAOT = 0.0
DQPDOT = 0.0
C --- SAVE INITIAL CONDITIONS IN OUTPUT BUFFER
IOB = 1
LINE = MAXLIN
DO 50 I=1,20
DO 50 J=1,9
50  RESULT(I,J)=0.0
RESULT(2,IOB) = QD
RESULT(3,IOB) = PP
RESULT(4,IOB) = QHX
RESULT(5,IOB) = QR1
RESULT(6,IOB) = QR2
RESULT(7,IOB) = YR
RESULT(8,IOB) = YI
RESULT(9,IOB) = P1
RESULT(10,IOB) = P2
RESULT(11,IOB) = YS
RESULT(12,IOB) = PG
RESULT(13,IOB) = QP
RESULT(14,IOB) = QL
RESULT(15,IOB) = QG
RESULT(16,IOB) = PGR
RESULT(17,IOB) = PO
RESULT(18,IOB) = PA
RESULT(19,IOB) = QA
RESULT(20,IOB) = QB
RESULT(21,IOB) = QO
RESULT(22,IOB) = QSH
RESULT(23,IOB) = QAN
RESULT(24,IOB) = PC2
RESULT(25,IOB) = PC1
IOT = 0
ISTOP = 0
LOOPS = 0.5+TPRNT/DT
LAST = 0.5+ISTOP/TPRNT
DO 90 I=1,10
QDSVD(I) = 0
QPSVD(I) = 0
QLSVD(I) = 0
QGSVD(I) = 0
90  QASVD(I) = 0
IHAVE = I
DIVID = 1
SUMQD = QD
SUMQP = QP
SUMQL = QL
SUMQG = QG
SUMQA = QA
QDSVD(IHAVE) = QD

```

SPB:0602	301
SPB:0604	302
SPB:0606	303
SPB:0608	304
SPB:0610	305
SPB:0612	306
SPB:0614	307
SPB:0616	308
SPB:0618	309
SPB:0620	310
SPB:0622	311
SPB:0624	312
SPB:0626	313
SPB:0628	314
SPB:0630	315
SPB:0632	316
SPB:0634	317
SPB:0636	318
SPB:0638	319
SPB:0640	320
SPB:0642	321
SPB:0644	322
SPB:0646	323
SPB:0648	324
SPB:0650	325
SPB:0652	326
SPB:0654	327
SPB:0656	328
SPB:0658	329
SPB:0660	330
SPB:0662	331
SPB:0664	332
SPB:0666	333
SPB:0668	334
SPB:0670	335
SPB:0672	336
SPB:0674	337
SPB:0676	338
SPB:0678	339
SPB:0680	340
SPB:0682	341
SPB:0684	342
SPB:0686	343
SPB:0688	344
SPB:0690	345
SPB:0692	346
SPB:0694	347
SPB:0696	348
SPB:0698	349
SPB:0700	350
SPB:0702	351
SPB:0704	352
SPB:0706	353
SPB:0708	354
SPB:0710	355
SPB:0712	356
SPB:0714	357
SPB:0716	358
SPB:0718	359
SPB:0720	360
SPB:0722	361
SPB:0724	362

GPSVD(IHAVE) = QP
 NLSVD(IHAVE) = NL
 UGSVD(IHAVE) = NG
 GASVD(IHAVE) = GA

SPB:0726 363
 SPB:0728 364
 SPB:0730 365
 SPB:0732 366
 SPB:0734 367
 SPB:0736 368
 SPB:0738 369
 SPB:0740 370
 SPB:0742 371
 SPB:0744 372
 SPB:0746 373
 SPB:0748 374
 SPB:0750 375
 SPB:0752 376
 SPB:0754 377
 SPB:0756 378
 SPB:0758 379
 SPB:0760 380
 SPB:0762 381
 SPB:0764 382
 SPB:0766 383
 SPB:0768 384
 SPB:0770 385
 SPB:0772 386
 SPB:0774 387
 SPB:0776 388
 SPB:0778 389
 SPB:0780 390
 SPB:0782 391
 SPB:0784 392
 SPB:0786 393
 SPB:0788 394
 SPB:0790 395
 SPB:0792 396
 SPB:0794 397
 SPB:0796 398
 SPB:0798 399
 SPB:0800 400
 SPB:0802 401
 SPB:0804 402
 SPB:0806 403
 SPB:0808 404
