LUPO - A PROGRAM FOR PREDICTION OF STEADY-STATE TEMPERATURE, FLOW RATE AND PRESSURE DROPS IN A CLOSED PRESSURIZED WATER LOOP WITH OR WITHOUT BOILING

by

G. GAGGERO* and B. PANELLA**

* Euratom
** Politecnico di Torino
This document was prepared under the sponsorship of the Commission of the European Communities.

Neither the Commission of the European Communities, its contractors nor any person acting on their behalf:

Make any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe privately owned rights; or

Assume any liability with respect to the use of, or for damages resulting from the use of any information apparatus, method or process disclosed in this document.

This report is on sale at the addresses listed on cover page 4

at the price of FF 15.-- FB 150.-- DM 12.-- Lit 1870 Fl. 11.--

When ordering, please quote the EUR number and the title, which are indicated on the cover of each report.

Printed by SMEETS
Brussels, November 1967

This document was reproduced on the basis of the best available copy.
LUPO - A PROGRAM FOR PREDICTION OF STEADY-STATE TEMPERATURE, FLOW RATE AND PRESSURE DROPS IN A CLOSED PRESSURIZED WATER LOOP WITH OR WITHOUT BOILING

by

G. GAGGERO* and B. Panella**

* Euratom
** Politecnico di Torino

1967

Joint Nuclear Research Center
Ispra Establishment - Italy
Scientific Information Processing Center - CETIS
and
Politecnico di Torino, Impianti Nucleari
SUMMARY

A method is described for predicting steady-state bulk fluid temperature, void fraction, pressure drops and mass flow rate in a closed pressurized water loop, operating at forced or natural circulation. The model treats the one-dimensional transfer of mass, momentum and energy throughout the whole liquid, subcooled boiling and bulk boiling regions of the coolant using semiempirical heat transfer and pressure drop correlations developed by other investigators. A representation of subcooled boiling, based upon the model proposed by Bowring in HPR-10, is used.

Variations in heat transfer and hydraulic characteristics of the coolant due to changes in temperature and state are handled by continuously calculating local values of thermodynamic and physical properties (specific heat, density, quality, viscosity, thermal conductivity, etc.).

The method has been programmed for the IBM 7090 and IBM 360/65 computers by using FORTRAN IV language. The code, named LUPO, is described in this report, along with the numerical treatment and calculation procedure.

In Appendix 4 a comparison with experimental data is presented.

Work performed by the authors under an agreement between Politecnico di Torino (financed by CNR) and Euratom-CETIS.

KEYWORDS

COOLANT LOOPS  TEMPERATURE
WATER COOLANT  MASS
LIQUID FLOW  HEAT TRANSFER
CONVECTION  PROGRAMMING
PRESSURE  COMPUTERS

Forced convection, natural convection, flow rate, L-codes, Fortran, IBM 7090
Contents

1. Introduction 5
2. Description of the Facility 6
3. Derivation of a Physical Model 7
   3.1 General Consideration 7
   3.2 Bowring Model and Void Fraction Prediction 9
   3.3 Elevation Head 11
   3.4 Acceleration Pressure Drop 13
   3.5 Friction Pressure Drops 14
   3.6 Local Pressure Drops 19
4. Description of a Numerical Method 19
   4.1 Division of the Loop 19
   4.2 Working Equations 20
   4.3 Flow Rate Calculation Method 22
5. The LUPO Code 23
   5.1 Structure of the Program 23
   5.2 Flow Chart 24
   5.3 Listing and Sample Print-out 38
   5.4 FORTRAN Nomenclature 91
   5.5 Possible Future Development of the Program 94

Nomenclature 95
References 98
Appendices:
   1. The Lottes-Flinn Model 100
   2. Expansion Losses in Two Phase Flow 101
   3. Comparison with Experimental Results 102
   4. Analytical Formulation of Martinelli-Nelson Multiplier 102
List of Figures

Fig. 1 Hydraulic loop scheme
Fig. 2 Section of the heated channel of the loop at Polytechnical School of Turin
Fig. 3 Void fraction versus channel length and bubble radius at detachment versus pressure from Ref. [2]
Fig. 4 Parameter β versus pressure from Ref. [2] and Shape of curves representing the elevation head and the total pressure drop versus flow rate
Fig. 5 Comparison between results of the calculation and experimental results
Fig. 6 Schematic representation of the loop at Polytechnical School of Turin
LUPO - A PROGRAM FOR PREDICTION OF STEADY-STATE TEMPERATURE, FLOW RATE AND PRESSURE DROPS IN A CLOSED PRESSURIZED WATER LOOP WITH OR WITHOUT BOILING

1. INTRODUCTION

In the design and operation of nuclear power reactors it is necessary to predict the heat transfer and hydraulic behavior of the coolant over a wide range of conditions. Analysis often includes the case in which the coolant enters the heated channel as a subcooled liquid and leaves as a two-phase mixture with bulk boiling.

One of the limitations to the increase of the power is the tendency towards hydrodynamic instability displayed by a boiling water reactor when power is increased. This is particularly true in the operation of natural circulation systems.

The mechanism of boiling and two phase flow is so complex that even for steady-state calculation it is difficult to obtain accurate results. All the attempts published up to now to describe the behavior of boiling water loops have been based on several assumptions and approximations. The choice of the equations to be used for computing heat transfer, void fraction and pressure drop in the nucleate and bulk boiling regions is complicated by the presence in the literature of several methods for treating this phenomenon and by the lack of experimental information of general validity.

The group of the heat transfer laboratory of the Polytechnical School of Turin has been working for some years on the natural and forced circulation in a closed loop with pressurized water.

Much of the information contained in the published literature has been reviewed and a theoretical model derived in such a form that many assumptions and approximations can be eliminated or limited.

Accuracy and consistency of theoretically and experimentally derived equations for each of the several coolant conditions occurring in a system have been previously examined.

Manuscript received on August 29, 1967.
The physical model includes a representation of all liquid, subcooled boiling and bulk boiling conditions. Special care has been used in treating the subcooled boiling region, which has been divided into two sub-regions, following the Bowring model, the highly subcooled and the slightly subcooled region. Having in mind to prepare a tool to predict steady-state bulk fluid temperature, void fraction, pressure drops and mass flow rate in a closed loop, a representation of the hydraulics of all the components of a typical loop (riser, heat-exchanger, cold leg, pump) has been introduced in our model. A description of the loop, as it has been assumed, is given in Section 2 of this Report. The physical model is described in details in Section 3. It differs from a previous one developed at the Polytechnic School of Turin, and described in Ref.[1], mainly for the fact that bulk boiling has been included, but also by the introduction of Bowring representation of subcooled boiling.

The analytical method, derived by the physical model, is presented in Section 4. It has been programmed for IBM 7090 and IBM 360/65 to reduce the large computing effort usually required to obtain solutions. The code, named LUPO, has been written in Fortran IV language.

2. DESCRIPTION OF THE FACILITY

A schematic representation of the hydraulic circuit considered is given in Fig. 1 and a simplified section of the heated channel in Fig. 2.

It consists of an heated channel AB that discharges through a fitting BC into a riser CD. From here the water (or water and steam) flows to a collector E. Between two collectors E and F there is a heat exchanger consisting of a variable number of pipes in parallel. The water in F is returned to the inlet M by a downcomer GH, which feeds the pump I.

An inlet fitting MA is situated at the bottom of the heated channel.

It is thought that most present-day off-pile water loops could be adequately represented by this general circuit.
Pump I is optional and any component of the circuit between B and A can effectively be eliminated by specifying zero length for it.

The number of pipes of the heat exchanger is an input quantity as well as the localized pressure drop coefficients $K_i$, introduced to account for elbows, flanges, fittings and valves eventually present in each of the main components of the circuit.

A different diameter may be specified for test-section (heated channel, AB), riser CD, heat exchanger pipes EF, cold leg GM.

The pressure rise across the pump I is determined from a specified pump characteristic.

The geometric dimensions and hydraulic variables, which must be specified as input data are listed in Section 5.

3. DERIVATION OF A PHYSICAL MODEL
3.1 General Considerations

In this section the thermohydraulic equations describing a general hydraulic circuit are presented and discussed.

The circuit may be divided into components each of which has uniform flow area along its length and shows particular thermohydraulic characteristics. The coolant, flowing along the circuit, passes through different zones, suggested by the way in which heat transfer occurs, by the physical state of the fluid or, finally, by the practice of evaluating pressure drops in them.

Five regions, at least, may be defined:

a) Isothermal single-phase region, in which the physical properties of the fluid are constant both across and along the channel.

b) No-local boiling (heated) region, in which the fluid temperature is below the saturation temperature and convection is the only heat-transfer mechanism. Fluid and wall temperatures rise along the channel.
c) **Local boiling** region, in which the fluid temperature is below the saturation temperature, but the wall temperature is above it so that local boiling may start. Bubbles, generated at the wall, grow, leave the surface and collapse after a short distance in the subcooled liquid.

d) **Bulk-boiling** region, in which the fluid has reached the saturation temperature with steam production.

e) **Adiabatic** region, in which the two-phase fluid flows without mass exchange between the phases, in non-heated channels.

Region c), also called subcooled boiling region, may, in turn, be subdivided into "highly subcooled" and "slightly subcooled" regions. Two-phase fluid is present in regions c) to d).

It is very important to be able to correctly evaluate pressure drops in all the above cited regions, if reliable values of the flow rate are desired from the calculation.

Simply stated, the loop steady state flow rate is that value, which satisfies the equation:

\[
\sum \Delta P_{fr}^{\text{loop}} + \sum \Delta P_{acc}^{\text{loop}} + \sum \Delta P_{elev}^{\text{loop}} + \Delta P_{pump} = 0\]

(1)

where:

\(
\sum \Delta P_{fr}^{\text{loop}} = \text{frictional pressure drop around the loop including losses from entrance and exit flanges, orifices and elbows (form losses)}.
\)

\(
\sum \Delta P_{acc}^{\text{loop}} = \text{acceleration pressure drop around the loop}.
\)

\(
\sum \Delta P_{elev}^{\text{loop}} = \text{difference in the elevation head between hot and cold legs of the loop}.
\)

\(\Delta P_{pump} = \text{pressure generated by the pump in forced circulation loops}.
\)

Both frictional pressure drop and elevation head are strongly related to the voidage in the circuit, because the friction coefficient and the fluid
density in the hot portion of the loop are very sensitive to the void-fraction.

In the following sections a method will be described for evaluating the voidage distribution along the test-section and the riser when two-phase fluid is present, and the related pressure drops. The method is based on the Bowring theory.

Each term in equation (1) will be discussed and various available correlations will be examined.

3.2 Bowring Model and Void Fraction Prediction

The Bowring theory (Ref. [2]) rests upon the subcooled voidage model. In previous models voidage in the subcooled region has been assumed to be a wall effect. There are a first region, at high degrees of subcooling, where the voidage is small, and a second, at low degrees of subcooling, where the void fraction increases rapidly with decreasing subcooling.

The difference in the new model lies in taking into account the bubbles detachment in the slightly subcooled region. At low degrees of subcooling, bubbles detach from the heated surface and are swept downstream, recon­densing slowly as they move through the subcooled region. In short the void fraction in this region is basically a "bulk fluid" effect.

In Fig. 3 the transition point B represents the condition for bubbles to leave the surface and the rapid increase in void fraction as in the bulk boiling region.

The complete voidage picture is made of:

1. highly subcooled region, where voidage is a wall effect and it is usually negligible.
2. slightly subcooled region, where voidage is a free bubble effect; there is in addition a local wall voidage arising from bubbles before detachment from the wall.
3. bulk boiling region: this may be calculated in the normal way.
Of course there are some differences between the build-up of voids in the slightly subcooled and bulk boiling regions: in the subcooled region bubbles are in a bulk of subcooled water so that they collapse after a short distance; part of the heat flux raises the bulk temperature of the water and part produces void, whereas in the bulk boiling region all the heat is used in the production of steam; finally the transition between regions I and II (Fig. 3) is governed by different and more complex criteria than that one between the II region and bulk boiling region.

Transition points are calculated by transition subcoolings:

a) \( \theta_{scb} = \frac{\Phi}{\lambda} - \beta \Phi^{1/4} \) gives the condition for subcooled boiling to start, by using the Jens - Lottes equation (Ref. [2]). In our units \( \beta \) is given by the following relation

\[
\beta = 62.745855 e^{-0.0163(p-1)}
\]  

(2)

b) \( \theta_d = \eta \frac{\Phi}{V} \) relates the subcooling at which bubbles can detach to the heat flux and velocity. The equation (and the value of \( \eta \) ) were obtained from experimental subcooled void data.

Heat is removed in the test section: as latent heat content of bubbles (\( \Phi_e \)), by convection caused by bubble agitation of the boundary layer (\( \Phi_a \)), by single phase heat transfer between patches of bubbles (\( \Phi_{sp} \)):

\[
\Phi = \Phi_e + \Phi_a + \Phi_{sp}
\]

By introducing the empirical parameter \( \varepsilon \), defined as:

\[
\varepsilon = \frac{\Phi_a}{\Phi_e}
\]

and by considering \( \Phi_{sp} = 0 \) (Ref. [2]), \( \Phi_e \) is given by:

\[
\Phi_e = \frac{\Phi}{1 + \varepsilon}
\]

Then the subcooled void equation will be:

1) in the bulk boiling region all the heat is used in the production of the steam, and the weight fraction is related to heat flux by the equation:
\[ x = \left( \frac{P}{\rho AV} \right) \cdot \int_{ML}^{z} \frac{\Phi}{dz} \]  
\( \text{(3)} \)

where \( P \) is the wetted perimeter and \( ML \) is the length of the channel at which bulk boiling begins.

2) in the slightly subcooled region, the equation of the rise of local weight fraction may be written as:

\[ x_b = \left( \frac{P}{\rho AV} \right) \int_{zd}^{z} \frac{\Phi}{(1 + \varepsilon)} dz \]  
\( \text{(3')} \)

Then the void fraction is expressed by following equation:

\[ \alpha = \frac{x}{x + S \cdot \frac{\rho_f}{\rho_f} (1 - x)} \]  
\( \text{(4)} \)

The whole voidage is the sum of the free bubble voidage and the wall voidage.

The wall voidage (Ref.[2]) is given by the relation:

\[ \alpha_w = \frac{\delta}{A} \]  
\( \text{(5)} \)

where \( \delta \) is the effective thickness of the steam film and it is the lesser of:

\[ \delta = 0.066 \cdot R_d \]

\[ \delta = \frac{Pr \cdot K \cdot V}{1.07 \cdot \eta \cdot \nu^2} \]

where \( Pr \) is Prandtl number and \( K \) is the thermal conductivity.

