11G
BNWL-1295
UC-80

2.
4-70

VOID FRACTION PROFILE
IN A NUCLEAR REACTOR VESSEL
DURING COOLANT BLOWDOWN

N. P. Wilburn

April 1970

AEC RESEARCH &
DEVELOPMENT REPORT

ROUTE TO			DATE

BNWL-1295

LEGAL NOTICE

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

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

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

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

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

3 3679 00061 8449

BNWL-1295

UC-80, Reactor Technology

VOID FRACTION PROFILE IN A NUCLEAR REACTOR
VESSEL DURING COOLANT BLOWDOWN

N. P. Wilburn

Reactor Engineering Department
Physics and Engineering Division

April 1970

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

BNWL-1295

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

VOID FRACTION PROFILE IN A NUCLEAR REACTOR
VESSEL DURING COOLANT BLOWDOWN

N. P. Wilburn

ABSTRACT

This report, BNWL-1295, discusses an experimental and analytical study of the phenomena that occur in the reactor vessel and piping during a postulated accidental loss of coolant from a light water cooled nuclear power reactor. The report reviews the findings of several authors in their study of liquid-vapor in a vessel, and the consideration of the two-phase flow which occurs in the outlet pipe or orifice. The principal concern of this study is the liquid-vapor action during blowdown (with top, middle and bottom nozzles) from a vessel without internal structures.

CONTENTS

LIST OF FIGURES	vii
LIST OF TABLES	ix
INTRODUCTION	1
SUMMARY	2
CONCLUSIONS	3
DISCUSSION	4
Development of the Model	4
General Approach to the Problem	4
Geometric Considerations	4
Thermodynamic and Mass Transport Considerations	6
Overall Balances	7
Infinitesimal Volume Balances	8
Rate of Gas Generation, w_g	11
Gas Phase Velocity, u_g	14
Balances at Withdrawal Plane	16
Boundary and Initial Conditions	18
Method of Solution	19
Dimensional Analysis	21
Results	25
Steady State	25
Bottom Blowdown	29
3/4-Full Vessel	32
Full Vessel	32
Middle Blowdown	39
3/4-Full Vessel	39
Full Vessel	39
General	45
Top Blowdown	48
1/2-Full Vessel	48
Comparisons	53
With Moody's Predictions	53
With FLASH2 Predictions	57
With CSE Experimental Data.	61

CONCLUSIONS 65

TABLE OF NOMENCLATURE 67

REFERENCES 69 .

APPENDIX A: Solution to First Order Quasi-Linear
Partial Differential Equations A-1

APPENDIX B: Use of the BURP Code. B-1

APPENDIX C: Details of the BURP Code. C-1

FIGURES

1	Schematic View of Vessel	5
2	Void Fraction Profile - Steady-State Case 1	27
3	Characteristic Behavior - Steady-State Case 1	28
4	Void Fraction Profile - Steady-State Case 2	30
5	Characteristic Behavior - Steady-State Case 2	30
6	Overall Properties During Bottom Blowdown (3/4 Full Vessel)	33
7	Foam Level During Bottom Blowdown (3/4 Full Vessel)	35
8	Overall Properties During Bottom Blowdown (Full Vessel)	36
9	Foam Level During Bottom Blowdown (Full Vessel)	38
10	Overall Properties During Middle Blowdown (3/4 Full Vessel)	40
11	Foam Level During Middle Blowdown (3/4 Full Vessel)	42
12	Overall Properties During Middle Blowdown (Full Vessel)	43
13	Foam Level During Middle Blowdown (Full Vessel)	46
14	Void Fraction Profile, Middle Blowdown	47
15	Gas Phase Velocity Profile, Middle Blowdown	47
16	Overall Properties During Top Blowdown (1/2 Full Vessel)	49
17	Foam Level During Top Blowdown (1/2 Full Vessel)	51
18	Void Fraction Profiles During Top Blowdown	51
19	Characteristics Behavior During Top Blowdown (1/2 Full Vessel)	52
20	Comparison of Moody and BURP Predictions, Foam Level for Bottom Blowdown	54
21	Comparison of FLASH2 Predictions with Those of BURP Middle Blowdown, 3/4 Full Vessel	58
22	Comparison of FLASH2 Predictions of Foam Level with Those of BURP - Top Blowdown, 1/2 Full Vessel	60
23	Comparison of BURP Predictions with CSE Data, Top Blowdown, Run B53BTN	63
24	Comparison of BURP Predictions with CSE Data, Middle Blowdown, Run B28MN	64

TABLES

1	Experimental Blowdown Run Conditions for Comparison with Model Predictions	62
C-1	Main Program BURPMN	C-3
C-2	FORTTRAN Variables Used in BURPMN	C-21
C-3	Subroutine AMSINT	C-28
C-4	Subroutine BURPDE	C-34
C-5	FORTTRAN Variables Used in BURPDE (Not already defined in Table C-2)	C-43
C-6	Subroutine STMTBL	C-45
C-7	Subroutine DERIV	C-55
C-8	Subroutine GMOODY	C-57
C-9	Subroutine SING and UBUB	C-60
C-10	Subroutine TB1D	C-60
C-11	Subroutine TB1DG	C-61
C-12	Subroutine TABINT	C-62

VOID FRACTION PROFILE IN A NUCLEAR REACTOR
VESSEL DURING COOLANT BLOWDOWN

N. P. Wilburn

INTRODUCTION

This report discusses an experimental and analytical study of the phenomena that occur in the reactor vessel and piping during a postulated accidental loss of coolant from a light water cooled nuclear power reactor. This study is important for a number of reasons. First, the rate at which the coolant is removed from the core determines, to a large extent, the rate at which heat is removed from the core and thus its temperature. In turn, the temperature of the core determines its integrity, both as to the failure of the cladding and as to the behavior of the structure itself. Second, the forces exerted upon the core assembly are directly dependent upon the coolant flow patterns and its density profiles. Third, the blowdown rate itself is dependent upon the local fluid properties in the vicinity of the effluent point from the reactor vessel.

Blowdown from a nuclear reactor vessel has been studied by a number of authors. The problem has been logically divided into the two parts: liquid-vapor action in the vessel, and the consideration of the two-phase critical flow which occurs in the outlet pipe or orifice. A number of models have been proposed to describe the latter.^(1,4,5,6) However, the one which seems to have the widest acceptance or use is Moody's.⁽¹⁾

The problem of the liquid-vapor action has been considered by various authors in differing degrees and viewpoints. Harris⁽⁹⁾ was among the first to consider the problem. He considered the effects of different rupture sizes on the phase separation within a vessel. Nahavandi⁽¹⁰⁾ formed a lumped

parameter model to predict local properties throughout a liquid-vapor system during blowdown. Redfield⁽²⁾ formulated a multi-node computer model which included the effects of local coolant properties. However, this model included the effects of local coolant properties. However, this model included an empirical factor which was essentially the slope of an assumed linear void fraction profile. Redfield later extended this work⁽¹¹⁾ as have others.⁽¹²⁾ In none of the above cases have the detailed differential equations been considered which describe the liquid-vapor action in a vessel during blowdown. In all these cases the importance of the local properties in determining blowdown rates has been recognized.

More recently it has been shown experimentally that the blowdown rates at constant stagnation pressure show a marked and clear dependence upon the geometric ratio of the blowdown orifice area to the vessel cross sectional area, A_E/A_V .^{(7)*} It has also been noted that the foam level in the vessel as it depends upon time can be characterized by the same ratio A_E/A_V .⁽⁸⁾ The dependence upon this ratio should be explained by the liquid-vapor action. Moody⁽¹³⁾ took the first step toward analyzing the liquid-vapor action in detail. Some disagreement with his approach has been discussed in the comments on his paper;^(14,15) and, other points of disagreement are considered at various places within this paper.

SUMMARY

The detailed analysis of the liquid-vapor action is complicated by many factors. With anything but the simplest geometry the hydrodynamics becomes very complex. Heat transfer is occurring at large rates from the fuel elements. Bubble formation rates depend upon nucleation sites. Large temperature

* *Note: See Table of Nomenclature, page 67 for definition of symbols used.*

gradients exist. All the phenomena are inherently three-dimensional. In addition, there is very limited knowledge of how bubbles form and grow under the conditions of blowdown. The momentum equations which have been written to describe two-phase flow are either extremely simplified or too complex to be solved.

In spite of the complex nature of the ultimate general problem, some insight can be obtained by considering simpler cases. Therefore, in this study the liquid vapor action during blowdown from a vessel without internal structures are reviewed. The problem is assumed to be one-dimensional. The complex bubble formation problem will be replaced by assuming that bubbles are formed uniformly throughout the vessel in such a way that they all have an instantaneous terminal rise velocity which is a known function of the overall and local vessel conditions. Results for blowdowns from top, middle, and bottom nozzles are presented and compared with Moody's predictions,⁽¹³⁾ with FLASH2 predictions,⁽²⁾ and with the experimental data.^(7,8)

CONCLUSIONS

- The model derived in this study and implemented in the Computer code BURP predicts pressure, and foam level histories for top, middle and bottom blowdowns satisfactorily.
- The assumption of a constant or linear void fraction profile as is done in some lumped parameter codes (such as FLASH2) is not valid.
- Some more realistic way should be developed to handle the boundary condition at the effluent point from the vessel.

More detailed conclusions may be found on page 65.⁽⁸⁸⁾

DISCUSSION

DEVELOPMENT OF THE MODEL

General Approach to the Problem

In order to make the ensuing mathematical derivations a bit more understandable and to clarify the direction in which they are proceeding, the following synopsis of the approach to the problem is given.

The pressure vessel to be considered is first described geometrically and the assumptions as to thermodynamics and transport processes are stated. The overall mass, energy, and volume balances are shown to lead to expressions for dp/dt , dn_g/dt and dm_{λ}/dt . In these expressions h_E is unknown and it must be determined from the state of the fluid in the vessel in the vicinity of the withdrawal plane. Explicitly h_E is found from material and energy balances around the plane at z_E .

These latter balances depend upon α_E^+ , α_E^- , u_g^- and G . The α 's can be found at a time, t , by integration of the characteristic equations which result from the partial differential equations describing the balances on an infinitesimal volume of foam. By an alternative arrangement of these balances and partial integration, u_g^- is determined. G depends on h_E in some non-linear fashion, therefore, to solve the balances, an iterative technique is employed.

Once h_E is found by the above procedure, the status of the whole system is specified and the void fraction profile, the gas velocity profile, the blowdown rate, the pressure, and similar values can be computed.

Geometric Considerations

Figure 1 depicts schematically the pressure vessel selected for this analysis. It contains no internal flow restrictions or resistances wherein frictional losses occur. The cross sectional area of the vessel, A_V , must be a continuous

Neg 0695613-25

FIGURE 1. Schematic View of Vessel

function of distance from the bottom of the vessel, z . Thus, constrictions are allowed as long as there are no step changes in area. The differential equations are derived for this situation but results herein are presented only for the case $A_V = \text{constant}$.

The vessel is of length L and the foam vapor interface is at H . Only one such interface (near the top) is assumed to exist for this development, but the criteria for the creation of others, such as beneath constrictions, will be shown.

The blowdown occurs from a plane located at z_E . All flow from the vessel is into this plane and no transverse flow exists.

Thermodynamic and Mass Transport Considerations

The conditions which are listed below are assumed to be those existent for the pressure vessel in this development.

- Liquid and vapor throughout the system are saturated and in equilibrium.
- Pressure is uniform throughout the vessel; thus effects of the gravity head and frictional losses are disregarded.
- Properties of the mixture are uniform across the plane at any elevation z , but are not necessarily uniform from one elevation to another.
- The depressurization process occurs isentropically within the vessel, that is - there is no heat added to the system or frictional losses.
- The rate of liquid vaporization at any point within the vessel during depressurization is proportional to the mass of liquid present.

The blowdown rate at any instant is fully determined by the pressure in the vessel (P), and the fluid conditions in the vicinity of the plane, z_E . A model describing the process such as Moody's⁽¹⁾ is assumed.

- Kinetic energy and potential energy induced by gravity are negligible.
- Bubble rise velocity with respect to the liquid (i.e. slip velocity) is constant, or a sole function of the void fraction (α) and the specific internal fluid properties such as that given by Wilson's correlation.(16)

Overall Balances

The overall volume, mass, and energy balances at a time, t , can be written in terms of the pressure and effluent enthalpy histories up to the time t .

$$V = m_g v_g(P) + m_l v_f(P) \quad (1)$$

$$m_o - m_g - m_l = \int_0^t G(h_E, P) A_E dt \quad (2)$$

$$m_o U_o - m_l U_f(P) - m_g U_g(P) = \int_0^t G(h_E, P) A_E h_E dt \quad (3)$$

These equations may be expressed in differential form where the differentials with respect to pressure are taken along the saturation curve.

$$\left(m_g \frac{\partial v_g}{\partial P} + m_l \frac{\partial v_f}{\partial P} \right) \frac{dP}{dt} + v_f \frac{dm_l}{dt} + v_g \frac{dm_g}{dt} = 0 \quad (1')$$

$$- \frac{dm_l}{dt} - \frac{dm_g}{dt} = A_E G \quad (2')$$

$$- \left(m_g \frac{\partial U_g}{\partial P} + m_l \frac{\partial U_f}{\partial P} \right) \frac{dP}{dt} - U_f \frac{dm_l}{dt} - U_g \frac{dm_g}{dt} = A_E G h_E \quad (3')$$

The three time derivatives can then be expressed explicitly after defining Δ by the following

$$\Delta = \left(m_g \frac{\partial v_g}{\partial P} + m_l \frac{\partial v_f}{\partial P} \right) U_{fg} - \left(m_l \frac{\partial U_f}{\partial P} + m_g \frac{\partial U_g}{\partial P} \right) v_{fg} \quad (4)$$

$$\frac{dP}{dt} = \frac{A_E G}{\Delta} \left[v_\ell (h_g - h_E) + v_g (h_E - h_f) \right] \quad (5)$$

$$\frac{dm_\ell}{dt} = \frac{A_E G}{\Delta} \left[(h_E - U_g) \left(m_g \frac{\partial v_g}{\partial P} + m_\ell \frac{\partial v_f}{\partial P} \right) + v_g \left(m_g \frac{\partial U_g}{\partial P} + m_\ell \frac{\partial U_f}{\partial P} \right) \right] \quad (6)$$

$$\frac{dm_g}{dt} = \frac{A_E G}{\Delta} \left[(U_f - h_E) \left(m_g \frac{\partial v_g}{\partial P} + m_\ell \frac{\partial v_f}{\partial P} \right) - v_f \left(m_g \frac{\partial U_g}{\partial P} + m_\ell \frac{\partial U_f}{\partial P} \right) \right] \quad (7)$$

The expressions on the right hand side of the Equations 5, 6, and 7 depend only on the system pressure P and the effluent enthalpy h_E . This system can be directly integrated given the initial conditions provided h_E is known. h_E must be determined from liquid-vapor action internal to the vessel or by making some assumption such as that the internal fluid is homogeneous. (2) Here h_E is determined from material and energy balances made about the withdrawal plane, but first the conditions in the vicinity of the withdrawal plane must be determined.

Infinitesimal Volume Balances

Consideration of an infinitesimal volume dV located at a point z in the foam, for the time period dt , leads to the following mass balances for the gas and liquid phases, respectively.

$$-\frac{\partial}{\partial V} \left(\frac{\alpha u_g A_V}{v_g} \right) + \dot{w}_g = \frac{\partial \left(\frac{\alpha}{v_g} \right)}{\partial t} \quad (8)$$

$$-\frac{\partial}{\partial V} \left(\frac{(1-\alpha) u_\ell A_V}{v_f} \right) - \dot{w}_g = \frac{\partial \left(\frac{1-\alpha}{v_f} \right)}{\partial t} \quad (9)$$

Assumption 3 indicates that the foam properties are independent of the other 2 coordinates and thus allows the volume to be expressed by:

$$dV = A_V dz \quad (10)$$

Assumptions 1 and 2 indicate that the specific internal properties of the gas and liquid are independent of elevation z and depend upon time only through the system pressure P . Thus Equations 8 and 9 can be written in the expanded form:

$$-\frac{u_g}{v_g} \frac{\partial \alpha}{\partial z} - \frac{\alpha}{A_V v_g} \frac{\partial (u_g A_V)}{\partial z} + \dot{w}_g = \frac{1}{v_g} \frac{\partial \alpha}{\partial t} + \alpha \frac{\partial \left(\frac{1}{v_g} \right)}{\partial P} \frac{dP}{dt} \quad (8')$$

$$+\frac{u_l}{v_f} \frac{\partial \alpha}{\partial z} - \frac{1-\alpha}{A_V v_f} \frac{\partial (u_g A_V)}{\partial z} - \dot{w}_g = \frac{-1}{v_f} \frac{\partial \alpha}{\partial t} + (1-\alpha) \frac{\partial \left(\frac{1}{v_f} \right)}{\partial P} \frac{dP}{dt} \quad (9')$$

Assumption 8 essentially replaces the momentum equation for the infinitesimal volume with the following,

$$u_g - u_l = c(\alpha, P) \quad (11)$$

This more or less implies that the bubble upon formation is considered to be instantaneously at terminal slip velocity, and that this velocity is independent of the bubble size and shape. This is probably not too unreasonable for the pressures present during the two-phase portion of the blowdown. Combination of 11 and 9' yields:

$$\begin{aligned} \frac{u_g - c}{v_f} \frac{\partial \alpha}{\partial z} - \frac{1-\alpha}{A_V v_f} \left(\frac{\partial (u_g A_V)}{\partial z} - \frac{\partial (c A_V)}{\partial z} \right) &= \frac{-1}{v_f} \frac{\partial \alpha}{\partial t} \\ &+ (1-\alpha) \frac{\partial \left(\frac{1}{v_f} \right)}{\partial P} \frac{dP}{dt} + \dot{w}_g \end{aligned} \quad (12)$$

If Equation 8' is multiplied by $v_g (1-\alpha)$, Equation 12 is multiplied by $-\alpha v_f$, and the results are added, the partial derivative of the velocity can be eliminated.

$$\frac{a(1-a)}{A_V} \frac{\partial (cA_V)}{\partial z} + \frac{\partial a}{\partial z} (ac - u_g) - \frac{\partial \alpha}{\partial t} = -\dot{w}_g v_g v_f \left(\frac{1-a}{v_f} + \frac{a}{v_g} \right) + \alpha(1-\alpha) \frac{\partial \ln(v_f/v_g)}{\partial P} \frac{dP}{dt} \quad (13)$$

Since c has been assumed to be a known function of P and a only, Equation 13 can be written in an alternative form

$$\frac{\partial \alpha}{\partial z} \left(ac - u_g - \alpha(1-\alpha) \frac{\partial c}{\partial \alpha} \right) - \frac{\partial \alpha}{\partial t} = -\dot{w}_g v_g v_f \left(\frac{1-\alpha}{v_f} + \frac{\alpha}{v_g} \right) + \alpha(1-\alpha) \frac{\partial \ln(v_f/v_g)}{\partial P} \frac{dP}{dt} + a(1-a)c \frac{d \ln A_V}{dz} \quad (13')$$

$$= f(\alpha, t, z)$$

g , as will be shown below, depends only upon α and the overall vessel conditions, P and dP/dt . P and dP/dt can be considered to be sole functions of time in light of Equation 5 once the **blowdown** model prescribing G as a function of P and h_E is specified. Since v_g and v_f depend only on P , it is seen that the right hand side of Equation 13' depends only on t , a , and z . The form of Equation 13' is thus that of a quasi-linear first order partial differential equation. The corresponding characteristic equations for the system can be found using the methods outlined in Appendix A.

$$\frac{dz}{-\alpha(1-\alpha) \frac{\partial c}{\partial \alpha} + ac - u_g} = \frac{-dt}{1} = \frac{d\alpha}{f(\alpha, t, z)} \quad (14)$$

The partial differential equation can thus be solved and a and z determined along a characteristic by integrating the two ordinary differential equations for z and a ,

$$\frac{dz}{dt} = u_g - \alpha c + \alpha(1-\alpha) \frac{\partial c}{\partial \alpha} \quad (14')$$

$$\frac{d\alpha}{dt} = \dot{w}_g v_g v_f \left(\frac{1-\alpha}{v_f} + \frac{\alpha}{v_g} \right) - \alpha(1-\alpha) \frac{\partial \ln v_f/v_g}{\partial P} \frac{dP}{dt} - \alpha(1-\alpha) c \frac{d \ln A_V}{dz}$$

providing an expression for $\dot{w}_g$ can be found.

Inspection of Equation 14' shows how the void fraction (α) depends directly upon the changing cross sectional area of the vessel A_V . In particular when a constriction occurs $d \ln A_V / dz$ will be large and negative and thus the void fraction will rapidly increase in the vicinity. This buildup of α only causes problems when $u_g > 0$. Where $u_g < 0$ (i.e. when for a bottom blowdown, the rate is such as to pull the bubbles downward) the characteristic slope (dz/dt) is already negative and simply becomes more negative as seen in Equation 14'. If $u_g > 0$ a point occurs with increasing α that $dz/dt = 0$ which means physically that the gas cannot pass through the constriction. This effect has been observed experimentally. (17)

In this analysis the area of the vessel (A_V) and the bubble rise velocity (c) will be assumed constant. The treatment of the cases of variable area and bubble rise velocity is reserved for later papers.

Rate of Gas Generation, w_g

The rate of gas generation per unit volume ($\dot{w}_g$) can be found in terms of the rate of depressurization (dP/dt) by using Assumptions 4 and 5. In order to simplify this derivation, a pseudo-extended system is defined which encompasses all of the original fluid in the vessel at any later time t . Thus it includes all of the fluid currently in the vessel ($m_g + m_\ell$) and all of that which has flowed out of the vessel

$$\left(\int_0^t GA_E dt \right).$$

As far as is known at any point in the vessel, the depressurization could just as well be the result of a piston being withdrawn instead of an actual blowdown.

Using this device the whole extended system can be viewed as expanding isentropically and the mass and entropy equations are as follows.

$$\hat{m}_O = m_O = \hat{m}_R + \hat{m}_g = m_{RO} + m_{gO} = \text{constant} \quad (15)$$

$$\hat{m}_O \hat{s}_O = m_O s_O = \hat{m}_\ell s_f + \hat{m}_g s_g = \text{constant} \quad (16)$$

Eliminating $\hat{m}_\ell$ between Equations 15 and 16 results in equations for the amount of gas and liquid in the extended system.

$$\hat{m}_g = \frac{m_O (s_O - s_f)}{s_g - s_f}, \quad \hat{m}_\ell = \frac{m_O (s_g - s_O)}{s_g - s_f} \quad (17)$$

The overall rate of gas generation throughout the extended system is found by differentiating $\hat{m}_g$ in Equation 17.

$$\frac{d\hat{m}_g}{dt} = \left[-\frac{m_O}{s_{fg}} \left(\frac{\partial s_f}{\partial P} \right)_{\text{SAT}} - \frac{m_O (s_O - s_f)}{s_{fg}^2} \left(\frac{\partial s_g}{\partial P} - \frac{\partial s_f}{\partial P} \right)_{\text{SAT}} \right] \frac{dP}{dt} \quad (18)$$

or alternatively

$$\frac{d\hat{m}_g}{dt} = \frac{m_O}{s_{fg}^2} \frac{dt}{dt} \left[(s_O - s_g) \frac{\partial s_f}{\partial P} - (s_O - s_f) \frac{\partial s_g}{\partial P} \right]_{\text{SAT}} \quad (18')$$

From Equation 18, it is evident that $d\hat{m}_g/dt$ depends only upon P , P_O and dP/dt .

Assumption 5 is now used to find $\dot{w}_g$. If an infinitesimal volume δV containing a mass of liquid δm_ℓ is considered, then the vaporization rate is given by:

$$\dot{w}_g = \frac{1}{\delta V} \frac{\delta m_\ell}{m_\ell} \frac{dm_g}{dt} = \frac{1 - \alpha}{v_f m_\ell} \frac{dm_g}{dt} \quad (19)$$

$\dot{w}_g$ can be separated into two factors, $1 - \alpha$, which obviously depends only on α , and

$$g = \frac{1}{v_f m_\ell} \frac{dm_g}{dt} \quad (20)$$

which by inspection of Equations 17 and 18 is seen to depend only on P and dP/dt .

$$\dot{w}_g = (1 - \alpha) g \quad (21)$$

Using Equation 21, and now holding the area of the vessel, A_v , constant, the characteristic Equation 14' can be written

$$\frac{d\alpha}{dt} = -(g_2 \alpha^2 + g_1 \alpha + g_0) \quad (22)$$

where

$$\begin{aligned} g_0 &= -v_g g \\ g_1 &= (2 v_g - v_f) g + \frac{\partial \ln (v_f/v_g)}{\partial P} \frac{dP}{dt} \\ g_2 &= -(v_g - v_f) g - \frac{\partial \ln (v_f/v_g)}{\partial P} \frac{dP}{dt} \end{aligned} \quad (23)$$

The g_0 , g_1 , g_2 functions are seen to be sole functions of time once dP/dt is determined using Equation 5. The right hand side of Equation 22 thus only depends upon α and t , and can be integrated directly by numerical techniques to give α as a function of time on the characteristic. It remains to determine u_g so that Equation 14' can be integrated to obtain z at the same point and thus give α versus z throughout the vessel.

Gas Phase Velocity, u_g

An expression for the gas phase velocity u_g can be found by combining the infinitesimal mass and energy balances so as to eliminate the derivative of α with respect to time t . If Equation 8 is multiplied by v_g , Equation 9 multiplied by v_l , the results added and then combined with Equations 10 and 11, there is found

$$\frac{1}{A_V} \frac{\partial}{\partial z} \left(u_g A_V - c A_V + \alpha c A_V \right) + \dot{w}_g v_{fg} = \left[\alpha \frac{\partial \ln v_g}{\partial P} + (1 - \alpha) \frac{\partial \ln v_f}{\partial P} \right] \frac{dP}{dt} \quad (24)$$

Substitution of Equation 21 into 24 and partial integration yields

$$\begin{aligned} (u_g - c + c\alpha)A_V = & \left(-v_{fg} g + \frac{\partial \ln v_g}{\partial P} \frac{dP}{dt} - \frac{\partial \ln v_f}{\partial P} \frac{dP}{dt} \right) \int_{z_0}^z \alpha A_V dz \\ & + \left(v_{fg} g + \frac{\partial \ln v_f}{\partial P} \frac{dP}{dt} \right) \int_{z_0}^z A_V dz + C(t) \end{aligned} \quad (25)$$

From Equation 25, u_g can be found at any time t providing a , P and dP/dt are known.

$C(t)$ is a function only of time to be determined at z_0 . $C(t)$ takes on different values for the two possible cases of interest. First if z is less than z_E , z_0 is taken equal to 0. $a = 0$ at $z = 0$ since the bubbles rise as soon as they're formed and $u_g = c$ from Equation 11, since u_l must be zero at the wall. Therefore,

$$C(t) = 0 \quad [z < z_E] \quad (26)$$

Second, for the case of z in the foam and above z_E , $z_0 = z_E$. In this case at z_E , $u_g = u_g^+$, which is determined from mass and energy balances around the plane at z_E .

$$C(t) = (u_g^+ - c + c a_E^+) A_{VE} [z > z_E] \quad (27)$$

Equation 25 can be written in another form which may make clearer what the terms are that make up the expression for the gas phase velocity,

$$\begin{aligned}
 u_g &= c(1 - \alpha) + \frac{v_{fg}^g}{A_V} \int_{z_0}^z A_V (1 - \alpha) dz \\
 &\quad (1) \qquad (2) \\
 &+ \frac{1}{A_V} \frac{\partial \ln v_f}{\partial P} \frac{dP}{dt} \int_{z_0}^z A_V (1 - \alpha) dz \\
 &\quad (3) \\
 &+ \frac{1}{A_V} \frac{\ln v_g}{\partial P} \frac{dP}{dt} \int_{z_0}^z \alpha A_V dz + \frac{C(t)}{A_V} \\
 &\quad (4) \qquad (5)
 \end{aligned} \quad (25')$$

Term (1) is the steady state gas velocity at z which can be obtained from Equation 11 and a steady state volumetric rate balance. Term (2) is the component resulting from vaporization of liquid between z_0 and z . Term (3) is the component resulting from liquid phase density change between z_0 and z . Term (4) is the component resulting from gas phase density change between z_0 and z . Term (5) results from the lower boundary conditions.