 SPB:0810 405
 SPB:0812 406
 SPB:0814 407
 SPB:0816 408
 SPB:0818 409
 SPB:0820 410
 SPB:0822 411
 SPB:0824 412
 SPB:0826 413
 SPB:0828 414
 SPB:0830 415
 SPB:0832 416
 SPB:0834 417
 SPB:0836 418
 SPB:0838 419
 SPB:0840 420
 SPB:0842 421
 SPB:0844 422
 SPB:0846 423
 SPB:0848 424

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C --- SOLVE FOR (QD) FLOW RATE AT PUMP DISCHARGE

95 IDT = INT+1
 TTIME = DT*IDT + DT*ISTOP*LOOPS
 NRAR = FNHR(ICASE, TTIME, T1)
 IF ((TTIME.GT.TSPIKE).AND. (TTIME.LT.(TSPIKE+WIDTH)))
 & NRAR = SNHR(ICASE, TTIME, T1, TSPIKE, WIDTH, HEIGHT)
 A = RHOL*G*HH*NRAR*NRAR
 R = QD/(NRAR*QMAX)
 C = RHOL*QD*QD*(1./A1**2 - 1./A2**2)/2.0
 FWD = 1.229+B*(-0.16+B*(0.192+B*(-0.28+0.039*B)))
 FQD = FGD*A+C
 A = (3.0*PCT*RHOL*(Y1-Y2))/AR
 A = A + (PCT*RHOL*L2)/A2
 A = A + RHOL*L1/A1
 B = (9.0*PCT*PCT*RHOL*C3)/(2.0*AR*AR)
 B = B + (PCT*PCT*RHOL*C2)/(2.0*A2*A2)
 B = B - RHOL/(2.0*A2*A2)
 B = B*QD*QD
 C = (QD-QP)*(QD-QP)*(1.0+C1)*RHOL/(2.0*A1*A1)
 D = DQD*DT
 C = C-(RHOL*L1/A1)*D
 DQDDT = (FWD-C-B)/A
 DQD = DQDDT*DT
 QDN = QD+DQD

C --- SOLVE FOR (YR) LIQUID LEVEL IN REACTOR VESSEL

DYRDT = 3.0*(QRP-QR1)-QD
 DYRDT = DYRDT/AR
 DYR = DYRDT*DT
 YRN = YR+DYR

C --- SOLVE FOR (RHGR) AND (RHGO)

MDOTS = 9.604E-05
 IF (PGR.LT.2167.999) MDOTS=5.585E-03
 MRAPS = 3.0*MDOTG + 9.604E-05
 IF (PGR.GT.2167.001) MRAPS=MRAPS+5.498E-03
 A = MDOTS-RHGR*QR
 B = RHGR*AR*DYRDT
 C = AR*(YR-YR)
 DRGDT = (A+B)/C
 DRGR = DRGDT*DT
 RHGRN = RHGR+DRGR
 A = QR*(RHGO+RHGR)/2.
 B = 3.0*GA*(PHGO+RHOGA)/2.
 DRGDDT = (A+B-MRAPS)/VO
 DRGO = DRGDDT*DT
 RHGON = RHGO+DRGO

C --- SOLVE FOR (YI) LIQUID LEVEL IN PUMP TANK

A0 = 18.6+YI*(1.844+0.0468*YI)
 DYIDT = (QIH-X-QAN-QSH-QL)/A0
 DYI = DYIDT*DT
 YIN = YI+DYI

C --- SOLVE FOR (P1)

VOL = 334.37+YI*(-18.69+YI*(-0.92-0.0157*YI))
 A0 = 18.6+YI*(1.844+0.0468*YI)
 A = P2+PP -RHOL*G*(YI-YBDT)
 B = A0*A/VOL + RHOL*G
 A = (R*T*MDOTG-A*QG)/VOL

ROY C. INGERSOLL RESEARCH CENTER

```
OPIDT = A+H-RHOL*G*QL*DSIND(THETA)/AS - DPADT
OP1 = OPIDT*DT
PIN = P1+IP1
C --- SOLVE FOR (PGR)
PGRN = RHOL*G*H*T
C --- SOLVE FOR (PF) SUCTION PRESSURE AT PUMP
A = RHOL*L1/A1
H = RHOL*(1.+C1)/(P.*A)*A1
PPN = PGRN-RHOL*G*(Y0-YRN)
PPN = PPN-B*(UD-UP)*(UD-UP)
C = DIVID*UDN-SUMUD
C = C/(D1*DIVID*(DIVID+1))
D = 1.0
IF (DIVID.GT.1) D = DT*DIVID*(DIVID+1)
U = (DIVID*UP-SUMUP)/D
PPN = PPN - A*(C-D)