3.3 Elevation Head

The loop elevation pressure drop, or thermal driving head (in natural circulation) is given by:

\[ \sum_{\text{loop}} \Delta P_{\text{elev}} = \int_{0}^{L} \rho_{cl} dz - \int_{0}^{L} \rho_{hl} dz \]  
\( \text{(6)} \)

where subscripts 'cl' and 'hl' mean respectively cold and hot leg.
The single-phase densities in equation (6) are easily evaluated from the fluid static pressure and temperature. When boiling occurs in the hot leg, the exact evaluation of the density requires the knowledge of void distribution along the channel.

If only local boiling takes place, it is customary to regard the void as a wall phenomenon and, consequently, to evaluate the density from the mean liquid temperature.

In the present model, this has been done only for the highly-subcooled region. In the slightly-subcooled region, the void distribution has been first evaluated following Bowring's model, and then the density

$$\rho = (1 - \alpha)\rho_f + \alpha\rho_g$$

(7)

according to the momentum equation.

This assures the applicability of the model to channels of small size also.

Whenever bulk-boiling region is present the density of the two-phase fluid may be given by equation (7) or by

$$\rho = (1 - x_v)\rho_{fsat} + \rho_g x_v$$

(8)

according to the energy equation.

The meaning of the symbols used in equations (7) and (8) is the following:

- $\alpha$ = void fraction or steam volume fraction
- $\rho_f$ = density of liquid
- $\rho_g$ = density of gas
- $\rho_{fsat}$ = density of liquid at saturation temperature
- $x_v$ = volumetric quality, defined as:

$$x_v = \frac{V_g A_g}{V_g A_g + V_f A_f} = \frac{S_r \alpha}{S_r \alpha + (1 - \alpha)}$$

(9)

$S_r$ = slip ratio.
The use of equation (8) in the present model is justified, because it has been recognized, Ref.[3], that the elevation head must be evaluated by using the energy equation instead of the momentum equation, which, in turn, applies to transient problems.

3.4 Acceleration Pressure Drop

The total acceleration pressure drop is obtained by summing the acceleration pressure drops due to changes in area and density around the loop.

If negligible terms are omitted, one can write:

\[
\sum_{\text{loop}} \Delta P_{\text{acc}} = \frac{w^2}{2gA_{ts}^2} \left[ \chi_{\text{ts-ex}} - \chi_{c1} \right] \cdot \left[ 1 - \frac{A_{ts}}{A_{\text{exc}}} \right]^2
\]  \hspace{1cm} (10)

where:

\[
\chi = \frac{1}{\rho} \quad \text{for nonboiling regions}
\]

\[
\chi = \left[ \frac{(1 - x)^2}{1 - \alpha} + \frac{\chi^2 p_f}{\alpha \rho_g} \right] \frac{1}{\rho_f}
\]  \hspace{1cm} (11)

for two-phase regions

Subscripts "ts-ex", "c1" and "exc" refer respectively to test-section exit, cold-leg and heat-exchanger.

Equation (11) is valid under the condition of slip-flow. If the fog-flow model is considered, the following relationship applies:

\[
\chi = \left[ (1 - x) + x \frac{\rho_f}{\rho_g} \right] \frac{1}{\rho_f}
\]  \hspace{1cm} (12)

Equation (12) predicts values of acceleration pressure drop which are higher than those given by equation (11).

The true value, probably, lies between these two limits. In the absence of any experimental data, the use of equation (12) could be advisable because it results in a conservative prediction of the pressure drop.
Equation (10) is derived in Ref. [4].

For the special case in which the heat-exchanger consists of \( n_{\text{exc}} \) pipes in parallel, the following new relationship has been derived and introduced in the present model:

\[
\sum_{\text{loop}} \Delta P_{\text{acc}} = \frac{G_{ts}^2}{zg} \left[ \chi_{ts-ex} - \chi_{cl} \right] \cdot \left[ 1 - \frac{1}{n_{\text{exc}}} \left( \frac{D_{ts}}{D_{\text{exc}}} \right) ^4 \right] + \frac{n_{\text{exc}}^2 - 1}{n_{\text{exc}}^2} \left( \frac{D_{ts}}{D_{\text{ris}}} \right) ^4
\]  

(13)

### 3.5 Friction Pressure Drop

Several types of flow must be considered.

a) Isothermal turbulent flow of single-phase fluid.

Pressure drop is given by the expression:

\[
\Delta P_f = f_{iso} \frac{L G^2}{D 2 \rho g}
\]

(14)

where the friction factor \( f_{iso} \) is given by the Colebrook relation for the transition and turbulent regions or by:

\[
f_{iso} = 0.0055 \left[ 1 + \sqrt{3.5 / 20000 \left( \frac{6}{D} + 10^{-6} \sqrt{Re} \right)} \right]
\]

(15)

for full turbulence region.

Equation (15) is valid when the diameter \( D \) is expressed in centimeters and has been derived from Ref. [5].

b) Non-isothermal turbulent flow of single-phase fluid.

Equation (14) becomes:

\[
\Delta P_f = f_{iso} \cdot \left( \frac{f}{f_{iso}} \right) \cdot \frac{L G^2}{D 2 \rho g}
\]

(16)

where \( \left( \frac{f}{f_{iso}} \right) \) is a correction factor which accounts for the variation along the radius of the temperature and consequently of the physical properties of the fluid. The coefficient \( f_{iso} \), in equation (16) must be evaluated by using the average temperature.
Many semiempirical correlations are reported in the literature in order to evaluate the correction factor \((f/f_{iso})\):

\[
\left( \frac{f}{f_{iso}} \right) = \left( \frac{\mu_w}{\mu_B} \right)^{0.13} \quad \text{Reference [6], Kreith and Summerfield (17)}
\]

\[
\left( \frac{f}{f_{iso}} \right) = \left( \frac{\mu_B}{\mu_w} \right)^{10} \cdot \left( \frac{\rho_B}{\rho_w} \right)^{-0.5} \quad \text{Reference [7], Maurer and Le Torneau (18)}
\]

\[
\left( \frac{f}{f_{iso}} \right) = 1 - 0.0018 \frac{\Phi}{\lambda} \quad \text{Reference [1] (19)}
\]

where \(\lambda\) is calculated from Dittus-Boelter correlation:

\[
\lambda = 0.023 \frac{K}{D} \quad \text{Re}^{0.8} \quad \text{Pr}^{1/3} \quad \text{(20)}
\]

\(\Phi\) = heat flux expressed in units coherent with \(\lambda\) so that the ratio \(\Phi/\lambda\) results a temperature measured in °C.

In the present model equation (19) has been adopted, which is valid for pressures in the range between 50 and 120 Kg/cm².

c) Local Boiling.

No sufficient experimental and theoretical work has been carried out up to now on pressure drops in local boiling region.

Semiempirical correlations have been proposed by Reynolds and Rohde, based on experiments on horizontal and vertical circular channels, performed by Reynolds and Buchberg respectively, Ref. [5]. Mendler, Ref.[4], performed calculations of local boiling pressure drops with water at 800 to 2000 psia, by means of the following correlation for \((f/f_{iso})_{LB}\):

\[
\left( \frac{f}{f_{iso}} \right)_{LB} = 1 + \left[ \left( \frac{f}{f_{iso}} \right)_{sat} - 1 \right] \cdot \frac{t - t_{scb}}{\bar{t} - t_{scb}} \quad \text{(21)}
\]

where \((f/f_{iso})_{sat}\) is equal to the value of \(\Phi_{LO}^2\) at 4, 2 per cent quality and may be evaluated by means of correlation, Ref.[5]:

\[
\left( \frac{f}{f_{iso}} \right)_{sat} = 19.579 \left( 0.5931697 \right)^{0.5931697} \quad \text{(22)}
\]
The temperature at which local boiling starts, and may be calculated as:

\[ t_{scb} = t_{sat} + \Delta t_{sat} - \Phi \frac{\Delta t_{sat}}{\lambda} \]  \hspace{1cm} (23)

or, following Bowring:

\[ t_{scb} = t_{sat} + \beta \Phi^{1/4} - \Phi \frac{\Delta t_{sat}}{\lambda} \]  \hspace{1cm} (23')

where \( \beta \) is given by relation (2) of Sect. 3.2, and \( \Delta t_{sat} \) by one of the following two empirical correlations:

\[ \Delta t_{sat} = 62.62096 \Phi^{1/4} e^{-\frac{P}{61.2414}} \]  \hspace{1cm} (24)

\[ \Delta t_{sat} = 145.7 \Phi^{1/2} e^{-\frac{P}{87.89}} \]  \hspace{1cm} (25)

Both equations (24) and (25) have been included in the present model and the choice is left to the user.

We note that equation (23), in which \( \Delta t_{sat} \) is evaluated by means of (24), and equation (23') give the same results.

In the present model, the local boiling region has been divided, following Bowring theory, into a highly subcooled and a slightly subcooled region.

In both regions the relation (16) is valid, but the correction factor \( \frac{f}{f_{iso}} \text{LB} \) has to be calculated in a different manner.

In the highly subcooled region, in which voidage is a wall effect, \( \frac{f}{f_{iso}} \text{LB}_1 \) is evaluated by means of relation (21). In the second region, where voidage is mainly a bulk effect, the multiplier \( \frac{f}{f_{iso}} \text{LB}_2 \) is evaluated by using the Lottes-Flinn relation (see Appendix 1), i.e.:

\[
\left( \frac{f}{f_{iso}} \right)_{LB_2} = \frac{1}{3} \left[ 1 + \frac{1}{\alpha_{ex}(1 - S \frac{\rho_g}{\rho_f})} + \frac{1}{\left[ 1 - \alpha_{ex}(1 - S \frac{\rho_g}{\rho_f}) \right]^2} \right] \]  \hspace{1cm} (26)
where \( \alpha_{ex} \) is the void fraction at the end of the slightly subcooled region given by equation (4).

The validity of Lottes-Flinn correlation applied to the local boiling region has been proved by the experimental results by Sher, Ref.[11], which have shown that local boiling pressure drop may be predicted by means of bulk boiling correlations if local void fractions are known.

We note that equations (26) and (21) does not give the same value at the boundary between highly and slightly subcooled regions: equation (26) gives \((f/f_{iso})_{LB} = 1\) and equation (21) gives

\[
\left(\frac{f}{f_{iso}}\right)_{LB} = \left[\left(\frac{f}{f_{iso}}\right)_{sat} - 1\right] \frac{t_d - t_{scb}}{t_{sat} - t_{scb}}
\]

To avoid discontinuity on pressure drop we corrected equation (26) by adding the following term:

\[
\left(\frac{f}{f_{iso}}\right)^{\ast} = \left[\left(\frac{f}{f_{iso}}\right)_{sat} - 1\right] \frac{t_d - t_{scb}}{t_{sat} - t_{scb}}
\]

Another way to get over the difficulty consists in the adoption in both regions of equation (26). The two options are present in the digital program, but the first one seems to give results in better agreement with experiments carried out at the Polytecnical School of Turin.

\[d)\ \text{Bulk Boiling}\]

Two-phase friction pressure drop correlations reported in the literature are of two types:

1) a friction factor method in which the friction factor is computed considering a homogeneous mixture of the two phases, is used;

2) a non-dimensional ratio, obtained by dividing the two-phase friction pressure drop by the liquid-phase friction pressure drop, evaluated at the total flow rate, is correlated with quality, pressure and mass flow rate.

The first approach does not give results in agreement with experiments. The most widely accepted correlation of the second type is that by Martinelli and Nelson, Ref.[16].
It is presented in graphical form and no analytical expression for it is available, except the one derived in Appendix 4. Moreover it does not take into account a dependence on mass flow rate. Also Sher and Green, Ref.[17], present their correlation of experimental measurements in a graphical and numerical form.

Only three analytical correlations for the two-phase multiplier \( (f/f_{iso})_{bb} \) are available in the literature: the one by Levy, Ref.[18], the one by Marchaterre, Ref.[19], and the one by Lottes and Flinn, Ref.[20]. Levy proposes for the two-phase multiplier the following expression:

\[
\left( \frac{f}{f_{iso}} \right)_{bb} = \frac{(1 - x)^{1.80}}{(1 - \alpha)^2}
\]

in which \( (f/f_{iso})_{bb} \) is related to quality and pressure since the "momentum model" correlation between quality and void fraction is dependent on pressure through the ratio \( \left( \frac{\rho_{fsat}}{\rho_g} \right) \), but not to mass flow rate. Marchaterre proposes the expression (for vertical upflow):

\[
\left( \frac{f}{f_{iso}} \right)_{bb} = \frac{(1 - x)^2}{1 - \alpha} + \alpha \cdot \frac{2g(\rho_f - \rho_g)\rho_D}{f_{iso} \cdot G^2}
\]

Comparison of this relation with experimental results does not appear to be very satisfactory. Lottes and Flinn propose the correlation:

\[
\left( \frac{f}{f_{iso}} \right)_{bb} = \frac{1 - x}{1 - \alpha} = 1 + x \left( \frac{\rho_f}{\rho_g} \cdot \frac{1}{S_r} - 1 \right)
\]

in which \( S_r \) is the slip ratio.

Comparison of this relation with experimental results obtained at Argonne is fairly satisfactory, Ref.[5].

In the present model Lottes-Flinn correlation has been used with the assumption of constant slip-ratio along the channel.

The average value of the two-phase multiplier is given by:

\[
\left( \frac{f}{f_{iso}} \right)_{bb} = \frac{1}{l_{ts} - z_{bb}} \int_{z_{bb}}^{l_{ts}} \left[ 1 + \frac{1}{\rho_g} - \frac{1}{\rho_{out}} \right] \left[ x_{ex} - \frac{x_{D_{ts}}}{W \cdot r} \Phi(1_{ts} - z) \right] dz
\]

Derivation of equation (29') is shown in Appendix 1.
3.6 Local Pressure Drops

In the loop there are several local pressure drops, due to:

- test section entrance and exit fittings,
- valves and nozzles,
- bends

In a turbulent flow system, losses can be visualized in terms of kinetic energy of the fluid, using the velocity-head concept (Ref. [8]).

The general expression for local pressure drops is:

$$\Delta p_{loc} = K \frac{G^2}{2 \rho g_c}$$

where $K$ is the loss coefficient, which assumes different values for enlargement, contraction and the like. Single phase pressure drop coefficients may be calculated as in "Mauro 1" (Ref. [12]), according to Ref. [8], [13], [14], [15].