Use of Equation 25 with either Equation 26 or 27 allows determination of u_g in the foam at any point in time. These values of u_g can then be combined into Equation 14' to determine values of z for the characteristics. This then completes the solution for the void fraction α as a function of z with the sole exception of the determination of u_g^+ necessary for Equation 27. u_g^+ is determined by making mass and energy balances at the withdrawal plane.

Balances at Withdrawal Plane

Three different situations are possible during blowdown either in different or the same blowdown.

- i. The withdrawal plane is above the foam. ($z_E > H$)
- ii. The withdrawal plane is in the foam. ($z_E \leq H$)
- iii. The withdrawal plane is at the bottom of the vessel. ($z_E = 0$)

In the first case, $h_E = h_g$ and nothing further is needed since the integration of Equations 5, 6, and 7 and all equations dependent on these can proceed directly. The second case is more complicated and requires that material and energy balances be written at the withdrawal plane.

$$\frac{u_g^- \alpha_E^- A_{VE}}{v_g} + \frac{u_\ell^- (1 - \alpha_E^-) A_{VE}}{v_f} - \frac{u_g^+ \alpha_E^+ A_{VE}}{v_g} - \frac{u_\ell^+ (1 - \alpha_E^+) A_{VE}}{v_f} = G A_E \quad (28)$$

$$\begin{aligned} & \frac{u_g^- \alpha_E^- A_{VE} h_g}{v_g} + \frac{u_\ell^- (1 - \alpha_E^-) A_{VE} h_f}{v_f} - \frac{u_g^+ \alpha_E^+ A_{VE} h_g}{v_g} \\ & - \frac{u_\ell^+ (1 - \alpha_E^+) A_{VE} h_f}{v_f} = G A_E h_E \end{aligned} \quad (29)$$

In these two equations there are essentially only three unknowns, u_g^+ , α_E^+ , and h_E . A_{VE} and A_E are known from the geometry. The values u_ℓ^- , u_ℓ^+ are replaced using Equation 11, while v_g , v_f , h_f , h_g come from knowledge of P . G depends only on P and h_E . Value α_E^- is determined by integration of the characteristic Equations 14 in the foam below z_E , and u_g^- is found from Equation 25. In most of these "known" variables dP/dt is required implicitly, and dP/dt depends on G which depends on h_E .

So if α_E^+ can be evaluated (which is shown to be possible below) what appears to be necessary is a rather elaborate iterative scheme in which h_E is assumed where necessary in Equations 1 through 27. Then all the variables in Equations 28 and 29 are determined except u_g^+ and h_E .

These two variables are then found by simultaneous solution of Equations 28 and 29 and the process is repeated using the computed values of h_E , until convergence. The void fraction just above the withdrawal plane, α_E^+ , can be determined in most cases by integration of Equation 14. When $(dz/dt) z_E^+ < 0$ the slopes of the characteristics just above z_E are negative which means α_E^+ must be determined by the conditions above z_E independently of those existing below z_E . However, when $(dz/dt) z_E^+ \geq 0$ the conditions below z_E influence those above z_E since in this case the gas bubbles are passing through the withdrawal plane. Another equation is needed to determine α_E^+ . It can be obtained by noting that the total volume of gas plus liquid above the withdrawal plane is constant.

$$\frac{dV^u}{dt} = 0 = u_g^+ \alpha_E^+ A_{VE} + u_\ell^+ (1 - \alpha_E^+) A_{VE} \quad (1) \quad (1')$$

$$+ \frac{m_\ell^u}{m_\ell} \frac{dm_g}{dt} v_{fg} + \left(m_g^u \frac{\partial v_g}{\partial P} + m_\ell^u \frac{\partial v_f}{\partial P} \right) \frac{dP}{dt} \quad (2) \quad (3) \quad (30)$$

In Equation 30, terms (1) and (1') represent the volume of gas or liquid which flows in or out of the upper volume;

(2) is the volumetric gas generation rate: (3) is the volume change induced by expansion. Equation 30 is valid for all values of (dz/dt) at z_E^+ , but is redundant when $[(dz/dt) \text{ at } z_E^+] < 0$. In this latter case it is merely an integral form

of the differential balances which lead to the characteristic Equation 14. When $[(dz/dt) \text{ at } z_E^+] \geq 0$, Equation 30 in combination with Equations 28 and 29 allow solution for α_E^+ , u_g^+ and h_E . These values of u_g^+ and α_E^+ provide the boundary conditions for integration of Equations 14 and 25 in the upper volume above z_E .

The third case for a bottom blowdown is simply a degenerate form of the second case in which the terms in Equations 28 and 29 for conditions below z_E simply vanish.

$$- \frac{u_g^+ \alpha_E^+ A_{VE}}{v_g} - \frac{u_l^+ (1 - \alpha_E^+) A_{VE}}{v_f} = GA_E \quad (31)$$

$$- \frac{u_g^+ \alpha_E^+ A_{VE} h_g}{v_g} - \frac{u_l^+ (1 - \alpha_E^+) A_{VE} h_f}{v_f} = GA_E h_E \quad (32)$$

Here again if $[(dz/dt) \text{ at } z_E^+] < 0$, α_E^+ is determined and the iterative solution for h_E and u_g^+ proceeds directly; if $[(dz/dt) \text{ at } z_E^+] \geq 0$, then Equation 30 must also be used.

Boundary and Initial Conditions

The void fraction profile at the initial time, t_0 , can be anything that is desired. For this study where blowdowns are occurring the following initial conditions are taken

$$\left. \begin{array}{l} \alpha = 0 \text{ for } z < H_0 \\ \alpha = 1 \text{ for } z \geq H_0 \end{array} \right\} t = t_0 \quad (33)$$

In the "steady-state" cases described where $P = P_0$ for all t , other void fraction profiles are assumed to investigate the behavior of the system. Once the void fraction profile is specified, u_g is immediately determined by Equation 25.

The boundary conditions on the vessel have already been given in the discussion above. Those at the withdrawal plane are given in Equations 28 and 29 (or possibly 31 and 32). a must equal zero at the bottom of the vessel when $z_E \neq 0$ because no bubbles can come from below, and when $z_E = 0$, a ($z = 0$) equals α_E^+ and is found as discussed above.

This then completes the set of equations necessary to determine the state of the fluid, the void fraction profile, and other values for the times after blowdown is initiated.

Method of Solution

In the derivations made above, it has been shown that the system during blowdown can be described by a set of ordinary differential equations. These equations can be grouped into five categories: 1. the overall balances - Equations 5, 6, and 7, and 2. through 5. which are the void fraction a and distance z for the characteristics in the upper volume above z_E and for those in the lower volume below z_E as given in Equation 14'. This set can be written in vector notation

$$\frac{d\bar{y}}{dt} = \bar{F}(\bar{y}, t) \quad (34)$$

where

$$\bar{y} = (P, m_g, m_l, \alpha_1^L, \alpha_2^L, \dots, \alpha_{NL}^L, z_1^L, \dots, z_{NL}^L, \alpha_1^U, \dots, \alpha_{NU}^U, z_1^U, \dots, z_{NU}^U) \quad (35)$$

In this form any one of a number of numerical integration methods can be used to obtain a solution provided that $\bar{F}$ can be readily calculated. The method chosen was a generalized Adams-Moulton predictor-corrector having fifth-order accuracy.⁽³⁾ The subroutine (AMSINT) used for this integration is reproduced in Appendix C. The problem is thus reduced to that of computing $\bar{F}$ given $\bar{y}$, since in this case $\bar{F}$ doesn't depend explicitly upon t .

The $\bar{y}$ vector is set up originally from the initial conditions and input specifications as to how many characteristics are to be defined for the upper (NU) and lower (NL) volumes. In order to facilitate later interpolations at z_E and H , extra fictitious lower characteristics above z_E and extra fictitious upper characteristics below z_E and above H are carried throughout the calculations. As the integration proceeds, the components of $\bar{F}$ are computed in a subroutine called DE given $\bar{y}$ (Appendix C) in the following order. The internal properties of fluid are obtained from P and the saturated steam tables. The required partial derivatives with respect to pressure (Equations 6, 7, 13 and 18) along the saturation curve are evaluated numerically from the tables. The term $\hat{m}_g$ is found from Equation 17. The terms α_E^+ and α_E^- are determined through interpolation in the $\bar{y}$ vector. The foam level H is found from the relation

$$m_\ell = \int_0^{z_E} \frac{A_V(1 - \alpha^L)}{v_f} dz + \int_{z_E}^H \frac{A_V(1 - \alpha^U)}{v_f} dz \quad (36)$$

if $z_E < H$ or if $z_E \geq H$ from

$$m_\ell = \int_0^H \frac{A_V(1 - \alpha^L)}{v_f} dz$$

The value of H is checked to see if $H > z_E$ and if so h_E is set equal to h_σ . If not a trial value of h_E is assumed from which $G(h_E, P)$ is calculated using Moody's critical flow model for two-phase flow through an orifice. ⁽¹⁾

From G and h_E , the first three components of $\bar{F}$ are obtained using Equations 5, 6, and 7. Since F_1 is dP/dt , $\dot{w}_g$ can be now computed using Equations 18 and 19 and then g from Equation 20. The u_g^L are found from Equation 25' at each of the lower

characteristics and u_g^- by interpolation in the results. The u_g^+ and the next iterate for h_E are finally determined from Equations 28 and 29 or 31 and 32. The initial guess for h_E is taken from the previous time step and convergence is assumed if the derived value of h_E differs from the original guess by less than 0.05 Btu/lb.

In the computation G can change drastically between time steps at transition ($H \approx z_E$). Most numerical integration schemes cannot handle such discontinuities. Therefore, the jumps in G can be smoothed with an exponential filter having a time constant substantially smaller than the oscillation rate typical for G when $H \approx z_E$ but long enough to stabilize the numerical integration procedure.

Once H has become less than z_E , the calculations for the upper characteristics are abandoned. If then H becomes greater than z_E , again, the values of h_E are found by interpolation from the lower characteristics. The foam level can never swing very far above z_E because of the great increase in critical flow for the two phases as compared with the single phase gas. Therefore, little error will occur by this method.

After h_E has been determined, the gas phase velocity on the upper characteristics, and g_0 , g_1 , and g_2 are calculated. The rest of the components for $\bar{F}$, which are the $d a^L/dt$, $d \alpha^U/dt$, $d z^L/dt$, $d z^U/dt$, can then be computed using Equation 14'.

Dimensional Analysis

Dimensional analysis may be applied to a set of differential equations which model a physical system in order to determine the basic set of parameters which control the behavior of the system. Usually these parameters consist of ratios of the coefficients of the describing differential equations in combination with geometric quantities. Most non-linear

parts of the model cannot be treated by dimensional analysis and this type of analysis is therefore usually valid only for fixed values of the non-linear quantities.

For the system considered in this report the equation of state for water, the critical flow function, G , and the thermodynamic path followed are the non-linearities. Therefore, comparisons of system behavior for fixed values of the basic set of parameters is limited to the same initial pressure, P_o , the same relative quantities of gas and liquid (m_{g_o} and m_{l_o}) expressed as some dimensionless quantities, and the same initial void fraction distribution expressed as some function of a dimensionless distance.

The first problem is to select the normalizing mass and distance for the system. This is done by considering Equation 33 which is used to determine the foam level H at any time t , this quantity being the response variable of most interest in this study. Rewriting Equation 36

$$m_l = \int_0^H \frac{(1 - \alpha)}{v_f} A_V dz \quad (36')$$

Now if m_l is normalized with the initial liquid mass m_{l_o} and z with the vessel height L , for the case of a constant area vessel, Equation 36' can be written as

$$\begin{aligned} m_l/m_{l_o} &= \int_0^{H/L} \frac{L}{H_o} \frac{(1 - \alpha)}{v_f} \frac{A_V H_o}{m_{l_o}} d\left(\frac{z}{L}\right) \\ &= \int_0^{H/L} \frac{L}{H_o} (1 - \alpha) \frac{v_{f_o}}{v_f} d\left(\frac{z}{L}\right) \end{aligned} \quad (36'')$$

Since this selection gives a very neat expression for the foam level H in terms of dimensionless quantities, the normalizing mass and distance for the system are chosen to be m_{l_o} and L , respectively.

In the ensuing analysis for clarity of presentation the functions f_n are defined as needed. The f_n encompass all the non-linearities of the system but are independent of the geometry and bubble-rise velocity c . Thus, Equations 5, 6, and 7 may be written

$$\begin{aligned}\frac{dP}{dt} &= \frac{A_E}{m_{\ell o}} f_0 \\ \frac{d\left(\frac{m_g}{m_{\ell o}}\right)}{dt} &= \frac{A_E}{m_{\ell o}} f_1 \\ \frac{d\left(\frac{m_\ell}{m_{\ell o}}\right)}{dt} &= \frac{A_E}{m_{\ell o}} f_2\end{aligned}\tag{37}$$

Following Moody⁽¹³⁾ a dimensional time

$$t^* = \frac{A_E}{m_{\ell o}} t\tag{38}$$

is now introduced. However, here t^* is based upon the initial mass of liquid rather than the total initial mass as was used by Moody.⁽¹³⁾

Thus Equation 37 can be expressed

$$\begin{aligned}\frac{dP}{dt^*} &= f_0 \\ \frac{d\left(\frac{m_g}{m_{\ell o}}\right)}{dt^*} &= f_1 \\ \frac{d\left(\frac{m_\ell}{m_{\ell o}}\right)}{dt^*} &= f_2\end{aligned}\tag{37'}$$

The gas phase velocity Equation 25 can be normalized using the bubble rise velocity c (= constant)

$$\frac{u_g}{c} = (1 - \alpha) + \frac{A_E}{m_{\ell 0}} \frac{L}{c} f_3 \quad (38)$$

as can the Equation 14' for the position of the characteristic

$$\frac{d(z/L)}{dt^*} = \left(\frac{u_g}{c} - \alpha \right) \frac{m_{\ell 0} c}{A_E L} \quad (39)$$

The Equation 14' for the void fraction on the characteristic becomes (constant A_V)

$$\frac{d\alpha}{dt^*} = f_4 \quad (40)$$

The equations for the balances at the withdrawal plane can be written.

$$\begin{aligned} \frac{u_g^-}{c} \frac{\alpha_E^-}{v_g} + \frac{u_\ell^-}{c} \frac{1-\alpha_E^-}{v_f} - \frac{u_g^+}{c} \frac{\alpha_E^+}{v_g} - \frac{u_\ell^+}{c} \frac{1-\alpha_E^+}{v_f} &= G \frac{A_E}{c A_V} \\ \frac{u_g^-}{c} \frac{\alpha_E^- h_g}{v_g} + \frac{u_\ell^-}{c} \frac{(1-\alpha_E^-) h_f}{v_f} - \frac{u_g^+}{c} \frac{\alpha_E^+ h_g}{v_g} - \frac{u_\ell^+}{c} \frac{(1-\alpha_E^+) h_f}{v_f} &= \frac{G A_E h_E}{c A_V} \end{aligned} \quad (41)$$

It is now noted that

$$\frac{H_0}{L} \frac{A_E L}{m_{\ell 0} c} = \frac{A_E v_{f0}}{c A_V} \quad (42)$$

Finally, inspection of the equations derived in this section shows that if the following dimensionless variables are selected, namely: $m_g/m_{\ell 0}$, $m_\ell/m_{\ell 0}$, z/L , u_g/c , u_ℓ/c , a ; and if the initial conditions P_0 , α_0 (z/L), and H_0/L are given; and if the vessel parameter z_E/L is given; then the system response is completely specified as a function of the dimensional time t^* and the parametric grouping $A_E/A_V c$ which is the same as

Moody⁽¹³⁾ concluded and has been observed experimentally.⁽⁷⁾ However, in this study the initial mass of liquid was chosen as the normalizing factor rather than the total mass $m_{go} + m_{lo}$ as Moody⁽¹³⁾ chose. In reality this normalizing mass is a bit arbitrary. It is this author's opinion that m_{lo} is preferred because of the groupings GA_E/m_{lo} which occurs as a result of this selection. This is the length of two phase blowdown for the instantaneous mass flux G .

RESULTS

A large number of test cases have been run on a digital computer using the Bubble Rise Phenomena (BURP) code which is based on the model developed in this paper and is presented for the most part in Appendix C. Instructions as to the format of the input data deck of cards is given in Appendix B. The limitations of the code are also described in Appendix C. The results of the test cases that have been run are described in this section and presented in the figures using the dimensional and dimensionless parameters developed in the last part of the previous section. The three major cases of bottom, middle, and top blowdowns are considered for a constant area vessel with constant bubble-rise velocity. The differences between a full and 3/4-full vessel are noted in the first two cases. Some of these results are compared with those predicted by Moody,⁽¹³⁾ and by FLASH2.⁽²⁾ Finally, the model predictions are compared with some very recently acquired data from the Containment Systems Experiment reactor simulator vessel.

Steady State

Before considering what the model predicts for the cases of bottom, middle, and top blowdowns, it will be instructive to see what occurs for two steady-state cases ($P = P_0 = \text{constant}$) where initial void fraction distributions are assumed in the foam. For $P = \text{constant}$ the describing equations take on quite

simple forms as would be expected. To begin with Equation 25' for the gas phase velocity becomes

$$u_g = c (1 - \alpha) \quad (43)$$

so that once α is specified u_g is determined as is u_ℓ from Equation 11.

$$u_\ell = -\alpha c \quad (44)$$

The equations for the characteristics in the case of a constant area vessel and constant bubble rise velocity are now:

$$\frac{d\alpha}{dt} = 0 \quad (45)$$

$$\frac{dz}{dt} = u_g - \alpha c = c (1 - 2 \alpha)$$

Equation 45 implies that the void fraction will be constant on a characteristic. As a result, the slope of the characteristic, will be constant and be given by

$$\frac{dz}{dt} = c (1 - 2 \alpha_0) \quad (46)$$

If as a first case a void fraction profile is assumed, which is linear in z for a while and then constant, like that shown in Figure 2 at $t = 0$, the characteristic behavior will be like that of Figure 3 ($c = 2$ ft/sec assumed). This type of initial profile is similar to those which develop during either middle or top blowdowns. It is seen from Figure 3 that the characteristics originating in the linear portion of the initial profile eventually intersect. This corresponds to a type of shocking phenomenon which is pictured in Figure 2. The front is completely established by 0.25 sec and remains intact until the gas is disengaged from the foam (at $t = 0.429$ sec). This type of shocking phenomenon is typical of hyperbolic partial differential equations of which the model herein is an example. This same type of behavior can occur sometimes in the

Neg 0695613-3

FIGURE 2. Void Fraction Profile - Steady-State Case 1

Neg 0695613-4

FIGURE 3. Characteristic Behavior- Steady-State Case 1

dynamic case of top blowdown or middle blowdown wherein $z_E > H$. Treatment of such cases is straightforward graphically but leads to extremely complicated coding if the problem is to be solved on a computer. Fortunately, the problem doesn't occur in bottom blowdowns.

For the second constant pressure, a sawtooth profile such as is shown in Figure 4 for $t = 0$ is assumed. The behavior of the profile with time should give some indication of what will happen in the most general case of a profile arbitrarily varying with distance. The behavior of the characteristics for this system is pictured in Figure 5. As is seen, the characteristics originating in the linear portions of the profile having $d\alpha_0/dz > 0$ eventually intersect, whereas those originating where $d\alpha_0/dz < 0$ diverge. The corresponding image in Figure 4 shows the developing shock described before, as well as the lengthening tail. After the shock has been established, the two sets of diverging characteristics begin intersecting and the result is a reduction in the heights of the peaks and in the shocks, a sort of piling up of the void fraction. Eventually, therefore, the profile will become smooth.

Bottom Blowdown

Bottom blowdowns are divided into two classes depending upon whether the gas phase velocity is greater than zero at the effluent plane, $z_E = 0$. Moody⁽¹³⁾ has named these classes "liquid" and "mixture" blowdowns, respectively. If $u_g \geq 0$, Equation 31 can be written (since α_E^+ will equal 0.)

$$-\frac{GA_E}{A_V} - \frac{u_\ell^+}{v_f} \geq 0 \quad (47)$$

or alternatively using Equation 11

$$\frac{GA_E}{A_V} \leq \frac{u_\ell^+}{v_f} \leq \frac{c}{v_f} \quad (48)$$

Neg 0695613-21

FIGURE 4. Void Fraction Profile - Steady-State Case 2

Neg 0695613-22

FIGURE 5. Characteristic Behavior - Steady-State Case 2

Rewriting Equation 48 to obtain the dimensional group derived above, we have

$$\frac{A_E}{A_V c} \leq \frac{1}{v_f G} \quad (49)$$

which is the same condition as Moody⁽¹³⁾ obtained for "liquid" blowdowns. Typically for the cases considered below of $P_o = 1000$ psia, $\frac{1}{v_f G}$ is about 0.006.

If $u_g^+ < 0$ (mixture blowdown) according to Equation 14', (dz/dt) is less than zero at $z = z_E = 0$. (dz/dt) increases with z , becoming greater than zero as u_g increases with z , because of the contribution of terms 1 and 4 in Equation 25'. This means that all characteristics which are located in the foam at any time t were originally located in the foam at $t = 0$. Therefore, since the right hand side of Equation 14' for a is independent of z in the case of a constant area vessel, the equations and initial conditions for a are the same on all characteristics in the foam. Hence, a must be constant throughout the foam at any given time t . This situation occurs also in the case of middle blowdowns where u_g^+ is less than zero.

If α is constant in the foam above z_E , the gas phase and liquid phase velocity profiles must be linear in z for a constant bubble-rise velocity and constant area vessel. This is readily seen upon examination of Equation 25. In this situation, the coefficients of the dz under the integral signs are constant with respect to z and can be factored out leaving

ρz

3/4-Full Vessel

The overall properties during the bottom blowdown of a 3/4-full vessel are given in Figures 6a, b, c, and d. The mass velocity, pressure, total weight, and effluent void fraction are presented as functions of the dimensional time - $t^* = A_E / m_{\ell 0} t$. The variation with the value of the parameter $A_E / A_V c$ is shown. $A_E / A_V c = 0$ is representative of a "liquid" blowdown, or a small break, or a very large bubble rise velocity, and is set off distinctly from the other curves. $A_E / A_V c = \infty$ is the case where no disengagement of the gas takes place at all. There is some variation of the overall properties curves as $A_E / A_V c$ varies between 0.01 and ∞ which is different than Moody⁽¹³⁾ noted; however, the differences are slight and in some cases indistinguishable (e.g; pressure curves for $A_E / A_V c = 0.1$ to ∞) on the scales used. The curves are only plotted up to transition - that is where the vapor phase begins to come through.

Figure 7 shows the variation in the behavior of the foam level with t^* for different values of $A_E / A_V c$. The separation of the curves is quite distinct in this case as compared to the overall properties behavior.

Full Vessel

The overall properties during a bottom full vessel blowdown are given in Figures 8a, b, c, and d. These curves are similar to those for the 3/4 full vessel when plotted in terms of the dimensional parameters as shown. However, the two-phase portion of the blowdown lasts longer in terms of t^* in this case.

The foam level remains higher for much longer periods in terms of t^* for the same values of $A_E / A_V c$ as compared with the 3/4-full vessel. During the latter portions of the blowdown

Neg 0695613-23

FIGURE 6a. Overall Properties During Bottom Blowdown
(3/4 Full Vessel)

Neg 0695613-44

FIGURE 6b. Overall Properties During Bottom Blowdown
(3/4 Full Vessel)

Neg 0695613-24

FIGURE 6c. Overall Properties During Bottom Blowdown
(3/4 Full Vessel)

Neg 0695613-16

FIGURE 6d. Overall Properties During Bottom Blowdown
(3/4 Full Vessel)

Neg 0695613-17

FIGURE 7. Foam Level During Bottom Blowdown (3/4 Full Vessel)

Neg 0695613-18

FIGURE 8a. Overall Properties During Bottom Blowdown
(Full Vessel)

Neg 0695613-19

FIGURE 8b. Overall Properties During Bottom Blowdown
(Full Vessel)

Neg 0695613-20

FIGURE 8c. Overall Properties During Bottom Blowdown (Full Vessel)

Neg 0695613-9

FIGURE 8d. Overall Properties During Bottom Blowdown (Full Vessel)

Neg 0695613-10

FIGURE 9. Foam Level During Bottom Blowdown (Full Vessel)

the void fraction in the foam is very high and it is somewhat questionable whether such high levels of H could be maintained or whether surface tension effects would cause the foam to collapse (see Figure 9).

Middle Blowdown

3/4-Full Vessel

The overall properties of mass velocity, pressure, total weight and effluent void fraction during a blowdown from middle nozzle for an initially 3/4-full vessel is shown in Figure 10. The curves for A_E/A_{Vc} between 0.01 and ∞ are very close to being identical in this case, much more so than in the case of bottom blowdown. Only when the foam level history is considered in Figure 11 is much difference noted.

The foam level drops to the withdrawal plane at z_E where the predicted blow into the nozzle oscillates between single-phase and two-phase. The single-phase critical flow rate is much lower than that of the two-phase and thus the foam swells and the more rapid two-phase rate occurs again. The net effect is that the foam level will remain at z_E for some time. At this point the assumptions of one-dimensionality and the infinitesimally small withdrawal plane at z_E can be seriously questioned. Most likely during an actual blowdown fluids from both the vapor and the foam will enter the nozzle of finite width in the "z" dimension. However, the net effect in time is probably the same. This problem will be considered in a later paper and here only the period up to transition ($H \approx z_E$) will be considered.

Full Vessel

The overall properties during a middle nozzle blowdown from an initially full vessel are shown in Figure 12. Here as in the case of the 3/4-full vessel, there is little distinction

Neg 0695613-11

FIGURE 10a. Overall Properties During Middle Blowdown (3/4 Full Vessel)

Neg 0695613-12

FIGURE 10b. Overall Properties During Middle Blowdown (3/4 Full Vessel)

Neg 0695613-13

FIGURE 10c. Overall Properties During Middle Blowdown (3/4 Full Vessel)

Neg 0695613-14

FIGURE 10d. Overall Properties During Middle Blowdown (3/4 Full Vessel)

Neg 0695613-15

FIGURE 11. Foam Level During Middle Blowdown (3/4 Full Vessel)

Neg 0695613-33

FIGURE 12a. Overall Properties During Middle Blowdown (Full Vessel)

Neg 0695613-35

FIGURE 12b. Overall Properties During Middle Blowdown (Full Vessel)

Neg 0695613-34

FIGURE 12c. Overall Properties During Middle Blowdown (Full Vessel)

Neg 0695613-37

FIGURE 12d. Overall Properties During Middle Blowdown (Full Vessel)

for values of $A_E/A_V c$ between 0.01 and ∞ . For reference the complete blowdown history through transition is included for the case of $A_E/A_V c = 0$, which corresponds to an infinite bubble rise velocity and complete and instantaneous disengagement of the gas phase from the foam.

The foam level histories for this case are presented in Figure 13. As in the case of the bottom blowdown the foam level remains higher for a longer period of time. The void fraction again is close to 1.0 during the latter part of the blowdown.

General

As in the case of bottom blowdown, when $A_E/A_V c$ is greater than approximately 0.006 for a P_o of 1000 psia, the void fraction profile is constant above z_E . However, below z_E the profile changes in shape with time as the "influence" of the bottom propagates up into the foam. These effects are noted in Figure 14. The velocity of the propagation is not quite as fast as the gas phase velocity resulting in Equation 14'. The difference can be thought of as the result of the liquid phase dropping in to fill the space left by the rising gas bubbles.

The jump in the void fraction at z_E in the profile for $t = 4.0$ sec might seem unusual upon first inspection. In this case, both u_g^- and u_l^- are positive as can be seen from Figure 15 and Equation 11. The terms u_g^+ and u_l^+ are negative. The result is that two streams are flowing into z_E , one from above and the other from below and thus such a jump in void fraction is to be expected.

Figure 15 gives the gas phase velocity profiles for the same case as is shown in Figure 14. The term u_g is seen to be linear in z for z greater than z_E . This is a result of the constant a in this region as was discussed in the foregoing.