C --- SOLVE FOR (P2)
P2N = YS+DT*QL*DSIND(THETA)/AS - YROT
P2N = RHOL*G*P2N
P2N = P1+PA-PPN+P2N
C --- SOLVE FOR (JP) FLOW RATE FROM PUMP TANK TO PUMP SYSTEM
C --- SOLVE FOR FLOW RATES & PRESSURES IN THE CHAMBER AREAS
QDSHDT = P2+PP-PC1-SH1*QSH*ABS(QSH)
QDSHDT = SH1*QDSHDT/(RHOL*SHL*SHLCCF)
QSH = QSH+DT*QDSHDT
QIMX = QDN*FQIMX
QLEAK = QDN*FQLEAK
QBEAR = QDN*FQBEAR
QCH = QSH+QBEAR
QPN = QAN+QSH+2.0*QBEAR+QLEAK
DJPOT = (QPN-UP)/DT
PC2 = PPN+IP*QPN*ABS(QPN)-RHOL*G*(YBOT-Y0)
PC1 = PC2+CHI*QCH*ABS(QCH)
A = (PPN+P2N-PC2)/ANI
QAN = SQRT(ABS(A))
IF (A.LT.0.0) QAN=-QAN
C --- SOLVE FOR (QL) LIQUID FLOW RATE FROM PUMP TANK TO STANDPIPE
U = 0.0
X05 = +0.5
IF (QL.LT.0.0) X05 = -0.5
IF (Y1.LT.YN) GO TO 120
110 A = RHOL*(L4+9PL)/A5
B = RHOL*QL*AH9(QL)
H = B*(X05/(A1*A5)+0.18783/(AN*AN))
C = 32.0*MU*(L3+9PL)*QL/(HS*HS*AS)
DQLDT = (P1-B-(C+D))/A
GO TO 190
120 IF ((YN-H).GE.Y1) GO TO 140
IF (P1.GE.0) GO TO 130
IF ((YS-YN+H).LE.0) GO TO 185
GO TO 110
130 A = Y1-YN+(H+HS)/2.0
B = LS/(A*AS/HS)
B = RHOL*(B+SPL/AS)
C = (Y1-YN+H)/H
C = 0.18783/(C*C*AN*AN)
C = RHOL*QL*ABS(QL)*(C*X05/(AS*AS))
D = 2.0*A*HS
D = 2.0*LS*D*D
D = D/(A*AS*AS)
A = 32.0*SPL/(HS*HS*AS)
D = MU*QL*(D+A)
SPB:0850 425
SPB:0852 426
SPB:0854 427
SPB:0856 428
SPB:0858 429
SPB:0860 430
SPB:0862 431
SPB:0864 432
SPB:0866 433
SPB:0868 434
SPB:0870 435
SPB:0872 436
SPB:0874 437
SPB:0876 438
SPB:0878 439
SPB:0880 440
SPB:0882 441
SPB:0884 442
SPB:0886 443
SPB:0888 444
SPB:0890 445
SPB:0892 446
SPB:0894 447
SPB:0896 448
SPB:0898 449
SPB:0900 450
SPB:0902 451
SPB:0904 452
SPB:0906 453
SPB:0908 454
SPB:0910 455
SPB:0912 456
SPB:0914 457
SPB:0916 458
SPB:0918 459
SPB:0920 460
SPB:0922 461
SPB:0924 462
SPB:0926 463
SPB:0928 464
SPB:0930 465
SPB:0932 466
SPB:0934 467
SPB:0936 468
SPB:0938 469
SPB:0940 470
SPB:0942 471
SPB:0944 472
SPB:0946 473
SPB:0948 474
SPB:0950 475
SPB:0952 476
SPB:0954 477
SPB:0956 478
SPB:0958 479
SPB:0960 480
SPB:0962 481
SPB:0964 482
SPB:0966 483
SPB:0968 484
SPB:0970 485
SPB:0972 486
```

ROY C. INGERSOLL RESEARCH CENTER

```
140  DQD = (PI-C-D)/B
      GO TO 190
      IF ((PI+RHOL*G*(YN-YI-H)).GE.0) GO TO 185
      IF ((YS-YN+H).LE.0) GO TO 185
      D = RHOL*G*(YN-YI-H)
      GO TO 110
185  DLN = 0.0
      GO TO 200
190  DQL = DQD*DT
      DLN = DL+DQL
200  CONTINUE
C --- EQUATE NEW AND OLD PARAMETERS
      QD = QDN
      PP = PPN