The exit local pressure drop, when slightly subcooled or bulk boiling occurs at the end of test section, is given by the Romie relation, based on Richardson hypothesis (Ref. [9]), further corrected by an expression which makes for $\alpha = 0$ the drop so calculated equal to the value given by hydraulic relation. The final relation (derived in Appendix 2) is:

$$\Delta p_{loc, \text{exit}} = \frac{G^2_{\text{ris}}}{g_c (\rho_{\text{out}} + \rho_{\text{ris}})} \left[ K_{\text{out}} - 2 \left( \frac{D_{\text{ts}}}{D_{\text{ris}}} \left( 1 - \frac{D_{\text{ts}}}{D_{\text{ris}}} \right) \right) \right] +$$

$$+ \frac{G^2_{\text{ts}}}{g_c \cdot \rho_{\text{out}} \left( \frac{D_{\text{ts}}}{D_{\text{ris}}} \right)^2 \left( 1 - \left( \frac{D_{\text{ts}}}{D_{\text{ris}}} \right)^2 \right)} \left[ \frac{2 \rho_g}{\rho_f \cdot \alpha} + \frac{(1 - x)^2}{1 - x} \right]$$

4. DESCRIPTION OF THE NUMERICAL METHOD

4.1 Division of the loop

The loop is first of all divided into four components:
a) test section
b) riser
c) exchanger
d) downcomer

Only test section and riser are further divided in short axial lumps (up to 350) so that the calculation is there done by using linearized forms of the working equations. In each lump the enthalpy and fluid properties are computed, as shown in chapter 4.2. Because fluid properties change from all liquid to highly subcooled region and after to slightly and to bulk boiling, changes are made in working equations, by using Bowring model to determine the region boundaries. The number of mesh points in the heated channel and in the riser are specified by the user.

4.2 Working equations

Working equations are derived from mass and energy conservation equations.

a) Conservation of mass:
   the steady state mass flow rate is constant throughout every section of the loop.

b) Conservation of energy and heat balance:
   for given inlet temperature ($t_{in}$), heat flux ($\Phi$), heat transfer coefficient ($\lambda_{in}$), the wall temperature at the entrance of test section is:
   
   \[ t_{w, in} = t_{in} + \frac{\Phi}{\lambda_{in}} \]  

   (32)

   For every lump of the test section the heat balance gives:
   
   \[ h_{out}^j = h_{in}^j + 4 \frac{\Phi \cdot \Delta z_j}{G_{ts} \cdot D_{ts}} \]  

   (33)

   For every lump of the riser the heat balance gives:
   
   \[ h_{out}^j = h_{in}^j - \lambda_{ris} \cdot S_{ris} \cdot (t_{a} - t_j) \frac{1}{w} \]  

   (34)
where subscript "a" refers to air, and $\lambda_{\text{ris}}$ is the overall heat loss coefficient of the riser.

Temperatures are calculated from enthalpies by means of the expression:

$$ t = h - A $$

where $A$ is given by the following relation:

$$ A = 1.6634 + 1.5323 \times 10^{-10} \cdot h^{-0.4229448} $$

which results from numerical interpolation of table values.

Equation (35) is valid for pressures in the range between 20 and 100 Kg/cm² and for temperatures greater than 40 °C. Enthalpy must be expressed in units Kcal/Kg.

The mean temperature of the downcomer is obtained by adding to the test section inlet temperature $\Delta t_{\text{cl}}$ degrees. $\Delta t_{\text{cl}}$ is an input quantity predetermined by experiments.

The exchanger mean temperature is assumed to be the average between riser and downcomer mean temperatures. From the knowledge of temperature distribution around the loop it is possible to determine the coordinates of the boundaries of all regions and, then, to compute fluid properties in each of them. Equations used to evaluate thermodynamic properties of water are those listed in Ref. [1].

The equation for the enthalpy of water, $h$, is derived from Ref. [10]. Specific heat capacity, $c_p$, at constant pressure is calculated by the differential of the enthalpy equation with respect to temperature. The equation for the thermal conductivity, $K$, of water has been derived from values listed in Table VII of Ref. [10]. Density of water is calculated from an equation put forward by M. Tratz, which is available from Ref. [10].

In general, several regions are determined in the loop (see section 3.1) and in each region the mean properties are evaluated.
c) Conservation of momentum.

The equation (1) in section 3.1 is integrated to the whole loop. In each region pressure drops are computed with mean values of properties by relations, which are in sections 3.3, 3.4, 3.5 and 3.6.

In the test section lump temperature is compared continuously with Bowring's model boundary values, so dividing the test section into different regions. Different relations for pressure drops are, then, used in each of them. In the riser, if the outlet temperature is equal to the saturation value, the equation (34) allows in every lump to calculate the enthalpy, which must be compared with the saturation value. If it is greater or equal, the quality is found by the relation:

\[
x = \frac{h - h_{\text{sat}}}{h_g - h_{\text{sat}}}
\]

and, calling \(x\) the smooth value in every lump, the friction pressure drop two phase multiplier is given by:

\[
R_{\text{ris}} = \frac{1}{n_{\text{ris}}} \sum_{j=1}^{n_{\text{ris}}} \left( \frac{f}{f_{\text{iso}}^j} \right)
\]

where \(\left( \frac{f}{f_{\text{iso}}^j} \right)\) is given by the following equation:

\[
\left( \frac{f}{f_{\text{iso}}^j} \right) = \left[ 1 + \left( \frac{1}{\frac{\rho_{\text{ris}}}{\rho_{\text{iso}}^j}} - 1 \right) \right] \frac{2}{x}
\]

4.3 Flow rate calculation

The steady state flow rate calculation is done by solving the equation (1) of Section 3.1 implicitly, that is by using an iterative procedure. This procedure is the "method of halving". At each calculation step, (i.e. at each flow rate value), all pressure drops are evaluated along with the "relative error" \(\varepsilon = (\Delta p_{\text{mot}} - \Delta p_{\text{res}})/\Delta p_{\text{mot}}\), (where \(\Delta p_{\text{mot}} = \Delta p_{\text{elev}} + \Delta p_{\text{pump}}\) and \(\Delta p_{\text{res}} = \Delta p_{\text{fr}} + \Delta p_{\text{acc}}\)), and a new flow rate value is chosen depending on the sign of \(\varepsilon\). As many steps are performed as they are necessary to make \(\varepsilon\) less than a prescribed value.

Precisely an interval of flow rates is given, in which we presume to find the solution; this interval is divided in four parts, and for the five flow
rate values the relative error is calculated.
In the subinterval where the relative error changes sign the midpoint is
chosen and this flow rate value is used for a new calculation cycle until
the relative error is less than a fixed value.
Fig. (4) shows the shape of curves, representing the gravitational driving
force and the total pressure drop, versus the flow rate.

5. THE LUPO CODE

5.1 Structure of the Program

The program includes a "Main Program", six "Subroutines" and eleven
"Functions", called by the "Main Program".

a) Main Program.
First statements are of input data reading and printing. Then the Code
computes constant quantities (non-depending upon the flow rate) and clears
several variables. At pages 9, 10 and 11 there is the mean properties and
friction pressure drops calculation, in every test section region. Then
the code computes temperatures, mean properties and friction pressure
drops in the riser, in the exchanger and in the cold leg. At page 12 there
is the local pressure drops, the acceleration and the elevation pressure
drops calculation.

Then the program computes and prints the relative error, and in
accordance with this value, it decides what it will make: to continue
iterations or to read restart input data; however, it prints results.

Restart input data are inlet temperature or thermal power; if they are not
the program stops.

b) Subroutines
Six subroutines must be used in addition to the Main Program. These
subroutines are:
PUMP  TRIST
DROP  DPEL
COTES  FLOW

PUMP - SUBROUTINE PUMP computes the driving force of a pump in
the forced circulation

DROP - SUBROUTINE DROP computes friction pressure drops in two
phase regions.
COTES - SUBROUTINE COTES is used to integrate by means of Cotes formula the expression derived from Lottes-Flinn model for the friction two-phase multiplier calculation.

TRIST - SUBROUTINE TRIST computes the temperature distribution, mean properties and the friction multiplier in the riser.

DPEL - SUBROUTINE DPEL computes the elevation head.

FLOW - SUBROUTINE FLOW computes at each iteration step the new value of flow rate according to the numerical treatment, described in Section 4.3.

c) Functions

The LUPO Code includes eleven FUNCTIONS

The FUNCTIONS: ENタルP, DENSIT, VISCOS, CSP, COND, SAT, ACCA compute the fluid enthalpy, density, viscosity, specific heat capacity, thermal conductivity, saturation temperature, heat transfer coefficient, respectively.

FUNCTIONS: DP, DPL, DPLU compute acceleration, local pressure drops and local two phase pressure drops at the exit of the test section, respectively.

FUNCTION COMP computes the two phase multiplier, derived from the Lottes-Flinn model.

5.2 Flow Chart

At following pages the flow chart of the program is shown. For symbols see the nomenclature at the end of report.
Main Program

Read input data

Δz = hTs/hTs

A

MI = O KIND = 1

Print input data

Compute constant quantities

CALL FLOW

WXX = WX

KIND = 2

HS = 0.2

Compute

Tsat, hin, ΔTsat, φ, M, Ρ

Tcl, Pin, Cin, Pin, A in

Ccl, Kcl, Cpcl, Acl

Print

Tsat, hin, ΔTsat, φ, A, Ρ

Start internal loop
CALL PUMP

Compute $G_{rs}, G_{c1}, G_{exch}, G_{ris}$

Compute $T_{w,in}, T_{scb}$

Compute $T_{win}, N_{Re,in}, h_{in}, \Delta T_{scb}, T_{scb}, h_{scb}$

Compute $T_d$

Compute $V_{in}, \Delta T_d, T_d$

Compute liquid temperature distribution in test section

If $T_{in} < T_{scb}$, go to D

If $T_{in} \geq T_{scb}$, go to E

All liquid region temperatures Calculation

$A = 1$

$J = 1$

$Z_{lb} = 0$

$J = 1$

$T_{in} < T_d$

$Z_d = 0$

$A = 1$

$B = 1$
YES

Compute $h_{out,j}, T_j, T_{mj}$

$T_{mj} < T_{scb}$

YES

$j = j + 1$

NO

$Z_{LB} = \frac{\Delta Z}{(A-0.5)}$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$D$

Compute $h_{out,j}, T_j, T_{mj}$

$T_{mj} < T_d$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$

$A = j$

$Z_{LB} = l_{ts}$

$A = 0$

NO

$L$

YES

$F$

NO

$j < n_{ts}$

YES

$D$
Slightly subcooled boiling temperatures calculation

\[ B = 1 \]

\[ j = j + 1 \]

\[ Z_d = \Delta Z \text{ (B-05)} \]

\[ j < n_{ts} \]

\[ Z_d = l_{ts} \]

\[ B = 0 \]

Compute

\[ h_{out,j}, x_j, h_{out,J}, T_1, T_{m,j} \]

\[ T_{mj} < T_{sat} \]

Bulk boiling region temperatures and mean density calculation

\[ C = j \]

\[ T_{m,j} = T_{sat} \]

\[ j = j + 1 \]

\[ Z_{bb} = \Delta Z \text{ (C-05)} \]

\[ j < n_{ts} \]

\[ Z_{bb} = l_{ts} \]

\[ C = 0 \]
Compute \( h_{out} \), \( X_j, X_{v2} \), \( q_{v2} \), \( j = j + 1 \)

\( j < n_{ts} \) \( \rightarrow \) \( \text{YES} \)

\( \text{NO} \)

\( \text{All liquid region calculation} \)

\( F \)

\( T_{out} = T_{mj} \)

\( AL = 0 \) \( \rightarrow \) \( \text{YES} \)

\( \varepsilon \)

\( \text{NO} \)

\( A > 0 \) \( \rightarrow \) \( \text{YES} \)

\( \text{NO} \)

\( T_{scb} = T_{out} \)

\( Z_{lb} = L_{ts} \)

\( \delta \)

\( \varepsilon \)

Compute \( q_{sr}, h_{sr}, k_{sr}, c_{r,sr}, N_{Re,sr} \)

\( M \)
Compute \( h_{sr}, f_{iso, sr}, \frac{(f/f_{iso})_{sr}}{r}, \Delta P_f, sr \)

\[ Z_{LB} = l_{ts} \]

If \( Z_{LB} = l_{ts} \):

- YES: \( Z_d = l_{ts} \)
- NO: \( \rho_{out} = \rho_{LB} \)

If \( A = 0 \):

- YES: \( G \)
- NO: \( E \)

If \( B > 0 \):

- YES: Highly subcooled region calculation
  - Compute \( T_d = T_{out} \), \( Z_d = l_{ts} \)
  - Compute \( q_{LB}, T_{mLB}, q_{LB}, N, Re, LB \)
  - Compute \( Z_0, f_{iso, LB}, \alpha W \)
  - Compute \( (f/f_{iso})_{sat, LB} \)
  - Compute \( \Delta P_f, LB \)
  - \( Z_d = l_{ts} \)

If \( KKK-D \):

- YES: \( \rho_{out} = \rho_d \)
- NO: \( G \)

If \( KKK-D \):

- YES: \( \rho_{out} = \rho_d \)
- NO: \( G \)
Slightly subcooled region calculation

Compute
\( x_{bb}, \alpha_{bb}, \alpha, \rho_1, \chi_{bb}, \rho_{v,1} \)

Compute
\( R_1, T_{m1}, Z_1 \)

CALL DROP

Compute \( \Delta P_{f,1} \)

\( Z_{bb} = l_{ts} \)

YES

Compute \( \rho_{out}, x_{ex}, \alpha_{ex} \)