Neg 0695613-31

FIGURE 13. Foam Level During Middle Blowdown (Full Vessel)

Neg 0695613-1

FIGURE 14. Void Fraction Profile, Middle Blowdown

Neg 0695613-2

FIGURE 15. Gas Phase Velocity Profile, Middle Blowdown

The velocity profile below z_E is curved and, generally decreases with time and then increases. The profiles for the liquid phase velocity are identical but displaced, in this case of a constant bubble rise velocity of $c = 2$ ft/sec.

Top Blowdown

Blowdown from the top of a reactor vessel differs from the two previously considered cases in that initially vapor phase alone flows critically out of the vessel (except in the special case of a completely full vessel). For some top blowdowns only the vapor phase is withdrawn; however, in most cases, after the initial vapor phase blow, two-phase blowdown begins because the foam level has swelled right up to the top of the vessel. The behavior of the system under conditions of top blowdown differs little, qualitatively speaking, when the initial fluid level is varied. Therefore, only the case of a 1/2-full vessel is considered.

1/2-Full Vessel

The overall properties of mass velocity, pressure, and total vessel weight during a top blowdown of vapor phase alone are presented in Figure 16. The effluent void fraction in this case is always 1.0. The single phase blowdown occurs in the case of 1/2-full vessel for values of $A_E/A_V c$ less than approximately 0.001. The most noteworthy item in comparing these plots with those given earlier is the concave nature of the pressure and mass velocity curves in the former case as compared with the convex nature of the latter.

The foam level during the blowdown is given in Figure 17. The value of $A_E/A_V c = 0$. corresponds to complete disengagement of the gas phase from the foam. The 0.0005 curve shows the typical case of swell followed by decrease. The 0.001 curve terminates because the current version of the computer program is unable to handle cases of intersecting characteristics which

Neg 0695613-36

FIGURE 16a. Overall Properties During Top Blowdown
(1/2 Full Vessel)

Neg 0695613-38

FIGURE 16b. Overall Properties During Top Blowdown
(1/2 Full Vessel)

Neg 0695613-39

FIGURE 16c. Overall Properties During Top Blowdown
(1/2 Full Vessel)

occurs at this point. The $A_E/A_{Vc} = 0.002$ and greater curves indicate that the foam swells to the vessel top causing **two-phase blowdown** to ensue. This event is also shortly followed by the characteristics intersecting.

The void fraction profiles at various times during a typical blowdown are given in Figure 18 for the value of $A_E/A_{Vc} = 0.001$. Again, the constant value of void fraction in the upper part of the foam is observed. This constant part of the curves corresponds to the region of the foam whose characteristics originated in the foam at time zero. This is apparent upon inspection of Figure 19 where the characteristic behavior is plotted.

Another interesting feature of void fraction profiles is the overlapping, almost linear portions in the lower part of the foam. This is reflected in the almost uniform spacing of the characteristics originating after time zero. These latter characteristics converge whereas those in the foam at time zero diverge. The convergence causes the "shocking" phenomenon

Neg 0695613-26

FIGURE 17. Foam Level During Top Blowdown
(1/2 Full Vessel)

Neg 0695613-32

FIGURE 18. Void Fraction Profiles During Top Blowdown
(1/2 Full Vessel)

Neg 0635613-42

FIGURE 19. Characteristics Behavior During Top Blowdown
(1/2 Full Vessel)

apparent in the $t = 32$ curve of Figure 18. This is very much like what occurs in the steady-state case discussed in the foregoing.

COMPARISONS

With Moody's Predictions

Moody⁽¹³⁾ has also studied the problem considered in this paper: that of liquid-vapor action in a reactor vessel under conditions of blowdown. It appears as though he took the three cases of blowdown (top vapor, bottom liquid, and bottom mixture) studied in his earlier paper⁽¹⁾ to ascertain the overall properties of a particular blowdown, namely the mass velocity, pressure and total weight of fluid histories. Then using these overall histories, a set of equations describing the liquid-vapor action in terms of a moving coordinate system (that of the bubble plane) were integrated graphically to obtain the foam level history. He then expressed his results in terms of the parameter $A_E/A_V c$ (as is done here) and the dimensional time $t_M^* = A_E/m_{t0} t$ (here $t^* = A_E/m_{\ell 0} t$ is used). Some of his results are presented and compared with those of BURP (computer code based on the model presented here) in Figure 20a and b wherein plots versus t^* are made.

Moody's bottom-liquid blowdown corresponds to BURP's with $A_E/A_V c = 0.$, and when the respective overall and foam level histories are compared no differences are noted. In the case of top vapor blowdown again no differences are seen when the overall histories are compared. However, in the case of bottom mixture blowdowns ($A_E/A_V c \geq 0.006$) a marked difference is seen in the overall histories and this is exemplified in particular for the pressure as seen in Figure 20b. The difference is presumably caused by the different boundary conditions assumed at the withdrawal plane ($z_E = 0.$). Moody assumed that the effluent void fraction would be equal to that in the foam

Neg 0695613-29

FIGURE 20a. Comparison of Moody and BURP Predictions, Foam Level for Bottom Blowdown

Neg 0695613-30

FIGURE 20b. Comparison of Moody and BURP Predictions, Pressure for Bottom Blowdown

whereas in the case of BURP Equations 31 and 32 are used. The result is that BURP predicts different overall histories for different values of $A_E/A_V c$ whereas Moody shows only one.

The foam level histories for bottom blowdown are compared in Figure 20a. For the mixture cases ($A_E/A_V c \geq 0.006$) they are quite different. It is especially puzzling that Moody's model predicts a rise after an initial decrease in foam level. This would appear to violate the assumption that no direct transfer of liquid to gas (or vice versa) will occur at the foam-vapor interface, since such a rise would compress the vapor phase and cause condensation.

The marked differences in slope of the foam level at time zero between BURP and Moody's is also of concern. Possibly this might be caused by the different boundary condition mentioned above. As will be noted below, neither the later swell or the initial steep slope of the foam level curve predicted by Moody are observed in experimental data.

The predictions of BURP and Moody of foam level for top blowdown are compared in Figure 20c. As is seen, the foam levels predicted for complete vapor disengagement ($A_E/A_V c = 0.0$) are identical as would be expected, since this is only dependent upon the vapor critical flow model used. However, the cases of $A_E/A_V c = 0.001$ are markedly different with BURP predicting a much greater swell. Presumably this results from the different bubble-rise velocity models which were assumed. Whereas, BURP has $c = \text{constant}$, Moody's assumption when put on the same basis as in this paper is:

$$c = \frac{\text{constant}}{1 - a}$$

This results in a much greater rate of vapor disengagement as the void fraction a increases during the blowdown, and hence

Neg 0695613-41

FIGURE 20c. Comparison of Moody and BURP Predictions, Foam Level for Top Blowdown

the predicted foam level would be lower. Unfortunately, the current computer code (BURP) could not handle such a velocity dependence on a , and direct comparison is therefore difficult.

With FLASH2 Predictions

The predictions of FLASH2 are compared with those of BURP for a middle blowdown of a 3/4-full vessel in Figure 21. The differences between these two predictions are quite small, especially in the pressure and foam level histories. This is to be expected when it is noted that: FLASH2 uses the Moody critical flow model as does BURP; FLASH2 uses an effluent void fraction (α_E) determined either by assuming that it is equal to the value obtained from a constant profile or one obtained from an assumed linear profile (e.g.: Quality Gradient factor $\neq 0$.) whereas in BURP the material balance at the withdrawal plane is used - Equations 31 and 32. These latter equations will give values of α_E for BURP very close to those given by FLASH2 in this case.

The predictions of BURP and FLASH2 are compared for the case of a top vapor blowdown in Figure 22. The pressure and mass velocity histories are necessarily identical. The predictions of foam level, however, are very different for the same parameters. This results from the different models used by FLASH2 and BURP for the rate of vapor disengagement from the foam, $\dot{m}_{gH}$. BURP effectively uses

$$\dot{m}_{gH}^o = \frac{\alpha_H A V^c}{v_g} \text{ whereas FLASH2 uses the average void fraction } (\bar{\alpha})$$

in place of α_H (the void fraction at the interface). Inspection of Figure 18 will indicate that use of $\bar{\alpha}$ will be a gross error. The result is that the rate $\dot{m}_{gH}^o$ is too low in FLASH2 and it will predict a foam level too high in the case of top

Neg 0695613-8

FIGURE 21(a)

Neg 0695613-5

FIGURE 21(b)

FIGURE 21 (a and b). Comparison of FLASH2 Predictions with Those of BURP Middle Blowdown, 3/4 Full Vessel

Neg 0695613-7

FIGURE 21(c).

Neg 0695613-6

FIGURE 21(d).

FIGURE 21 (c and d), Comparison of FLASH2 Predictions with Those of BURP Middle Blowdown, 3/4 Full Vessel

Neg 0695613-40

FIGURE 22. Comparison of FLASH2 Predictions of Foam Level with Those of BURP - Top Blowdown, 1/2 Full Vessel

blowdown. In the case of middle and bottom blowdowns, the error in using $\bar{\alpha}$ for α_H is small as can be seen upon looking at Figure 14.

With CSE Experimental Data

The initial conditions and vessel parameters used as input to the BURP code in making comparisons with two experimental blowdown runs made at CSE are listed in Table 1. The details of how the data for the runs were collected has been given elsewhere^(7,8,17) as has a description of the experimental facility.

The experimental conditions had to be converted to those for an equivalent cylindrical vessel since BURP is unable to handle cases involving variable area of the vessel. Both runs were actually fired with a slight overpressure of nitrogen, so the initial pressure P_0 was selected to be the saturation pressure at the initial fluid temperature.

Whenever the BURP code or any other code which uses the Moody critical flow model is to be used to predict the results of an experimental blowdown run, a constant orifice coefficient must be used to obtain the effective area of the effluent orifice. The correct value can be obtained by requiring the prediction of the pressure history to match that of the data. This was done in the cases compared here.

The comparison of BURP's predictions with that of the experimental data is given in Figure 23 for Run B53BTN and Figure 24 for Run B28MN. The pressure history predictions are quite good, pointing up again that with the proper orifice coefficient Moody's critical flow model does quite well in prediction of pressure histories. BURP's prediction of the foam levels for both runs is quite acceptable. In a way, the

TABLE 1. Experimental Blowdown Run Conditions for Comparison with Model Predictions

<u>Run Number</u> <u>Type Run</u>	<u>B53BIN</u> <u>Top Nozzle</u>	<u>B28N</u> <u>Middle Nozzle</u>
<u>Actual Vessel Conditions</u>		
Initial Pressure	995 ^(a)	1047 ^(a) psia
Initial Temperature	541	537 °F
Initial Liquid Level	9.45	13.0 ft
Vessel Height	17.0	17.0 ft
Vessel Volume	152	152 ft ³
Effluent Nozzle Height	12.8	3.7 ft
Nozzle Area (A_E)	0.0156	0.147 ft ²
<u>Equivalent Cylindrical Vessel Conditions</u>		
Initial Pressure (P_o)	970 ^(a)	943 ^(a) psia
Initial Liquid Level (H_o)	8.82	12.10 ft
Vessel Height (L)	15.85	15.85 ft
Vessel Volume ($A_V L$)	152	152 ft ³
Effluent Nozzle Height (Z_E)	15.62	3.54 ft
Effective Nozzle Area ($C_E A_E$)	0.0120	0.1098 ft ²
Nozzle Coefficient (C_E)	0.77	0.752
Initial Liquid Weight (M_{lo})	3920	5488 lb
Vessel Area (A_V)	9.57	9.57 ft ²
Bubble Rise Velocity (C)	2.0	2.5 ft/sec

a. NOTE: Blowdown runs were initiated slightly subcooled, so saturation pressures were used for the model comparisons.

Neg 0695613-28

FIGURE 23(a) .

Neg 0695613-27

FIGURE 23(b) .FIGURE 23 (a and b).Comparison of BURP Predictions with CSE
Data, Top Blowdown, Run B53BTN

Neg 701374-1

FIGURE 24 (a) .

Neg 701374-2

FIGURE 24 (b) .

FIGURE 24 (a and b). Comparison of BURP Predictions with CSE Data, Middle Blowdown, Run B28MN

bubble-rise velocity used in the two cases can be thought of as another parameter to make the model fit the data similar to that of the orifice coefficient. Both have to be determined empirically. It is encouraging that the bubble rise velocities required for the best fit to the foam level histories are reasonably close to the experimental values. (16)

CONCLUSIONS

The following conclusions can be drawn in light of the results obtained in this study.

1. The model derived in this study and implemented in the computer code BURP predicts pressure, and foam level histories for top, middle and bottom blowdowns satisfactorily.
2. However, two empirical parameters - the effluent orifice coefficient and bubble rise velocity - are required in order to match experimental data.
3. The assumption of a constant or linear void fraction profile as is done in some lumped parameter codes, e.g. FLASH2 - is not valid. The actual profiles differ markedly from either of these assumptions.
4. However, the assumption of a linear or constant void fraction leads to an adequate prediction of foam level by the lumped parameter codes in the cases of bottom and middle nozzle blowdowns.
5. The average void fraction or one predicted by a linear void fraction profile for the interface, should not be used in an expression for vapor disengagement in the case of top vapor blowdowns because of the prediction of overly high foam levels that would result.
6. Some more realistic way to handle the boundary condition at the effluent point from the vessel should be developed.

The assumption of an infinitesimally thin mathematical plane (whereas in actuality it is a pipe opening of finite size) not only is unrealistic, but it leads to numerical problems when the foam level passes the point. This is true in both BURP and FLASH2.

7. It is not recommended that BURP or some extension of it be developed to replace existing lumped parameter codes. The detailed integration carried out in BURP is not necessary if its results can be implemented simply into a lumped code.
8. The work with BURP should be extended so as to determine the effects of variable vessel area and a bubble rise velocity which is dependent upon void fraction.

TABLE OF NOMENCLATURE

A	- area (ft^2)
c	- relative bubble rise velocity (ft/sec)
$\vec{F}$	- vector function
f	- defined by Equation 12
G	- mass flux ($\text{lb}/\text{ft}^2 \text{ sec}$)
g, g_0, g_1, g_2	- defined by Equations 20 and 23
H	- height of foam (ft)
h	- specific internal enthalpy (Btu/lb)
L	- length of vessel (ft)
m	- mass of fluid (lb)
P	- pressure ($\text{lb}/\text{in.}^2$)
s	- specific internal entropy ($\text{Btu}/\text{lb} - ^\circ\text{R}$)
t	- time (sec)
U	- specific internal energy (Btu/lb)
u	- velocity of phase (ft/sec)
V	- volume of vessel (ft^3)
v	- specific volume (ft^3/lb)
$\dot{w}_g$	- rate of vaporization ($\text{lb}/\text{ft}^3\text{-sec}$)
z	- axial distance from bottom of vessel (ft)
Δ	- defined by Equation 4
α	- void fraction of gas phase ()
δ	- infinitesimal operator

Subscripts

f	- saturated liquid
g	- saturated vapor
fg	- vaporization
l	- saturated liquid
o	- initial value
V	- vessel

E	- withdrawal plane or fluid
SAT	- saturated conditions
NL	- number of characteristics selected for lower volume below z_E
NU	number of characteristics selected for upper volume above z_E

Superscripts

+	- infinitesimal distance above withdrawal plane
-	- infinitesimal distance below withdrawal plane
^	- pseudo-extended system
u	- upper volume above withdrawal plane

REFERENCES

- F. J. Moody. "Maximum Flowrate of a Single Component Two Phase Mixture," J. Heat Transfer, Series C 87, p. 134. February 1965.
- J. A. Redfield, J. H. Murphy and V. C. Davis. FLASH2: A Fortran IV Program for the Digital Simulation of a Multinode Reactor Plant During Loss of Coolant, WAPD-TM-666. Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, April 1967.
3. D. L. Shell. Ordinary Differential Equation Solution System, DF58AGT679. General Electric Company, Schenectady, New York, September 1958.
4. S. Levy. Prediction of Two-Phase Critical Flowrate, GEAP-4395. General Electric Company, Schenectady, New York, October 1963.
5. H. K. Fauske. Contribution to the Theory of Two-Phase One Component Critical Flow, ANL-6633. Argonne National Laboratory, Argonne, Illinois, October 1962.
6. J. E. Cruver and R. W. Moulton. "Critical Flow of Liquid-Vapor Mixture," A.I.Ch.E. J., vol. 1, p. 52. 1967.
7. Nuclear Safety Quarterly Report for July, August, September, and October 1967, BNWL-754. Battelle-Northwest, Richland, Washington, June 1968.
8. Nuclear Safety Quarterly Report for August, September, October 1968, BNWL-926. Battelle-Northwest, Richland, Washington, December 1968.
9. T. A. Harris. "Analysis of the Coolant Expansion Due to a Loss-of-Coolant Accident in a Pressurized Water, Nuclear Power Plant," Nucl. Sci. Eng., vol. 3, pp. 238-244. 1959.
10. A. N. Nahavandi. "A Digital Computer Analysis of Loss of Coolant Accident for a Multicircuit Core Nuclear Power Plant," Nucl. Sci. Eng., vol. 14, pp. 272-286. 1962.
11. J. A. Redfield and J. H. Murphy. "Void Fraction and Residual Water Predictions During Loss of Coolant," Trans. Am. Nucl. Soc., vol. 11, no. 2, p. 685. November 1968.
12. K. V. Moore and W. H. Retlig. Relap 2-A Digital Program for Reactor Blowdown and Power Excursion Analysis, IDO-17263. Idaho Operations Office, Idaho Falls, Idaho, March 1968.

13. F. M. Moody. "Liquid/Vapor Action in a Vessel During Blowdown," J. Eng. for Power, Series A, no. 1, vol. 91, pp. 53-61. January 1969.
14. N. P. Wilburn. Discussion on "Liquid/Vapor Action in a Vessel During Blowdown," J. Eng. for Power, Series A, no. 1, vol. 91, p. 133. April 1969.
15. F. J. Moody. Author's Closure "Liquid/Vapor Action in a Vessel During Blowdown," J. Eng. for Power, Series A, no. 2, vol. 91, p. 134. April 1969.
16. J. F. Wilson, et al. "The Velocity of Rising Steam in a Bubbling Two Phase Mixture," Trans. Am. Nucl. Soc., vol. 5, no. 1, p. 151. 1962.
17. Nuclear Safety Quarterly Report for November, December, 1968, January, 1969, BNWL-1009. Battelle-Northwest, Richland, Washington, March 1969.

APPENDIX A
SOLUTION TO FIRST ORDER QUASI-LINEAR
PARTIAL DIFFERENTIAL EQUATIONS

APPENDIX A
SOLUTION TO FIRST ORDER QUASI-LINEAR
PARTIAL DIFFERENTIAL EQUATIONS

If one is given a partial differential equation which can be expressed in the following form

$$P(x,y,z) \frac{\partial z}{\partial x} + Q(x,y,z) \frac{\partial z}{\partial y} = R(x,y,z) \quad (A-1)$$

where P, Q, and R are arbitrary functions then a solution of the form

$$u(x,y,z) = \text{constant} \quad (A-2)$$

can be assumed. This solution describes a series of 3-dimensional surfaces. For example $x^2 + y^2 + z^2 = a^2$ is a series of spheres centered at the origin of radius "a".

Equation (A-2) is now differentiated partially with respect to x and y.

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial z} \frac{\partial z}{\partial x} = 0; \quad \frac{\partial u}{\partial y} + \frac{\partial u}{\partial z} \frac{\partial z}{\partial y} = 0$$

or

$$\frac{\partial z}{\partial x} = - \frac{\frac{\partial u}{\partial x}}{\frac{\partial u}{\partial z}}; \quad \frac{\partial z}{\partial y} = - \frac{\frac{\partial u}{\partial y}}{\frac{\partial u}{\partial z}}. \quad (A-3)$$

In Equation (A-3), $\partial u / \partial z \neq 0$ for if it were = 0, our assumption (A-2) would be violated in that u would not be a function of z.

Substitution of (A-3) into (A-1) gives,

$$P \frac{\partial u}{\partial x} + Q \frac{\partial u}{\partial y} + R \frac{\partial u}{\partial z} = 0 \quad (A-4)$$

which can be written in vector notation

$$(P\vec{i} + Q\vec{j} + R\vec{k}) \cdot \nabla u = 0 \quad (A-5)$$

where $\bar{i}$, $\bar{j}$, $\bar{k}$ are the Cartesian unit vectors in x , y , z space and ∇ is the gradient operator. Now since ∇u is normal to the surface $u = \text{constant}$, Equation (A-5) says in effect that the vector

$$T = P\bar{i} + Q\bar{j} + R\bar{k}$$

lies in the tangent plane of the surface $u = \text{constant}$. Therefore, T is tangent to any curve which lies in the integral surface of Equation (A-1) which passes through the tangent point. Thus, Equation (A-1) or its equivalent Equation (A-5) determine at any point in some three-dimensional region a "direction" specified by $\bar{T}$. Now if a particle moves from a given initial point in such a way that its direction is given by $\bar{T}$, it traces out a curve called a "characteristic" of the partial differential equation.

Any surface built up from these "characteristic" curves will have the property that its tangent plane contains $\bar{T}$ and hence, the normal vector is ∇u . Therefore, any surface built up from these characteristic curves is a solution to the partial differential Equation (A-1).

How are the equations for these characteristic curves obtained? Assume $\bar{r}$ is a vector from the origin to a characteristic and s is some arc length measure along the characteristic. Then the tangent to the curve is given by

$$\frac{d\bar{r}}{ds} = \frac{dx}{ds} \bar{i} + \frac{dy}{ds} \bar{j} + \frac{dz}{ds} \bar{k} \quad (\text{A-6})$$

and this must have the same direction as $\bar{T}$. Therefore

$$P = \mu \frac{dx}{ds}, \quad Q = \mu \frac{dy}{ds}, \quad R = \mu \frac{dz}{ds} \quad (\text{A-7})$$

where μ is an arbitrary function of x , y , z (A-7) can be written

$$\frac{dx}{P} = \frac{dy}{Q} = \frac{dz}{R} = \frac{ds}{\mu}. \quad (\text{A-8})$$

Hence, the partial differential Equation (A-1) can be solved by integrating any two of the three ordinary differential equations implicit in (A-8).

APPENDIX B
USE OF THE BURP CODE

APPENDIX B

USE OF THE BURP CODE

All of the BURP input is provided using the free-field format feature of FORTRAN IV where the variables are either separated by a comma or the end of the record. The order of the input fields are as follows for each sequential card number. Since each card is printed out, identification information can be supplied after the last comma required on a card.

Card No.	FORTRAN Variable	Description	Units
1	PO	the initial vessel pressure	psia
2	HO	the initial foam height	ft
3	HV	the vessel height	ft
4	Z _E	height of the withdrawal plane	ft
5	AE	area of the break	ft ²
6	DELT	initial integration time interval	sec
7	DELTMN	minimum integration time interval allowed; if negative DELT is taken as maximum allowed	sec
8	DELTP	printout interval	sec
9	TMAX	maximum time for problem	sec
10	GFRCT	greatest fractional change allowed in G before smoothing	
	DTG	time constant in smoothing filter for G	sec
11	EP	maximum error allowed in P	psia
	EL	maximum error allowed in m _l	lb
	EG	maximum error allowed in m _g	lb
	EAL	maximum error allowed in a for lower characteristics	
	EZL	maximum error allowed in Z for lower characteristic	ft
	EAU	maximum error allowed in a for upper characteristic	

<u>Card No.</u>	<u>FORTIRAN Variable</u>	<u>Description</u>	<u>Units</u>
	EZU	maximum error allowed in Z for upper characteristic	ft
12	DELZL	initial distance between lower characteristics	ft
	DELZU	initial distance between upper characteristics	ft
13	DELTPL	plot interval	sec
	INP (1 to 10)	plot controls	
14	NA	number of entries in vessel area table	
15	Z(1), AREA(1)	distance versus area	ft, ft ²
16	Z(2), AREA(2)		

APPENDIX C
DETAILS OF THE BURP CODE

APPENDIX C

DETAILS OF THE BURP CODE

The "BURP" (Bubble Rise Phenomena) code which is used to carry out the calculations based on the model developed in this paper consists of a main FORTRAN program, BURPMN, and eleven FORTRAN subprograms. These programs were coded for the Univac 1108 FR5 FORTRAN compiler. BURPMN is listed in Table C-1. Its purpose is to read in the data for the problem, set up the problem, do the various bookkeeping and red tape operations throughout the integration, call the integration routine AMSINT, print out the results, and call the PLOT routine to construct graphs of the results. A list of the FORTRAN variables used in BURPMN and their corresponding mathematical equivalents in this paper are given in Table C-2.

BURPMN as it is presented in Table C-1 is restricted in the following ways:

1. constant area vessel
2. constant bubble-rise velocity
3. routine quits if characteristics intersect
4. no provision to handle case of very small breaks where dz_u/dt at z_E becomes greater than zero
5. integration of dz_u/dt not performed since with above restrictions a^U is a constant
6. routine quits when foam height equals zero
7. an infinite bubble-rise velocity solution is found by setting $c = 0$. and replacing the statement specifying GLC in BURPDE with "GLC = 0."

AMSINT is a generalized Adams-Moulton integration routine which has been described.⁽³⁾ It is listed in Table C-3.

BURPDE listed in Table C-4, is the DE subroutine required by AMSINT and is the heart of BURP. The general procedure followed in this routine has been outlined above under the

heading "Method of Solution." The FORTRAN variables used in BURPDE are described in Table C-5.

STMTBL is a routine which returns the saturated steam properties upon entry with any of the 10 possible arguments through a 4-point Lagrangian interpolation in the Keenan and Keyes steam tables. Here only the pressure is used as an argument. STMTBL is listed in Table C-6.

DERIV (Table C-7) is used by BURPDE to obtain the derivatives of some of the properties of saturated steam with respect to pressure. A quadratic is fit to 4 points from the steam tables by an orthogonal least squares approach and the derivative is found analytically at the pressure P.

GMQODY (Table C-8) is a routine used to compute the maximum two-phase flowrate given the stagnation enthalpy and pressure. A 2-dimensional 4-point Lagrangian interpolation is used in the tables obtained from the LEAK subroutine of FLASH2.(2)

UBUB (Table C-9) is a function subprogram which computes the bubble rise velocity which for this study is a constant.

SING (Table C-9) is a routine required by AMSINT for action to be taken when AMSINT cannot satisfy the input error criteria (see Appendix B).

TB1D and TB1DG (Tables C-10 and C-11) are used to perform interpolation in various tables during the calculation.

TABINT (Table C-12) is the routine used to perform the 4-point Lagrangian interpolations required by TB1D, TB1DG, and GMQODY.

PL:1 is a special routine which performs the plotting of the results on a digital plotter. It is unique to the local computer installation and not of general use and is therefore not listed herein.