      YR = YRN
      RHOG = RHGRN
      PGR = PGRN
      RHUG = RHUGN
      YI = YIN
      P1 = PIN
      P2 = P2N
      QP = QPN
      QL = QLN
C --- SOLVE FOR (QR1) FLOW RATE IN LINE #1
C --- SOLVE FOR (QR2) FLOW RATE IN LINE #2
      QR1 = QD-QP
      QR2 = QD-NHX-2.0*QBEAR-QLEAK
      QD = -0.2228
      IF (YR.GT.16.3) QD = QD+1.989/RHOL
      PD = RHUG*P*T
C --- SOLVE FOR (PG) GAS PRESSURE IN PUMP TANK
      PG = P2+PP -RHOL*G*(YI-YBOT)
      RHUG = PG/(P*T)
C --- SOLVE FOR (QG) GAS FLOW RATE FROM PUMP TANK TO STANDPIPE
      IF (YI.GE.YN) GO TO 285
      IF ((YN-H).GE.YI) GO TO 230
      IF (P1.LT.0) GO TO 220
      ASGN = +1.2058
      BSGN = +1.0
210  A = ASGN*(YN-YI)*AN/(H*SQRT(RHOG))
      B = RHOL*G*(YN-YI)/2.0
      QG = A*SQRT(BSGN*(P1+B))
      GO TO 300
220  IF ((YS-YN+H).GT.0) GO TO 285
      A = P1+RHOL*G*(YN-YI)/2.0
      IF (A.GE.0) GO TO 285
      ASGN = -1.2058
      BSGN = -1.0
      GO TO 210
230  A = P1+RHOL*G*(YN-YI-H)
      IF (A.LT.0) GO TO 250
      ASGN = +1.2058
      BSGN = +1.0
240  B = P1+RHOL*G*(YN-YI-H/2.0)
      A = ASGN*AN/SQRT(RHOG)
      QG = A*SQRT(BSGN*B)
      GO TO 300
250  IF (YS.GT.(YN-H)) GO TO 285
      A = P1+RHOL*G*(YN-YI-H/2.0)
      IF (A.GE.0) GO TO 285
      ASGN = -1.2058
      BSGN = -1.0
```

```
SPB:0974 487
SPB:0976 488
SPB:0978 489
SPB:0980 490
SPB:0982 491
SPB:0984 492
SPB:0986 493
SPB:0988 494
SPB:0990 495
SPB:0992 496
SPB:0994 497
SPB:0996 498
SPB:0998 499
SPB:1000 500
SPB:1002 501
SPB:1004 502
SPB:1006 503
SPB:1008 504
SPB:1010 505
SPB:1012 506
SPB:1014 507
SPB:1016 508
SPB:1018 509
SPB:1020 510
SPB:1022 511
SPB:1024 512
SPB:1026 513
SPB:1028 514
SPB:1030 515
SPB:1032 516
SPB:1034 517
SPB:1036 518
SPB:1038 519
SPB:1040 520
SPB:1042 521
SPB:1044 522
SPB:1046 523
SPB:1048 524
SPB:1050 525
SPB:1052 526
SPB:1054 527
SPB:1056 528
SPB:1058 529
SPB:1060 530
SPB:1062 531
SPB:1064 532
SPB:1066 533
SPB:1068 534
SPB:1070 535
SPB:1072 536
SPB:1074 537
SPB:1076 538
SPB:1078 539
SPB:1080 540
SPB:1082 541
SPB:1084 542
SPB:1086 543
SPB:1088 544
SPB:1090 545
SPB:1092 546
SPB:1094 547
SPB:1096 548
```

```

GO TO 240
285  QG = Q.G
300  CONTINUE
C --- SOLVE FOR (PA)    GAS PRESSURE IN STANDPIPE
A = CA/4.0
B = RHUGO + PA/(R*T)
C = PG*NG/PA
D = ABS(C)
DPADT = PA
PA = PU + A*B*C*D
DPADT = (PA-DPADT)/DT
RHUGA = PA/(R*T)
A = PGR-PU
B = CR*(RHUGO+RHUGR)/4.