Bulk boiling region calculation

Compute
\( \rho_{out}, x_{ex}, \alpha_{ex}, \alpha_2, \rho_2, Z_2 \)
Compute ΔPlacj

i = i + 1

NO

i > 4

YES

Compute ΔPlac5

Compute Δloc,5,TP

Compute ΔPres

Compute E

CALL FLOW

YES

ICN > 0

NO

YES

MIMI < IMAX

NO

ICN = 1

WRITE

Max number of iteration has been reached
Subroutine TRIST

IND=1

NO

α

Compute h_{out,i}

h_{out,i} = h_{out}

T_{m,i} = T_{sat} + \hat{T}_{m} + \hat{r}_{m} = R_{ris} = 0

Δ = 1

A

Compute h_{out,i}

h_{out,i} = h_{out}

X_{out,i} = 0

h_{i} = h_{out,i}

YES

Compute X_{out,i}

T_{out,i} = T_{sat}

NO

Compute T_{out,i}

\text{Compute } X_{m,i} = X_{out,i}/2

\text{Compute } (l'f_{iso})_{i} = (l'f_{iso})_{i} = R_{i}

\text{Compute } \alpha_{m,i} = \text{Compute } \gamma_{i}, \nu_{i}, \phi_{i}

\text{Compute } X_{in,i} = X_{out,i}

h_{in,i} = h_{out,i}

T_{m,i} = T_{m,i} + T_{out,i}

\text{Compute } \hat{\varphi}_{i} = \hat{\varphi}_{i} + \hat{\varphi}_{i}

Δ = Δ + 1

\text{Compute } T_{ris} = T_{m,i}/n_{ris}

\varphi_{ris} = \varphi_{ris}/n_{ris}

R_{ris} = R_{ris}/n_{ris}

K = 1

\text{Compute } \hat{R}_{ris} = R_{ris} = R_{k}

K = K + 1

\text{Compute } R_{ris} = R_{ris}/n_{ris}

\text{Return}

NO

\text{Compute } \varphi_{i}

\text{Compute } F_{iso,i}

R_{i} = f_{iso,i}

\text{NO}

\text{YES}

\text{Compute } T_{ris} = T_{ris}/n_{ris}

\varphi_{ris} = \varphi_{ris}/n_{ris}

R_{ris} = R_{ris}/n_{ris}

\text{Return}
SUBROUTINE FLOW

ICN=0

MIM1=MIM1+1

K IND=1

NO

IK=MIM1-1

NO

|ε|≤εmax

NO

MIM1>6

NO

W(K)=Wx

E(K)=ε

Wx=Wx+ΔW

MIM1=6

NO

NCN=1

YES

I=1

NO

E(I)/E(I+1) ≥ 0

NO

I=I+1

YES

I>4

YES

Write N zero has been found between Wx and Wmax

Write W(K), E(K) for K=1:5

YES

NO

ΔW=ΔW/2

Wz=Wz+ΔW

ε1=ε(I)

Return

NO

Write Solution has been obtained in N iterations

ICN=1

RETURN

ε/ε1<0

YES

ΔW=ΔW/2

ΔW=ΔW/20

NO

Wz=Wz+ΔW

ε1=ε

RETURN

C

A
5.3.1 Listing and sample Print-out

The listing in FORTRAN language follows. The "Main" is the first; SUBROUTINES and FUNCTIONS follow it.
For the FORTRAN nomenclature see the following section. At the end of listing there is a sample print-out with input data and results of a typical calculation.
***LUPO*** A PROGRAM FOR SINGLE AND TWO-PHASE PRESSURE DROPS CALCULATION IN PRESSURIZED WATER CLOSED LOOPS.

(JUNE 28, 1967) C. DAGGERO, B. PANELLA

** Title: Problem Title (Any Alphabetic Character String)**

** MAX: Maximum number of iterations**

** NZETA: Number of test section lumps**

** INDL: Riser temperature calculation parameter**

** IPRINT: Printing parameter**

** IDT: Delta-Sat Calculation Parameter**

** KKK: Pump head (kg/cm**2**)**

** DEPL: Maximum relative error**

** DPPUMP: Pump head (kg/cm**2**) evaluated by subroutine PUMP**

** TSLT: Test section length (cm)**

** CLLT: Cold Leg length (cm)**

** EXLT: Exchanger length (cm)**

** RILT: Riser length (cm)**

** FILLT: Outlet fitting length (cm)**

** TSD: Test section internal diameter (cm)**

** CDL: Cold Leg internal diameter (cm)**

** EXD: Exchanger internal diameter (cm)**

** RID: Riser internal diameter (cm)**

** ROUG: Test section roughness coefficient**

** ROUL: Loop roughness coefficient**

** SLIP: Slip ratio**

** DELTA: Angle of loop with respect to horizontal (radian)***

** EPS1: Reordering parameter for local quality calculation**

** PDO: Bubble average radius at detachment**

** LAMDA: Evaporation heat (kcal/kg)**

** RFC: Saturated steam density (kg/cm**3**)**

** ENUTFS: Saturated water enthalpy (kcal/kg)**
PROGRAM MAIN

READ 5,1001 (TITLE(I),I=1,18)
READ (5,1002) P,EMAX,PUMP
READ (5,1002) TS,TILT
READ (5,1002) ROG,ROU,RSLIP
READ (5,1002) RST,ROG,RSLIP
READ (5,1002) BLM,BLK,BLK,BLK
READ (5,1002) XTCL,XTRIS
KPUMP=0
READ (5,1002) (CC(I),I=1,6)
KPUMP=1
CONTINUE
READ (5,1002) (CC(I),I=1,6)
CONTINUE
READ (5,1002) POWER=0.2388
EXCN=NEXC
ZETA=NZETA
NRR=NZETA/5
NS=NZETA-NRR*5
IF(BR.GT.0.0.GTO 1400
SIGMA=ITSD/RO
SIGMA=SIGMA*SIGMA
BR=SIGMA*(1.0-SIGMA)
CONTINUE
KIND=1
MIM=0
PRINT INPUT DATA
WRITE (6,2001)
WRITE 6,2002 (TITLE(I),I=1,18)
WRITE (6,2003)
IF(IMAX.LE.1) GOTO 6
WRITE (6,2004)
GO TO 7
WRITE (6,2005)
CONTINUE
WRITE (6,2013) NZETA,NEXC,IMAX,IPRINT,INDL,IPRINT,INDL,KT
WRITE (6,2014) N=1
DO 8,K=1,4
WRITE (6,2007)
LABEL(N),LABEL(N+1),LABEL(N+2),XL(K),XL(K+1)
CONTINUE
7 CONTINUE
WRITE (6,2007)
LABEL(N),LABEL(N+1),LABEL(N+2)
CONTINUE
8 CONTINUE
WRITE (6,2007)
LABEL(N),LABEL(N+1),LABEL(N+2),XL(K),XL(K+1)
C CONVERT CONSTANT QUANTITIES
C
CALL FLOW WX)
WXX = WX
KIND=2
PGRK=3.1415926
HS=0.2
ACCG=981.0
CR=1.073.0
ALFAW=1.264*RO/TS
ETA=(14.0+0.1*P)*4.187E+3
FI=POWER/(PGRK*TSL*TSD)
TSAT=SAT(DUMMY)
ROSAT=DENSITE(SAT)
GAMSAT=ROG/ROSAT
DROSG=ROSAT-ROG
DTIN=TSAT-TIN
IF(DTIN.E0.0) GO TO 33
DTIN=15.620957*(FI**0.25)*EXP(-P/61.2414)
BETA=62.748555*EXP(-P-1.0)/61.3497
GO TO 34
33 DTSAT=145.7*(FI**0.5)*EXP(-P/87.89)
BETA=145.7*EXP(-P/87.89)*FI**0.25
CONTINUE
34 CONTINUE
TSCB=TSAT+DTSAT
TCL=TSAT+XTCL
EIN=ENTALP(TIN)
WRITE (6,2030) TSAT,EIN,DTSAT,FI,ETA,BETA
DO IC=1,2
RO(I)=DENSIT(T(I))
CK(I)=CONDIT(I)
CP(I)=CSP(I)
AM(I)=VISCOS(T(I))
CONTINUE
10 CONTINUE
IF (PRINT.NE.0) GO TO 100
WRITE (6,2045)
C START INTERNAL LOOP
C
IF (PRINT.NE.0) GO TO 100
WRITE (6,2045)
CALL PUMP(WX,CC,DPPUMP)
CONTINUE
DO 20 I=1,4
G(I)=WX/4.0 IF(I.EQ.3) G(I)=G(I)/EXCN
CONTINUE

COMPUTE TWIN
REYN(I)=G(I)*0.1*AMU(I)
HIN=ACCA(REYN(I),AMU(I),CP(I),CK(I),TD)
TWIN=TIN+HIN
IF(TWIN.GT.TWSCB) TWIN=TWSCB

COMPUTE TD
V=G(I)/PQ(I)
TD=ETA*F1/V
TD=TSAT-TD

COMPUTE LIQUID TEMPERATURE DISTRIBUTION IN TEST-SECTION
FIN1=TIN
TT(I)=TIN
FORTRAN IV G LEVEL 0, MOD 0  

MAIN

DATE = 67233 15/28/40

0136  BP=FI*DELTAZ/(G(J)+TSO)*4.0
0137  IF(TWIN.LT.TWSCB) GO TO 14
0139  J=1
0136  ZLB=0.0
0140  TSCB=TSCB+TIN
0141  DTSCB=TSAT-TSCB
0142  ROTA=ROA(1)
0143  TB=TIN
0144  IF(TWIN.LT.TDGO) GO TO 49
0146  1=1.0
0146  ZD=0.0
0147  KKK=1
0148  ROTA=ROA(1)
0149  TG=TIN
0150  GO TO 18
0151  49 A=1.0
0152  GO TO 19
0153  16 CONTINUE

ALL LIQUID REGION TEMPERATURES CALCULATION

AL=1.0
0154  DO 40 J=1,NZETA
0155  EOUT1=FINI+BP
0156  TM(J)=EU01-(1.6534+F0+1.5323E-10*(EOUT1**4.42244))
0157  TM(J)=FINI+TM(J)
0158  TM(J)=T(J+1)+T(J+1))/2.0
0159  C1=1.0
0160  C2=CDT(1)
0161  CPZ=CSP(TM(J))
0162  AMUZ=VISCOS(TM(J))
0163  REYNZ=G(J)+D(J)/AMUZ
0164  TWALL=TM(J)+FRAC(AMUZ,CPZ,CKZ,TSO)
0165  IF(TWALL.GE.TWSCB) GO TO 46
0166  40 CONTINUE
0167  GO TO 60

HIGHLY SUBCOOLED LOCAL BOILING REGION TEMPERATURES CALCULATION

A=1
0168  TSCB=TM(J)
0169  DTSCB=TSAT-TSCB
0170  TB=TSCB
0171  ROTA=OENSIT(TSCB)
0172  J=1
0173  ZLB=DELTAZ*(A-0.5)
0174  IF(J1.LE.NZETA) GO TO 19
0175  ZL=TSAT
0176  A=0.0

EURATOM - C.C. ISPRRA - CETIS
SLIGHTLY SUBCOOLED LOCAL BOILING REGION TEMPERATURES CALCULATION

51 B=J
 0188 l=J+1
 0189 ZD=DELTAZ*(B-0.5)
 0190 IF(JL.LE.NZETA) GO TO 18
 0192 ZD=TSLT
 0193 B=0.0
 0194 GO TO 60
 0195 CONTINUE
 0196 Z=ZD
 0197 DD 52, J=J1, NZETA
 0198 EUOTI=EINTI*RP
 0199 Z*=Z+DELTAZ
 0200 XX=PGRK*TSD/(wx*RLANOA*1.0+EPSI)*FI*(Z-ZD)
 0201 EUOTF = EUOT1-EOUTG**xx)/(1.0-xx)
 0202 TI(J+1)=EUOTF-(1.6614*1.5323E-10*EUOTF**4.4229448))
 0203 TM(J)=(TT(J)+TT(J+1))/2.0
 0204 EINT1=EOUT1
 0205 IF(TM(J)-Tsat)52,54,54
 0206 CONTINUE
 0207 ZBB=TSLT
 0208 GO TO 60

BULK BOILING REGION TEMPERATURES AND MEAN DENSITY CALCULATION

54 C=J
 0209 TM(J)=TSAT
 0210 AJ=NZETA-J
 0211 J=J+1
 0212 ZBB=DELTAZ*(C-0.5)
 0213 IF(JL.LE.NZETA) GO TO 35
 0214 C=0.0
 0215 ZBB=TSLT
 0216 GO TO 60
 0217 CONTINUE
 0218 DENT=EOUTG-EOUTFS
ALL LIQUID REGION CALCULATION

60 TOUT = T(MJ)
0230 R0.5 = DENSIT TOUT)
0231 EOUT = EOUT1
0232 IF (IAL_EQ.0,0) GO TO 27
0233 IF (A_GT.0,0) GO TO 61
0234 62 TSCB = TOUT
0235 ROTS = DENSIT (TSCB)
0236 TLR = TSL T
0237 TMM = (TSCB + TIN) / 2.0
0238 ROTM = DENSIT (TMM)
0239 ROSR = (ROS1 + ROTM + ROTB) / 3.0
0240 AMSR = (AMUI + AMSM) / 2.0
0241 AMTR = (AMU2 + AMRR) / 2.0
0242 CCTV = Cin(tscb)
0243 CPSR = (CPI + CPTB) / 2.0
0244 CKTB = CONO TSCB)
0245 CKSR = (CK11 + CKTR) / 2.0
0246 HSR = ACCA REYSR * AMR * CPSR * CKSR * TS0
0247 FISOSR = FISO + SIF (71.0 + ROGTS * 2.0E+4 + 1.0E+5 / REYSR) * 2.0E+4
0248 FISOSR = 1.0 + 2.0E-3 * FII / HSR
0249 DROPSR = (FISOSR * FISSR * G(11) ** 2 * TLR / TSO) / (2.0 * ACCG * AMR)
0250 PFRIC = PFRIC + DROPSR
0251 IF (ILB .LE. 1.0) GO TO 28
0252 IF (ILB .EQ. 0.0) GO TO 190

HIGHLY SUBCOOLED BOILING REGION CALCULATION

0255 T0 = TOUT
0256 TD = TSL T
0257 190 ROTS = DENSIT (TD)
0258 TMB = (TD + TR) / 2.0
0259 ROTA = ROTB + ROTD / 2.0
0260 AMTD = VISCOS (TD)
FORTRAN IV G LEVEL 0, MOD 0