TABLE C-1. Main Program BURPMN

```

C BURPMN (BU)BBLE (R)ISE (P)HENOMENA MAIN PROGRAM
C      IS A CODE WHICH USES AMSINT AND BURP2A TO COMPUTE THE VOID
C      FRACTION PROFILE IN 4 REACTOR PRIMARY PRESSURE VESSEL DURING
C      BLOWDOWN
C
      PARAMETER NP=200,NPI=2*NP+209                                - PLOT DIU.
      PARAMETER NTP=-4
      COMMON      STBKK(295,10),STB(10)
      COMMON /INDEX/      IIL(50)      ,IIU(50)      ,IILZ(50)      ,IIUZ(50)
1      ,IIN(100)      ,INL(50)      ,INU(50)      ,INP(10)
      COMMON /CHAR/      UGU(50)      ,ULU(50)      ,UGL(50)      ,ULL(50)
1      ,ALFM1U(50)      ,ALFM1L(50)
      COMMON /COND/      WLT      ,WTO      ,SO      ,ALFEM
1      ,ALFFP      ,ZE      ,ALK      ,XE      ,HE
2      ,AE      ,WDOTG      ,AVE      ,ARM1E      ,ALFE
3      ,H      ,UGEP      ,UGEM      ,G      ,IHSW
      COMMON /VESSEL/      AREA(100)      ,Z(100)      ,ARM1(100)
      COMMON /COND/      NU      ,NL      ,NA
      COMMON /AMS/      YP(200)      ,Y1(200)      ,F(200,6)      ,Y2(200)
1      ,TF(6)
      COMMON /DES/      TIO(200)      ,NBE      ,GFRCT      ,DTG
      COMMON /PLOTS/      YPL(NPI)
      DIMENSION      XP(NPI,10)      ,AO(14,100)      ,IXP(NPI,10)
      DIMENSION      Y(200)      ,E(200)      ,F1(200)
      EQUIVALENCE (XP,XP)
      DATA (IXP(2*NP+1,I),I=1,10)/10*1/                                - NPLTS
      DATA (IXP(2*NP+2,I),I=1,10)/10*1/                                - NPTS(1)
      DATA (IXP(2*NP+32,I),I=1,10)/ 5*10,5*10/                          - MXDIV
      DATA (IXP(2*NP+33,I),I=1,10)/10*10/                              - MYDIV
      DATA ((IXP(J+2*NP+33,I),I=1,10),J=1,10)/10*0,
2      10*0,                                - NOPTS(1)
3      10*0,                                - NOPTS(2)
4      10*0,                                - NOPTS(3)
5      10*2,                                - NOPTS(4)
6      10*2,                                - NOPTS(5)
7      10*1,                                - NOPTS(6)
8      10*0,                                - NOPTS(7)
9      10*3,                                - NOPTS(8)
0      10*1/                                - NOPTS(9)
      DATA (IXP(2*NP+44,I),I=1,10)/10*1/                                - NOPTS(10)
      DATA (IXP(2*NP+44,I),I=1,10)/10*1/                                - NTYPE

```

TABLE C-1. (contd)

DATA ((IXP(J+2*NP+73,I),J=1,6),I=1,10)/	-	XTITLE(1)
1 36H TIME (SEC)	,	-
1 36H TIME (SEC)	,	
1 36H TIME (SEC)	,	-
1 36H TIME (SEC)	,	
1 36H TIME (SEC)	,	
2 36H DISTANCE (FT.)	,	-
2 36H DISTANCE (FT.)	,	
2 36H DISTANCE (FT.)	,	-
2 36H DISTANCE (FT.)	,	
2 36H DISTANCE (FT.)	/	-
DATA ((IXP(J+2*NP+85,I),J=1,6),I=1,10)/	-	XTITLE(2)
1 36H	,	-
1 36H	,	
1 36H	,	
1 36H	,	
1 36H	,	
1 36H	,	-
1 36H	,	
1 36H	,	-
1 36H	,	-
1 36H	/	-
DATA ((IXP(J+2*NP+97,I),J=1,6),I=1,10)/	-	YTITLE(1)
136H FOAM LEVEL (FT)	,	- YTITLE(1)
236H PRESSURE (PSIA)	,	- YTITLE(1)
336H TOTAL WEIGHT (LBS)	,	- YTITLE(1)
436H MASS VELOCITY (LBS/SEC)	,	- YTITLE(1)
536H EFFLUENT VOID FRACTION ()	,	- YTITLE(1)
636H	,	- YTITLE(1)
736H VOID FRACTION ()	,	- YTITLE(1)
836H GAS PHASE VELOCITY (FT/SEC)	,	- YTITLE(1)
936H LIQ. PHASE VELOCITY (FT/SEC)	,	- YTITLE(1)
036H	/	- YTITLE(1)
-DATA ((IXP(J+2*NP+109,I),J=1,6),I=1,10)/	-	YTITLE(2)
136H	,	-
236H	,	-
336H	,	-
436H	,	-
536H	,	-
636H	,	-

TABLE C-1. (contd)

```

736H      ,
836H      ,
936H      ,
036H      /
DATA ((IXP(J+2*NP+121,I),J=1,6),I=1,10)/      - OVTITL
136H      ,
236H      ,
336H      ,
436H      ,
536H      ,
636H      9
736H      TIME          SECS.      ,
836H      TIME          SECS.      ,
936H      TIME          SECS.      ,
036H      /
DATA (IXP(2*NP+134,I),I=1,10)/10*36/      - NC01
DATA (IXP(2*NP+135,I),I=1,10)/10*36/      - NC02
DATA (IXP(2*NP+136,I),I=1,10)/10*36/      - NCA1
DATA (IXP(2*NP+137,I),I=1,10)/10*36/      - NCA2
DATA (IXP(2*NP+138,I),I=1,10)/10*36/      - NC
DATA (IXP(2*NP+139,I),I=1,10)/10*2.0/      - XSTART
DATA (IXP(2*NP+140,I),I=1,10)/10*2.625/      - YSTART
DATA (IXP(2*NP+141,I),I=1,10)/10*0./      - XMIN
DATA (IXP(2*NP+142,I),I=1,10)/6.,6*0.,-10.,-10.,0./      - YMIN
DATA (IXP(2*NP+203,I),I=1,10)/10*5.5/      - XSYM
DATA (IXP(2*NP+204,I),I=1,10)/10*5.0/      - YSYM
DATA (IXP(2*NP+205,I),I=1,10)/10*10./      - XSCALE
DATA (IXP(2*NP+206,I),I=1,10)/10*5./      - YSCALE
DATA (IXP(2*NP+207,I),I=1,10)/10*1.0/      - PSCALE
DATA (IXP(2*NP+208,I),I=1,10)/5*100.,5*20./      - XMAX
DATA (IXP(2*NP+209,I),I=1,10)/16.,1000., 5000., 40., - YMAX
11.0,10.,1.0,10.,10.,10./
NAMELIST /PRCHAR/IIL,IIU,IILZ,IIUZ,Y,UGL,UGU,ULU,ULL,ALFM1U,ALFM1L
NAMELIST/PRCOND/TPRT,WLT,WTO,SO,ALFEM,ALFEP,ZE,XE,HE,WDOTG,AVE,
1          ARM1E,H,STB
NAMELIST/PRICON/NU,NL
IBUG=0
■■NP=0

```

C
C*****READ IN INITIAL VESSEL CONDITIONS

TABLE C-1. (contd)

```

C
C*****PRESSURE
      READ(5,1)P0
      CALL INSAVE(IINP)
C*****LIQUID LEVEL
      READ(5,1)H0
      CALL INSAVE(IINP)
      H=H0
C*****HEIGHT OF VESSEL
      READ(5,1)HV
      CALL INSAVE(IINP)
C*****HEIGHT OF WITHDRAWAL PLANE
      READ(5,1)ZE
      CALL INSAVE(IINP)
C*****BREAK AREA
      READ(5,1)AE
      CALL INSAVE(IINP)
C
C*****READ IN INTEGRATION PARAMETERS
C*****INITIAL DELTA T
      READ(5,1)DELT
      CALL INSAVE(IINP)
C*****MIN. DELTA T
      READ(5,1)DELTMIN
      CALL INSAVE(IINP)
C*****PRINTOUT INTERVAL
      READ(5,1)DELTPO
      DELTP=DELTPO
      CALL INSAVE(IINP)
C*****PROBLEM END TIME
      READ(5,1)TMAX
      CALL INSAVE(IINP)
C*****SMOOTHING FACTORS FOR G AT TRANSITION
      READ(5,1)GFRCT,DTG
      CALL INSAVE(IINP)
C
C*****READ IN ERROR TOLERANCES FOR AMSINT
C*****PRESSURE,WT. GAS,WT. LIQ.,ALPHA,Z
      READ(5,1)EP,EG,EL,EAL,EAU,EZL,EZU
      CALL INSAVE(IINP)

```

TABLE C-1. (contd)

```

C*****READ IN DISTANCES BETWEEN LOWER CHAR*, AND BETW. UPPER CHAR.
      READ(5,1)DELZL,DELZU
      CALL INSAVE(IINP)
C*****READ IN PLOT CONTROL PARAMETERS
      READ(5,1)DELTPL,(INP(I),I=1,10)
      CALL INSAVE(IINP)
      IPLTT=0
      KTPL=1
      TPLT=DELTPL
C*****READ IN AREA VS. Z. TABLE
      READ(5,1)NA
      CALL INSAVE(IINP)
      DO 100 I=1,NA
        READ(5,1)Z(I),AREA(I)
        CALL INSAVE(IINP)
      100 CONTINUE
      WRITE(6,14)((AO(I,J),I=1,14),J=1,IINP)
C*****COMPUTE INTEGRAL OF AREA
      ARM1(1)=0.

      DO 200 I=2,NA
        ARM1(I)=(ARM1(I-1)*AREA(I-1)+(AREA(I-1)+AREA(I))*(Z(I)-Z(I-1))*0.5)
        1      /AREA(I)
      200 CONTINUE
C*****GET INITIAL FLUID PROPERTIES
      CALL STMTBL(1,P0,ISTM,$20000)
      HE=STB(5)
C*****VOL. OF LIQ-VL0
      CALL TB1D(H0,VL0,Z,ARM1,NA)
      CALL TB1D(H0,ARH,Z,AREA,NA)
      VL0=VL0*ARH
C*****TOTAL VOL.-VLT
      CALL TB1D(HV,VLT,Z,ARM1,NA)
      CALL TB1D(HV,ART,Z,AREA,NA)
      VLT=VLT*ART
C*****MASS OF LIQUID,GAS,TOTAL AND INIT. SPEC. ENTROPY
      WLTO=VL0/STB(3)
      WGT0=(VLT-VL0)/STB(4)
      WTO=WLTO+WGT0
      S0=(WGT0*STB(8)+WLTO*STB(7))/WTO

```

TABLE C-1. (contd)

```

C*****GET AREA AT WITHDRAWAL PLANE AND INTEGRAL OF AREA
      CALL TB1D(ZE,AVE,Z,AREA,NA)
      CALL TB1D(ZE,ARM1E,Z,ARM1,NA)
C*****DETERMINE NUMBER OF CHARACTERISTICS (4 IS MIN FOR INTERPOLATION)
      NL=AMIN1(ZE,H0)/DELZL+3.
      IF(NL.GT.50)NL=50
      IF(NL.LT.4)NL=4
      IF(ZE.LE.0.)NL=0
      NU=(H0-ZE)/DELZU+2.
      HSW=0
      IF(NU.GT.50)NU=50
      IF(NU.LT.4)NU=4
C*****SET UP Y-VECTOR
      Y(1)=P0
      Y(2)=WLT0
      Y(3)=WGTO
      IF(NL.EQ.0)GOTO 450
      DO 300 I=1,NL
C*****INITIAL VOID FRACTION .EQ.0
      Y(I+3)=0.
      IIL(I)=I+3
300  CONTINUE
      J=NL+4
      Y(J)=0.
      IILZ(1)=J
      KL=1
      INL(1)=1
      DO 400 I=2,NL
      INL(I)=I
      J=J+1
      Y(J)=Y(J-1)+DELZL
      IILZ(I)=J
400  CONTINUE
450  K=2*NL+3
      DO 500 I=1,NU
      J=I+K
C*****INITIAL VOID FRACTION .EQ.0
      Y(J)=0.
      IIU(I)=J
500  CONTINUE

```

TABLE C-1. (contd)

```

      J=2*NL+4+NU
      Y(J)=ZE
      IIUZ(1)=J
      INU(1)=1
      DO 600 I=2,NU
      INU(I)=I
      J=J+1
      Y(J)=Y(J-1)+DELZU
      IIUZ(I)=J
600  CONTINUE
      DO 700 I=1,100
      TTO(I)=0.
      TTO(I+100)=0.
      700  IIN(I)=I
C*****SET MAX* ERROR VECTOR
      E(1)=EP
      E(2)=EL
      E(3)=EG
      DO 800 I=1,NL
      E(I+3)=EAL
800  E(I+ NL +3)=EZL
      DO 900 I=1,NU
      E(I+NL+NL+3)=EAU
900  E(I+NL+NL+NU+3)=EZU
      NDIM=2*NL+2*NU+3
C*****IF INTERFACE IS BELOW ZE--MAKE SUITABLE ADJUSTMENTS
      IF(H0.GT.ZE)GOTO 950
      NU=0
      NDIM=2*NL+3
      IHSW=2
950  CONTINUE
C*****
C*****BEGIN MAIN COMPUTATION LOOP, AFTER INITIALIZATION
      T=DELT
      KT=1
      CALL AMSINT(1,T,TC,Y,E,NDIM,DELT,0.,Y,DELTMN,$4450)
      TPRT=0.
      KTP=0
      TPRT0=0
      ASSIGN 4410 TO NPR

```


TABLE C-1. (contd)

```

      GOTO 3100
1000 CONTINUE
      NDIM=2*(NU+NL)+3
C*****ADD LOWER CHAR. IF LOWEST ABOVE DELZL
      IF(NL.EQ.0)GOTO 1560
      K=IILZ(1)
      IF(Y(K).LT.DELZL)GOTO 1500
C*****AND ONLY IF IMPOSSIBLE FOR AMSINT TO BACK UP SO AS TO CALC. NEG Z
      IF(TTO(K).GT.TF(1))GOTO 1500
C***** ARE THERE .GT. 2 CHAR. ABOVE LOWER VOL. SO 1 CAN BE ELIMINATED
      J=IILZ(NL-2)
      IF(Y(J).LE.ZE.AND.Y(J).LE.H)GOTO 1200
      J=IILZ(NL)
      K=IIL(NL)
      L=NL
1090 DO 1100 I= L,2,-1
      IILZ(I)=IILZ(I-1)
      INL(I)=INL(I-1)
      IIL(I)=IIL(I-1)
1100 CONTINUE
      GOTO 1350
C*****IF NGT ELIMINATE CHAR* BETW. 2 CLOSEST BUT NOT CHAR. NO. 0
1200 XZ=100.*DELZL
      DO 1300 I=NL,3,-1
      J=IILZ(I)
      K=IILZ(I-2)
      IF((Y(J)-Y(K)).GT.XZ)GOTO 1300
      IF(INL(I-1).EQ.0)GOTO 1300
      XZ=(Y(J)-Y(K))
      L=I-1
1300 CONTINUE
      J=IILZ(L)
      K=IIL(L)
      GOTO 1090
1350 CONTINUE
      KL=KL-1
      Y(J)=0.
      Y(K)=0.
      Y1(J)=0.
      Y1(K)=0.

```

TABLE C-1. (contd)

```

      Y2(J)=0.
      Y2(K)=0.
      YP(J)=0.
      YP(K)=0.
      TTO(J)=TC
      TTO(K)=TC
      E(J)=EZL
      XZ=UBUB(0.)
      XA=STB(4)*WDOTG/WLT/STB(3)
      DO 1400 I=1,6
        F(J,I)=XZ
        F(K,I)=XA
1400  CONTINUE
      INL(1)=KL
      IILZ(1)=J
      IIL(1)=K
1500  CONTINUE
C*****CHECK FOR INTERSECTING LOWER CHAR* AND FICTICIOUS CHAR.
      DO 1550 I=NL,2,-1
        L=IILZ(I)
        IF(Y(L).GT.ZE.OR.Y(L).GT.H)E(L)=100.*EZL
        M=IILZ(I-1)
        IF(Y(L).LE.Y(M).AND.Y(L).LE.ZE.AND.Y(L).LE.H)GOTO 20200
1550  CONTINUE
1560  IF(IHSW.GE.1)GO TO 2900
      IF(NU.EQ.4)GOTO2900
C*****ADJUST UPPER CHAR* SO ONLY 2 ARE .LT.ZE
      J=IIUZ(3)
      K=IIUZ(1)
      IF(Y(K).GT.ZE)GOTO 20100
      IF(Y(J).GE.ZE)GOTO 2800
      J=IIU(1)
      NU=NU-1
      DO 1600 I=1,NU
C*****CHECK FOR INTERSECTING UPPER CHAR.
      L=IIUZ(I+1)
      M=IIUZ(I)
      IF(Y(L).LE.Y(M))GOTO 20300
      INU(I)=INU(I+1)
      IIUZ(I)=IIUZ(I+1)

```

TABLE C-1. (contd)

```

      IIU(I)=IIU(I+1)
1600 CONTINUE
      ASSIGN 2800 TO NBRO
1650 CONTINUE
C*****SCAN IIU TO FIND CHAR* IN Y(2*NL+3+NU+1),POSS. Y(IIU(NU+1))
      M=2*NL+NU+4
      DO 1700 L=1,NU
        IF(IIU(L).EQ.M)GOTO 1800
1700 CONTINUE
      IF(J.NE.M)GOTO 20400
      GOTO 2000
C*****MOVE IT TO Y(J) SO TO KEEP UPPER Z VALUES TOGETHER
1800 Y(J)=Y(M)
      Y1(J)=Y1(M)
      Y2(J)=Y2(M)
      YP(J)=YP(M)
      TTO(J)=TTO(M)
      E(J)=E(M)
      DO 1900 I=1,6
        F(J,I)=F(M,I)
1900 CONTINUE
      IIU(L)=J
C*****SCAN IIUZ TO FIND CHAR* IN Y(2*NL+2*NU+5)--AND +4)
2000 N=2*NL+2*NU+5
      DO 2100 L=1,NU
        IF(IIUZ(L).EQ.N)GOTO2200
2100 CONTINUE
      IF(K.NE.N)GOTO 20500
      GOTO 2400
C*****MOVE Y(N) TO K POSITION
2200 Y(K)=Y(N)
      Y1(K)=Y1(N)
      Y2(K)=Y2(N)
      TTO(K)=TTO(N)
      E(M)=EZU
      YP(K)=Y(N)
      DO 2300 I=1,6
        F(K,I)=F(N,I)
2300 CONTINUE
      IIUZ(L)=K

```

TABLE C-1. (contd)

```

2400 DO 2500 L=1,NU
      IF(IIUZ(L).EQ.N-1)GOTO2600
2500 CONTINUE
      GOTO 20500
C*****MOVE Y(N-1) TO M POSITION
2600 Y(M)=Y(N-1)
      Y1(M)=Y1(N-1)
      Y2(M)=Y2(N-1)
      TTO(M)=TTO(N-1)
      E(M)=EZU
      YP(M)=YP(N-1)
      DO 2700 I=1,6
        F(M,I)=F(N-1,I)
2700 CONTINUE
      IIUZ(L)=M
C*****REDUCE DIM. OF Y VECTOR
      NDIM=NDIM-2
      GOTO NBRO
C*****ADJUST UPPER CHAR. SO ONLY 2 FICTICIOUS ABOVE FOAM LEVEL
2800 ASSIGN 2900 TO NBRO
      K=IIUZ(NU-2)
      IF(Y(K).LT.H)GOTO 2900
      K=IIUZ(NU)
      J=IIU(NU)
      NU=NU-1
      GOT01650
C*****PERFORM INTEGRATION ALONG CHARACTERISTIC UP TO T PLUS DELT
2900 IF(ABS(T-TPRT)/T.LT.1.E-6.OR.T.GT.TPRT)GOTO 3100
3000 KT=KT+1
      T=KT*DELT
      CALL AMSINT(2,T,TC,Y,E,NDIM,DELT,0.,Y,DELTMM,$4450)
      IF(Y(I).LE.14.7)GOTO 20600
      IF(IHSW.NE.1)GOTO 1000
      IHSW=2
      NU=0
      GOTO 1000
3100 IF(IHSW.GE.1.AND.TPRT.NE.0.)GOTO 3200
      CALL AMSINT(4,TPRT,TC,Y,E,NDIM,DELT,0.,Y,DELTMM,$4450)
3200 CALL DE(TC ,Y,F1,$4450)
3250 IF(NL.EQ.0) GOTO 3350

```

TABLE C-1. (contd)

```

      DO 3300 I=1,NL
      J=IIL(I)
      ULL(I)=UGL(I)-UBUB(Y(J))
3300  CONTINUE
3350  IF(IHSW.GE.1)GOTO 4000
      DO 3400 I=1,NU
      J=IIU(I)
      ULU(I)=UGU(I)-UBUB(Y(J))
3400  CONTINUE
C
C*****PRINT OUT
4000  IF(IBUG.EQ.0)GOTO4010
      WRITE(6,PRCOND)
      WRITE(6,PRICON)
      WRITE(6,PRCHAR)
4010  CONTINUE
      CALL STMTBL(1,Y(1),ISTM,$20000)
      CALL TB1D(H,ARH,Z,AREA,NA)
      CALL TB1D(H,VLH,Z,ARM1,NA)
      VLH=VLH*ARH
      WT=Y(2)+Y(3)
      WG=(VLT-VLH)/STB(4)
      GT=G*AE
      XE=(HE-STB(5))/(STB(6)-STB(5))
      ALFE=STB(4)*(HE-STB(5))
      ALFE=ALFE/(ALFE+STB(3)*(STB(6)-HE))
C*****STORE DATA FOR PLOT TYPES 1 THRU 6
      IPLTT=IPLTT+1
      IF(IPLTT.GT.NP)GOTO 4016
      XP(IPLTT+NP,1)=H
      XP(IPLTT+NP,2)=Y(1)
      XP(IPLTT+NP,3)=WT
      XP(IPLTT+NP,4)=GT
      XP(IPLTT+NP,5)=ALFE
      XP(IPLTT+NP,6)=0.
      DO 4015 I=1,6
4015  XP(IPLTT,I)=TC
C*****STORE DATA FOR AND DO PLOTS TYPE 7-10,BYPASS IF NOT TIME TO PLOT
4016  IF(ABS(T-TPLT)/T.GT.1.E-6.AND.T.LT.TPLT)GOTO 4080
      KTPL=KTPL+1

```

TABLE C-1. (contd)

```

      TPLT=KTPL*DELTPL
      KP=0
      LP=NP
      IF(NL.EQ.0)GOTO4040
      DO 4020 I=1,NL
      KP=I
      LP=I+NP
      K=IILZ(I)
      IF(Y(K).GT.H.AND.NU.EQ.0)GOTO 4060
      IF(Y(K).GT.ZE)GOTO4030
      J=IIL(I)
      XP(LP,7)=Y(J)
      XP(LP,8)=UGL(I)
      XP(LP,9)=ULL(I)
      XP(KP,7)=Y(K)
      XP(KP,8)=Y(K)
      XP(KP,9)=Y(K)
4020  CONTINUE
      KP=NL+1
      LP=NL+NP+1
4030  XP(KP,7)=ZE
      XP(KP,8)=ZE
      XP(KP,9)=ZE
      XP(LP,7)=ALFEM
      XP(LP,8)=UGEM
      XP(LP,9)=ULEM
4040  CONTINUE
      KP=KP+1
      LP=LP+1
      XP(KP,7)=ZE
      XP(KP,8)=ZE
      XP(KP,9)=ZE
      XP(LP,7)=ALFEP
      XP(LP,8)=UGEP
      XP(LP,9)=-UBUB(ALFEP)+UGEP
      DO 4050 I=1,NU
      K=IIUZ(I)
      IF(Y(K).LE.ZE)GOTO4050
      KP=KP+1
      LP=LP+1

```

TABLE C-1. (contd)

```

      IF(Y(K).GT.H)GOTO4060
      J=IIU(I)
      XP(LP,7)=Y(J)
      XP(LP,8)=UGU(I)
      XP(LP,9)=ULU(I)
      XP(KP,7)=Y(K)
      XP(KP,8)=Y(K)
      XP(KP,9)=Y(K)
4050  CONTINUE
4060  XP(KP,7)=H
      XP(KP,8)=H
      XP(KP,9)=H
      IF(NU.EQ.0)GOTO 4062
      CALL TB1DG(H,XP(LP,7),Y,Y,IIUZ,IIU,NU,NB)
      CALL TB1DG(H,XP(LP,8),Y,UGU,IIUZ,IIN,NU,NB)
      CALL TB1DG(H,XP(LP,9),Y,ULU,IIUZ,IIN,NU,NB)
      GOTO 4063
4062  CALL TB1DG(H,XP(LP,7),Y,Y,IILZ,IIL,NL,NB)
      CALL TB1DG(H,XP(LP,8),Y,UGL,IILZ,IIN,NL,NB)
      CALL TB1DG(H,XP(LP,9),Y,ULL,IILZ,IIN,NL,NB)
4063  CONTINUE
      KP=KP+1
      LP=LP+1
      XP(KP,7)=H
      XP(KP,8)=H
      XP(KP,9)=H
      XP(LP,7)=1.
      XP(LP,8)=0.
      XP(LP,9)=0.
      KP=KP+1
      LP=LP+1
      XP(KP,7)=HV
      XP(KP,8)=HV
      XP(KP,9)=HV
      XP(LP,7)=1.
      XP(LP,8)=0.
      XP(LP,9)=0.
      DO 4070 I=7,9
      IF(INP(I).EQ.0)GOTO4070
      JPLT=1

```

TABLE C-1. (contd)

```

      IXP(2*NP+2,I)=KP
      CALL NECODE(IXP(2*NP+124,I),1)
      WRITE(NTP,15)T
      CALL PLTIT(I,KP)
4070  CONTINUE
4080  CONTINUE
      WRITE(6,2)TC
      WRITE(6,3)Y(1),STB(2),WTO,ALFE,STB(3),STB(5),WT,HE
      WRITE(6,4)STB(4),STB(6),Y(2),GT,STB(7),STB(9),Y(3),XE,STB(8),
1      STB(10),WG,H
      WRITE(6,5)
      NLN=MAX0(NU,NL)+1
      ASSIGN 4100 TO NH
      DO 4400 I=1,NLN
      IF(MOD(I,5).EQ.1)WRITE(6,9)
      WRITE(6,9)
      IF(I.GT.NL+1)GOTO4200
      IF(I.NE.NL+1)GOTO NH
      IF(NL.EQ.0) GOTO 4200
      IF(IHSW.GE.1)GOTO4400
      ULEM=-UBUB(ALFEM)+UGEM
      WRITE(6,6)I,ZE,ALFEM,UGEM,ULEM
      WRITE(6,10)
      GOT04200
4100  J=IIL(I)
      K=IILZ(I)
      WRITE(6,12)INL(I)
      WRITE(6,6)I,Y(K),Y(J),UGL(I),ULL(I)
4200  IM1=I-1
      IF(IHSW.GE.1)GOTO 4400
      IF(Y(K).GT.H)ASSIGN 4200 TO NH
      IF(IM1.GT.NU)GOTO4400
      IF(IM1.NE.0)GOTO4300
      ULEP=-UBUB(ALFEP)+UGEP
      WRITE(6,8)IM1,ZE,ALFEP,UGEP,ULEP
      WRITE(6,11)
      GOT04400
4300  J=IIU(IM1)
      K=IIUZ(IM1)
      WRITE(6,13)INU(IM1)

```


TABLE C-1. (contd)

```

      WRITE(6,8)IM1,Y(K),Y(J),UGU(IM1),ULU(IM1)
4400 CONTINUE
      GOTO NPR
C***** INCREASE PRINTOUT RATE DURING TRANSITION ONLY
4410 IF( ABS((H-ZE)/HV).GT.0.05)GOTO 4440
      ASSIGN 4440 TO NPR
      TPRT0=TPRT
      KTP=0
      DFLTP=DELT
4440 CONTINUE
      IF((H-ZE)/HV.GT.-0.05) GOTO 4445
      TPRT0=0.
      KTP=TPRT/DELTP0
      DELTP=DELTP0
      ASSIGN 4445 TO NPR
4445 CONTINUE
      KTP=KTP+1
      TPRT= KTP*DELTP+TPRT0
      IF(T.LT.TMAX)GOTO3000
C*****DO PLOTS IF ANY
4450 DO 4500 I=1,6
      IF(INP(I).EQ.0)GOTO4500
      JPLT=1
      IXP(2*NP+2,I)=IPLTT
      CALL PLTIT(I,IPLTT)
4500 CONTINUE
      IF(JPLT.EQ.1)CALL CPLOT(12.,0.,999)
      STOP
C
C*****ERROR MESSAGES
20000 WRITE(6,99)
      99 FORMAT(1H1,31HSTMTBL CALLED FROM MAIN PROGRAM)
      STOP
20100 WRITE(6,98)
      98 FORMAT(1H1,28HUPPER CHAR. ARE ALL ABOVE ZE)
      CALL DESING(G,H,I,$4450)
20200 WRITE(6,97)
      97 FORMAT(1H1,28HLOWER CHAR* HAVE INTERSECTED)
      CALL DESING(G,H,I,$4450)
20300 WRITE(6,96)