C = ABS(A/B)
QB = AB*SQRT(C)
IF (A.LT.0) QB = -QB
QA = QG*PG/PA
C --- SOLVE FOR (YS)    LIQUID LEVEL IN STANDPIPE
YS = YHOT*(PP-PA-P1+P2)/(RHOL*G)
CALL SP:SEG (YS,SPL,THETA)
IF (SWITCH(14)) WRITE(KP,1005) YTIME,(CASE(I),I=IC1,IC2),CONFIG
C *** SAVE RESULTS & CHECK FOR I/O & ANALYSIS COMPLETION ***
JUMP = 1
IHAVE = IHAVE+1
IF (IHAVE.GT.10) IHAVE=1
IF (DIVID.LT.10) DIVID=DIVID+1
SUMQD = SUMQD+QD-QDSVD(IHAVE)
QDSVD(IHAVE) = QD
SUMQP = SUMQP+QP-QPSVD(IHAVE)
QPSVD(IHAVE) = QP
SUMQL = SUMQL+QL-QLSVD(IHAVE)
QLSVD(IHAVE) = QL
SUMQG = SUMQG+QG-QGSVD(IHAVE)
QGSVD(IHAVE) = QG
SUMQA = SUMQA+QA-QASVD(IHAVE)
QASVD(IHAVE) = QA
CALL DATSW (15,ISW15)
IF (IOT.LI,LOOPS) GO TO 440
320  IOB = IOB+1
RESULT(1,IOB) = DT*IDT + DT*ISTOP*LOOPS
RESULT(2,IOB) = SUMQD/DIVID
RESULT(3,IOB) = PP
RESULT(4,IOB) = DIHX
RESULT(5,IOB) = QR1
RESULT(6,IOB) = QR2
RESULT(7,IOB) = YR
RESULT(8,IOB) = YI
RESULT(9,IOB) = P1
RESULT(10,IOB) = P2
RESULT(11,IOB) = YS
RESULT(12,IOB) = PG
RESULT(13,IOB) = SUMQP/DIVID
RESULT(14,IOB) = SUMQL/DIVID
RESULT(15,IOB) = SUMQG/DIVID
RESULT(16,IOB) = PGR
RESULT(17,IOB) = PU
RESULT(18,IOB) = PA
RESULT(19,IOB) = SUMQA/DIVID
RESULT(20,IOB) = QB

```

```

SPB:1098 549
SPB:1100 550
SPB:1102 551
SPB:1104 552
SPB:1106 553
SPB:1108 554
SPB:1110 555
SPB:1112 556
SPB:1114 557
SPB:1116 558
SPB:1118 559
SPB:1120 560
SPB:1122 561
SPB:1124 562
SPB:1126 563
SPB:1128 564
SPB:1130 565
SPB:1132 566
SPB:1134 567
SPB:1136 568
SPB:1138 569
SPB:1140 570
SPB:1142 571
SPB:1144 572
SPB:1146 573
SPB:1148 574
SPB:1150 575
SPB:1152 576
SPB:1154 577
SPB:1156 578
SPB:1158 579
SPB:1160 580
SPB:1162 581
SPB:1164 582
SPB:1166 583
SPB:1168 584
SPB:1170 585
SPB:1172 586
SPB:1174 587
SPB:1176 588
SPB:1178 589
SPB:1180 590
SPB:1182 591
SPB:1184 592
SPB:1186 593
SPB:1188 594
SPB:1190 595
SPB:1192 596
SPB:1194 597
SPB:1196 598
SPB:1198 599
SPB:1200 600
SPB:1202 601
SPB:1204 602
SPB:1206 603
SPB:1208 604
SPB:1210 605
SPB:1212 606
SPB:1214 607
SPB:1216 608
SPB:1218 609

```

ROY C. INGERSOLL RESEARCH CENTER

ROY C. INGERSOLL RESEARCH CENTER

```
RESULT(21,I08) = Q0
RESULT(22,I08) = QSH
RESULT(23,I08) = QAN
RESULT(24,I08) = PC2
RESULT(25,I08) = PC1
ISTOP = ISTOP+1
IDT = 0
JUMP = 2
IF (I08.LT.MAXI08) GO TO 440
IF (LINE.LT.MAXLIN) GO TO 410
IPAGE = IPAGE+1
CALL F:DATIME (IADRL)
WRITE(LP,5000) ITIME, IPAGE,LPAGE, CONFIG, (CASE(I),I#ICT,IC2)
LINE = 0
410 WRITE(LP,5009)
DO 420 I=1,25
WRITE(LP,5010) LABEL(I), (RESULT(I,J),J=1,I08)
420 CONTINUE
LINE = LINE+I
I08 = 0
JUMP = 3
440 IF ((ISTOP.LT.LAST).AND.(ISW15.EQ.2)) GO TO 95
IF((JUMP.EQ.3).AND.(ISW14.EQ.1)) END FILE LP
GO TO (320, 400, 30), JUMP

900 PAUSE 'DATA ERROR: CONFIGURATION CARDS'
GO TO 20