MAIN

DATE = 67233

0261 AMLB=(AMTB+AMTD)/2.0
0262 REYLB=G1*E11/AMLB
0263 FISOLB=5.5E-3*(1.0+(ROGTS*2.0F+4.1.0E+6/REYLB)**4)
0264 IF(KKK.EQ.0) GO TO 770
0265 GAMMAO=RCG/ROT0
0266 PSI0=SLIPR*GAMMAO
0267 PP=1.0/(1.0-ALFAW*(1.0-PSI0))
0268 FFISLB=CR*1.0+PP+PP**2)
0269 GO TO 771
0270 770 FFISAT=19.579*(P**(-0.5931697))*(1.0+0.95868E-7*G(1)**(-0.919337))
0271 FFISLB=1.0+FFISAT-1.0*(TM0-TSCH)/DTSCH
0272 XFSLB=(FFISAT-1.0)*(TD-TSCH)/DTSCH
0273 771 CONTINUE
0274 ZD=Z-DI2
0275 DROPLB=(FISOLB*FFISLB*G1)**2*ZD/TS0/(2.0*ACCG*ROI)
0276 IF(ZD.EQ.ZSLT) GO TO 500
0277 28 IF(F.EQ.0.0) GO TO 29
0278 IF(F.EQ.0.0) GO TO 21
0279 C SLIGHTLY SURCOOLEO BOILING REGION CALCULATION
0280 22 ZB3=ZSLT
0281 21 XBB=PGRK*TS0/(W*W+LANDA*(1.0+EPS1))*F1*(ZBB-ZD)
0282 GAMMAI=ROG/ROI
0283 PSI1=SLIPR*GAMMAI
0284 ALFAABB=XBB/(XBB+PSI1)*(1.0-XBB)
0285 ALFABB=ALFAABB+ALFAW
0286 ALFABB=ALFAABB+ALFAW/2.0
0287 R01=(ROI+R015)/2.0
0288 R01=(ROI+R015)/2.0
0289 XBB=XRBB/2.0
0290 XBB=XBB/(XBB*(1.0-GAMMAI)*GAMMAI)
0291 RMS=R01-XBB*(1.0-R01)
0292 IF(KKK.EQ.0) GO TO 772
0293 PP=1.0/(1.0-ALFAWB*(1.0-PSI1))
0294 RMOLT=CR*(1.0+PP+PP**2)
0295 GO TO 773
0296 772 PP=1.0/(1.0-ALFAWB*(1.0-PSI1))
0297 RMOLT=XFSLB+CR*(1.0+PP+PP**2)
0298 CONTINUE
0299 TM1=(TOUT+TD)/2.0
0300 ZT=ZBB-ZD
0301 CALL DROP(TM3,T3,ROG1,T01,PDR01,FIS1)
0302 IF(ZM1-EQ.0.0) GO TO 400
0303 C BULK BOILING REGION CALCULATION

EURATOM - C. C. R. ISRA - CETIS
C

29 CONTINUE
23 Z2=TSLT-288
   XE=(EOUT-EOUTFS)/(EOUTG-EOUTFS)
   XEX=XE
   RO2=RO(15)
   ALFAE=XE/(XF+PSI)*(1.0-XE)
   ROOUT=(1.0-ALFAE)*RO2+ALFAE*RO
   ALFAM2=(ALFAE+ALFAAR)/2.0
   ROM2=(1.0-ALFAAR)*RO2+ALFAAR*RO
   ALFAEX=ALFAE
   IF(Z2-2.0**HS124,24,25 24 RMOLT2=(COMP1883+COMP1TSLT))/2.0
   GO TO 26
25 CALL COTFS(ZBB,TSLT,HS,RMOLT2)
26 CALL DROPS(TSAT,72,ROAR2,ROAR2,TSD,PSI,ROAR2,PSI2)
400 ROOUT=1.0-ALFABB*RO(5)+ALFAAR*RO
   XEB=Z38
   ALFAEX=ALFABB
   GO TO 500
500 ROOUT=RO(10)
   GO TO 700
600 ROOUT=RO(18)
700 CONTINUE
820 CONTINUE
   ROM=RO(4)
   GO TO 13
   841 CONTINUE
   PST1=ROG/RO(5)*SLIPR
   CALL TRIST(INDL,ROIS,ROM,FSM(4))
  12 CONTINUE
  844 PST1=ROG/RO(5)*SLIPR
   CALL TRIST(INDL,ROIS,ROM,FSM(4))
  12 CONTINUE

AMU(I)=VISCONS(I)
IF(I,GT,3) GO TO 15
RL(I)=DENSIT(I)
15 CONTINUE
13 CONTINUE
DO 30 I=2,4
30 CONTINUE
DATE=67233
IF(INDL.GT.0.AND.I.EQ.4) GO TO 14
FISO(I)=5.5E-3*(1.O+(ROUGL*2.0F+4+1.0E+6/REYN(I))**CR)
14 DPFRIC(I)=FISO(I)*G(I)**2/((2.O*ACCG*RO(I))**2)
PPFRIC=PPFRIC+DPFRIC(I)
30 CONTINUE
DPACC=DP(REOUT)
710 DPELEV=0.0
710 CONTINUE
GO TO 730
C COMPUTE DPELEV ACCORDING TO THE ENERGY CONSERVATION THEOREM
720 CONTINUE
CALL DPFL(Z1,ZL,FITLT,RCMS,ROMR,ROMP,DPELEV)
730 DPMOT=DPPUMP+DPELEV
DO 76 I=1,4
76 CONTINUE
DPPLK(I)=DP(LK(I),I)
50 CONTINUE
IF(TOT=750,800,900)
750 CONTINUE
DPLX(I)=DPLU XFX,ALFAXX,GAMMA,ROOUT)
GO TO 900
800 DPLX(5)=OPPL5(5),5)
900 CONTINUE
DPLX=OPPL5(1)+DPLX(2)+DPLX(3)+DPLX(4)+DPLX(5)
DPRT=DPPUMP+PPFRIC+DPLX
DE=(DPRTPMOT)/DPRT
CALL FLOW(WX)
IF(LEN,GT,0) GO TO 1100
1100 CONTINUE
IF(MINL.LE.1MAX) GO TO 1100
IF=1
WRITE (6,2043)
WRITE (6,2043)
GO TO 1100
1100 CONTINUE
WRITE (6,2043)
GO TO 1100
1180 CONTINUE
IF(IPRINT.NE.O) GO TO 1100
C PRINT RESULTS
WRITE (6,2044) WX,TOUT,DPMOT,DPRT,DPROPS,OPPL5(5),EPISSR,EPISLR,EPILC
C
C
C
C
C
C
C
FORTRAN IV LEVEL 0, MOD 0

MAIN

DATE = 67222

15/28/60

0393 WRITE (6, 2031) WXX
0394 WRITE (6, 2032)
0395 N=6
0396 DO 222, K=2,4
0397 WRITE (6, 2033) LARFL(N), LARFL(N+1), LARFL(N+2), T(K), G(K), REYN(K), F
0398 1150(K)
0399 N=N+3
0400 IF (ICN.EQ.0) GO TO 1251
0401 WRITE (6, 2036) TSCB, TORD, TCSR, AMTB, AMSR, CPTB, CPSR, CKB, CKSR
0402 IF (ICN.EQ.0) GO TO 1252
0403 WRITE (6, 2036) TO, TMLR, TORD, TCSR, AMTB, AMSR, REYL, FISOL, FFISOL
0404 IF (ICN.EQ.0) GO TO 1253
0405 WRITE (6, 2037) ALFAM1, R1, ROM1, FIS1, RMULT1
0406 IF (ICN.EQ.0) GO TO 1260
0407 WRITE (6, 2038) ALFAM2, R02, ROM2, FIS2, RMULT2
0408 CONTINUE
0409 WRITE (6, 2039) WXX
0410 WRITE (6, 2015)
0411 WRITE (6, 2014) WXX
0412 WRITE (6, 2016) TWIN, TSCB, TD, TOUT
0413 WRITE (6, 2017)
0414 WRITE (6, 2018) ZLB, Z0, Z1, Z2
0415 WRITE (6, 2019)
0416 WRITE (6, 2020) IXEX, ALFAE, ALFAE
0417 WRITE (6, 2021)
0418 WRITE (6, 2022)
0419 WRITE (6, 2023) DPPFIC(2), DPPFIC(3), DPPFIC(4), DROPSR, DROPSR, DROPSR
0420 WRITE (6, 2024)
0421 WRITE (6, 2025) (DPLC(I), I=1,5), DPLCT
0422 WRITE (6, 2026) DPPC
0423 WRITE (6, 2028) DPPUMP, DPPLEV
0424 WRITE (6, 2027) DPPM
0425 WRITE (6, 2029) DPMOT
0426 WRITE (6, 2030)
0427 ND 3315 K=1, NRR
0428 NK1=N+1, NRR
0429 NK2=NK+1, NRR
0430 NK3=NK2+1, NRR
0431 NK4=NK3+1, NRR
0432 3315 WRITE (6, 2041) TM(K), TM(NRR1), TM(NRR2), TM(NRR3), TM(NRR4)
0433 IF (ICN.EQ.0) GO TO 3316
0434 NR4=NR4+1
0435 WRITE (6, 2042) (TM(I), I=NR4, NZETA)
0436 CONTINUE
0437 WXX = WXX
0438 IF (ICN.EQ.0) GO TO 100
FORTRAN IV G LEVEL 0, MOD 0       MAIN       DATE = 72233
15/28/49

C
C       READ RESTART DATA IF ANY
C
0439       1200 READ (5,1002) POWER2,TIN2,WMIN,WMAX
0440       IF TIN2 .LE.1250,1250,1262
0441       1262 TIN=TIN2
0442       1250 IF(Power2 .GT.2388)
0443       1280 POWER=POWER2.0.2388
0444       1280 POWER=POWER2
0445       1270 IF(TIN2-Power2)1300,1300,1400
0446       1300 STOP
C
C       INPUT-OUTPUT FORMATS
C
0447       999 FORMAT (1015)
0448       1001 FORMAT (18A4)
0449       1002 FORMAT 6E12.0
0450       2001 FORMAT (1H1,130X,23H * L U P O ** * )
0451       2002 FORMAT (1HO,18A4/)
0452       2003 FORMAT (1HO,17H TYPE OF PROBLEM )
0453       2004 FORMAT (1H+,19X,5H STEADY STATE FLOW RATE AND PRESSURE DROPS CALCULATION)
0454       2005 FORMAT (1H+,19X,5HPRESSION DROPS CALCULATION )
0455       2006 FORMAT (1HO,14H * INPUT DATA //22X,11H LENGTH (CM),13X,13H DIAMETER )
0456       2007 FORMAT (2X,3A4,6X,F11.3,13X,F9.3)
0457       2008 FORMAT (1HO,10H ANGLE )=F10.5,7H (RAD)
0458       2009 FORMAT (1HO,10H PRESSURE,9X,F16.5,12H (KG/CM2)/2X,5HPOWER,13X,F15.5,12H (KW)
0459       2010 FORMAT (1HO,9H TEST SECTION ROUGHNESS COEF. )=3X,F10.6/2X,29H TEST SECTION ROUGHNESS COEF. ,3X,F10.6/2X,7H TEST SECTION ROUGHNESS COEF. ,5X,F10.6
0460       2011 FORMAT (1HO,27H LOCAL PRESSURE LOSS COEFF.,//2X,21H TEST SECTION, EXIT,4X,F10.5/17H TEST SECTION, EXIT,4X,F10.5/)
0461       2012 FORMAT (1HO,11H SLIP RATIO )=F10.5,7H,7HPRESSURE,21X,F10.5/2X,21H SLIP RATIO,1X,F10.5,6H (CM)  1/7X,17HMAT, EVAPORATOR, 21H PLANAR RADIUS AT DETACHMENT,1X,F10.5,11H (KCAL/KG/CM3)/17H TEST SECTION, EXIT,4X,F10.5/17H TEST SECTION, EXIT,4X,F10.5/)
0462       2013 FORMAT (1HO,7H ZETA =I4,2X,6H N FXC =I3,2X,6H MAX =I3,2X,8HIPRINT =I
0463       2014 FORMAT (1HO,10X,39H RESULTS OF CALCULATION FOR FLOW RATE =F10.6,10
1H (KG/SEC)/

```
FORTRAN IV G LEVEL 0, MOD 0  MAIN  DATE = 67233  15/2A/49

0464 2015 FORMAT 4H0* 13H TEMPERATURES,17H (CELSIUS DEG.)
0465 2016 FORMAT 1H0.12H INLET WALL TEMP.,7X,E13.6/2X,12HTEMP. AT 7FB,11X,E
113.6/2X,11HTEMP. AT 78D,11X,E
0466 2017 FORMAT 5H0* 7 TEMPERATURES (CM)
0467 2018 FORMAT(2H0,22H LIQUID FLOW REGION,12X,E13.6/2X,31H HIGHLY SUBC
OLED BOILING REGION,3X,E13.6/2X,33H SLIGHTLY SUBCOOLED BOILING REG
2ION,1X,E13.6/2X,19H BULK BOILING REGION,15X,E13.6/2)
0468 2019 FORMAT (5H0* 7 TEMPERATURE AND VOID FRACTION )
0469 2220 FORMAT(2H0,12H QUALITY,29X,E13.6/2X,2H VOID FRACTION AT THE END OF BULK BOILING,1X,E13.6/2)
0470 2021 FORMAT (5H0* 14H PRESSURE DROP,12H KG/C M**2)
0471 2022 FORMAT(2H0,10H FRICTION)
0472 2023 FORMAT(1H0,9H COLD LEG,21X,E13.6/2X,9H EXCHANGER,20X,E13.6/2X,5H
DROP,1X,E13.6/2)
0473 2024 FORMAT (1H0,8H LOCAL )
0474 2025 FORMAT (1H0,6H INLET, 24X,E13.6/2X,8H COLD LEG, 21X,E13.6/2X,9H
0475 2026 FORMAT (1H0,14H ACCELERATION)
0476 2027 FORMAT (1H0,20H TOTAL PRESSURE DROP,9X,E14.6/2)
0477 2028 FORMAT (1H0,20H FLUID PRESSURE PISP,9X,E14.6/2X,14H ELEVATION HEAD
1.15X,E13.6/2)
0478 2029 FORMAT (1H0,21H TOTAL ELEVATION HEAD,9X,E13.6/2)
0479 2030 FORMAT /// 33H *** CONSTANT QUANTITIES VALUES /// 1H , 5H TSAT,15X
,1H ETA,15X,1H JNL,15X,1H (f)eltas sat, 7X
* ,E13.6/2X,15H INLET FLOW RATE,7X,E13.6/2X,31H (DELTA-T) SAT, 7X
* ,E13.6/2X,10H HEAT FLUX,10X,E13.6/2X,6H ETA,16X,E13.6/2X,5H R
* ETA,15X,E13.6/2)
0480 2031 FORMAT (1H0,4H *** INTERMEDIATE RESULTS FOR FLOW RATE =E13.6,
*2X,8H(KG/SEC))
0481 2032 FORMAT /// 2H3X,1H,14X,4H KFYN,10X,4HFISO/7)
0482 2033 FORMAT /// 2X,14X,1H,4HFISO/7)
0483 2034 FORMAT /// 22H ** ALL LIQUID REGION ///
0484 2035 FORMAT /// 22H ** ALL LIQUID REGION ///
0485 2036 FORMAT /// 3H HIGHLY SUBCOOLED BOILING REGION ///
0486 2037 FORMAT /// 3H HIGHLY SUBCOOLED BOILING REGION ///
```