```

TABLE C-1. (contd)

```

96 FORMAT(1H1,28HUPPER CHAR. HAVE INTERSECTED)
   CALL DESING(G,H,I,$4450)
20400 WRITE(6,95)
95 FORMAT(1H1,33HFOUL-UP IN ALPHA(LAST) CHAR. SCAN)
   CALL DESING(G,H,I,$4450)
20500 WRITE(6,94)
94 FORMAT(1H1,29HFOUL-UP IN Z(LAST) CHAR. SCAN)
   CALL DESING(G,H,I,$4450)
20600 WRITE(6,93)
93 FORMAT(1H1,18HP .LT. ATMOSPHERIC )
   CALL DESING(G,H,I,$4450)
C
C %****FORMATS
1 FORMAT( )
2 FORMAT(1H1,21HVESSEL CONDITIONS AT ,F6.2, 5h SEC./1H )
3 FORMAT(1H , 5HP   =,1X,F6.1,4X,7HPSIA   ,3X,
1      5HTEMP=,1X,F6.1,4X,7HDEG.   ,3X,
2      5HWT0 =,   F7.1,4X,7HLBS.   ,3X,
3      5HALFE=,4X,F6.4,1X,7H----   /1H ,
4      5HVF  =,4X,F6.4,1X,8HCUFT/LB.,2X,
5      5HHF  =,2X,F6.2,3X,7HBTU/LB. ,3X,
6      5HWT  =,   F7.1,4X,7HLBS.   ,3X,
7      5HHE  =,1X,F7.2,3X,7HBTU/LB )
4 FORMAT(1H , 5HVG  =,4X,F6.4,1X,8HCUFT/LB.,2X,
1      5HHG  =,1X,F6.1,4X,7HBTU/LB. ,3X,
2      5HWLT =,   F7.1,4X,7HLBS.   ,3X,
3      5HG   =,1X,F7.2,3X,7HLB/SEC /1H ,
4      5HSF  =,4X,F6.4,1X,8HBTU/LB-R,2X,
5      5HUF  =,1X,F6.1,4X,7HBTU/LB. ,3X,
6      5HWGT =,1X,F6.1,4X,7HLBS.   ,3X,
6      5HXE  =,4X,F6.4,1X,         /1H ,
7      5HSG  =,4X,F6.4,1X,8HBTU/LB-R,2X,
8      5HUG  =,1X,F6.1,4X,7HBTU/LB. ,3X,
8      5HWG  =,1X,F6.1,4X,7HLBS.   ,3X,
9      5HFOAM=,2X,F6.2,3X,7HFT.   )
5 FORMAT(1H0,22X,21HLOWER CHARACTERISTICS,21X,1H*,22X,21HUPPER CHARA
1CTERISTICS/1H ,130(1H*)/1H ,2(1X,1H1,11X,1HZ,10X,5HALPHA,11X,2HUG,
212X,2HUL, 8X,1H*)/1H ,2(11X,4H(FT),10X,3H( ), 9X,8H(FT/SEC), 7X,
38H(FT/SEC), 4X,1H*)/1H ,130(1H*))
6 FORMAT(1H+, 13,7X,F6.2,7X,F7.4,6X,F8.4,6X,F8.4)

```

TABLE C-1. (contd)

```

7 FORMAT(1H )
8 FORMAT(1H+,65X,I3,7X,F6.2,7X,F7.4,6X,F8.4,6X,F8.4,6X)
9 FORMAT(1H ,64X,1H*,64X,1H*)
10 FORMAT(1H+,5X,3HZE-)
11 FORMAT(1H+,70X,3HZE+)
12 FORMAT(1H+,5X,I3)
13 FORMAT(1H+,70X,I3)
14 FORMAT(1H1,10HINPUT DECK,(/1H ,14A6))
15 FORMAT(F6.2)
C*****
C*****TRANSFER PLOT INFO TO PLOT ARRAY AND DO PLOT
16 FORMAT(A6)
   SUBROUTINE PLTIT(MPLT,ND)
   30 25000 I=1,NPI
   YPL(I)=XP(I,MPLT)
25000 CONTINUE
   WRITE(6,50)MPLT
   50 FORMAT(1H1,23HDESCRIPTION OF PLOT NO. I3)
   CALL PLOT(ND)
   RETURN
C*****
C*****SAVE INPUT CARD IMAGES FOR LATER LISTING
   SUBROUTINE INSAVE(I)
   IF(I.EQ.100)RETURN
   I=I+1
   51 FORMAT(13A6,A2)
   READ(NTP,51)(AO(J,I),J=1,14)
   RETURN

```

TABLE C-2. FORTRAN Variables Used in BURPMN

AE - $[A_E]$	Area of the blowdown effluent orifice, ft^2
ALFE - $[\alpha_E]$	Void fraction of the effluent fluid
ALFEM - $[\alpha_E^-]$	Void fraction of the fluid just below the withdrawal plane at Z_E
ALFEP - $[\alpha_E^+]$	Void fraction of the fluid just above the withdrawal plane at Z_E
ALFM1L - $[\frac{1}{A_V} \int_0^Z a A_V dz]$	Integral of the void fraction times area below the withdrawal plane divided by area at z , ft
ALFM1U - $[\frac{1}{A_V} \int_{Z_E}^Z a A_V dz]$	Integral of the void fraction times area above the withdrawal plane divided by area at z , ft
ALK -	Not used
AO -	Temporary storage for the input card images
AREA - $[A_V]$	Area of the vessel as a function of the distance z , ft^2
ARH -	Area of the vessel at the foam interface, ft^2
A - $[\frac{1}{A_V} \int_0^Z A_V dz]$	Integral of the area of the vessel divided by the area at z , ft
ARM1E - $[\frac{1}{A_{VE}} \int_0^{Z_E} A_V dz]$	Integral of the area of the vessel up to Z_E divided by area of the vessel at Z_E , ft
ART -	Area of the vessel at the top of the vessel, ft^2
AVE - $[A_{VE}]$	Area of the vessel at Z_E , ft^2
DELT -	Initial integration time interval, sec
DELTMN -	Minimum integration time interval; if negative DELT is taken as maximum integration time interval, sec

TABLE C-2. (contd)

DELTP -	Current printout interval, sec
DELTP0 -	Initial printout interval, sec
DELTPL -	Plot out interval, sec
DELZL -	Initial interval between characteristics in lower vessel below Z_E , ft
DELZU -	Initial interval between characteristics in the upper vessel above Z_E , ft
DTG -	Time constant of step changes greater than GFRCT in the maximum flow rate from the vessel. Used to stabilize numerical solution when discontinuities in mass flow rate occur between two-phase and single-phase vapor flow, sec
E -	Vector of the errors to be applied to the integration vector Y (dimensions depend upon associated quantity in Y)
EAL -	Maximum error associated with void fraction on lower characteristics
EAU -	Maximum error associated with void fraction on upper characteristics
EG -	Maximum error associated with gas phase mass, lb
EL -	Maximum error associated with liquid phase mass, lb
EP -	Maximum error associated with vessel pressure, psia
EZL -	Maximum error associated with distance Z of lower characteristics, ft
EZU -	Maximum error associated with distance Z of upper characteristics, ft
F - $[\bar{F}]$	Vector function of the time t and the vector Y used in the subroutine AMSINT and BURPDE
F1 -	Scratch storage for the vector F for calls to BURPDE from BURPMN
G - [G]	Critical mass flux, lb/sec/ft ²

TABLE C-2. (contd)

GFRCT -	Maximum fractional change in G allowed before damping with time constant DTG applied
GT - $[GA_E]$	Critical flow rate G times area of the effluent orifice, lb/sec
H - $[H]$	Height of the foam at time t, ft
HE - $[h_E]$	Specific enthalpy of the effluent fluid, Btu/lb
HV - $[L]$	Height of the vessel, ft
HO - $[H_0]$	Height of the liquid at time t = 0, ft
I -	Scratch variable usually used as a DO loop index
IBUG -	Variables set to 1 or 0 at the beginning of BURPMN to control debugging print out
IHSW -	Equals 0 when H is greater than Z_E and has never been less than Z_E ; equals 1 when H has become less than the subroutine BURPDE but has not yet been noted by the main program BURPMN; equals 2 when BURPMN detects that H has become less than Z_E . This switch is used in the computation of the effluent enthalpy h_E in the subroutine BURPDE.
IIL -	Directive vector indicating which components of the Y vector are the void fraction in the lower part of the vessel on the characteristics
IILZ -	Directive vector indicating which components of the vector Y are the distances of the characteristics in the lower part of the vessel
IIN -	Directive vector in which the components are equal to the component indices (IIN (I) = I)
IINP -	Index corresponding to input card number
IIU -	Directive vector indicating which components of the vector Y are the void fraction on the upper characteristics

TABLE C-2. (contd)

IIUZ -	Directive vector indicating which component of the Y vector are the distances Z of the upper characteristics
IM1 -	Scratch variable equal to I-1
INL -	Vector containing the identification numbers of the lower characteristics originally numbered 1 through NL
INP (I) -	Vector plot control parameters: 0 means do not draw plot Number I; one means draw plot Number I
INU -	Identification numbers of the upper characteristics
IPLTT -	Plot index; equals number of points to be plotted
ISTM -	Index obtained from subroutine SIMIBL
IXP -	Plot control information set up in DATA statements
J -	Scratch variable used as DO loop index
JPLT -	Indicator showing whether any plots have been made: 0 equals no plots; 1 equals at least one plot
K -	Scratch variable used as a DO loop index
KL -	Index used to indicate new identification number of generated lower characteristics
KP -	Scratch variables used in setting up plots of void fraction and velocity as a function of distance
KT -	The integral number of DELT's corresponding to the current value of T
KTP -	The integral number of DELTP's corresponding to current value of TPRT
KTPL -	Integral number of DELTPL's corresponding to current value of TPLT
L -	Scratch variable used as DO loop index

TABLE C-2. (contd)

LP -	Scratch variable used in the generation of the plots for void fraction and velocity versus distance
M -	Scratch variable
N -	Scratch variable
NA -	Number of entries in the AREA table
NB -	Branch index used to indicate errors upon return from the subroutine TBIDG
NBRO -	Branch variable used in the deletion of upper characteristics
NDIM -	Dimension of the Y vector
NH -	Switch variable use to suppress printout of lower characteristic information above H
NL -	Number of lower characteristics
NLN -	Equal to the maximum of NL or NU
NPR -	Branch variable used to control printout rate when foam level reaches vicinity of Z_E
NU -	Number of characteristics
PO - $[P_0]$	Initial pressure of the vessel, psia
STB -	Contains the current values of the properties of the saturated steam at the pressure P which is the first component of the Y vector
STBKK -	Table containing the saturated steam properties from the Keenan and Keyes steam tables
SO -	Initial value of the specific internal entropy, Btu/lb/deg R
T -	Current time, sec
TC -	Time up to which AMSINT has calculated, sec
TF -	Six component vector containing times corresponding to the components of the six dimensional vector F
TMAX -	Maximum value of time to which problem is to proceed, sec

TABLE C-2. (contd)

TPLT -	Time for next set of plots, sec
TPRT -	Time for next printout, sec
TPRTO -	Initial value of TPRT used when printout time interval changes, that is when H comes in the vicinity of z_E
TTO -	Vector containing the times at which the lower characteristics originated
UBUB - [c]	Function subprogram to compute the bubble rise velocity, ft/sec
UGEM - $[u_g^-]$	Velocity of the gas phase immedi- ately below the plane at z_E , ft/sec
UGEP - $[u_g^+]$	Velocity of the gas phase immedi- ately above the withdrawal plane z_E , ft/sec
UGL - $[u_g]$	Velocity of the gas phase associated with the lower characteristics, ft/sec
UGU - $[u_g]$	Velocity of the gas phase associated with the upper characteristics, ft/sec
ULEM - $[u_l^-]$	Velocity of the liquid phase immedi- ately below withdrawal plane z_E , ft/sec
ULEP - $[u_l^+]$	Velocity of the liquid phase immedi- ately above withdrawal plane z_E , ft/sec
ULL - $[u_l]$	Velocity of the liquid phase associ- ated with the lower characteristics, ft/sec
ULU - $[u_l]$	Velocity of the liquid phase associ- ated with the upper characteristics, ft/sec
VLH -	Volume of the vessel up to the foam level H, ft ³
VLT -	Total of volume of the vessel, ft ³
VLO -	Initial volume of the liquid phase, ft ³

TABLE C-2. (contd)

WDOTG - $\dot{w}_g$	Vaporization rate of the liquid, lb/sec/ft ³
WG -	Weight of the gas above the gas foam interface, lb
WGTO -	Initial weight of the gas, lb
WLT -	Weight of the liquid in the foam, lb
WLTO -	Initial weight of the liquid, lb
WT -	Total weight of the vessel contents, lb
WTO -	Total initial weight of the vessel contents, lb
XA -	$d\alpha/dt$ for $a = 0$, sec ⁻¹
XE -	Effluent void fraction
XP -	Storage for the plotted variables
XZ -	Initial value of dz/dt for a and Z equals 0, ft/sec
Y -	The vector of unknown quantities. See Equation (35)
YP -	The predicted value of the Y vector as computed by subroutine AMSINT
YPL -	Storage for transfer of plot infor- mation to the plot subroutine
Y1 -	Intermediate trial Y vector computed by subroutine AMSINT
Y2 -	Intermediate trial Y vector computed by subroutine AMSINT
Z -	Table of distances corresponding to the AREA table, ft
ZE -	Elevation of the withdrawal plane above the bottom of the vessel, ft

TABLE C-3. Subroutine AMSINT

```

CAMIN
C THIS IS A SUBROUTINE TO SOLVE A SET OF N SIMULTANEOUS
C FIRST ORDER DIFFERENTIAL EQUATIONS USING THE GENERALIZED
C ADAMS-MOULTON METHOD* REFERENCE DF58AGT679--D F SHELL
C SUBROUTINE AMSINT(IX,XF,XC,Y,EMAX,ND,H1,X0,Y0,HF,$)
C CALL LIST---
C IX IS A CONTROL INTEGER--1 MEANS FIRST ENTRY TO SUBR--RETURN IF X=XF=+
C                               2 MEANS LATER ENTRY TO SUBR--RETURN IF X=XF=+
C                               3 MEANS FIRST ENTRY TO SUBR--CALC UP TO X=XF
C                               4 MEANS LATER ENTRY TO SUBR--CALC UP TO X=XF
C XF IS MAX(MIN) VALUE OF X TO WHICH INTEGRATION PROCDFDS
C XC IS CURRENT VALUE OF X TO WHICH Y CORRESPONDS WHEN RETURN
C Y IS VECTOR OF DEPENDENT VARIABLES
C EMAX IS MAXIMUM TOLERABLE ERROR IN Y--A VECTOR
C ND NUMBER OF Y DIMENSIONS
C H1 IS ESTIMATE OF SUITABLE INTEGRATION INTERVAL (MAY BE NEGATIVE)
C XG IS INITIAL VALUE OF X
C Y0 IS INITIAL VALUE OF Y VECTOR
C HF IS SMALLEST STEP ABSOLUTE THAT IS PERMITTED--ROUTINE QUILTS IF
C   ABSF(H)-ABSF(HF) IS MINUS--IF HF IS NEGATIVE H1 IS TAKEN TO BE
C   MAXIMUM PERMISSIBLE STEPSIZE
C $ IS ERROR RETURN
C
C SUBROUTINES REQUIRED---
C DE(X,Y,F)--WHERE X AND Y ARE DEFINED ABOVE AND F(X,Y) IS VALUE OF
C   RIGHT SIDE OF FIRST ORDER DIFF EQ DY/DX = F(X,Y)
C SING(X,Y,N,J)--WHERE X,Y,N ARE DEFINED ABOVE AND Y(J) IS COMPONENT
C   WHICH BECAME SINGULAR
C
C   DIMENSION Y(200),EMAX(200),Y0(200),P(6,27),C(5,9)
C   DATA ((P(I,J),I=1,6),J=1,9)/
1  16128., 22808., 8218., 1645., 107., 0.0203,
2  3840., 5512., 2135., 570., 107., 0.0277,
3  1152., 1675., 694., 278., 107., 0.0339,
4  768., 1163., 648., 278., 25., 0.0335,
5  192., 297., 187., 107., 25., 0.0430,
6  96., 151., 106., 91., 40., 0.0502,
7  360., 589., 625., 455., 59., 0.0497,
8  96., 161., 206., 200., 59., 0.0597,
9  126., 215., 322., 469., 236., 0.0663/

```

TABLE C-3. (contd)

```

DATA ((P(I,J),I=1,6),J=10,18)/
A 2016., 3880., 2366., 539., 37., 0.0358,
B 480., 952., 625., 190., 37., 0.0477,
C 144., 293., 206., 94., 37., 0.0573,
D 96., 211., 200., 94., 99 0.0563,
E 24., 55., 59., 37., 9., 0.0704,
F 30., 71., 85., 80., 36., 0.0804,
G 90., 229., 415., 320., 44., 0.0792,
H 6., 16., 35., 36., 11., 0.0924,
I 126., 347., 889., 1372., 704., 0.1008/
DATA ((P(I,J),I=1,6),J=19,27)/
J 504., 1648., 1526., 413., 31., 0.0588,
K 120., 416., 415., 150., 31., 0.0756,
L 36., 131., 140., 76., 31., 0.0882,
M 6., 25., 36., 19., 2., 0.0861,
N 6., 27., 44., 31., 8., 0.1033,
O 30., 143., 260., 275., 128., 0.1148,
P 45., 242., 665., 550., 82., 0.1127,
Q 6., 35., 116., 128., 41., 0.1268,
R 63., 388., 1505., 2492., 1312., 0.1353/
DATA ((C(I,J),I=1,5),J=1,9)/
1 2016., 856., 1246., 91., 5.,
2 96., 40., 61., 6., 1.,
3 144., 59., 94., 14., 5.,
4 96., 37., 72., 14., 1.,
5 24., 9., 19., 5., 1.,
6 30., 11., 25., 10., 4.,
7 90., 31., 95., 40., 4.,
8 6., 2., 7., 40., 1.,
9 126., 41., 161., 140., 64./
DIMENSION DYP(200),DYC(200),E(200)
COMMON/AMS/ YP(200),Y1(200),F(200,6),Y2(200),TF(6)
N=ND
GOTO(1,2,1,2),IX
C COMPUTE A STARTING H
1 ASSIGN12TO ICE
11 H=H1
C GO THROUGH INITIAL EXTRAPOLATION
12 CALLDE(X0,Y0(1),F(1,2),$300)
TF(2)=X0

```

TABLE C-3. (contd)

```

      DO101I=1,N
101  Y1(I)=Y0(I)+H*F(I,2)/4.
      X=X0+H/4.
      CALLDE(X,Y1(1),F(1,3),$300)
      TF(3)=X
      DO102I=1,N
102  Y2(I)=Y1(I)+H*(3.*F(I,3)-F(I,2))/8.
      X=X+H/4.
      CALLDE(X,Y2(1),F(1,4),$300)
      TF(4)=X
      DO103I=1,N
103  YP(I)=Y2(I)+H*(19.*F(I,4)-20.*F(I,3)+7.*F(I,2))/12.
1031 X=X+H/2.
C PERFORM INITIAL CORRECTION AND TEST
      CALLDE(X,YP(1),F(1,5),$300)
      TF(5)=X
      ASSIGN107TOITEST
      DO104I=1,N
      Y(I)=Y0(I)+H*(37.*F(I,2)+72.*F(I,3)-14.*F(I,4)+F(I,5))/384.
      IF(ABS (Y1(I)-Y(I))-EMAX(I))104,104,1041
1041 ASSIGN1031TOITEST
104  Y1(I)=Y(I)
      X=X0+H/4.
      CALLDE(X,Y1(1),F(1,3),$300)
      DO105I=1,N
      Y(I)=Y1(I)+H*(-5.*F(I,2)+56.*F(I,3)+46.*F(I,4)-F(I,5))/384.
      IF(ABS (Y2(I)-Y(I))-EMAX(I))105,105,1051
1051 ASSIGN1031TOITEST
105  Y2(I)=Y(I)
      X=X+H/4.
      CALLDE(X,Y2(1),F(1,4),$300)
      DO106I=1,N
      Y(I)=Y2(I)+H*(F(I,2)-4.*F(I,3)+7.*F(I,4)+2.*F(I,5))/12.
      IF(ABS (YP(I)-Y(I))-EMAX(I))106,106,1061
1061 ASSIGN1031TOITEST
106  YP(I)=Y(I)
      GOTOITEST,(1031,107)
107  X=X+H/2.
      IT1=-1
      IT2=-1

```

TABLE C-3. (contd)

```

      IT3=0
20  CALLDE(X,YP(1),F(1,5),$300)
      TF(5)=X
200  ITC=3*IT1+IT2
      ITP=-3*ITC-IT3+14
      ITC=5-ITC
      DO201I=1,N
        DYP(I)=(P(2,ITP)*F(I,5)-P(3,ITP)*F(I,4)+P(4,ITP)*F(I,3)-P(5,ITP)*
1F(I,2))*H/P(1,ITP)
201  Y1(I)=YP(I)+DYP(I)
      X=X+H
      CALLDE(X,Y1(1),F(1,6),$300)
      TF(6)=X
      DO202J=1,N
        DYC(J)=(C(2,ITC)*F(J,6)+C(3,ITC)*F(J,5)-C(4,ITC)*F(J,4)+C(5,ITC)*
1F(J,3))*H/C(1,ITC)
        E(J)=P(6,ITP)*(DYC(J)-DYP(J))
        IF(EMAX(J)-ABS(E(J)))210,202,202
707  Y(J)=DYC(J)-E(J)+YP(J)
      ASSIGN204TOLOW
      TF(1)=TF(2)
      TF(2)=TF(3)
      TF(3)=TF(4)
      TF(4)=TF(5)
      DO203I=1,N
        Y2(I)=YP(I)
        YP(I)=Y(I)
        F(I,1)=F(I,2)
        F(I,2)=F(I,3)
        F(I,3)=F(I,4)
        F(I,4)=F(I,5)
        IF(EMAX(I)/40.-ABS(E(I)))2031,2031,203
2071 ASSIGN205TOLOW
203  CONTINUE
      ITT=1
      IT0=0
      GOTOLOW,(204,205)
204  IF(HF)2041,2042,2042
2041 IF(H-H1/2.0)2042,2042,205
2042 IT0=-1

```

TABLE C-3. (contd)

```

      H=H*2.
205  IT4=IT3
      IT3=IT2
      IT2=IT1
      IT1=IT0
      ASSIGN211TO  ICE
      XC=X
      2  IF((X-XF)/H)20, ,240
      IF(X-XC)240,206,240
206  RETURN
C  REDUCE INTERVAL SIZE AND RECALCULATE
210  H=H/2.
      IF(ABS (HF)-ABS (H))2100,2100,220
'2100 GOTO  ICE,(12,211)
211  IF(IT1)212,212,213
212  IT1=IT1+1
      X=X-2.*H
      GOT0200
213  IF(ITT)220,2131,2131
2131  IF(IT2)214,214,220
214  IT1=IT2+1
      IT2=IT3
      IT3=IT4
      H=2.*H
      X=X-3.*H
      TF(5)=TF(4)
      TF(4)=TF(3)
      TF(3)=TF(2)
      TF(2)=TF(1)
      DO215 I=1,N
      YP(I)=Y2(I)
      F(I,5)=F(I,4)
      F(I,4)=F(I,3)
      F(I,3)=F(I,2)
215  F(I,2)=F(I,1)
      ITT=-1
      GOT0200
C  TAKE CARE OF SINGULARITY OUTPUT
220  CALLSING(X,Y,N,J)
      RETURN 11

```

TABLE C-3. (contd)

```

C COMPUTE SPECIAL VALUES OF Y.
 24C GOTO(206,206,250,250),IX
 250 IF(IT1)2503,2501,2502
 2501 HI=H
      GOT0251
 7502 HI=2.*H
      GOT0251
 2503 HI=H/2.
 251 IF(IT2)2511,2513,2512
 2511 H2=HI/2.
      GOT0252
 2512 H2=2.*HI
      GOT0252
 2513 H2=HI
 252 IF(IT3)2521,2523,2522
 2521 H3=H2/2.
      GOT0253
 2522 H3=2.*H2
      GOT0253
 2523 H3=H2
 253 Q1=H2+HI
      Q2=H2+H3
      R1=H3+Q1
      U=XF-X+HI
      U1=((U/4.+(H2+Q2)/3.)*U+H2*Q2/2.)*U/(HI*Q1*R1)
      U2=((U/4.-(HI-H2-Q2)/3.)*U-(HI*H2-H2*Q2+Q2*HI)/2.)*U/(HI*H2*Q2)-1.
      U3=((U/4.-(HI-Q2)/3.)*U-HI*Q2/2.)*U/(H2*H3*Q1)
      U4=((U/4.-(HI-H2)/3.)*U-HI*H2/2.)*U/(H3*Q2*R1)
      DO260I=1,N
 260 Y(I)=Y2(I)+U*(U1*F(I,5)-U2*F(I,4)+U3*F(I,3)-U4*F(I,2))
      XC=XF
      RETURN
 300 RETURN 11
      END

```


TABLE C-4. Subroutine BURPDE

```

C BURP-2A (BU)BBLE (R)ISE (P)HENOMENA
C     IS A CODE TO DESCRIBE THE VOID FRACTION IN A PRESSURE VESSEL
C     CONTAINING SATURATED WATER AND VAPOR AS A FUNCTION OF TIME
C     AND AXIAL DISTANCE DURING THE TWO PHASE BLOWDOWN. A MOODY
C     TWO PHASE CRITICAL FLOW MODEL IS TAKEN TO DESCRIBE THE
C     EFFLUENT MASS FLOWRATE. THE EFFLUENT CONDITIONS (PRESSURE
C     AND ENTHALPY) ARE COMPUTED FROM THE VOID FRACTION AT THE
C     WITHDRAWAL PLANE.
C
C     SUBROUTINE DE(T,Y,F,$)
C SUBROUTINE DE IS TO BE USED BY AMSINT (FL168) TO DO INTEGRATION ALONG
C CHARACTERISTICS OF THE P.D.E. WHICH DESCRIBES THE BURP
C CALL LIST T = CURRENT VALUE OF THE TIME
C     Y = IS DEPENDENT ARRAY INDEXED AS FOLLOWS--
C     1= P - PRESSURE IN THE VESSEL
C     2= WL- TOTAL WT OF LIQUID IN THE VESSEL
C     3= WG- TOTAL WT OF GAS IN THE VESSEL
C           ABOVE WITHDRAWAL PLANE--INDEXED BY IIL
C     4 THRU IA= ALPHA ON LOWER CHAR. THRU FIRST CHAR.
C     ID THRU IE= Z VALUES ON LOWER CHAR.--INDEXED BY IILZ
C     IB THRU IC= ALPHA ON UPPER CHAR. BEGINNING WITH
C           FIRST CHAR. BELOW WITHDRAWAL PLANE--
C           INDEXED BY IIU--FIRSTCHAR* ABOVE INTER-
C           FACE CARRIED AS FICTICIOUS VALUE FOR
C           INTERPOLATION AT INTERFACE
C     IF THRU IG= Z VALUES ON UPPER CHAR.--INDEXED BY IIUZ
C     F = VALUE OF RIGHT HAND SIDE OF CHAR. EQN.  $DY/DT=F(Y,T)$ 
C
COMMON      STBKK(295,10),STB(10)
COMMON /INDEX/      IIL(50)      ,IIU(50)      ,IILZ(50)      ,IIUZ(50)
1          ,IIN(100)      ,INL(50)      ,INU(50)      ,INP(10)
COMMON /CHAR/      UGU(50)      ,ULU(50)      ,UGL(50)      ,ULL(50)
1          ,ALFM1U(50),ALFM1L(50) ,ARM1CH(100)
COMMON /COND/      WLT          ,WG          ,SO          ,ALFEM
1          ,ALFEP          ,ZE          ,ALK          ,XE          ,HE
2          ,AE          ,WDOTG          ,AVE          ,ARM1E          ,ALFE
3          ,H          ,UGEP          ,UGEM          ,G          ,IHSW
COMMON /VESSEL/      AREA(100)      ,Z(100)      ,ARM1(100)
COMMON /ICOND/      NU          ,NL          ,NA
NL= NO.OF LOWER CHAR- .GE.4
NU= NO.OF UPPER CHAR. .GE.4