999 CALL EXIT
END
```

```
SPB:1222 611
SPB:1224 612
SPB:1226 613
SPB:1228 614
SPB:1230 615
SPB:1232 616
SPB:1234 617
SPB:1236 618
SPB:1238 619
SPB:1240 620
SPB:1242 621
SPB:1244 622
SPB:1246 623
SPB:1248 624
SPB:1250 625
SPB:1252 626
SPB:1254 627
SPB:1256 628
SPB:1258 629
SPB:1260 630
SPB:1262 631
SPB:1264 632
SPB:1266 633
SPB:1268 634
SPB:1270 635
SPB:1272 636
SPB:1274 637
SPB:1276 638
SPB:1278 639
```

SCALAR MAP

NBAR	000A(T)	L2	0021(T)	L1	0015(T)	MDOTG	0084(T)	IP	0087(T)	L2P	005A(T)
LS	0099(T)	MU	0081(T)	MDOTS	016F(T)	MRAPS	0171(T)	KR	000A(P)	LP	000B(P)
G	000C(P)	R	000F(P)	MAXLIN	0012(P)	MAXI08	0013(P)	IC000	0014(P)	MT	0062(P)
I0D0	0063(P)	KP	0064(P)	ISW14	0010(T)	Y1	0012(T)	A1	0018(T)	C1	0018(T)
Y2	001E(T)	A2	0024(T)	C2	0027(T)	AR	002A(T)	C3	002D(T)	HR	0030(T)
QMAX	0033(T)	YT	0036(T)	Y0	0039(T)	YTR	003C(T)	VO	003F(T)	AB	0042(T)
CB	0045(T)	AA	0048(T)	CA	004B(T)	FOBEAR	004E(T)	FOLEAK	0051(T)	FOIHX	0054(T)
YBOT	0057(T)	AP	005D(T)	CHI	0060(T)	CHL	0063(T)	CHA	0066(T)	ANI	0069(T)
ANL	006C(T)	ANA	006F(T)	SHI	0072(T)	SHL	0075(T)	SHA	0078(T)	T	007B(T)
RHOL	007E(T)	AN	008A(T)	AS	008D(T)	HS	0090(T)	H	0093(T)	YN	0096(T)
ICASE	009C(T)	T1	009D(T)	TSTOP	00A0(T)	DT	00A3(T)	TPRNT	00A6(T)	YR	00A9(T)
Y1	00AC(T)	PU	00AF(T)	PA	00B2(T)	SHLCCF	00B5(T)	PCT	00B8(T)	OPADT	00BB(T)
TSPIKE	00BE(T)	WIDTH	00C1(T)	HEIGHT	00C4(T)	IC1	00C7(T)	IC2	00C8(T)	IPAGE	00C9(T)
LPAGE	00CA(T)	I	00CB(T)	TTIME	00D5(T)	QD	00D8(T)	QL	00DE(T)	QG	00E1(T)
QA	00F4(T)	QH	00F7(T)	QD	00EA(T)	PGR	00ED(T)	A	00F0(T)	RHOGN	00F3(T)
RHUGO	00F6(T)	RHUGA	00F9(T)	QIHX	00FC(T)	BREAR	00FF(T)	QLEAK	0102(T)	QP	0105(T)
R	0108(T)	C	010B(T)	PP	010E(T)	DR1	0111(T)	QR2	0114(T)	P1	0117(T)
QSH	011A(T)	QCH	011D(T)	PC2	0120(T)	PC1	0123(T)	P2	0126(T)	QAN	0129(T)
PG	012C(T)	Y	012F(T)	SPL	0132(T)	THETA	0135(T)	DQDOT	0138(T)	I08	013B(T)
LINE	013C(T)	J	013D(T)	IDT	013F(T)	ISTOP	0140(T)	LOOPS	0141(T)	LAST	0142(T)
IHAVE	0143(T)	DIVID	0144(T)	SUMQD	0147(T)	SUMQP	014A(T)	SUMQL	014D(T)	SUMQG	0150(T)
SUMQA	0153(T)	FND	0156(T)	D	0159(T)	DQDOT	015C(T)	DQD	015F(T)	QDN	0162(T)
DYHDT	0165(T)	DYR	0168(T)	YRN	016B(T)	DRGRDT	0174(T)	DRGR	0177(T)	DRGDT	017A(T)
RHOGN	017D(T)	DRGDOT	0180(T)	DRGO	0183(T)	RHOGON	0186(T)	A0	0189(T)	DYIDT	018C(T)
DYI	018F(T)	YIN	0192(T)	VOL	0195(T)	DP1DT	0198(T)	DP1	019B(T)	P1N	019E(T)
PGRN	01A1(T)	PPN	01A4(T)	P2N	01A7(T)	DQSHDT	01AA(T)	QPN	01AD(T)	X05	01B0(T)
DQLDT	01B3(T)	QLN	01B6(T)	DQL	01B9(T)	RHOG	01BC(T)	ASGN	01BF(T)	B8GN	01C2(T)
JUMP	01C5(T)	ISW15	01C6(T)								

ARRAY MAP

LABEL 0015(P) CONFIG 0107(T) CASE 0065(P) RESULT 01EB(T) QDSVD 048E(T) QPSVD 04AC(T)
 QLSVD 04CA(T) QGSVD 04EB(T) GASVD 0506(T) ITIME 0524(T) IADRL 052B(T) IOLIST 0060(P)