FORTRAN IV G LEVEL 0, MOD 0  MAIN

DATE = 67233  15/29/40

0487  2038 FORMAT (//,24H RULK BOILING REGION //,13X,E14.7/2
0488  2039 FORMAT (11H RELATIVE ERROR,15X,E13.4)
0489  2040 FORMAT (11H TEST SECTION TEMPERATURES //)
0490  2041 FORMAT (5X,5E15.3)
0491  2042 FORMAT (5X,5E15.3)
0492  2043 FORMAT (11H MAX. ITER. NUMBER HAS BEEN REACHED**)
0493  2044 FORMAT (11H TEST SECTION TEMPERATURES //)
0494  2045 FORMAT (11H,3X,9H RATE,3X,10H EXIT TEMP,4X,9H TAPRES,4X,9H TAPFCS,3X,10H TAPEXIT,2X,9H FISO-SR,2X,9H FISO-BR//)
0495  C  END
SUBROUTINE FLOW(WX)

COMPUTES AT EACH ITERATION STEP THE NEW VALUE OF FLOW RATE
BY USING THE METHOD OF HALVING

DIMENSION W(5), ERR(5)
COMMON/FLOWC/WMIN, WMAX, W, EMAX, MIMI, KIND, ICN

ICN=0
MIMI=MIMI-1
IM=1, 2, KIND
WX=WMAX
DW=(WMAX-WMIN)/0.25
RETURN

2 CONTINUE
IK=MIMI-1
IF (ABS(DE).LE.EMAX) GO TO 100
IF (MIMI.GT.4) GO TO 1
WX=W(IK)
ERR(IK)=DE
WX=WX+.DW
IF (MIMI.LT.6) GO TO 4
DO 4 I=1,4
IF (ERR(I)/ERR(I))=5,4,4
CONTINUE
ICN=1
WRITE (6,1100)
1100 FORMAT (1H1, 2X, 52H* * NC ZERO HAS BEEN FOUND BETWEEN WMIN - WMAX
1 ** */*
WRITE (6,1200) (W(K), ERR(K), K=1,5)
1200 FORMAT (10X,E15.7,5X,E15.7)
3 CONTINUE
RETURN
5 CONTINUE
DW=DW/2.0
WX=W(IK)+DW
F=ERR(I)
RETURN
7 CONTINUE
IF (DE/0.1111, 12, 12
11 DW=-DW/2.0
GO TO 13
12 DW=DW/2.0
WX=W(IK)+DW
* * * * * * * * *
13 FLOW
RETURN
ISN 0046  100 WRITE (6,1000) IK
ISN 0047  1000 FORMAT (1H0,38H* * SOLUTION HAS BEEN OBTAINED IN =,15,2X,10HITE
ISN 0048   ICN=1
ISN 0049   RETURN
ISN 0050   END
SUBROUTINE TRIST(IND, RS, RR, FFRS)

COMPUTES TEMPERATURE DISTRIBUTION AND FRICTION MULTIPLIER IN RISER

WHEN IND = 1

DD (1) = RISER LUMPS NUMER

DD (2) = OVERALL HEAT TRANSFER COEFFICIENT (KCAL/CMS*SEC*DEGR.)

DD (3) = TOTAL SURFACE (CMS*2)

DD (4) = AIR TEMPERATURE (C DEGR.)

COMMON P, G, ROGTS, CR, ACCG, DFPUMP, DELTA, ROGTS, D TM
COMMON TRISTE/1 (5), DD (6) XE, EOUT, EOUTG, EFSAT, ROGTS, WX, TSAT, PST, ROS

C)

DATA C1, C2, C3/1.6434, 1.5323E-10, 4.422944/

GO TO 110, 20, 10

10 CONTINUE

IND = 2

GAM = ROG/ROS

S = DD (31)/DD (1)

DEN = EOUTG-FFSAT

NUMP = DD (1160.5)

20 CONTINUE

X1 = XE

E1 = EOUT

T1 = TSAT

T2 = T1 - DD (4)*WX

IF (E1 .GT. EFSAT) GO TO 3

X2 = 0.0

RETURN

END

5

XMAS = (X16XP)/2.0

PR1 = (1.0611.0-PST)/PST1 XM

REYN = (4)!/(4)!/VISCOSIT

PR1 = PR1**.5-SE**(1.060.0651.0666/REYN)**CR

ALFAM = XM/(XM16PST)*1.0-XM)

RRS = 1.0-ALFAM*PST1ALFAM*ROG

XMV = XM/(1.0-CR) &GAM

RRS = ROGTS-XMV*PST1-ROG)

GO TO 4
ISN 0041
2 CONTINUE
X2=(E2-IFSAT)/DFN
ISN 0042
T2=TSAT
ISN 0043
GO TO 5
ISN 0044
3 CONTINUE
T2=EL-(C1SC2*EL*C3))
ISN 0045
RRS=DENSIT(T2)
ISN 0046
RRR=RRS
ISN 0047
REYN=G(4)*D(4)/VISCCS(T2)
ISN 0048
FRIII=5.5E-3*(1.06*(REUGL*2.0+64.1.066/REYN)**CR)
ISN 0049
4 CONTINUE
T2=T2
ISN 0050
X1=X2
ISN 0051
E1=E2
ISN 0052
E2=E2
ISN 0053
T2M=T2M&T2
ISN 0054
RS=RS&RRS
ISN 0055
RR=RR&RR
ISN 0056
1 CONTINUE
T(4)=T2M/DD(1)
ISN 0057
RS=RS/DD(1)
ISN 0058
RR=RR/DD(1)
ISN 0059
DO 30 K=1,NLUMP
ISN 0060
FFRS=FFRS&FP K)
ISN 0061
30 CONTINUE
ISN 0062
FFRS=FFRS/DD(1)
ISN 0063
END
ISN 0064
RETURN
ISN 0065
END
REAL FUNCTION VISCOS(T)

FUNCTION VISCOS(T)
COMPUTES VISCOSITY OF LIQUID WATER AS A FUNCTION OF PRESSURE, P
AND TEMPERATURE, T
P IN UNITS (KG/CM**2)
T IN UNITS (CELSIUS DEG.)
VISCOS IN UNITS (KG*SEC/CM**2)

COMMON P
DIMENSION R(4)
DATA B /4.0794E63,1.650E-6,1.369E-8,2.731E-8/
AMUO=1.0/(1.120.062.1482*(T-8.435)**3(0)**(1.0-8.435)**2))
TA=0.435*T
VISCOS=AMUO*10.0**((B(2)*P/T)&B(3)+P&LOG10(TA))&1.0E-3
RETURN
END
REAL FUNCTION DENSIT(T)

FUNCTION DENSIT(T) COMPUTES DENSITY OF LIQUID WATER AS A FUNCTION OF PRESSURE, P AND TEMPERATURE, T IN UNITS (KG/CM**3) DENSIT IN UNITS (KG/CM**3)

COMMON P
DIMENSION C(15)
DATA C /3.122199E+8,1.995850E+5,1.367926E+16,1.500795E+0

1.2.9411764E-1,1.130706E-4,9.949927E-5,5.27134E-17.241145E-5,7.6
278621E-11.052358E-11.131026E+11.5108E-9,6.241398E+1.19991E+3

SIGMA=P/225.65
TAU=(T6273.16)/647.3
ETAU=TAU**2
UTAU=3.7*ETU-C(1)*STAU-C(2)/ETAU

DENSIT=1.0/P
END
REAL FUNCTION SAT(DUMMY)

FUNCTION SAT
COMPUTES SATURATION TEMPERATURE OF WATER AS A FUNCTION
OF PRESSURE, P
P IN UNITS (KG/CM**2)
SAT IN UNITS (CELSIUS DEG.)

DIMENSION P(6)
DATA E /7.4978413E00,-1.9590182E-2,1.1430815E-4,-4.12447E-7,-6.44995E-11/,FE/175.2781/

DO 1 I=1,6
    SAT=SAT&IE**I
1 CONTINUE
RETURN
END
REAL FUNCTION COND(T)

COMPUTES THERMAL CONDUCTIVITY OF LIQUID WATER AS A FUNCTION OF PRESSURE, \( P \) AND TEMPERATURE, \( T \)

\( P \) IN UNITS (KG/CM**2)
\( T \) IN UNITS (CELSIUS DEGREES)
\( \text{COND} \) IN UNITS (KCAL/SEC*CM*Celsius Degrees)

COMMON \( P \)

DIMENSION \( A(5,6) \)

DATA \( A(5,6) \) /1.6806856E-6,-2.450802E-8,1.5679544E-10,
2E-11,-6.5034530E-14,1.0285662E-13,1.0325614E-10,1.012641E-11,1.0,
3.871537E-13,9.677572E-16,1.545972E-19,6.015828E-13,8.011722E-13,
4.413140626E-16,4.496890E-19,1.0494531E-20,6.123041E-21,6.5432,
5.297E-19,3.9380525E-19,1.9851484E-20,3.2506926E-21,1.0776626E-18,
6.5778136E-19,-4.3069694E-21,2.274953E-23,-3.6928275E-26/

\( \text{COND}=0.0 \)

DO 1 \( I=1,6 \)

CAPP=1 \( I=I-1 \)

CONTINUE

\( \text{COND}=\text{COND}+\text{CAPP}\times T**IE \)

GO TO 1

RETURN

END
REAL FUNCTION CSP(T)

FUNCTION CSP(T)
END

COMPUTES HEAT SPECIFIC CAPACITY OF WATER AS A FUNCTION
OF PRESSURE, P AND TEMPERATURE, T

IN UNITS (KG/CM**2)

IN UNITS (CELSIUS DEGREES)

IN UNITS (KCAL/KG*OEGR.)

DATA F /-1.969097E00,0.9961839E00,-2.01786L1E1,5.340
19602E61,-6.276714E61,4.5989995E61,-1.92997333E61,1.534097646F-6,
27443985E-5,1.1991E51,1.238366666E51,7.19965564E51,1.022749E61,1.3425
324E61,1.5007056E00,8.155226748E09,-1.760746E13,-1.304174E60,7
4.58620689E60,9.41066676E60,6.1191876E-17,-0.2961175E00,-7.2411
555E-5,0.0537154E50,0.7676621E60,6.14129685E60,6.0909595E60,1.752
6358E-11,0.551342E30,1.51835E-76,0

 compiler options - NAME= MAIN,DPT=02,LINFCNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NODEIT,NODT

COMPILER OPTIONS - NAME= MAIN,DPT=02,LINFCNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NODEIT,NODT

ISN 0002

ISN 0003

COMMON P

DIMENSION F(30),C(2)

DATA F /-1.969097E00,0.9961839E00,-2.01786L1E1,5.340
19602E61,-6.276714E61,4.5989995E61,-1.92997333E61,1.534097646F-6,
27443985E-5,1.1991E51,1.238366666E51,7.19965564E51,1.022749E61,1.3425
324E61,1.5007056E00,8.155226748E09,-1.760746E13,-1.304174E60,7
4.58620689E60,9.41066676E60,6.1191876E-17,-0.2961175E00,-7.2411
555E-5,0.0537154E50,0.7676621E60,6.14129685E60,6.0909595E60,1.752
6358E-11,0.551342E30,1.51835E-76,0

7/FDF1,7211567E-1/

ISN 0006

SIGMA=P/225.65

ISN 0007

TAU=(T-273.16)/647.3

ISN 0008

ETAU=TAU**4

ISN 0009

DTAU=TAU**10

ISN 0010

PTAU=TAU**11

ISN 0011

UTAU=3.7E8-(C(1)*STAU-C(2))/ETAU

ISN 0012

W=UTAU*SIGN(1.72*UTAU)**26*(F(14)*(SIGMA-F(15))*TAU))

ISN 0013

VTAU=F 91*STAU**2/ETAU

ISN 0014

SIGMAFF

ISN 0015

DO 1 I= 1, 8

J=I

SIGMAI=SIGMAI*(F(1)**(I))

CONTINUE

ISN 0016

DO I=1,8

IF=I

ISN 0017

ISN 0018

SIGMAI=SIGMAI*(F(1)**(I))

1 CONTINUE

ISN 0019

1 CONTINUE

ISN 0020

DUTAU=F(4)*TAU**(-7)

ISN 0021

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0022

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0023

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0024

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0025

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0026

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0027

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0028

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0029

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

ISN 0030

DUTAU=F(11)*TAU-F(12)*TAU**(-7)

CSPE=F(16)*F(17)*W**2+F(21)*W**2+F(22)*CSLA&SIGMA*CSPL1*SIGMA1*OEGR

CSPE=F(16)*F(17)*W**2+F(21)*W**2+F(22)*CSLA&SIGMA*CSPL1*SIGMA1*OEGR
REAL FUNCTION ENTPH(T)

FUNCTION ENTPH(T)
COMPUTES ENTHALPY OF LIQUID AS A FUNCTION OF PRESSURE, P
AND TEMPERATURE, T
ENTPH IN UNITS (KCAL/KG)

COMMON P
DIMENSION C(4)
DATA C/-9.941553E3,1.1141047E5,-6.367257E5,2.16643

DATA D/-4.721840E6,9.01440171E6,6.76171126E6,4.25359285E6,-1.56
20709956,7.54919393E6,5.285356E6,6.1191876E-17,3.2941179E0,5.38
320649E-1,4.14666667E-1,1.0226848E-1,1.139706E-4,6.244398E6,1.19
49910E5,6.637514E6,0.741165E-5,0.7676621E0002,1.05135AF-14,1.1
509E-5,6.54346E07,6.3.122199E08,1.399585E05,1.361292E6,
614.9857E6000/7

SIGMA=P/225.65

TAU=(T&973.16)/647.3

STAU=TAU**12

PTAU=TAU**11

UTAU=C(3)*STAU-C(1)*STAU-C(2)/ETAU

VTAU=C(18)*STAU+C(19)/ETAU

SIGMA=C(3)*STAU*2+C(18)*STAU**2+C(19)*STAU

SIGMA=1

DO 1 I=1,9

I=I+1

ITAU=TAU

I=I+1

CONTINUE

1 CONTINUE

11=0

II=0

WHILE

I=I+1

RETURN

END
SUBROUTINE COTES(XA, XB, HS, TCT)