```

TABLE C-4. (contd)

```

COMMON /DES/ .      TTO(200)      ,NBE      ,GFRCT      ,DTG
DIMENSION Y(200) ,F(200)      ,IIS(6)      ,A(20,6)      ,B(102)
1      ,D(8)
DATA TL0,TL1,TL2/3*-1.E+35/,GL2/0./
DATA (IIS(I),I=1,6)/3,4,7,8,9,10/
DEFINE YI(I)=Y(I)
NL=NL
NU=NU
i=T

C*****FIRST GET PROPERTIES OF FLUID AT P=Y(1), THEN COMPUTE DERIVATIVES
C      WRT P BY FITTING QUADRATIC TO 4 PTS, AND DIFFERENTIATING IN DERIV
C      CALL STMTBL(1,Y(1),ISTM,$5000)
C*****STB NOW HAS PROPERTIES AT P, ISTM IS INDEX OF TWO TABLE ENTRIES
C      BELOW P
C      DO 100 I=1,6
C          J=IIS(I)
C          DO 100 K=1,4
C              L=ISTM-1+K
C              A(K,I)=STBKK(L,J)
100 CONTINUE
C      CALL DERIV(A,STBKK(ISTM,1),Y(1),D,6,4)
C      D(7)=D(1)/STB(3)
C      D(8)=D(2)/STB(4)

C
C*****D(I) NOW CONTAINS FOLLOWING DERIVATIVES ALONG SAT. CURVE--
C      D(1) = D(VF)/DP
C      D(2) = D(VG)/DP
C      D(3) = D(SF)/DP
C      D(4) = D(SG)/DP
C      D(5) = D(UF)/DP
C      D(6) = D(UG)/DP
C      D(7) = D(LN(VF))/DP
C      D(8) = D(LN(VG))/DP
C
C*****NOW COMPUTE WLT=TOTAL MASS OF LIQUID ASSUMING FICTICIOUS OVERALL
C      ISENTROPIC PATH
C      WLT=WU*(STB(8)-S0)/(STB(8)-STB(7))
C*****GET ALPHA E PLUS AND MINJS-ALFEP AND ALFEM,AND COMPUTE TERMS
C      BYPASS IF FOAM BELOW ZE

```

TABLE C-4. (contd)

```

      IF(IHSW.GT.1)GOTO 200
      CALL TB1DG(ZE,ALFEP,Y,Y,IIUZ,IIU,NU,NB)
      IF(NB.NE.1)GOTO 5300
      CP=UBUB(ALFEP)
      T1=ALFEP*AVE/STB(4)
      T2=(1.-ALFEP)*AVE/STB(3)
      T5=T1+T2
      T7=CP*T2
      T8=STB(6)*T1+STB(5)*T2
      T10=STB(5)*T7
      IF(NL.EQ.0)GOTO 150
      CALL TB1DG(ZE,ALFEM,Y,Y,IILZ,IIL,NL,NB)
      IF(NB.NE.1)GOTO 5230
      CM=UBUB(ALFEM)
      T3=ALFEM*AVE/STB(4)
      T4=(1.-ALFEM)*AVE/STB(3)
      T6=T3+T4
      T9=STB(6)*T3+STB(5)*T4
      T7=T7-CM*T4
      T10=T7*STB(5)
      GOTO 200
150  T6=0.
      ALFAI=STB(3)*Y(2)
      T9=0.
      IF(ALFAI.LT.0.)GOTO 5900
      GOTO 350
C
C*****COMPUTE INTEGRAL OF AREA*ALPHA*DZ IN UPPER AND LOWER REGIONS USING
C  TRAPEZOIDAL FORMULA
200  CONTINUE
      ALFM1L(1)=YI(IILZ(1))*YI(IIL(1))*0.5
      CALL TB1D(YI(IILZ(1)),AR2,Z,AREA,NA)
      AINT2=YI(IIL(1))*AR2
      DO 300 I=2,NL
      AR1=AR2
      AINT1=AINT2
      CALL TB1D(YI(IILZ(I)),AR2,Z,AREA,NA)
      AINT2=YI(IIL(I))*AR2
      ALFM1L(I)=(ALFM1L(I-1)*AR1+0.5*(AINT1+AINT2)*(YI(IILZ(I))
1      -YI(IILZ(I-1))))/AR2

```

TABLE C-4. (contd)

```

300 CONTINUE
C*****GET INTEGRAL OF(1.-ALPHA)UP TO ZE, SUBTRACT FROM VOL. OF LIQUID
IF(IHSW.GT.1)GOTO 1250
IHSW=0
CALL TB1DG(ZE,ALFAI,Y,ALFM1L,IILZ,IIN,NL,NB)
IF(NB.NE.1)GOTO5400
ALFAI=Y(2)*STB(3)+(ALFAI-ARM1E)*AVE
C*****BYPASS INTEGRATION ON UPPER CHAR* IF FOAM BELOW ZE
IF(ALFAI.LT.0.)GOTO 1200
350 ALFM1U(1)=0.
CALL TB1D(YI(IIUZ(1)),AR2,Z,AREA,NA)
CALL TB1D(YI(IIUZ(1)),ARM1CH(1),Z,ARM1,NA)
ARM1CH(1)=ARM1CH(1)*AR2
AINT2=YI(IIUZ(1))*AR2
B(1)=AR2
DO 400 I=2,NU
AR1=AR2
AINT1=AINT2
CALL TB1D(YI(IIUZ(I)),AR2,Z,AREA,NA)
CALL TB1D(YI(IIUZ(I)),ARM1CH(I),Z,ARM1,NA)
B(I)=AR2
AINT2=YI(IIUZ(I))*AR2
ALFM1U(I)=(ALFM1U(I-1) +0.5*(AINT1+AINT2)*(YI(IIUZ(I))
1 -YI(IIUZ(I-1))))
ARM1CH(I)=ARM1CH(I)*AR2-ALFM1U(I)
400 CONTINUE
C*****ADJUST UPPER ALPHA*AREA INTEGRAL TO BE ZERO AT ZE
CALL TB1DG(ZE,ALFM1E,Y,ALFM1U,IIUZ,IIN,NU,NB)
IF(NB.NE.1)GOTO 5500
DO 500 I=1,NU
ALFM1U(I)=(ALFM1U(I)-ALFM1E)/B(I)
ARM1CH(I)=ARM1CH(I)-ARM1E*AVE+ALFM1E
500 CONTINUE
C*****COMPUTE FOAM LEVEL
CALL TB1DG(ALFAI,H,ARM1CH,Y,IIN,IIUZ,NU,NB)
IF(NB.NE.1)GOTO5600
C
C*****NOW BEGIN MAIN ITERATION LOOP TO GFT G
900 IT=0
1000 IT=IT+1

```

TABLE C-4. (contd)

```

      IF(IT.GT.10)GOTO 5700
C*****COMPUTE EFFLUENT MASS FLOWRATE FROM HE AND P BY MOODY MODEL
C      HE FROM PREVIOUS PASS THRU DE
      G=GMOODY(Y(1),HE)
      CALL GSMOO($6000)
C*****INVERT 3X3 MATRIX TO GET DP/DT,D(WL)/DT, AND D(WG)/DT--IE F(1),
C      F(2) AND F(3)
      DELTA=(Y(3)*D(2)+Y(2)*D(1))*(STB(10)-STB(9))
      1      -(Y(3)*D(6)+Y(2)*D(5))*(STB(4)-STB(3))
      DELTA=AE*G/DELTA
      F(2)=((HE-STB(10))*(Y(3)*D(2)+Y(2)*D(1))
      1      +STB(4)*(Y(3)*D(6)+Y(2)*D(5)))*DELTA
      F(1)=((HE-STB(5))*STB(4)-(HE-STB(6))*STB(3))*DELTA
      F(3)=(-(HE-STB(9))*(Y(3)*D(2)+Y(2)*D(1))
      1      -STB(3)*(Y(3)*D(6)+Y(2)*D(5))*DELTA
C*****COMPUTE FICTICIOUS OVERALL GAS GENERATION RATE--ISENTROPICALLY
      WDOTG=F(1)*W0*((S0-STB(8))*D(3)-(S0-STB(7))*D(4))/(STB(8)-STB(7))
      1      )**2
      GLC=WDOTG/ WLT/ STB(3)
C*****GLC IS LOWER CASE G, NOW COMPUTE D(LN(VG))/DT ETC
      DLNVG=D(8)*F(1)
      DLNVF=D(7)*F(1)
C*****COMPUTE GAS PHASE VELOCITY IN LOWER PART OF VESSEL
      AINT2=(STB(4)-STB(3))*GLC+DLNVF
      AINT1=DLNVG-AINT2
      IF(NL.EQ.0)GOTO 1150
      DO 1100 I=1,NL
      CALL TB1D (YI(IILZ(I)),AR1,Z,ARM1,NA)
      UGL(I)=UBUB(YI(IIL(I)))*(1.-YI(IIL(I)))+AINT1*ALFM1L(I)+AINT2*AR1
1100 CONTINUE
      IF(IHSW.GE.1)GOTO 2150
C*****INTERPOLATE TO GET GAS VELOCITY NEGATIVE SIDE OF ZE
      CALL TB1DG(ZE,UGEM,Y,UGL,IILZ,IIN,NL,NB)
C*****COMPUTE GAS VELOCITY ON POSITIVE SIDE OF ZE, THEN HE(=HI)
1150 UGEP=(T6*UGEM+T7-G*AE)/T5
      HI=(T9*UGEM-T8*UGEP+T10)/(G*AE)
C*****COMPUTE ITERATIVE ENTHALPY OF EFFLUENT AND COMPARE WITH GUESS

      IF(ABS(HE-HI).LT.0.05)GOTO 2000
      HE=HI

```

TABLE C-4. (contd)

```

      GOTO1000
C*****COMPUTATION OF FOAM LEVEL FOR H.LT.ZE
1200 IHSW=1
1250 HE=STB(6)
      B(1)=0.
      B(52)=Z(1)
      DO 1300 I=1,NL
        CALL TB1D(YI(IILZ(I)),AR1,Z,AREA,NA)
        CALL TB1D(YI(IILZ(I)),AINT1,Z,ARM1,NA)
        B(I+1)=AR1*(AINT1-ALFM1L(I))
        B(I+52)=YI(IILZ(I))
1300 CONTINUE
      CALL TB1D(Y(2)*STB(3),H,B,B(52),NL+1)
      IF(H.LE.Z(1))GOTO 5900
      IF(H.LT.ZE)GOTO 9GG
C*****WHEN FOAM RISES PAST ZE AGAIN CPLC HE, BY INTERPOLATION
      CALL TB1DG(ZE,ALFE,Y,Y,IILZ,IIL,NL,NB)
      T1=ALFE/STB(4)
      T2=(1.-ALFE)/STB(3)
      HE=(T1*STB(6)+T2*STB(5))/(T1+T2)
      GOTO 900
C
C*****END OF MAIN ITERATION LOOP
C
C*****COMPUTE GAS PHASE VELOCITY ON UPPER CHARACTERISTICS
2000 T11=UGEP-UBUB(ALFEP)*(1.-ALFEP)
      HE=H
      DO 2100 I=1,NU
        CALL TB1D(YI(IIUZ(I)),AR1,Z,ARM1,NA)
        UGU(I)=UBUB(YI(IIU(I)))*(1.-YI(IIU(I)))+T11
        1      +AINT1*ALFM1U(I) + AINT2*(AR1-AVE*ARM1E/B(I))
2100 CONTINUE
C
C*****COMPUTE D(ALPHA)/DT AND DZ/DT ON ALL CHAR.
2150 CONTINUE
      GLC0=-STB(4)*GLC
      GLC1=(2.*STB(4)-STB(3))*GLC+DLNVF-DLNVG
      GLC2=-GLC*(STB(4)-STB(3))+DLNVG-DLNVF
      IF(NL.EQ.0) GOTO 2250

```

TABLE C-4. (contd)

```

DO 2200 I=1,NL
J=IIL(I)
K=IILZ(I)
F(J)=-(GLC2*Y(J)*Y(J)+GLC1*Y(J)+GLC0)
F(K)=UGL(I)-UBUB(Y(J))*Y(J)
IF(TTO(K).GT.T)F(K)=UBUB(0.)
IF(TTO(J).GT.T)F(J)=-GLC0
2200 CONTINUE
2250 IF(IHSW.GE.1)GOTO 2350
DO 2300 I=1,NU
J=IIU(I)
K=IIUZ(I)
F(J)=-(GLC2*Y(J)*Y(J)+GLC1*Y(J)+GLC0)
F(K)=UGU(I)-UBUB(Y(J))*Y(J)
F(K)=0.
IF(TTO(K).GT.T)F(K)=0.
IF(TTO(J).GT.T)F(J)=0.
2300 CONTINUE
IF(UGEP-ALFEP*UBUB(ALFEP).GE.0.)GOTO 5800
2350 CONTINUE
RETURN
C
C*****DEBUGGING OUTPUTS
ENTRY DESING(X1,X2,X3,$)
2400 CALL OUT(6HY ,Y ,2*(NL+NU)+6)
CALL OUT(6HSTB ,STB ,10)
CALL OUT(6HD ,D ,98)
CALL OUT(6HWLT ,WLT ,1)
CALL OUT(6HALFEM ,ALFEM ,1)
CALL OUT(6HALFEP ,ALFEP ,1)
CALL OUT(6HHE ,HE ,1)
CALL OUT(6HALFM1L ,ALFM1L ,NL)
CALL OUT(6HALFM1U ,ALFM1U ,NU)
CALL OUT(6HB ,B ,50)
CALL OUT(6HG ,G ,1)
CALL OUT(6HWDOTG ,WDOTG ,1)
CALL OUT(6HGLC ,GLC ,1)
CALL OUT(6HGLC0 ,GLC0 ,1)
CALL OUT(6HGLC1 ,GLC1 ,1)
CALL OUT(6HGLC2 ,GLC2 ,1)

```

TABLE C-4. (contd)

```

CALL OUT(6HUGL ,UGL ,NL)
CALL OUT(6HUGEM ,UGEM ,1)
CALL OUT(6HUGEP ,UGEP ,1)
CALL OUT(6HHI ,HI ,1)
CALL OUT(6HUGU ,UGU ,NU)
CALL OUT(6HCP ,9CP ,1)
CALL OUT(6HCM ,9CM ,1)
CALL OUT(6HT1 ,T1 ,1)
CALL OUT(6HT2 ,T2 ,1)
CALL OUT(6HT3 ,T3 ,1)
CALL OUT(6HT4 ,T4 ,1)
CALL OUT(6HT5 ,T5 ,1)
CALL OUT(6HT6 ,T6 ,1)
CALL OUT(6HT7 ,T7 ,1)
CALL OUT(6HT8 ,T8 ,1)
CALL OUT(6HT9 ,T9 ,1)
CALL OUT(6HT10 ,T10 ,1)
CALL OUT(6HT11 ,T11 ,1)
CALL OUT(6HDLNVG ,DLNVG ,1)
CALL OUT(6HDLNVF ,DLNVF ,1)
CALL OUT(6HAINT1 ,AINT1 ,1)
CALL OUT(6HAINT2 ,AINT2 ,1)
CALL IOUT(6HIIL ,IIL ,NL)
CALL IOUT(6HINL ,INL ,NL)
CALL IOUT(6HINU ,INU ,NU)
CALL IOUT(6HIIU ,IIU ,NU)
CALL IOUT(6HIILZ ,IILZ ,NL)
CALL IOUT(6HIIUZ ,IIUZ ,NU)
CALL OUT(6HARM1 ,ARM1 ,NA)
CALL OUT(6HALFAI ,ALFAI ,1)
CALL OUT(6HARM1CH,ARM1CH,NU)
CALL OUT(6HALFM1E,ALFM1E,1)
CALL OUT(6HH ,H ,1)
CALL OUT(6HF ,F ,2*(NL+NU)+6)
CALL IOUT(6HIT ,IT ,1)
CALL OUT(6HT ,T ,1)
RETURN 4

```

C

C*****ERROR HANDLING ROUTINES

5000 ERR=1.

TABLE C-4. (contd)

```

5100 J=2*(NL+NU)+6
      F(J)=ERR
      GOTO 2400
5200 ERR=2.
      GOTO 5100
5300 ERR=3.
      GOTO 5100
5400 ERR=4.
      GOTO 5100
5500 ERR=5.
      GOTO 5100
5600 ERR=6.
      GOTO 5100
5700 ERR=7.
      GOTO 5100
5800 ERR=8.
      GOTO 5100
5900 ERR=9.
      GOTO 5100
6000 ERR=10.
      GOTO 5100
C*****
C*****DEBUGGING PRINTOUT ROUTINES
      SUBROUTINE OUT(HOL,X,NX)
      WRITE(6,1)HOL
      DIMENSION X(1)
      WRITE(6,2)(X(I),I=1,NX)
      RETURN
1  FORMAT(1H ,A6)
2  FORMAT(1H ,1P10E11.5)
      SUBROUTINE IOUT(HOL,IX,NX)
      DIMENSION IX(1)
      WRITE(6,1)HOL
      WRITE(6,2)(IX(I),I=1,NX)
      RETURN
1  FORMAT(1H ,A6)
2  FORMAT(1H ,30I4)
C*****
C*****ROUTINE TO SMOOTH G AT TRANSITION
      SUBROUTINE GSMOO($)
      IF(GFRCT.LE.0.)RETURN
      IF(X-TL2)7000,7200,
      TL0=TL1
      TL1=TL2
      GL0=GL1
      GL1=GL2
      GOTO 7200
7000 IF(X-TL1),,7200
      IF(X-TL0),7100,7100
      RETURN 1
7100 TL1=TL0
      GL1=GL0
7200 TL2=X
      IF(ABS((G-GL1)/G).LT.GFRCT) GOTO 7300
      G=GL1+(G-GL1)*(1.-EXP((TL1-TL2)/DTG))
7300 GL2=G
      RETURN
      END

```

TABLE C-5. FORTRAN Variables Used in BURPDE
(Not already defined in Table C-2)

AIN1 -	Scratch variable used in obtaining ALFMIU
AIN2	Scratch variable also used in obtaining ALFMIU
ALFAI -	Iteration variable used in the determination of the foam level H
A -	Scratch variable used for storing information from the steam tables
ALFM1E - $[\overline{A}_{vE} \int_{Z_1}^{Z_E} \alpha A_v dz]$	Integral of the void fraction times vessel area from the first upper characteristics to the withdrawal plane, ft
AR1, AR2 -	Scratch variables used in obtaining the integral of alpha times the area up to Z
B -	Scratch variable used to store either areas of the vessel corresponding to the current position of characteristic or used in the computation of the foam level for the case where H is less than Z_E
CM -	Value of the bubble-rise velocity immediately below the withdrawal plane
CP -	Value of the bubble-rise velocity immediately above the withdrawal plane
D -	Table of the derivatives of various internal properties of the saturated steam described in the comment cards of the subroutine BURPDE
DELTA - [A]	Corresponds to Greek letter delta as given in Equation (4)
DLNVF - $[\partial \ln v_f / \partial t]$	Derivative of the logarithm of the specific volume of the liquid phase with respect to time, sec^{-1}
DLNVG - $[\partial \ln v_g / \partial t]$	Derivative of the gas phase specific volume with respect to time, sec^{-1}

TABLE C-5. (contd)

ERR -	Variable indicating type of error which caused computation to terminate in the subroutine BURPDE
GLC - [g]	Variable defined by Equation (20)
GLC0, GLC1, GLC2 - [g ₀ , g ₁ , g ₂]	Variables defined by Equation (23)
GLO, GL1, GL2 -	Values of the critical flow rate G at times TLO, TL1 and TL2 used in the subroutine GSM00 in the smoothing of the mass flow rate for numerical stability
HI -	Iterative variable equal to HE, Btu/lb
IIS -	Vector set up in data statement to pick out desired internal properties from the steam tables
ISTM -	Variable fed back from the SIMIBL subroutine indicating the surrounding pressure entries from the steam table to the current value of the pressure
IT -	Iteration counter
J, K, L -	Scratch variables used as DO loop indices
NB -	Set equal to one on return from the TB1DG subroutine indicating that an error has occurred in the table interpolation procedure
TLO, TL1, TL2 -	Times used in the GSM00 smoothing subroutine
T1, T2, T3, T4, T5, T6, T7, T8, T9, T10 -	Variables corresponding to the various terms in Equations (28) and (28'). They are used in the computation of the effluent enthalpy (h _F) and the gas phase velocity (u _g) above the withdrawal plane
X -	Internal variable set equal to the input variable T, sec

TABLE C-6. Subroutine STMTBL

```

SUBROUTINE STMTBL(M,V,N1,$)
DIMENSION STVD(10),X(295,10)
DIMENSION A(4)
C SUBROUTINE PROGRAM,STEAM TABLES,SAT,INTERPROLATION
C FOLLOWING STATEMENTS TO APPEAR IN MAIN PROGRAM
C DIMENSION STV(10) WHERE STV IS ANY LEGAL FORTRAN VARIABLE
C DEFINITIONS
C THE CALL STATEMENT IS--CALL STMTBL(N,P,ISTM,$)
C WHERE N=INPUT COLUMN INTEGER,P=ASSIGNED VALUE OF THE COLUMN
C M=STEAM TABLE ROW ENTRY UPON WHICH INTERPOLATION IS TO BE MADE (
C ISTM=TABLE ENTRY INDEX 2 VALUES BELOW P, AND $ IS ERROR RETURN
C AYD STV=INTERPOLATED VALUES FOR P RANGING FROM 1 TO 10.
C THUS STV(J)= TABLE VALUE CORRESPONDING TO P IN COLUMN J.
C IF SCANNING ON UG OR HG, SINCE THESE VALUES REACH MAX. VALUES AT A
C 450PSIG, THIS PROGRAM WILL FIND VALUES ON ASCENDING SIDE ONLY
C DECENDING VALUES ARE REQD,USE 10*M
COMMON X,STVD
DATA ( X(I,1),I=1,272) /.20,.25,.30,.35,.40,.45,.50,.6,.7,.8,.9,
11.0,1.2,1.4,1.6,1.8,2.0,2.2,2.4,2.6,2.8,3.0,3.5,4.0,4.5,5.0,5.5,
26.0,6.5,7.0,7.5,8.0,8.5,9.0,9.5,10.,11.,12.,13.,14.,14.696,15.,
316.,17.,18.,19.,20.,21.,22.,23.,24.,25.,26.,27.,28.,29.,30.,31.,
432.,33.,34.,35.,36.,37.,38.,39.,40.,41.,42.,43.,44.,45.,46.,47.,
548.,49.,50.,51.,52.,53.,54.,55.,56.,57.,58.,59.,60.,61.,62.,63.,
664.,65.,66.,67.,68.,69.,70.,71.,72.,73.,74.,75.,76.,77.,78.,79.,
780.,81.,82.,83.,84.,85.,86.,87.,88.,89.,90.,91.,92.,93.,94.,95.,
896.,97.,98.,99.,100.,101.,102.,103.,104.,105.,106.,107.,108.,109.,
9110.,111.,112.,113.,114.,115.,116.,117.,118.,119.,120.,121.,122.,
A 123.,124.,125.,126.,127.,128.,129.,130.,
1131.,132.,133.,134.,135.,136.,137.,138.,139.,140.,141.,142.,143.,
2144.,145.,146.,147.,148.,149.,150.,152.,154.,156.,158.,160.,162.,
3164.,166.,168.,170.,172.,174.,176.,178.,180.,182.,184.,186.,188.,
4190.,192.,194.,196.,198.,200.,205.,210.,215.,220.,225.,230.,235.,
5240.,245.,250.,255.,260.,265.,270.,275.,280.,285.,290.,295.,300.,
6310.,320.,330.,340.,350.,360.,370.,380.,390.,400.,410.,420.,430.,
7440.,450.,460.,470.,480.,490.,500.,520.,540.,560.,580.,600.,620.,
8640.,660.,680.,700.,720.,740.,760.,780.,800.,820.,840.,860.,880.,
9900.,920.,940.,960.,980.,1000.,1050.,1100.,1150.,1200.,1250. /
DATA (X(I,1),I=273,295)/1300.,1350.,1400.,1450.,1500.,1600.,
11700.,1800.,1900.,2000.,2100.,2200.,2300.,2400.,2500.,2600.,
22700.,2800.,2900.,3000.,3100.,3200.,3206.2 /

```

TABLE C-6. (contd)

```

DATA (X(I,2),I=1,176 )/53.14,59.30,64.47,68.93,72.86,76.38,79.58,
185.21,90.08,94.38,98.24,101.74,107.92,113.26,117.99,122.23,126.08,
2129.62,132.89,135.94,138.79,141.48,147.57,152.97,157.83,162.24,
3166.30,170.06,173.56,176.85,179.94,182.86,185.64,188.28,190.80,
4193.21,197.75,201.96,205.88,209.56,212.,213.03,216.32,219.44,
5222.41,225.24,227.96,230.57,233.07,235.49,237.82,240.07,242.25,
6244.36,246.41,248.40,250.33,252.22,254.05,255.84,257.58,259.28,
7260.95,262.57,264.16,265.72,267.25,268.74,270.21,271.64,273.05,
8274.44,275.80,277.13,278.45,279.74,281.01,282.26,283.49,284.70,
9285.90,287.07,288.23,289.37,290.50,291.61,292.71,293.79,294.85,
B      295.90,296.94,297.97,298.99,299.99,300.98,
1301.96,302.92,303.88,304.83,305.76,306.68,307.60,308.50,309.40,
2310.29,311.16,312.03,312.89,313.74,314.59,315.42,316.25,317.07,
3317.88,318.68,319.48,320.27,321.06,321.83,322.60,323.36,324.12,
4324.87,325.61,326.35,327.08,327.81,328.53,329.25,329.96,330.66,
5331.36,332.05,332.74,333.42,334.10,334.77,335.44,336.11,336.77,
6337.42,338.07,338.72,339.36,339.99,340.62,341.25,341.88,342.50,
7343.11,343.72,344.33,344.94,345.54,346.13,346.73,347.32,347.90,
8348.48,349.06,349.64,350.21,350.78,351.35,351.91,352.47,353.02,
9353.57,354.12,354.67,355.21,355.76,356.29,356.83,357.36,357.89 /
DATA (X(I,2),I=177,295)/358.42,359.46,360.49,361.52,362.53,363.53,
1364.53,365.51,366.48,367.45,368.41,369.35,370.29,371.22,372.14,
2373.06,373.96,374.86,375.75,376.64,377.51,378.38,379.24,380.10,
3380.95,381.79,383.86,385.90,387.89,389.86,391.79,393.68,395.54,
4397.37,399.18,400.95,402.70,404.42,406.11,407.78,409.43,411.05,
5412.65,414.23,415.79,417.33,420.35,423.29,426.16,428.97,431.72,
6434.40,437.03,439.60,442.12,444.59,447.01,449.39,451.73,454.02,
7456.28,458.50,460.68,462.82,464.93,467.01,471.07,475.01,478.85,
8482.58,486.21,489.75,493.21,496.58,499.88,503.10,506.25,509.34,
9512.36,515.33,518.23,521.08,523.88,526.63,529.33,531.98,534.59,
X      537.16,539.68,542.17,544.61,550.57,556.31,
1561.86,567.22,572.42,577.46,582.35,587.10,591.73,596.23,604.90,
2613.15,621.03,628.58,635.82,642.77,649.46,655.91,662.12,668.13,
3673.94,679.55,684.99,690.26,695.36,700.31,705.11,705.40 /
DATA (X(I,3),I=1,174 )/.01603,.01604,.01605,.01605,.01606,.01607,
1.01608,.01609,.01610,.01612,.01613,.01614,.01616,.01618,.01620,
2.01621,.01623,.01624,.01626,.01627,.01629,.01630,.01633,.01636,
3.01638,.01640,.01643,.01645,.01647,.01649,.01651,.01653,.01654,
4.01656,.01658,.01659,.01662,.01665,.01667,.01670,.01672,.01672,
5.01674,.01677,.01679,.01681,.01683,.01685,.01687,.01689,.01691,