 IOSTAT 0520(T)

ROY C. INGERSOLL RESEARCH CENTER

EXTERNAL PROCEDURES

SWITCH	F:READ	F:STAT	:AB:	MIAB:	F:DATI	FNBAR	SNBAR	SOIT
SPISFG	DSIND	DATSW	EXIT	MIRE:	L188:	L188C	L144L1	L144R3
L144S1	L144M1	L144A3	L14N	L144L3	L144A1	L144D3	L144D1	L124R3
L188S2	L188A	L188C2	L144T1	L144M1	L144R2	L142R2	L142R3	L142L3
L144S1	L144T1	L142L1	L144S2	L188Y2	L188Z	L188X1	L188X	

LABEL MAP

:2000	0074	:2005	007A	:2010	007F	:5000	0087	:1005	00A8	:5005	00B6	:5006	0742
:5008	0707	:5007	07FC	:5009	09E6	:5010	09EF	:999	1AE6	:20	0A61	:900	1AD2
:30	0A9A	:80	0CA4	:50	0DE1	:90	0F45	:95	0FA2	:120	1460	:110	1400
:190	1586	:140	1540	:130	1487	:185	1580	:200	1598	:285	175F	:230	16C8
:220	1690	:210	1644	:300	1764	:250	1726	:240	16EF	:440	1AA6	:320	18E5
:400	1A10	:410	1A46	:420	1A98								

PROCEDURE BLOCK LENGTH: 1869
 DATA BLOCK LENGTH: 0530
 TOTAL PROGRAM LENGTH: 2099
 0 ERRORS

C *** ROUTINE TO DETERMINE LIQUID POSITION IN STANDPIPE

SPB:1280 1

BORG WARNER

ROY C. INGERSOLL RESEARCH CENTER

SUBROUTINE SP:SEG (YS, SPL, THETA)

SPB:1282 2

COMMON /BLUCK1/YSEG(6),SEGL(6),ANGL(6)

SPB:1284 3

SPB:1286 4

COMMON MAP

COMMON BLOCK /BLUCK1/

LENGTH 0036

YSEG 0000 SEGL 0012 ANGL 0024

THETA = 0.0

SPL = 0.0

DO 25 I=2,6

IF (YS.LE.YSEG(I)) GO TO 50

SPL = SPL+SEGL(I)

SPB:1288 5

SPB:1290 6

SPB:1292 7

SPB:1294 8

SPB:1296 9

25 CONTINUE

SPB:1298 10

I = 7

SPB:1300 11

50 I = I-1

SPB:1302 12

THETA = ANGL(I)

SPB:1304 13

SPL = SPL+(YS-YSEG(I))/DSIND(THETA)

SPB:1306 14

RETURN

SPB:1308 15

END

SPB:1310 16

SCALAR MAP

YS 0004(T) SPL 0005(T) THETA 0006(T) I 0007(T)

EXTERNAL PROCEDURES

DSIND

M:PSHC

L:44L1

L:44R2

L:44L2

L:44T2

L:44A2

L:44R3

L:44R2

L:44D3

M:POP

LABEL MAP

125 0025 150 0028

PROCEDURE BLOCK LENGTH: 005C

DATA BLOCK LENGTH: 000E

TOTAL PROGRAM LENGTH: 006A

0 ERRORS

ROY C. INGERSOLL RESEARCH CENTER

C *** FUNCTION TO COMPUTE NORMALIZED PUMP SPEED (NBAR)

FUNCTION FNBAR (ICASE, TNOW, T1)
INTEGER TARV(20), MAFN(20)SPB:1312 1
SPB:1314 2
SPB:1316 3
SPB:1318 4DATA TARV/0,95,195,295,395,495,655,755,855,955,1175,1375,1575,
1775,1975,2375,2775,3175,3575,3975/
DATA MAFN/1000,840,715,630,555,500,425,390,360,335,290,255,230,
205,185,155,135,115,100,100/SPB:1320 5
SPB:1322 6
SPB:1324 7
SPB:1326 8
SPB:1328 9

GO TO (100, 200, 300), ICASE

SPB:1330 10

C --- LOADING CONDITION

100 IF (TNOW .GE. T1) GO TO 110

105 FNBAR = 0.35

RETURN

110 IF (TNOW .LE. (T1+1300.)) GO TO 120

115 FNBAR = 1.0

RETURN

120 FNBAR = 0.35 + 0.0005*(TNOW-T1)

RETURN

SPB:1332 11
SPB:1334 12
SPB:1336 13
SPB:1338 14
SPB:1340 15
SPB:1342 16
SPB:1344 17
SPB:1346 18
SPB:1348 19
SPB:1350 20
SPB:1352 21

C --- UNLOADING CONDITION