SUBROUTINE COTES

COTES - SIMPSON INTEGRATION SUBROUTINE

TOT=0.0
NL=ABS(XB-XA)/HS
NSTEP=NL+1
STEP=NSTEP
HSTEP=ABS(XB-XA)/STEP
N3=NSTEP/3
N4=NSTEP-3*N3
X=XA
A=1.0*HSTEP/8.0
DELTA=HSTEP
FY=COMP(X)
DO 1 I=1, N3
  SUM=FY
  DO 2 K=1, 3
    SUM=SUM+FY
  2 CONTINUE
  ENT=A*SUM
  TOT=TOT+ENT
  1 CONTINUE
  IF(N4)<10,10,5
  HSTEP=ABS(XB-X)/2.0
  A=HSTEP/3.0
  DELTA=HSTEP
  SUM=FY
  DO 7 I=1,2
    X=X+DELTA
    FY=COMP(X)
    GO TO (9,8), I
  7 CONTINUE
  SUM=SUM+FY
  GO TO 2
  8 SUM=SUM+FY
  GO TO 7
  9 SUM=SUM+FY*4.0
  7 CONTINUE
  ENT=A*SUM
  TOT=TOT+ENT
  10 RETURN
END
REAL FUNCTION COMP(Z)

FUNCTION CEMP(?) COMPUTES LOCAL VALUE OF THE TWO-PHASE MULTIPLIED ACCORDING TO LOTZES-FLINN CORRELATION

DIMENSION XL(4)
COMMON /DAT1/PSI1,HFI,XF
COMMON /DAT3/XL,Z18,ZD,RSR,RDLB
EQUALENCE (XL(1),TSLT)
COMP=1.0*PSI1/(PS11*(XF-HFI*(TSLT-Z1)))**2
RETURN
END
REAL FUNCTION DP(ROUT)

FUNCTION DP

COMPUTES THE ACCELERATION PRESSURE DROP AROUND THE LOOP

ACCORDING TO EQUATION(13)

COMMON P.G,RODUCT,CR,ACCG,OPPUMP,DELTA,R

COMMON/DATE/0,EXCN,HR

DIMENSION C(4),R(4),P(4)

EQUIVALENCE(D(1),ISD1),(P(2),C(1)),(P(3),EXP),(P(4),RID)

OP= 1.0/RODUCT-1.0/RU(7)**1.0-1.0/EXCN**2*(TSO/EXP)**4*{EXCN**2-1.}

10/EXCN**2*(TSO/RID)**4*G(1)**2/(2.0*ACCG)

RETURN

END
SUBROUTINE PUMP(W,C,DPPUMP)
  C
  SUBROUTINE PUMP(W,C,DPPUMP)
  C COMPUTES THE FLOW RATE, W, OF A PUMP AS A FUNCTION OF
  C \( W \) IN UNITS (KG/SEC) AND \( DPPUMP \) IN UNITS (KG/CM**2)
  C
  DIMENSION C(6)
  DPPUMP=C(6)*W
  DO 1 I=1,6
    1 DPPUMP=DPPUMP*C(I-1)*W
  DPPUMP=DPPUMP*C(I)
  RETURN
END
REAL FUNCTION ACCA(RE,RMU,BCP,BK,RO)

FUNCTION ACCA COMPUTES HEAT TRANSFER COEFFICIENT BETWEEN THE WALL AND THE LIQUID
AS A FUNCTION OF REYNOLDS NUMBER(REYN), VISCOSITY(RMU), HEAT SPECIFIC CAPACITY(CP), CONDUCTIVITY(CK), DIAMETER(TOD)

P IN UNITS (KG/CM**2)
T IN UNITS (CELSIUS DEG.F)
ACCA IN UNITS (KCAL/SEC*CM**2*CELSIUS DEG.F)

DATA AA/0.33333333/,BB/2.3E-2/
PRAND=RMU*BCP/BK
ACCA=BB*BK/BD*(RE**0.8)*(PRAND)**AA
RETURN
END
REAL FUNCTION DPL(BR, I)

FUNCTION DPL
COMPUTES SINGLE PHASE LOCAL PRESSURE DROP AT THE EXIT
ACCORDING TO EQUATION (30)

DIMENSION G(4), RO(5)

COMMON P, G, ROGTS, CR, ACCG, DPPUMP, DELTA, RO

I = 1

GO TO (1, I + 1, 2, I)

DPL = BR * G(1) ** 2 / (2.0 * ACCG * RO(I))

RETURN

END
COMPILER OPTIONS - NAME = MAIN,OPT=0?,LINECNT=53,SOURCE,REDO,NOEDIT,MAP,NOEDIT,NOID

ISN 0002
C SUBROUTINE DPP(TX,ZL,R,RO,C,PO,FIS)
C SUBROUTINE DPP
C COMPUTES TWO PHASE PRESSURE DPP

ISN 0003
COMMON R,G,ROUGTS,CR,ACCG

ISN 0004
DIMENSION C(4)

ISN 0005
DEF=G(1)*G(1)/VISCOS(TX)

ISN 0006
FIS=5.5E-3*(1.0G(1)+2.0G(1)+DEF/G(1)+DEF/DEF)**CR

ISN 0007
PO=P*FIS*ZL*(G(1)**2)/(2.0*PO*ACCG*D)

ISN 0008
RETURN

ISN 0009
END
REAL FUNCTION DPLU(X,ALFA,GAMMA,ROT)

FUNCTION DPLU

COMPUTES EXIT LOCAL PRESSURE DROP ACCORDING TO EQUATION(31)

DIMENSION G(4),RO(5),D(4)

COMMON P,G,ROUTS,CR,ACCG,OPPUMP,DELTA,RO

EQUIVALENCE (D(1),I50),(D(2),CLD),(D(3),EXD),(D(4),RI0)

DPLU=2*(ALFA*GAMMA*(1.0-X)**2/CR)**2/(1.0-ALFA)**5.0)**2/(2.0*ACCG

RETURN

END
SUBROUTINE DPEL(Z0, Z1, Z2, FITLT, ROMB, ROMR, DPELEV)

COMMON P, G, POUTS, CR, ACCG, DPPUMP, DELTA, RO

DIMENSION XO(5), XL(4), GT(4)

DPEL = RO(2) * (XL(4) & XL(1) & FITLT)

IF (Z2 .EQ. 0.0) GO TO 1

DP2 = DP1 & FIT & Z2 & ROMB
FIT = 0.0

1  IF (Z1 .EQ. 0.0) GO TO 2

DP2 = DP1 & FIT & Z1 & ROMR
FIT = 0.0

2  DP2 = DP2 & ZLR & RO2R & Z0 & ROM & ROM & DPELEV = IDPEL - DP2 & SIN(DELTA) RETURN
END
### CONTROL SECTION

<table>
<thead>
<tr>
<th>NAME</th>
<th>ORIGIN</th>
<th>LENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>IHCFRXPR</td>
<td>0C</td>
<td>D4</td>
</tr>
<tr>
<td>IHCFXP</td>
<td>0E</td>
<td>00</td>
</tr>
<tr>
<td>IHCSXP</td>
<td>1A8</td>
<td>11E</td>
</tr>
<tr>
<td>IHCSQRT</td>
<td>2C1</td>
<td>4C</td>
</tr>
<tr>
<td>IHCSLOG</td>
<td>370</td>
<td>10C</td>
</tr>
<tr>
<td>IHCFRXPI</td>
<td>480</td>
<td>94</td>
</tr>
<tr>
<td>IHCSSCN</td>
<td>620</td>
<td>104</td>
</tr>
<tr>
<td>IHCUOPT</td>
<td>620</td>
<td>6</td>
</tr>
<tr>
<td>IHCTHCH</td>
<td>610</td>
<td>258</td>
</tr>
<tr>
<td>IHCELLOG</td>
<td>888</td>
<td>172</td>
</tr>
<tr>
<td>IHCLEXP</td>
<td>800</td>
<td>1CC</td>
</tr>
<tr>
<td>IHCUATB</td>
<td>80D</td>
<td>638</td>
</tr>
<tr>
<td>MAIN</td>
<td>120D</td>
<td>44DC</td>
</tr>
</tbody>
</table>

### ENTRY

<table>
<thead>
<tr>
<th>NAME</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRXPR=</td>
<td>00</td>
</tr>
<tr>
<td>FDFXP=</td>
<td>08</td>
</tr>
<tr>
<td>EXP</td>
<td>1A8</td>
</tr>
<tr>
<td>SRT</td>
<td>2C8</td>
</tr>
<tr>
<td>ALOGIO</td>
<td>370</td>
</tr>
<tr>
<td>ALOG</td>
<td>394</td>
</tr>
<tr>
<td>FRXPI=</td>
<td>488</td>
</tr>
<tr>
<td>COS</td>
<td>520</td>
</tr>
<tr>
<td>SIN</td>
<td>530</td>
</tr>
<tr>
<td>DLOGIO</td>
<td>888</td>
</tr>
<tr>
<td>DLOG</td>
<td>8A4</td>
</tr>
<tr>
<td>DEXP=</td>
<td>A00</td>
</tr>
<tr>
<td>MAIN</td>
<td>120D</td>
</tr>
<tr>
<td>VISCOS</td>
<td>56E8</td>
</tr>
<tr>
<td>DENSIT</td>
<td>58D0</td>
</tr>
<tr>
<td>SAT</td>
<td>58F0</td>
</tr>
<tr>
<td>COND</td>
<td>5980</td>
</tr>
<tr>
<td>CSP</td>
<td>6048</td>
</tr>
<tr>
<td>CSP</td>
<td>61E0</td>
</tr>
<tr>
<td>ENTALP</td>
<td>6738</td>
</tr>
<tr>
<td>FLOW</td>
<td>6B0C</td>
</tr>
<tr>
<td>TRIST</td>
<td>6F9C</td>
</tr>
<tr>
<td>COTES</td>
<td>769C</td>
</tr>
<tr>
<td>COMP</td>
<td>7A18</td>
</tr>
<tr>
<td>PUMP</td>
<td>7B48</td>
</tr>
<tr>
<td>NAME</td>
<td>ORIGIN</td>
</tr>
<tr>
<td>------------</td>
<td>--------</td>
</tr>
<tr>
<td>ACCA</td>
<td>7C20</td>
</tr>
<tr>
<td>DPL</td>
<td>7DF0</td>
</tr>
<tr>
<td>DROP</td>
<td>7F88</td>
</tr>
<tr>
<td>DPLU</td>
<td>81C8</td>
</tr>
<tr>
<td>DPEL</td>
<td>8370</td>
</tr>
<tr>
<td>DP</td>
<td>861C</td>
</tr>
<tr>
<td>IHCFCOMH*</td>
<td>87AC</td>
</tr>
<tr>
<td>IHCFCVTH*</td>
<td>97AC</td>
</tr>
<tr>
<td>IHCFIOSH*</td>
<td>A798</td>
</tr>
<tr>
<td>$BLANKCOM</td>
<td>B490</td>
</tr>
<tr>
<td>DAT1</td>
<td>B400</td>
</tr>
<tr>
<td>DAT2</td>
<td>B480</td>
</tr>
<tr>
<td>DAT3</td>
<td>B4F8</td>
</tr>
<tr>
<td>FLOWC</td>
<td>B518</td>
</tr>
<tr>
<td>TRISTE</td>
<td>B530</td>
</tr>
</tbody>
</table>

ENTRY ADDRESS 12C8
TOTAL LENGTH 858C
<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>SAMPLE</th>
<th>INPUT</th>
<th>DATE 8/22/1967</th>
<th>PAGE 1 OF LUPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