```

TABLE C-6. (contd)

```

6.01692,.01694,.01696,.01698,.01699,.01701,.01702,.01704,.01705,
7.01707,.01708,.01709,.01711,.01712,.01714,.01715,.01716,.01717,
8.01719,.01720,.01721,.01722,.01723,.01725,.01726,.01727,.01728,
9.01729,.01730,.01731,.01732,.01733,.01734,.01736,.01737,.01738,
C      .01739,.01740,.01741,.01742,.01743,.01744,
1.01745,.01746,.01747,.01748,.01749,.01750,.01751,.01752,.01753,
2.01754,.01754,.01755,.01756,.01757,.01758,.01759,.01760,.01761,
3.01761,.01762,.01763,.01764,.01765,.01766,.01767,.01768,.01768,
4.01769,.01770,.01771,.01772,.01772,.01773,.01774,.01775,.01775,
5.01776,.01777,.01778,.01778,.01779,.01780,.01781,.01782,.01782,
6.01783,.01784,.01784,.01785,.01786,.01787,.01787,.01788,.01789,
7.01790,.01791,.01791,.01792,.01792,.01793,.01794,.01794,.01795,
8.01796,.01797,.01797,.01798,.01799,.01800,.01800,.01801,.01801,
9.01802,.01802,.01803,.01804,.01804,.01805,.01806,.01806,.01807 /
DATA (X(I,3),I=175,295)/.01808,.01808,.01809,.01810,.01812,.01813,
1.01814,.01815,.01817,.01818,.01819,.01820,.01822,.01823,.01824,
2.01825,.01826,.01827,.01829,.01830,.01831,.01832,.01833,.01834,
3.01835,.01836,.01838,.01839,.01842,.01844,.01847,.01850,.01852,
4.01854,.01857,.01860,.01863,.01865,.01868,.01870,.01873,.01875,
5.01878,.01880,.01883,.01885,.01887,.01890,.01894,.01899,.01904,
6.01908,.01913,.01917,.01921,.01925,.01930,.0193,.0194,.0194,.0194,
7.0195,.0195,.0196,.0196,.0197,.0197,.0197,.0198,.0199,.0200,.0201,
8.0201,.0202,.0203,.0204,.0204,.0205,.0206,.0207,.0207,.0208,.0209,
9.0209,.0210,.0211,.0212,.0212,.0213,.0214,.0214,.0215,.0216,.0218,
X      .0220,.0221,.0223,.0225,.0227,.0229,.0231,
1.0233,.0235,.0239,.0243,.0247,.0252,.0257,.0262,.0268,.0274,.0280,
2.0287,.0295,.0305,.0315,.0329,.0346,.0371,.0444,.0503 /
DATA (X(I,4),I=1,204 )/1526.,1235.3,1039.5,898.5,791.9,708.5,
1641.4,540.,466.9,411.7,368.4,333.6,280.9,243.,214.3,191.8,173.73,
2158.85,146.38,135.78,126.65,118.71,102.72,90.63,81.16,73.52,67.24,
361.98,57.50,53.64,50.29,47.34,44.73,42.40,40.31,38.42,35.14,32.40,
430.06,28.04,26.80,26.29,24.75,23.39,22.17,21.08,20.089,19.192,
518.375,17.627,16.938,16.303,15.715,15.170,14.663,14.189,13.746,
613.330,12.940,12.572,12.226,11.898,11.588,11.294,11.015,10.750,
710.498,10.258,10.029,9.810,9.601,9.401,9.209,9.025,8.848,8.678,
88.515,8.359,8.208,8.062,7.922,7.787,7.656,7.529,7.407,7.289,7.175,
97.064,6.957,6.853,6.752,6.655,6.560,6.468,6.378,6.291,6.206,6.124,
D      6.044,5.966,5.890,5.816,5.743,5.673,5.604,
15.537,5.472,5.408,5.346,5.285,5.226,5.168,5.111,5.055,5.001,4.948,
24.896,4.845,4.796,4.747,4.699,4.652,4.606,4.561,4.517,4.474,4.432,

```

TABLE C-6. (contd)

34.391,4.350,4.310,4.271,4.232,4.194,4.157,4.120,4.084,4.049,4.015,
 43.981,3.947,3.914,3.882,3.850,3.819,3.788,3.758,3.728,3.699,3.670,
 53.642,3.614,3.587,3.560,3.533,3.507,3.481,3.455,3.430,3.405,3.381,
 63.357,3.333,3.310,3.287,3.264,3.242,3.220,3.198,3.177,3.155,3.134,
 73.114,3.094,3.074,3.054,3.034,3.015,2.977,2.940,2.904,2.869,2.834,
 82.861,2.768,2.736,2.705,2.675,2.645,2.616,2.587,2.559,2.532,2.505,
 92.479,2.454,2.429,2.404,2.380,2.356,2.333,2.310,2.288,2.234,2.183/
 DATA (X(I,4),I=205,295)/2.134,2.087,2.0422,1.9992,1.9579,1.9183,
 11.8803,1.8438,1.8086,1.7748,1.7422,1.7107,1.6804,1.6511,1.6228,
 21.5954,1.5689,1.5433,1.4944,1.4485,1.4053,1.3645,1.3260,1.2895,
 31.2550,1.2222,1.1910,1.1613,1.1330,1.1061,1.0803,1.0556,1.0320,
 41.0094,.9878,.9670,.9470,.9278,.8915,.8578,.8265,.7973,.7698,
 5.7440,.7198,.6971,.6757,.6554,.6362,.6180,.6007,.5843,.5687,.5538,
 6.5396,.5260,.5130,.5006,.4886,.4772,.4663,.4557,.4456,.4218,.4001,
 7.3802,.3619,.3450,.3293,.3148,.3012,.2884,.2765,.2548,.2354,.2179,
 8.2021,.1878,.1746,.1625,.1513,.1407,.1307,.1213,.1123,.1035,.0947,
 9.0858,.0753,.0580,.0503 /
 DATA (X(I,5),I=1,90)/21.21,27.36,32.52,36.97,40.89,44.41,47.60,
 153.21,58.07,62.36,66.21,69.70,75.87,81.20,85.91,90.14,93.99,97.52,
 2100.79,103.83,106.68,109.37,115.46,120.86,125.71,130.13,134.19,
 3137.96,141.47,144.76,147.86,150.79,153.57,156.22,158.75,161.17,
 4165.73,169.96,173.91,177.61,180.07,181.11,184.42,187.56,190.56,
 5193.42,196.16,198.79,201.33,203.78,206.14,208.42,210.62,212.75,
 6214.83,216.86,218.82,220.73,222.59,224.41,226.18,227.91,229.60,
 7231.26,232.89,234.48,236.03,237.55,239.04,240.51,241.95,243.36,
 8244.75,246.12,247.47,248.79,250.09,251.37,252.63,253.87,255.09,
 9256.30,257.50,258.67,259.82,260.96,262.09,263.20,264.30,265.38 /
 DATA (X(I,5),I=91,271)/266.45,267.50,268.55,269.58,270.60,271.61,
 1272.61,273.60,274.57,275.54,276.49,277.43,278.37,279.30,280.21,
 2281.12,282.02,282.91,283.79,284.66,285.53,286.39,287.24,288.08,
 3288.91,289.74,290.56,291.38,292.18,292.98,293.78,294.56,295.34,
 4296.12,296.89,297.65,298.40,299.15,299.90,300.64,301.37,302.10,
 5302.82,303.54,304.26,304.97,305.66,306.37,307.06,307.75,308.43,
 6309.11,309.79,310.46,311.12,311.78,312.44,313.10,313.75,314.40,
 7315.04,315.68,316.31,316.94,317.57,318.19,318.81,319.43,320.04,
 8320.65,321.25,321.85,322.45,323.05,323.64,324.23,324.82,325.40,
 9325.98,326.56,327.13,327.70,328.27,328.83,329.39,329.95,330.51,
 F 331.61,332.70,333.79,334.86,335.93,336.98,
 1338.02,339.05,340.07,341.09,342.10,343.10,344.09,345.06,346.03,
 2347.,347.96,348.92,349.86,350.79,351.72,352.64,353.55,354.46,

TABLE C-6. (contd)

```

3355.36,357.58,359.77,361.91,364.02,366.09,368.13,370.14,372.12,
4374.08,376.,377.89,379.76,381.6,383.42,385.21,386.98,388.73,
5390.46,392.16,393.84,397.15,400.39,403.56,406.66,409.69,412.67,
6415.59,418.45,421.27,424.,426.8,429.4,432.1,434.6,437.2,439.7,
7442.2,444.6,447.,449.4,454.1,458.6,463.,467.4,471.6,475.7,479.8,
8483.8,487.7,491.5,495.3,499.,502.6,506.2,509.7,513.2,516.6,520.,
9523.3,526.6,529.8,533.,536.2,539.3,542.4,550.,557.4,564.6,571.7 /
DATA (X(I,5),I=272,295)/578.6,585.4,592.1,598.7,605.2,611.6,624.1,
1636.3,648.3,660.1,671.7,683.3,694.8,706.5,718.4,730.6,743.0,756.2,
2770.1,785.4,802.5,825.0,872.4,902.7 /
DATA (X(I,6),I=1,174 )/1085.,1087.7,1090.,1091.9,1093.6,1095.1,
11096.4,1098.9,1101.,1102.8,1104.5,1106.,1108.6,1110.8,1112.8,
21114.6,1116.2,1117.7,1119.1,1120.3,1121.5,1122.6,1125.1,1127.3,
31129.3,1131.1,1132.7,1134.2,1135.6,1136.9,1138.1,1139.3,1140.4,
41141.4,1142.3,1143.3,1145.0,1146.6,1148.1,1149.5,1150.4,1150.8,
51152.0,1153.1,1154.2,1155.3,1156.3,1157.2,1158.1,1159.0,1159.8,
61160.6,1161.3,1162.0,1162.7,1163.4,1164.1,1164.7,1165.4,1166.0,
71166.5,1167.1,1167.6,1168.2,1168.7,1169.2,1169.7,1170.2,1170.7,
81171.1,1171.6,1172.0,1172.4,1172.9,1173.3,1173.7,1174.1,1174.4,
91174.8,1175.2,1175.6,1175.9,1176.3,1176.6,1176.9,1177.3,1177.6,
€ 1177.9,1178.2,1178.5,1178.8,1179.1,1179.4,
11179.7,1180.0,1180.3,1180.6,1180.8,1181.1,1181.3,1181.6,1181.9,
21182.1,1182.4,1182.6,1182.8,1183.1,1183.3,1183.5,1183.8,1184.0,
31184.2,1184.4,1184.6,1184.8,1185.1,1185.3,1185.5,1185.7,1185.9,
41186.1,1186.2,1186.4,1186.6,1186.8,1187.0,1187.2,1187.4,1187.5,
51187.7,1187.9,1188.1,1188.2,1188.4,1188.6,1188.7,1188.9,1189.0,
61189.2,1189.4,1189.5,1189.7,1189.8,1190.0,1190.1,1190.2,1190.4,
71190.5,1190.7,1190.8,1190.9,1191.1,1191.2,1191.3,1191.5,1191.6,
81191.7,1191.9,1192.0,1192.1,1192.2,1192.4,1192.5,1192.6,1192.7,
91192.9,1193.0,1193.1,1193.2,1193.3,1193.4,1193.5,1193.6,1193.8 /
DATA (X(I,6),I=175,295)/1193.9,1194.,1194.1,1194.3,1194.5,1194.7,
11194.9,1195.1,1195.3,1195.5,1195.7,1195.8,1196.0,1196.2,1196.4,
21196.5,1196.7,1196.9,1197.0,1197.2,1197.3,1197.5,1197.6,1197.8,
31197.9,1198.1,1198.2,1198.4,1198.7,1199.0,1199.3,1199.6,1199.9,
41200.1,1200.4,1200.6,1200.9,1201.1,1201.3,1201.5,1201.7,1201.9,
51202.1,1202.3,1202.4,1202.6,1202.7,1202.8,1203.1,1203.4,1203.6,
61203.7,1203.9,1204.1,1204.2,1204.3,1204.4,1204.5,1204.5,1204.6,
71204.6,1204.6,1204.6,1204.6,1204.6,1204.5,1204.5,1204.4,1204.2,
81204.0,1203.8,1203.5,1203.2,1202.9,1202.5,1202.1,1201.7,1201.2,
91200.7,1200.2,1199.7,1199.1,1198.6,1198.0,1197.4,1196.8,1196.1,

```


TABLE C-6. (contd)

H 1195.4,1194.7,1194.,1193.3,1192.6,1191.8,
 11189.9,1187.8,1185.6,1183.4,1181.0,1178.6,1176.1,1173.4,1170.7,
 21167.9,1162.1,1155.9,1149.4,1142.4,1135.1,1127.4,1119.2,1110.4,
 31101.1,1091.1,1080.2,1068.3,1054.8,1039.0,1020.3,993.1,934.4,
 4902.7 /
 DATA (X(I,7),I=1,107)/.0422,.0542,.0641,.0725,.0799,.0865,.0924,
 1.1028,.1117,.1194,.1263,.1326,.1435,.1528,.1610,.1683,.1749,.1809,
 2.1864,.1916,.1963,.2008,.2109,.2198,.2276,.2347,.2411,.2472,.2528,
 3.2581,.2629,.2674,.2718,.2759,.2798,.2835,.2903,.2967,.3027,.3083,
 X.3120,
 4.3135,.3184,.3231,.3275,.3317,.3356,.3395,.3431,.3466,.3500,.3533,
 5.3564,.3594,.3623,.3652,.3680,.3707,.3733,.3758,.3783,.3807,.3831,
 6.3854,.3876,.3898,.3919,.3940,.3960,.3980,.4000,.4019,.4038,.4057,
 7.4075,.4093,.4110,.4127,.4144,.4161,.4177,.4193,.4209,.4225,.4240,
 8.4255,.4270,.4285,.4300,.4314,.4328,.4342,.4356,.4369,.4383,.4396,
 9.4409,.4422,.4435,.4447,.4460,.4472,.4484,.4496,.4508,.4520,.4531/
 DATA (X(I,7),I=108,295)/.4543,.4554,.4565,.4576,.4587,.4598,.4609,
 1.4620,.4630,.4641,.4651,.4661,.4672,.4682,.4692,.4702,.4711,
 2.4721,.4731,.4740,.4750,.4759,.4768,.4778,.4787,.4796,.4805,.4814,
 3.4823,.4832,.4840,.4849,.4858,.4866,.4875,.4883,.4891,.4900,.4908,
 4.4916,.4924,.4932,.4940,.4948,.4956,.4964,.4972,.4980,.4987,.4995,
 5.5002,.5010,.5018,.5025,.5032,.5040,.5047,.5054,.5061,.5069,.5076,
 6.5083,.5090,.5097,.5104,.5111,.5118,.5124,.5131,.5138,.5151,.5165,
 7.5178,.5191,.5204,.5216,.5229,.5241,.5254,.5266,.5278,.5290,.5302,
 8.5313,.5325,.5336,.5348,.5359,.5370,.5381,.5392,.5403,.5414,.5425,
 9.5435,.5461,.5487,.5512,.5537,.5561,.5585,.5608,.5631,.5653,.5675,
 I .5697,.5719,.5740,.5760,.5781,.5801,.5821,
 1.5841,.5860,.5879,.5916,.5952,.5988,.6022,.6056,.6090,.6122,.6153,
 2.6184,.6214,.6243,.6272,.6301,.6329,.6356,.6383,.6410,.6436,.6462,
 3.6487,.6536,.6584,.6631,.6676,.6720,.6763,.6805,.6846,.6886,.6925,
 4.6963,.7001,.7037,.7073,.7108,.7143,.7177,.7210,.7243,.7275,.7307,
 5.7339,.7370,.7400,.7430,.7504,.7575,.7644,.7711,.7776,.7840,.7902,
 6.7963,.8023,.8082,.8196,.8306,.8412,.8516,.8619,.8721,.8820,.8921,
 7.9023,.9126,.9232,.9342,.9459,.9587,.9731,.9919,1.032,1.058 /
 DATA (X(I,8),I=1,89)/2.1163,2.0970,2.0812,2.0678,2.0563,2.0462,
 12.0372,2.0216,2.0085,1.9971,1.9871,1.9782,1.9628,1.9498,1.9386,
 21.9288,1.92,1.912,1.9047,1.8981,1.892,1.8863,1.8735,1.8625,1.8528,
 31.8441,1.8363,1.8292,1.8227,1.8167,1.811,1.8057,1.8008,1.7962,
 41.7918,1.7876,1.78,1.773,1.7665,1.7605,1.7566,1.7549,1.7497,
 X 1.7449,

TABLE C-6. (contd)

```

51.7403,1.736,1.7319,1.728,1.7242,1.7206,1.7172,1.7139,1.7108,
61.7078,1.7048,1.702,1.6993,1.6967,1.6941,1.6917,1.6893,1.687,
71.6848,1.6826,1.6805,1.6784,1.6763,1.6743,1.6724,1.6706,1.6687,
81.6669,1.6652,1.6634,1.6617,1.6601,1.6585,1.6569,1.6553,1.6538,
91.6523,1.6509,1.6494,1.648,1.6466,1.6452,1.6438,1.6425,1.6412 /
DATA (X(I,8),I=90,176 )/1.6399,1.6387,1.6374,1.6362,1.635,1.6338,
11.6326,1.6315,1.6303,1.6292,1.6281,1.6270,1.6259,1.6248,1.6238,
21.6228,1.6217,1.6207,1.6197,1.6187,1.6177,1.6168,1.6158,1.6149,
31.6139,1.6130,1.6121,1.6112,1.6103,1.6094,1.6085,1.6076,1.6068,
41.6060,1.6051,1.6043,1.6035,1.6026,1.6018,1.6010,1.6002,1.5994,
51.5986,1.5978,1.5971,1.5963,1.5956,1.5948,1.5941,1.5934,1.5927,
61.5919,1.5912,1.5905,1.5898,1.5891,1.5885,1.5878,1.5871,1.5865,
71.5858,1.5851,1.5844,1.5838,1.5831,1.5825,1.5819,1.5812,1.5806,
81.5800,1.5793,1.5787,1.5781,1.5775,1.5769,1.5763,1.5757,1.5751,
91.5745,1.5740,1.5734,1.5728,1.5722,1.5716,1.5710,1.5705,1.5699 /
DATA (X(I,8),I=177,295)/1.5694,1.5683,1.5672,1.5661,1.5650,1.5640,
11.563,1.562,1.561,1.56,1.559,1.558,1.557,1.5561,1.5551,1.5542,
21.5532,1.5523,1.5514,1.5506,1.5497,1.5488,1.5479,1.547,1.5462,
31.5453,1.5432,1.5412,1.5392,1.5372,1.5353,1.5334,1.5316,1.5298,
41.5280,1.5263,1.5246,1.5229,1.5212,1.5196,1.5180,1.5164,1.5149,
51.5133,1.5118,1.5104,1.5075,1.5046,1.5019,1.4992,1.4966,1.4941,
61.4916,1.4891,1.4867,1.4844,1.4821,1.4799,1.4777,1.4755,1.4734,
71.4713,1.4693,1.4673,1.4653,1.4634,1.4596,1.4560,1.4524,1.4489,
81.4454,1.4421,1.4389,1.4358,1.4327,1.4296,1.4266,1.4237,1.4209,
91.4181,1.4153,1.4126,1.4099,1.4072,1.4046,1.4020,1.3995,1.3970,
J      1.3945,1.3921,1.3897,1.3838,1.3780,1.3723,
X 1.3667,1.3612,1.3559,
1      1.3506,1.3454,1.3402,1.3351,1.3249,1.3149,1.3049,
21.2949,1.2849,1.2748,1.2646,1.2541,1.2434,1.2322,1.2205,1.2082,
31.1946,1.1792,1.1615,1.1368,1.0852,1.0580 /
DATA (X(I,9),I=1,177 )/21.21,27.36,32.52,36.97,40.89,44.41,47.60,
153.21,58.07,62.36,66.21,69.70,75.87,81.20,85.91,90.13,93.98,97.51,
2100.78,103.82,106.67,109.36,115.45,120.85,125.70,130.12,134.17,
3137.94,141.45,144.74,147.84,150.77,153.54,156.19,158.72,161.14,
4165.70,169.92,173.87,177.57,180.02,181.06,184.37,187.51,190.50,
5193.36,196.10,198.73,201.26,203.71,206.07,208.34,210.54,212.67,
6214.74,216.77,218.73,220.63,222.49,224.31,226.07,227.80,229.49,
7231.14,232.77,234.36,235.90,237.42,238.91,240.37,241.81,243.22,
8244.60,245.97,247.32,248.63,249.93,251.21,252.46,253.70,254.92,
9256.12,257.32,258.49,259.63,260.77,261.90,263.00,264.10,265.18,

```

```

K      266.24,267.29,268.34,269.36,270.38,271.39,
1272.38,273.37,274.34,275.30,276.25,277.19,278.12,279.05,279.96,
2280.86,281.76,282.65,283.52,284.39,285.26,286.11,286.96,287.80,
3288.63,289.45,290.27,291.08,291.88,292.68,293.47,294.25,295.03,
4295.80,296.57,297.33,298.08,298.82,299.57,300.30,301.03,301.75,
5302.47,303.19,303.90,304.61,305.30,306.00,306.69,307.38,308.05,
6308.73,309.41,310.07,310.73,311.39,312.05,312.70,313.35,313.99,
7314.63,315.26,315.89,316.52,317.15,317.77,318.38,318.99,319.60,
8320.21,320.80,321.40,322.00,322.59,323.18,323.77,324.35,324.93,
9325.51,326.08,326.65,327.22,327.78,328.34,328.90,329.45,330.01 /
DATA (X(1,9),I=178,295)/331.10,332.18,333.26,334.23,335.39,336.44,
1337.47,338.49,339.51,340.52,341.52,342.51,343.50,344.46,345.42,
2346.38,347.34,348.29,349.22,350.15,351.07,351.98,352.89,353.79,
3354.68,356.88,359.05,361.18,363.27,365.32,367.34,369.33,371.29,
4373.23,375.14,377.01,378.86,380.68,382.48,384.26,386.01,387.74,
5389.45,391.13,392.79,396.06,399.26,402.40,405.46,408.45,411.39,
6414.27,417.10,419.88,422.6,425.3,427.9,430.5,433.,435.5,438.,
7440.5,442.9,445.2,447.6,452.2,456.6,460.9,465.2,469.4,473.4,477.4,
8481.3,485.1,488.8,492.5,496.2,499.7,503.2,506.6,510.0,513.3,516.6,
9519.9,523.1,526.2,529.3,532.4,535.4,538.4,545.8,552.9,559.9,566.7,
L      573.4,580.,586.4,592.7,599.,605.1,617.,
1628.7,640.1,651.2,662.2,673.1,683.9,694.8,706.,717.3,728.8,741.,
2753.8,767.7,783.4,803.7,846.,872.9 /
DATA(X(1,10),I=1,174 )/1028.5,1030.6,1032.3,1033.7,1035.,1036.1,
11037.1,1038.9,1040.5,1041.9,1043.1,1044.3,1046.2,1047.9,1049.4,
21050.7,1051.9,1053.0,1054.1,1055.0,1055.9,1056.7,1058.6,1060.2,
31061.7,1063.1,1064.3,1065.4,1066.4,1067.4,1068.3,1069.2,1070.,
41070.8,1071.5,1072.2,1073.5,1074.7,1075.8,1076.9,1077.5,1077.8,
51078.7,1079.5,1080.4,1081.2,1081.9,1082.6,1083.3,1083.9,1084.6,
61085.1,1085.7,1086.3,1086.8,1087.3,1087.8,1088.3,1088.7,1089.2,
71089.6,1090.1,1090.5,1090.9,1091.3,1091.6,1092.0,1092.4,1092.7,
81093.1,1093.4,1093.7,1094.1,1094.4,1094.7,1095.0,1095.3,1095.5,
91095.8,1096.1,1096.4,1096.7,1097.0,1097.2,1097.4,1097.7,1097.9 ,
M      1098.2,1098.4,1098.6,1098.8,1099.1,1099.3,
11099.5,1099.8,1100.0,1100.2,1100.4,1100.6,1100.8,1101.0,1101.2,
21101.4,1101.6,1101.7,1101.9,1102.1,1102.2,1102.4,1102.6,1102.8,
31102.9,1103.1,1103.2,1103.4,1103.6,1103.7,1103.9,1104.1,1104.2,
41104.4,1104.5,1104.6,1104.7,1104.9,1105.0,1105.2,1105.3,1105.4,
51105.6,1105.7,1105.9,1106.0,1106.1,1106.3,1106.4,1106.5,1106.6,
61106.7,1106.8,1106.9,1107.1,1107.2,1107.3,1107.4,1107.5,1107.6,

```

TABLE C-6. (contd)

```

71107.7,1107.8,1107.9,1108.0,1108.1,1108.2,1108.3,1108.4,1108.5,
81108.6,1108.7,1108.8,1108.9,1109.0,1109.1,1109.2,1109.3,1109.4,
91109.5,1109.6,1109.7,1109.8,1109.8,1109.9,1110.0,1110.1,1110.2 /
  DATA(X(I,10),I=175,295)/1110.3,1110.4,1110.5,1110.6,1110.7,1110.9,
11111.0,1111.2,1111.4,1111.5,1111.7,1111.8,1111.9,1112.0,1112.2,
21112.3,1112.4,1112.5,1112.6,1112.8,1112.9,1113.0,1113.1,1113.2,
31113.3,1113.5,1113.6,1113.7,1114.0,1114.2,1114.4,1114.6,1114.8,
41115.0,1115.3,1115.4,1115.6,1115.8,1116.0,1116.1,1116.3,1116.4,
51116.6,1116.7,1116.8,1116.9,1117.0,1117.1,1117.4,1117.6,1117.8,
61117.9,1118.0,1118.2,1118.3,1118.4,1118.5,1118.5,1118.6,1118.7,
71118.7,1118.7,1118.7,1118.7,1118.7,1118.6,1118.6,1118.6,1118.4,
81118.3,1118.2,1118.0,1117.7,1117.5,1117.3,1117.0,1116.7,1116.3,
91116.0,1115.6,1115.2,1114.8,1114.4,1114.0,1113.6,1113.1,1112.6,
N      1112.1,1111.5,1111.,1110.5,1110.,1109.4,
11108.,1106.4,1104.7,1103.,1101.2,1099.4,1097.5,1095.4,1093.3,
21091.2,1086.7,1081.8,1076.8,1071.4,1065.6,1059.6,1053.1,1046.,
31038.6,1030.6,1021.9,1012.3,1001.2,988.2,972.7,949.9,898.4,872.9 /
  IF(M-1),100,
  IF((M-6)*(M-10)),200,
  IF((M-4)*(M-8)),300,
  IF(M-10),,400
100 N1=0
   N2=512
   N3=295
   N4=9
   ASSIGN 800 TO N5
   ASSIGN 900 TO N6
   GOTO 600
200 N1=0
   N2=512
   N3=235
   N4=9
   ASSIGN 800 TO N5
   ASSIGN 900 TO N6
   GOTO 600
300 N1=0
   N2=512
   N3=295
   N4=9
   ASSIGN 900 TO N5

```

TABLE C-6. (contd)

```

      ASSIGN 800 TO N6
      GOTO 500
430  IF((M-60)*(M-100))5000,,5000
      M=M/10
      N1=235
      N2=64
      N3=295
      N4=6
      ASSIGN 900 TO N5
      ASSIGN 800 TO N6
500  IF(V - X(N1+1,M)) 700,1350,5000
600  IF(V - X(N1+1,M))5000,1350,
700  DO 900 I=1,N4
      N2=N2/2
      N1=N1+N2
      IF(N1.GT.N3)GOTO800
      IF(V-X(N1,M))N5,1400,N6
800  N1=N1-N2
900  CONTINUE
      IF(N1.NE.1)N1=N1-1
      IF(N1.GT.N3-3)N1=N3-3
      DO 1100 K=1,4
      J=K-1+N1
      R=1.
      POFX=1.
      DO 1000 L=1,4
      I=L-1+N1
      IF(I-J),1000,
      R=R*(X(J,M)-X(I,M))
      POFX=POFX*(V-X(I,M))
1000 CONTINUE
      A(K)=POFX/R
1100 CONTINUE
      STVD(M)=V
      DO 1300 I=1,10
      IF(I-M),1300,
      STVD(I)=0.
      DO 1200 J=1,4
      K=N1-1+J
      STVD(I)=STVD(I)+A(I)*X(K,I)
1200 CONTINUE
1300 CONTINUE
      RETURN
1350 N1=N1+1
1400 DO 1500 I=1,10
      STVD(I)=X(N1,I)
1500 CONTINUE
      IF(N1.NE.1)N1=N1-1
      IF(N1.GT.N3-3)N1=N3-3
      RETURN
5000 WRITE(6,1)M,V
      1 FORMAT(28HERROR IN INPUT TO STMTBL, M=I3, 5H, V =F10.3)
      RETURN 4
      END

```

TABLE C-7. Subroutine DERIV

SUBROUTINE DERIV(FXTB,XTB,X,DFX,N,K)
 IS A ROUTINE TO OBTAIN DERIVATIVES OF TABULAR DATA OF N FUNCTIONS
 OF X*

CALL LIST--FXTB = K BY N ARRAY WHERE FXTB(I,N) CORRESPONDS
 TO XTB(I)
 XTB = K VALUES OF INDEPENDENT VARIABLE BRACKETING X
 X = INDEPENDENT VARIABLE WHERE DERIVATIVE NEEDED
 DFX = N VECTOR OF DERIVATIVES
 N = DIMENSION OF ARRAY .LT.10
 K = NUMBER OF DATA POINTS TO WHICH
 POLYNOMIAL IS FIT .LT.20

ROUTINE FITS A 2ND ORDER ORTHOGONAL POLYNOMIAL TO DATA, THEN
 COMPUTES DERIVATIVE RECURSIVELY* REF--FORSYTHE,G.E.,J.SIAN,VOL.5,
 P 74 (1957) AND SUBROUTINE ORTHLS IN BEEF LIBRARY.