200 IF (TNOW .LT. T1) GO TO 115

IF (TNOW .GT. (T1+1300.)) GO TO 105

FNBAR = 1.0 - 0.0005*(TNOW-T1)

RETURN

SPB:1354 22
SPB:1356 23
SPB:1358 24
SPB:1360 25
SPB:1362 26
SPB:1364 27

C --- TRIP CONDITION

300 IF (TNOW .LT. T1) GO TO 115

IF (TNOW .LE. (T1+24.)) GO TO 310

FNBAR = 0.10

RETURN

310 TDIF = TNOW-T1

DO 320 I=2,20

IF (TDIF .GT. 0.01*TARV(I)) GO TO 320

X1 = 0.01*TARV(I-1)

X2 = 0.01*TARV(I)

Y1 = 0.001*MAFN(I-1)

Y2 = 0.001*MAFN(I)

FNBAR = Y1 + (TDIF-X1) * (Y2-Y1) / (X2-X1)

RETURN

320 CONTINUE

FNBAR = 0.10

RETURN

END

SPB:1366 28
SPB:1368 29
SPB:1370 30
SPB:1372 31
SPB:1374 32
SPB:1376 33
SPB:1378 34
SPB:1380 35
SPB:1382 36
SPB:1384 37
SPB:1386 38
SPB:1388 39
SPB:1390 40
SPB:1392 41
SPB:1394 42
SPB:1396 43
SPB:1398 44
SPB:1400 45

SCALAR MAP

FNBAR	0007(T)	ICASE	0004(T)	TNOW	0005(T)	T1	0006(T)	TDIF	000A(T)	I	000D(T)
X1	000F(T)	X2	0012(T)	Y1	0015(T)	Y2	0018(T)				

ARRAY MAP

TARV	0007(P)	MAFN	001B(P)
------	---------	------	---------

EXTERNAL PROCEDURES

MIPSHC	L144B2	L144C2	L144Y2	L144L1	L144R3	L144L3	MIPUP	L144A1
L144S2	L144M1	L144S1	L144N	L142L2	L144Y3	L144S3	L144M3	L144D3

LI44A3

LABEL MAP

ROY C. INGERSOLL RESEARCH CENTER

:100	0036	:200	0064	:300	0081	:110	0046	:105	003E	:120	0058	:115	0050
:310	009A	:320	00F5										

PROCEDURE BLOCK LENGTH: 0130
DATA BLOCK LENGTH: 0027
TOTAL PROGRAM LENGTH: 0157
0 ERRORS

ROY C. INGERSOLL RESEARCH CENTER

```
C *** FUNCTION TO ADD A SPIKE TO THE NORMALIZED PUMP SPEED CURVE
      FUNCTION SNBAR (IC,TNOW,TPS, TSPIKE,WIDTH,HEIGHT)
      IF (TNOW.GT. (TSPIKE+0.5*WIDTH)) GO TO 50
C --- ON THE RISING SIDE OF THE SPIKE
      T1=TSPIKE
      X1=FNBAR(IC,T1,TPS)
      T2=TSPIKE+0.5*WIDTH
      X2=HEIGHT*FNBAR(IC,T2,TPS)
      GO TO 100
C --- ON THE FALLING SIDE OF THE SPIKE
50    T1=TSPIKE+0.5*WIDTH
      X1=HEIGHT*FNBAR(IC,T2,TPS)
      T2=TSPIKE+WIDTH
      X2=FNBAR(IC,T2,TPS)
C --- LINEAR INTERPOLATION TO FIND NEW NBAR DUE TO SPIKE
100   SNBAR= X1+(TNOW-T1)*(X2-X1)/(T2-T1)
      RETURN
      END
```

ADDEDS	SPB:1402	1
	SPB:1404	2
	SPB:1406	3
	SPB:1408	4
	SPB:1410	5
	SPB:1412	6
	SPB:1414	7
	SPB:1416	8
	SPB:1418	9
	SPB:1420	10
	SPB:1422	11
	SPB:1424	12
	SPB:1426	13
	SPB:1428	14
	SPB:1430	15
	SPB:1432	16
	SPB:1434	17
	SPB:1436	18
	SPB:1438	19

SCALAR MAP

SNBAR	0016(T)	IC	0004(T)	TNOW	0005(T)	TPS	0006(T)	TSPIKE	0007(T)	WIDTH	0008(T)
HEIGHT	0009(T)	T1	000A(T)	X1	000D(T)	T2	0010(T)	X2	0013(T)		

EXTERNAL PROCEDURES

FNBAR	M:PSHC	L:44C1	L:44M2	L:44A2	L:44T2	L:44L2	L:44R3	L:44S3
L:44L3	L:44M3	L:44D3	L:44A3	M:POP				

LABEL MAP

:50 0031 :100 0052

PROCEDURE BLOCK LENGTH: 0080
DATA BLOCK LENGTH: 0025
TOTAL PROGRAM LENGTH: 00A5
0 ERRORS