DIMENSION FXTB(20,1),XTB(20),DFX(1),POLY(20),POLYO(20),C(3,10),
 1 ALPHA(3), BETA(3)

BEGIN COMPUTATION

B=0.
 R0=K
 DO 100 I=1,K
 POLY(I)=1.
 POLYO(I)=0.
 100 CONTINUE
 II=1
 200 DO 400 J=1,N
 S=0.
 DO 300 I=1,K
 300 S=S+POLY(I)*FXTB(I,J)

COMPUTATION OF COEFFICIENTS IN POLYNOMIAL EQUATION

400 C(II,J)=S/R0
 IF(II.GE.3)GOTO1000

COMPUTATION OF ALPHA FOR POLYNOMIAL EQUATION

SUMXPS=0.

Table C-7. (contd)

```

      DO 500 I=1,K
500  SUMXPS=SUMXPS+XTB(I)*POLY(I)*POLY(I)
      ALPHA(II)=SUMXPS/R0
C
C      COPPUTATION OF A NEW POLYNOMIAL
C
      DO 600 I=1,K
      TEMP=POLY(I)
      POLY(I)=(XTB(I)-ALPHA(II))*POLY(I)-B*POLYO(I)
600  POLYO(I)=TEMP
C
C      COMPUTATION OF BETA FOR THE POLYNOMIAL EQN.
C
      R=0.
      DO 700 I=1,K
700  R=R+POLY(I)*POLY(I)
      BETA(II)=R/R0
      R0=R
      B=BETA(II)
      II=II+1
      GO TO 200
C
C      COMPUTE DERIVATIVES
C
1000 DO 1100 I=1,N
1100 DFX(I)=C(3,I)*(2.*X-ALPHA(1) -ALPHA(2)) +C(2,I)
      RETURN
      END

```

TABLE C-8. Subroutine GMOODY

```

FUNCTION GMOODY(PE,HF)
  IS ROUTINE TO COMPUTE THE TWO PHASE CRITICAL MASS FLOW RATE AS
  PREDICTED BY THE MOODY MODEL. THE TABLES OF G VS P AND H FROM
  FLASH-II ARE USED. A SPECIAL TWO DIMENSIONAL BINARY TABLE SEARCH
  IS USED WITH A 4 POINT LAGRANGIAN INTERPOLATION

  DIMENSION A(4),B(4),C(4),D(4)
  INSERT 84 CARDS FROM FLASH-II LEAK SUBROUTINE

  EQUIVALENCE (PM( 1 ),PM1(1)), (PM(41 ),PM2(1)), (PM(81 ),PM3(1))
  EQUIVALENCE (PM(121),PM4(1)), (PM(161),PM5(1)), (PM(201),PM6(1))
  EQUIVALENCE (PM(241),PM7(1)), (PM(281),PM8(1)), (PM(321),PM9(1))
  EQUIVALENCE (PM(361 ),PM10(1)), (PM(401 ),PM11(1)), (PM(441 ),
1PM12(1)), (PM(481 ),PM13(1)), (PM(521 ),PM14(1)), (PM(561 ),
2PM15(1)), (PM(601 ),PM16(1)), (PM(641 ),PM17(1)), (PM(681 ),
3PM18(1))

  DIMENSION PM(40,20)
  DIMENSION PM1(40), PM2(40)    , PM3(40)    , PM4(40)    , PM5(40)
  DIMENSION PM6(40), PM7(40)    , PM8(40)    , PM9(40)    , PM10(40)
  DIMENSION PM11(40),PM12(40)   , PM13(40)   , PM14(40)   , PM15(40)
  DIMENSION PM16(40),PM17(40)   , PM18(40)

  DATA (PM1(I) ,I=1,33)/14.7,0.0,180.,0.0,180.,0.0,180.,0.0,180.,
101.0,180.,0.0,180.1,0.0,277.1,0.0,374.2,0.0,471.2,0.0,568.2,0.0,
2665.2,0.0,762.3,0.0,859.3,0.0,956.3,0.0,1053.4,0.0,1150.4/
  DATA (PM2(I), I=1,33)/ 50.,4400.,180.,3500.,202.,2850.,220.,2000.,
1240.,1650.,245.,1429.,250.1,582.41,342.5,362.85,434.9,263.17,
2527.3,206.79,619.7,170.26,712.1,144.73,804.5,125.95,896.9,111.47,
3989.3,99.982,1081.7,90.638,1174.1/
  DATA (PM3(I), I=1,33)/ 100.,6900.,180.,5900.,222.,5000.,247.,
13500.,280.,2800.,290.,2340.,298.4,1162.8,387.3,767.40,476.2,
2573.18,565.0,457.44,653.9,380.47,742.8,325.63,831.7,284.58,920.6,
3252.72,1009.4,227.27,1098.3,206.47,1187.2/
  DATA (PM4(I) ,I=1,33)/ 200.,10005.,180.,9000.,243.,7800.,282.,
15350.,333.,4200.,348.,3369.,355.4,2003.4,439.7,1399.4,524.,1073.4,
2608.3,870.25,692.6,731.40,776.9,630.63,861.2,554.20,945.5,494.27,
31029.8,446.01,1114.1,406.33,1198.4/
  DATA (PM5(I) ,I=1,33)/ 400.,14650.,180.,13000.,270.,11250.,325.,
17280.,387.,5750.,407.5,4821.,424.0,3285.0,502.0,2472.8,580.1,

```


TABLE C-8. (contd)

21970.9,658.1,1635.6,736.2,1396.7,814.2,1218.2,892.3,1081.1,970.3,
 3971.67,1048.4,882.27,1126.4,807.90,1204.5/
 DATA (PM6(I) ,I=1,33)/ 600.,18000.,180.,15600.,290.,13500.,355.,
 18800.,430.,7000.,455.,6252.,471.6,4644.8,544.8,3543.4,617.9,
 22857.4,691.1,2388.6,764.2,2050.1,837.4,1794.9,910.6,1595.8,983.7,
 31436.2,1056.9,1305.6,1130.0,1196.6,1203.2/
 DATA (PM7(I) ,I=1,33)/ 800.,20850.,180.,18280.,308.,15800.,384.,
 110100.,465.,7900.,492.,6972.,509.8,5559.3,578.7,4398.9,647.6,
 23627.0,716.4,3085.6,785.3,2683.5,854.2,2375.0,923.1,2131.0,992.0,
 31932.2,1060.8,1767.1,1129.7,1627.8,1198.6/
 DATA (PM8(I) ,I=1,33)/ 1000.,23330.,180.,20380.,323.,17420.,404.,
 111100.,492.,8700.,524.,7767.,542.4,6398.2,607.3,5258.3,672.3,
 24430.3,737.2,3817.6,802.2,3349.8,867.1,2982.3,932.0,2686.6,997.0,
 32443.7,1061.9,2240.7,1126.9,2068.7,1191.8/
 DATA (PM9(I) ,I=1,33)/ 1200.,25600.,180.,22450.,338.,19200.,426.,
 112080.,519.,9520.,554.,8543.,571.7,7099.3,632.9,5967.5,694.0,
 25102.4,755.2,4442.1,816.4,3931.5,877.5,3527.5,938.7,3197.4,999.9,
 32923.0,1061.1,2691.6,1122.2,2495.9,1183.4/
 DATA (PM10(I) ,I=1,33)/ 1400.,27650.,180.,24220.,350.,20700.,445.,
 112800.,540.,10100.,577.,9064.,598.7,7761.6,656.2,6644.7,713.6,
 25777.5,771.1,5098.5,828.6,4555.6,886.0,4114.0,943.5,3748.6,1001.0,
 33441.9,1058.5,3180.9,1115.9,2956.3,1173.4/
 DATA (PM11(I) ,I=1,33)/ 1600.,29550.,180.,25920.,363.,22000.,462.,
 113600.,561.,10760.,602.,9646.,624.2,8448.7,678.0,7338.2,731.8,
 26442.1,785.6,5733.7,839.4,5163.9,893.1,4693.3,946.9,4299.2,1000.7,
 33964.9,1054.5,3678.1,1108.3,3429.4,1162.1/
 DATA (PM12(I) ,I=1,33)/ 1800.,31550.,180.,27580.,374.,23100.,476.,
 114280.,580.,11290.,623.,10135.,648.3,9033.6,698.4,7957.8,748.5,
 27069.7,798.6,6354.7,848.7,5768.0,898.8,5276.1,949.0,4859.1,999.1,
 34501.7,1049.2,4195.7,1099.3,3929.1,1149.4/
 DATA (PM13(I) ,I=1,33)/ 2000.,33080.,180.,28920.,384.,24270.,491.,
 114950.,600.,11780.,642.,10524.,671.7,9494.6,718.0,8510.2,764.4,
 27675.3,810.7,6972.6,857.1,6379.2,903.4,5874.2,949.7,5440.4,996.1,
 35064.6,1042.4,4736.2,1088.8,4447.0,1135.1/
 DATA (PM14(I) ,I=1,33)/ 2200.,37700.,180.,30070.,392.,25100.,502.,
 115600.,618.,12280.,661.,10951.,694.8,9960.5,737.2,9033.0,779.7,
 28225.8,822.1,7544.7,864.6,6961.6,907.0,6456.8,949.4,6017.0,991.9,
 35631.3,1034.3,5290.6,1076.8,4987.8,1119.2/
 DATA (PM15(I) ,I=1,33)/ 2400.,36200.,180.,31150.,400.,26270.,516.,
 116200.,635.,12710.,679.,11245.,718.4,10308.,756.7,9489.7,794.9,

TABLE C-8. (contd)

```

28762.2,833.2,8122.0,871.5,7559.6,909.7,7064.4,948.0,6626.6,986.3,
36237.5,1024.6,5890.0,1062.8,5578.0,1101.1/
  DATA (PM16(I) ,I=1,33)/ 2600.,37570.,180.,32140.,407.,27200.,528.,
116780.,650.,13120.,695.,11493.,743.0,10634.,776.7,9918.6,810.4,
29267.1,844.2,8681.2,877.9,8155.9,911.6,7684.9,945.3,7261.6,979.0,
36879.8,1012.8,6534.4,1046.5,6220.7,1080.2/
  DATA (PM17(I) ,I=1,33)/ 2800.,39130.,180.,33520.,417.5,28000.,
1539.,17380.,667.,13570.,713.,11630.,770.1,10944.,798.6,10322.,
2827.0,9754.8,855.5,9235.5,884.0,8761.5,912.4,8328.9,940.9,7933.7,
3969.4,7571.7,997.9,7239.6,1026.3,6934.0,1054.8/
  DATA (PM18(I) ,I=1,33)/ 3000.,40400.,180.,34600.,424.,28995.,550.,
118000.,684.,14000.,730.,11581.,802.5,11061.,824.3,10606.,846.1,
210176.,867.8,9772.7,889.6,9394.6,911.4,9040.7,933.2,8709.6,955.0,
38399.6,976.7,8109.1,998.5,7836.6,1020.3/
  IF (PE-PM(1,1))1000,1000,
  N1=0
  N2=16
  DO 300 I=1,4
  N2=N2/2
  N1=N1+N2
  IF (PE-PM(1,N1))200,400,300
200 N1=N1-N2
300 CONTINUE
400 IF (N1.NE.1)N1=N1-1
  N1P=N1
  DO 900 I=1,4
  K=N1P-1+I
  A(I)=PM(1,K)
  N1=0
  N2=16
  DO 600 J=1,4
  N2=N2/2
  N1=N1+N2
  IF (HE-PM(2*N1+1,K))500,700,600
500 N1=N1-N2
600 CONTINUE
700 IF (N1.NE.1)N1=N1-1
  N1=N1-1
  IF (N1.GT.12)N1=12
  DO 800 J=1,4
  N2=N1+J
  B(J)=PM(2*N2+1,K)
  C(J)=PM(2*N2,K)
800 CONTINUE
  CALL TABINT(B,C,HE,D(I))
900 CONTINUE
  CALL TABINT(A,D,PE,GMOODY)
  RETURN
1000 GMOODY=0.
  RETURN
. END

```

TABLE C-9. Subroutines SING and UBUB

```

      SUBROUTINE TB1D (X,FX,XTB,FXTB,KX)
C-----
C---ONE DIMENSIONAL TABLE SEARCH AND LAGRANGIAN INTERPOLATION ROUTINE
      DIMENSION XTB(64), FXTB(64)
      IF(X.GT.XTB(1))GOTO100
      FX=FXTB(1)
      RRETURN
100  N1=0
      N2=64
      DO 300 I=1,6
      N2=N2/2
      N1=N1+N2
      IF(N1.GT.KX)GOTO200
      IF(X-XTB(N1))200,400,300
200  N1=N1-N2
300  CONTINUE
      IF(N1.NE.1)N1=N1-1
      IF(N1.GT.KX-3)N1=KX-3
      CALL TABINT(XTB(N1),FXTB(N1),X,FX)
      RETURN
400  FX=FXTB(N1)
      RETURN
      END

```

TABLE C-10. Subroutine TB1D

```

      SUBROUTINE SING(X,Y,N,J)
      WRITE(6,1)J
1  FORMAT(21H1ERROR CRITERIA OF Y(I3,26H) CAUSED SING TO BE CALLED )
      CALL DESING(X,Y,N,$100)
100 RETURN
      END

```

```

      FUNCTION UBUB(A)
      UBUB=2.0
      RETURN
      END

```

TABLE C-11. Subroutine TB1DG

```

SUBROUTINE TB1DG(X,FX,XTB,FXTB,IX,IFX,KX,NB)
C   IS A GENERALIZED TABLE SEARCH ROUTINE--ONE DIMENSION
C   WHERE   X = INPUT VARIABLE
C           FX = OUTPUT VARIABLE
C           XTB = TABLE OF X VALUES
C           FXTB = TABLE OF FX VALUES
C           IX = INDEX TO XTB WHICH GIVES SEQUENCE OF XTR
C           IFX = INDEX TO FXTB WHICH GIVES CORRESPONDING SEQUENCE OF
C               FXTB
C           KX = LENGTH OF TABLES .LT. 64
C           NR = ERROR INDEX--1= OK, 2= X.LT.XTB(IX(1)) FX=FXTB(IFX(1))
C               3= X.GT.XTB(IX(KX)) FX=FXTB(IFX(KX))
C   DIMENSION XTR(2),FXTB(2),IX(2),IFX(2),A(4),B(4)
C   DEFINE XT(I)=XTB(I)
C   DEFINE FT(I)=FXTB(I)
C
C   BEGIN
C   NB=1
C   IF(X.GE.XT(IX(1)))GOTO100
C   FX=FT(IFX(1))
C   NB=2
C   RETURN
100 IF(X.LE.XT(IX(KX)))GOTO200
C   FX=FT(IFX(KX))
C   NB=3
C   RETURN
200 N1=0
C   N2=64
C   DO 400 I=1,6
C   N2=N2/2
C   N1=N1+N2
C   IF(N1.GT.KX)GOTO300
C   IF(X-XT(IX(N1)))300,600,400
300 N1=N1-N2
400 CONTINUE
C   IF(ABS(FT(IFX(N1))-FT(IFX(N1+1))-1.).LT.0.001)GOTO 600
C   IF(N1.EQ.1)N1=N1+1
C   IF(N1.EQ.KX-1)N1=N1-1
C   N1=N1-2
C   DO 500 I=1,64
C   A(I)=XT(IX(I+N1))
C   B(I)=FT(IFX(I+N1))
500 CONTINUE
C   CALL TABINT(A,B,X,FX)
C   RETURN
600 FX=FT(IFX(N1))
C   RETURN
C   END

```

TABLE C-12. Subroutine TABINT

```

CTBIN
C LAGRANGIAN TABLE INTERPOLATION SUBROUTINE-- 4 POINT
  SUBROUTINE TABINT (X,Y,XUNK,YUNK)
    DIMENSION X(4),Y(4)
    YOVERR=0.0
    DO 2 J=1,4
      R=1.0
      POFX=1.0
      DO 3 I=1,4
        IF (I-J)4,3,4
4      R=(X(J)-X(I))*R
      POFX=POFX*(XUNK-X(I))
3    CONTINUE
2    YOVERR=YOVERR+Y(J)/R*POFX
      YUNK =YOVERR
      RETURN
    END

```

DISTRIBUTIONNo. of
CopiesOFFSITE

1	<u>AEC Chicago Operations Office</u> D. M. Gardiner
1	<u>AEC Chicago Patent Group</u> G. H. Lee
2	<u>AEC Division of Naval Reactors</u> R. S. Brodsky
24	<u>AEC Division of Reactor Development and Technology</u> Assistant Director, Project Management Chief, Water Projects Branch Chief, Gas Cooled Projects Branch (2) Chief, Liquid Metal Projects Branch Assistant Director, Reactor Technology Assistant Director, Plant Engineering Assistant Director, Reactor Engineering Assistant Director, Nuclear Safety (5) Chief, Research and Development Branch H. L. Hamester R. R. Newton (5) Environmental and Sanitary Engineering Branch I. C. Roberts Assistant Director, Engineering Standards Assistant Director, Program Analysis Assistant Director, Army Reactors
15	<u>AEC Division of Reactor Standards</u> M. Bolotsky G. Burley E. G. Case (10) A. B. Holt R. Waterfield R. Impara
267	<u>AEC Division of Technical Information Extension</u>

No. of
Copies

5	<u>AEC Library, Washington</u> Advisory Committee on Reactor Safeguards F. R. Fraley Division of Compliance L. Kornblith, Jr. J. W. Flora, Region IV Division of Operational Safety H. Gilbert Division of Production G. B. Pleat
1	<u>AEG - Telefunken</u> h-213 6 Frankfort/Main 70 AEG - Hochhaus Süd Germany Dieter Ewers
1	<u>Aerojet-General</u> Idaho Falls, Idaho W. E. Nyer
1	<u>Aerojet-General</u> <u>Sacramento, California</u> F. L. Climent
1	<u>American Electric Power Co.</u> 2 Broadway New York, N.Y. 10004 Stephen J. Milioti
10	<u>Argonne National Laboratory</u> C. E. Dickerman S. Fistedis R. O. Ivins P. Lottes H. O. Monson D. Okrent R. C. Vogel P. G. Shewmon <u>LMFBR Program Office</u> A. Amorosi L. Baker

No. of
Copies

2	<u>Atomics International</u> H. Morewitz Liquid Metals Engr. Center R. W. Dickinson
1	<u>Auburn University</u> School of Engineering and Engineering Experiment Station G. H. Nix
4	<u>Babcock & Wilcox Co.</u> <u>Virginia</u> S. Delicate D. A. Nitti R. Wascher Washington L. R. Weissert
6	<u>Battelle Memorial Institute</u> A. R. Duffy D. L. Morrison/D. L. Ritzman S. Paprocki (2) D. N. Sunderman (2)
1	<u>Battelle Memorial Institute</u> <u>Frankfurt, Germany</u> G. Leistner/K. J. Kober
2	<u>Bechtel Corporation</u> R. F. Griffin W. P. Neuendorf
1	<u>Bettis Atomic Power Laboratory</u> <u>P. O. Box 79</u> West Mifflin, Pa. 15122 Dr. J. A. Redfield
2	<u>Brookhaven National Laboratory</u> A. W. Castleman J. M. Hendrie
1	<u>Canoga Park Area Office</u> R. L. Morgan

No. of
Copies

1	<u>Chalk River Nuclear Laboratories</u> Chalk River, Ontario, Canada Station 3 G. Hake
1	<u>Combustion Engineering</u> M. F. Valerino
1	<u>Consolidated Edison Company</u> J. J. Grob
1	<u>du Pont Company, Aiken (AEC)</u> A. H. Peters
1	<u>du Pont Company, Wilmington (AEC)</u> F. P. Allen <u>for</u> Lombard Squires
1	H. Etherington 84 Lighthouse Drive Jupiter, Florida 33458
1	W. L. Faith 2540 Huntington Drive San Marino, California 91108
3	<u>General Atomic Division (AEC)</u> A. J. Goodjohn (2) R. H. Ball
1	<u>General Electric Company</u> 621 S. W. Alder Street Portland, Oregon 97223 J. E. Grund
1	<u>General Electric Company</u> 175 Curtner Ave. San Jose, California 95125 Fred Moody
3	<u>General Electric Company, San Jose (AEC)</u> S. Vandenberg G. E. Wade E. Zebroski

No. of
Copies

1	<u>General Electric Company, Cincinnati (AEC)</u> J. F. White
4	<u>General Electric Company, San Jose (Trumbull)</u> P. Bray M. Siegler W. A. Sutherland D. A. Rockwell
1	<u>Harvard Air Cleaning Laboratory</u>
2	<u>Idaho Nuclear Corporation</u> J. A. Buckham C. M. Slansky
2	<u>Idaho Operations Office (AEC)</u> D. Williams
2	<u>IIT Research Institute</u> E. V. Gallagher T. A. Zaker
1	<u>Institut für Mess- und Regelungstechnik</u> <u>Laboratorium für Reaktorregelung und</u> <u>Anlagensicherung</u> Technische Hochschule München 8046 Garching Reactorstation Munich, Germany Prof. K. L. Garlid
1	<u>Institut für Reactorsicherheit</u> <u>5 Köln, Lukasstrasse</u> Germany Heinz G. Seipel
2	<u>Los Alamos Scientific Laboratory</u> J. H. Russel W. R. Stratton
1	H. G. Mangelsdorf 78 Knollwood Road Short Hills, New Jersey 07078

No. of
Copies

1	<u>MPR Associates, Inc.</u> T. Rockwell III
1	<u>National Bureau of Standards</u> C. Muehlhause
1	<u>Naval Ordnance Laboratory</u> J. Proctor
1	<u>North American Carbon, Inc.</u> P. O. Box 19737 Columbus, Ohio 43219 J. Louis Kovach
1	<u>North Carolina State University</u> M. N. Ozisik
1	<u>Nuclear Fuels Service</u> R. P. Wischow
14	<u>Oak Ridge National Laboratory</u> R. E. Adams R. Blanco J. Buchanan W. B. Cottrell (4) D. Ferguson C. E. Miller G. W. Parker L. F. Parsley P. Rittenhouse D. B. Trauger (2)
4	<u>Oak Ridge Operations Office (AEC)</u> D. Cope (2) E. Delaney W. L. Smalley
1	A. A. O'Kelly 2421 West Rowland Avenue Littleton, Colorado 80120

No. of
Copies

- 1 Ontario Water Resources Commission
Water Quality Surveys Branch
Division of Sanitary Engineering
135 St. Clair Avenue West
Toronto 7, Ontario, Canada
W. A. Steggles
- 1 Oregon State University
James G. Knudsen
- 1 Pacific Gas and Electric Company
W. Nutting
- 1 The Pennsylvania State University
College of Engineering
101 Hammond Building
University Park, Pennsylvania
N. J. Palladino
- 14 Phillips Petroleum Company
G. O. Bright
G. F. Brockett
S. Forbes (2)
C. Haire
G. B. Matheny
W. E. Nyer (2)
F. Schroeder (3)
N. K. Sowards
T. R. Wilson (2)
- 2 San Francisco Operations Office
Atomic Energy Commission
Lt. Col. J. B. Radcliffe
C. V. Backlund
- 1 Sargent & Lundy
Engineers
140 South Dearborn Street
Chicago, Illinois 60603
O. A. Hrynewych
- 1 Southern Nuclear Engineering, Inc.
P. O. Box 10
Dunedin, Florida
G. Brown

No. of
Copies

- 1 Stone and Webster Engineering Corp., Boston
 L. P. Deackoff
- 2 TRW Incorporated
 TRW Systems Group
 D. B. Langmuir
 S. M. Zivi
- United Engineers & Constructors, Inc.
 1401 Arch Street
 Philadelphia, Pa. 19105
 A. T. Molin
- United Kingdom Atomic Energy Authority
 Authority Health and Safety Branch
 Risley, Warrington, Lancs .
 England
 A. R. Edwards
- 2 University of California, Berkeley
 Institute of Engineering Research
 H. A. Johnson
 V. E. Schrock
- 1 University of Houston
 Cullen Boulevard
 Houston, Texas 77004
 C. W. Zabel, Dir. of Research
- 1 University of Illinois
 Department of Civil Engineering
 3129 Civil Engineering Building
 Urbana, Illinois 61801
 C. P. Siess
- 1 University of Minnesota
 Department of Chemical Engineering
 Minneapolis, Minnesota 55455
 H. S. Isbin
- 1 University of Tennessee
 606 Dougherty Hall
 Knoxville, Tennessee 37916
 S. H. Hanauer

No. of
Copies

- 1 University of Washington
 Wells Moulton
- 1 USAEC Scientific Representative
 c/o Atomic Energy of Canada, Ltd.
 Chalk River, Ontario, Canada
 H. J. Reynolds
- 7 Westinghouse Electric Corporation (AEC)
 (APD)
 E. Beckjord
 S. Fabic
 D. Fletcher
 H. Graves
 F. M. Heck
 R. A. Wiesemann
 (HTD)
 A. Lohmeier
- 1 Yankee Atomic Electric Co.
 441 Stuart St.
 Boston, Mass.
 John DeVincentis

ONSITE-HANFORD

- 1 AEC Chicago Patent Group
 R. K. Sharp (Richland)
- 2 RDT Asst. Dir. for Pacific Northwest Programs
- 3 AEC Richland Operations Office
 A. Brunstad
 W. E. Lotz
 C. L. Robinson
- 2 Atlantic Richfield Hanford Company
 G. R. Kiel
 ARHCO Files
- 3 Battelle Memorial Institute

No. of
Copies

8

Douglas United Nuclear

J. E. Mecca
 N. R. Miller
 W. F. Nechodom
 R. W. Reid
 J. W. Riches
 D. L. Renberger
 J. R. Spink
 DUN Files

72

Battelle-Northwest

F. W. Albaugh	R. E. Nightingale
R. T. Allemann	D. P. O'Keefe
J. M. Batch	H. M. Parker
A. L. Bement	D. W. Pearce
S. H. Bush	L. T. Pedersen
J. J. Cadwell	H. N. Pederson
L. A. Carter	A. M. Platt
T. T. Claudson	D. L. Reid
D. L. Condotta	R. L. Richardson
G. J. Dau	W. D. Richmond
F. G. Dawson	G. J. Rogers (10)
D. R. de Halas	L. C. Schwendiman
R. F. Foster	D. E. Simpson
J. C. Fox	J. C. Spanner
J. J. Fuquay	A. M. Sutey
W. A. Haney	E. E. Voiland
H. Harty	R. G. Wheeler
M. M. Hendrickson	N. P. Wilburn (2)
R. G. Hoagland	M. E. Witherspoon
J. F. Honstead	J. A. Williams
P. A. Hutton	N. G. Wittenbrock
R. T. Jaske	D. C. Worlton
B. M. Johnson (2)	F. R. Zaloudek
R. L. Junkins	Patent Section (2)
H. V. Larson	Technical Information
R. D. Leggett	Files (5)
A. S. Neuls	Technical
J. M. Nielson	Publications (3)