**DATA (Zones de 6 colonnes)**

A TEST CASE FOR LUPO, NATURAL CIRCULATION (8TH, 22, 1967)

```
<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>6</td>
<td>200</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>60.0</td>
<td>0.005</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200.0</td>
<td>4944.0</td>
<td>644.0</td>
<td>1042.0</td>
<td>32.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>5.0</td>
<td>2.0</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0002</td>
<td>0.00005</td>
<td>1.5</td>
<td>1.5308</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.66</td>
<td>0.09</td>
<td>373.4</td>
<td>0.00003</td>
<td>286.4</td>
<td>659.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.33</td>
<td>2.7</td>
<td>0.0</td>
<td>2.3</td>
<td>0.684</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.0</td>
<td>1.5-2</td>
<td>20000.0</td>
<td>30.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120.0</td>
<td>80.0</td>
<td>0.180</td>
<td>0.200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150.0</td>
<td>0.190</td>
<td>0.220</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

BLANK
### TEST CASE FOR LUPO, NATURAL CIRCULATION (3TH, 27, 1967)

**TYPE OF PROBLEM**: STEADY STATE FLOW RATE AND PRESSURE DROPS CALCULATION

**NZETA = 200**  **NEXC = 6**  **IMAX = 20**  **PRINT = 0**  **INOL = 1**  **TOT = 0**  **KKK = 0**

**INPUT DATA**

<table>
<thead>
<tr>
<th>TEST SECTION</th>
<th>LENGTH (CM)</th>
<th>DIAMETER (CM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLD LEG</td>
<td>194,000</td>
<td>5,000</td>
</tr>
<tr>
<td>EXCHANGER</td>
<td>14,000</td>
<td>2,000</td>
</tr>
<tr>
<td>RISER</td>
<td>101,200</td>
<td>4,000</td>
</tr>
</tbody>
</table>

**ANGLE** = 1.5708 (RAD)

- **PRESSURE**: 60.00000 (KG/CM**2**)
- **POWER**: 120.00000 (KW)
- **INLET TEMPERATURE**: 80.0000 (CELSIUS DEGR.)
- **MIN. FLOW**: 0.15000 (KG/SEC)
- **MAX. FLOW**: 0.20000 (KG/SEC)

**TEST SECTION ROUGHNESS COEF.**: 0.000200

**LOOP PIPES ROUGHNESS COEF.**: 0.000950

**LOCAL PRESSURE LOSS COEFF.**

- **K-TEST SECT. ENTRANCE**: 0.33000
- **K-COLD LEG**: 2.70000
- **K-EXCHANGER**: 0.0
- **K-RISER**: 2.30000
- **K-TEST SECT. EXIT**: 0.68100
- **BK-TEST SECT. EXIT**: 0.60420

**SLIP RATIO**: 1.50000

**EPSILON**: 1.56000

**BUBBLE RADIUS AT DETACHMENT**: 0.09000 (CM)

**HEAT EVAPORATION**: 373.89990 (KCAL/KG)

**STEAM DENSITY**: 0.00003 (KG/CM**3**)

**DELTAT**: 4.00000 (CELSIUS DEGR.)

**DELTATRIS**: 0.00000 (CELSIUS DEGR.)

**SATURATED WATER ENTHALPY**: 286.09985 (KCAL/KG)

**STEAM ENTHALPY**: 659.50000 (KCAL/KG)

*** CONSTANT QUANTITIES VALUES ***

<table>
<thead>
<tr>
<th>TSAT</th>
<th>HEAT FLUX</th>
<th>BETAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.74209E+02</td>
<td>4.56074F-02</td>
<td>8.37398E+04</td>
</tr>
<tr>
<td>6.11378E+01</td>
<td>1.57216E+01</td>
<td>3.40202E+01</td>
</tr>
<tr>
<td>(DELTA-T)SAT</td>
<td>INLET ENTHALPY</td>
<td>BETA</td>
</tr>
</tbody>
</table>

---

**EUROATOM - C. C. R. ISRA - CETIS**
<table>
<thead>
<tr>
<th>FLOW RATE</th>
<th>EXIT TEMP</th>
<th>DELTAPMOT</th>
<th>DELTAPRES</th>
<th>DELTAPETS</th>
<th>DELTAPEXIT</th>
<th>F/FISO-SP</th>
<th>F/FISO-HS</th>
<th>F/FISO-SS</th>
<th>F/FISO-AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.200000</td>
<td>218.587</td>
<td>0.14249E+00</td>
<td>0.15484E+00</td>
<td>0.11021E+00</td>
<td>0.25632E-01</td>
<td>0.81600</td>
<td>1.03674</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.195000</td>
<td>221.965</td>
<td>0.14779E+00</td>
<td>0.14881E+00</td>
<td>0.10605E+00</td>
<td>0.25449E-01</td>
<td>0.81257</td>
<td>1.08916</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.190000</td>
<td>225.510</td>
<td>0.15242E+00</td>
<td>0.14324E+00</td>
<td>0.10230E+00</td>
<td>0.24295E-01</td>
<td>0.80822</td>
<td>1.14263</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.185000</td>
<td>229.221</td>
<td>0.15788E+00</td>
<td>0.13846E+00</td>
<td>0.99294E-01</td>
<td>0.23170E-01</td>
<td>0.80371</td>
<td>1.20261</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.180000</td>
<td>233.117</td>
<td>0.16375E+00</td>
<td>0.13392E+00</td>
<td>0.96482E-01</td>
<td>0.22077E-01</td>
<td>0.79923</td>
<td>1.25789</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.192500</td>
<td>223.717</td>
<td>0.14981E+00</td>
<td>0.14603E+00</td>
<td>0.10418E+00</td>
<td>0.24868E-01</td>
<td>0.81011</td>
<td>1.11885</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.193750</td>
<td>222.836</td>
<td>0.14854E+00</td>
<td>0.14737E+00</td>
<td>0.10507E+00</td>
<td>0.25157E-01</td>
<td>0.81110</td>
<td>1.10401</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**SOLUTION HAS BEEN OBTAINED IN = 8 ITERATIONS**
** Intermediate Results for Flow Rate = 0.104375 (kg/sec)**

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>G</th>
<th>REYN</th>
<th>FISO</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLD LEG</td>
<td>8.400000E+01</td>
<td>9.899426E-01</td>
<td>1.458075E+01</td>
<td>2.812200E-01</td>
</tr>
<tr>
<td>EXCHANGER</td>
<td>1.526435E+01</td>
<td>1.031190E+02</td>
<td>1.144377E+01</td>
<td>2.099069E-02</td>
</tr>
<tr>
<td>RISER</td>
<td>2.213072E+02</td>
<td>9.899426E-03</td>
<td>4.125477E+01</td>
<td>2.163212E-02</td>
</tr>
</tbody>
</table>

* All Liquid Region

<table>
<thead>
<tr>
<th></th>
<th>TSC(TSC)</th>
<th>RO-MEAN</th>
<th>MU(TSC)</th>
<th>MU-MEAN</th>
<th>CP(TSC)</th>
<th>CP-MEAN</th>
<th>K(TSC)</th>
<th>K-MEAN</th>
<th>REYN-MEAN</th>
<th>H-MEAN</th>
<th>F/FISO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>213.53088E+01</td>
<td>0.8514938E+01</td>
<td>0.1267475E+00</td>
<td>0.1099243E+01</td>
<td>0.1571943E+05</td>
<td>0.102621E+06</td>
<td>0.4746189E-03</td>
<td>0.1866737E-01</td>
<td>0.8120655E-00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Highly Supersaturated Boiling Region

<table>
<thead>
<tr>
<th></th>
<th>T-MEAN</th>
<th>RO-TD(M)</th>
<th>RO-MEAN</th>
<th>RD(TD)</th>
<th>MU(TD)</th>
<th>MU-MEAN</th>
<th>REYN-MEAN</th>
<th>F/FISO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>222.39268E+01</td>
<td>0.8401394E+03</td>
<td>0.1193062E+05</td>
<td>0.2029125E+06</td>
<td>0.1691100E-01</td>
<td>0.1096585E-00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**HIGHLY SUPERCOOLED BOILING REGION**
# Results of Calculation for Flow Rate = 0.194375 (kg/sec)

## Temperatures (Celsius Degr.)

<table>
<thead>
<tr>
<th>Description</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Wall Temp.</td>
<td>0.205970E+03</td>
</tr>
<tr>
<td>Temp. at ZLB</td>
<td>0.213531E+03</td>
</tr>
<tr>
<td>Temp. at ZD</td>
<td>0.222400E+03</td>
</tr>
<tr>
<td>Outlet Temp.</td>
<td>0.222400E+03</td>
</tr>
</tbody>
</table>

## Lengths (cm)

<table>
<thead>
<tr>
<th>Region</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Liquid Flow Region</td>
<td>0.186500E+03</td>
</tr>
<tr>
<td>Highly Subcooled Boiling Region</td>
<td>0.139000E+02</td>
</tr>
<tr>
<td>Slightly Subcooled Boiling Region</td>
<td>0.0</td>
</tr>
<tr>
<td>Bulk Boiling Region</td>
<td>0.0</td>
</tr>
</tbody>
</table>

## Quality and Void Fraction

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit Quality</td>
<td>0.0</td>
</tr>
<tr>
<td>Void Fraction at ZLB</td>
<td>0.0</td>
</tr>
<tr>
<td>Void Fraction at the End of Bulk Boiling</td>
<td>0.0</td>
</tr>
</tbody>
</table>

## Pressure Drops (kg/cm²)

### Friction

<table>
<thead>
<tr>
<th>Region</th>
<th>Pressure Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Leg</td>
<td>0.553391E-03</td>
</tr>
<tr>
<td>Exchanger</td>
<td>0.544179E-03</td>
</tr>
<tr>
<td>Riser</td>
<td>0.259947E-03</td>
</tr>
<tr>
<td>All Liquid Region</td>
<td>0.963386E-01</td>
</tr>
<tr>
<td>Highly Subcooled Region</td>
<td>0.223964E-02</td>
</tr>
<tr>
<td>Slightly Subcooled Region</td>
<td>0.0</td>
</tr>
<tr>
<td>Bulk Boiling Region</td>
<td>0.0</td>
</tr>
<tr>
<td>Total Friction Pressure Drop</td>
<td>0.106936E+00</td>
</tr>
</tbody>
</table>

### Local

<table>
<thead>
<tr>
<th>Region</th>
<th>Pressure Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td>0.105749E-01</td>
</tr>
<tr>
<td>Cold Leg</td>
<td>0.138796E-03</td>
</tr>
<tr>
<td>Exchanger</td>
<td>0.0</td>
</tr>
<tr>
<td>Riser</td>
<td>0.136501E-03</td>
</tr>
<tr>
<td>Outlet</td>
<td>0.255026E-01</td>
</tr>
<tr>
<td>Total Local Pressure Drop</td>
<td>0.361528E-01</td>
</tr>
</tbody>
</table>

### Acceleration

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>0.502542E-02</td>
</tr>
</tbody>
</table>

### Fluid Pressure Rise

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid Pressure Rise</td>
<td>0.0</td>
</tr>
<tr>
<td>Elevation Head</td>
<td>0.147914E+00</td>
</tr>
</tbody>
</table>

### Total Pressure Drop

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Pressure Drop</td>
<td>0.148114E+00</td>
</tr>
</tbody>
</table>

### Total Elevation Head

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Elevation Head</td>
<td>0.147914E+00</td>
</tr>
</tbody>
</table>

### Relative Error

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Error</td>
<td>0.135035E-02</td>
</tr>
<tr>
<td>TFST SECTION TEMPERATURES</td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td></td>
</tr>
<tr>
<td>80.894</td>
<td>109.195</td>
</tr>
<tr>
<td>80.935</td>
<td>109.889</td>
</tr>
<tr>
<td>81.270</td>
<td>110.621</td>
</tr>
<tr>
<td>82.005</td>
<td>111.355</td>
</tr>
<tr>
<td>82.741</td>
<td>112.085</td>
</tr>
<tr>
<td>83.476</td>
<td>112.816</td>
</tr>
<tr>
<td>84.401</td>
<td>113.548</td>
</tr>
<tr>
<td>84.946</td>
<td>114.279</td>
</tr>
<tr>
<td>85.681</td>
<td>115.010</td>
</tr>
<tr>
<td>86.416</td>
<td>115.742</td>
</tr>
<tr>
<td>87.885</td>
<td>117.203</td>
</tr>
<tr>
<td>88.620</td>
<td>117.934</td>
</tr>
<tr>
<td>89.355</td>
<td>118.665</td>
</tr>
<tr>
<td>90.090</td>
<td>119.395</td>
</tr>
<tr>
<td>90.825</td>
<td>120.125</td>
</tr>
<tr>
<td>91.560</td>
<td>120.855</td>
</tr>
<tr>
<td>92.295</td>
<td>121.586</td>
</tr>
<tr>
<td>93.030</td>
<td>122.316</td>
</tr>
<tr>
<td>93.761</td>
<td>123.045</td>
</tr>
<tr>
<td>94.495</td>
<td>123.774</td>
</tr>
<tr>
<td>95.220</td>
<td>124.504</td>
</tr>
<tr>
<td>95.953</td>
<td>125.233</td>
</tr>
<tr>
<td>96.686</td>
<td>125.962</td>
</tr>
<tr>
<td>97.430</td>
<td>126.691</td>
</tr>
<tr>
<td>98.164</td>
<td>127.420</td>
</tr>
<tr>
<td>98.897</td>
<td>128.148</td>
</tr>
<tr>
<td>99.631</td>
<td>128.877</td>
</tr>
<tr>
<td>100.364</td>
<td>129.606</td>
</tr>
<tr>
<td>101.098</td>
<td>130.333</td>
</tr>
<tr>
<td>101.831</td>
<td>131.061</td>
</tr>
<tr>
<td>102.564</td>
<td>131.788</td>
</tr>
<tr>
<td>103.297</td>
<td>132.516</td>
</tr>
<tr>
<td>104.030</td>
<td>133.243</td>
</tr>
<tr>
<td>104.763</td>
<td>133.970</td>
</tr>
<tr>
<td>105.495</td>
<td>134.698</td>
</tr>
<tr>
<td>106.228</td>
<td>135.424</td>
</tr>
<tr>
<td>106.961</td>
<td>136.151</td>
</tr>
<tr>
<td>107.693</td>
<td>136.877</td>
</tr>
<tr>
<td>108.425</td>
<td>137.604</td>
</tr>
</tbody>
</table>
** *** LUPN ***

** TEST CASE FOR LUPN, NATURAL CIRCULATION (3TH, 22, 1967) **

** TYPE OF PROBLEM **
STEADY STATE FLOW RATE AND PRESSURE DROPS CALCULATION

NZETA = 200 NEXC = 6 IMAX = 20 IPRINT = 0 IND = 2 IDT = 0 KKK = 0

** * INPUT DATA * *

<table>
<thead>
<tr>
<th>LENGTH (CM)</th>
<th>DIAMETER (CM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST SECTION</td>
<td>200.000</td>
</tr>
<tr>
<td>COLD LEG</td>
<td>1914.000</td>
</tr>
<tr>
<td>EXCHANGER</td>
<td>614.000</td>
</tr>
<tr>
<td>RISER</td>
<td>1012.000</td>
</tr>
</tbody>
</table>

ANGLE = 1.57080 (RAD)

PRESSURE = 60.00000 (KG/CM**2)
POWER = 120.00000 (KJ)
INLET TEMPERATURE = 150.00000 (CELSIUS DEG.R.)
MIN. FLOW = 0.190000 (KG/SEC)
MAX. FLOW = 0.220000 (KG/SEC)

TEST SECTION ROUGHNESS COEFF. = 0.000200
LOCOP PIPES ROUGHNESS COEFF. = 0.000050

LOCAL PRESSURE LOSS COEFF.
K-FST SECT. ENTRANCE = 0.330000
K-COLD LEG = 2.700000
K-EXCHANGER = 0.0
K-RISER = 2.300000
K-FST SECT. EXIT = 0.641000
K-RK-TEST SECT. EXIT = 0.604200

SLIP RATIO = 1.50000
EPSILON = 1.66000
RUSHLE RADIUS AT DETACHMENT = 0.090000 (CM)
HEAT EVAPORATION = 373.39980 (KCAL/KG)
STEAM DENSITY = 0.00000 (KG/CM**3)
DELTADEL = 4.50000 (CELSIUS DEG.R.)
DELTADEL = 3.00000 (CELSIUS DEG.R.)
SATURATED WATER ENTHALPY = 286.09985 (KCAL/KG)
SATURATED ENTHALPY = 658.00000 (KCAL/KG)

*** CONSTANT QUANTITIES VALUES ***

<p>| TSAT | 2.747907E 02 |
| INFRT ENTHALPY | 1.519027E 02 |
| DELTA-TSAT | 1.579100E 01 |
| HEAT FLUX | 4.560014E-07 |
| FTA | 8.379938E 04 |
| PFTA | 3.402097E 01 |</p>
<table>
<thead>
<tr>
<th>FLOW RATE</th>
<th>EXIT TEMP.</th>
<th>DELTAPHOT</th>
<th>DELTAPRES</th>
<th>DELTAPETS</th>
<th>DELTAPEXIT</th>
<th>F/FISO-SR</th>
<th>F/FISO-US</th>
<th>F/FISO-SS</th>
<th>F/FISO-AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.220000</td>
<td>266.416</td>
<td>0.16833E+00</td>
<td>0.26042E+00</td>
<td>0.18915E+00</td>
<td>0.37144E-01</td>
<td>0.84354</td>
<td>1.47866</td>
<td>2.11003</td>
<td>0.0</td>
</tr>
<tr>
<td>0.212500</td>
<td>269.075</td>
<td>0.18638E+00</td>
<td>0.26333E+00</td>
<td>0.18946E+00</td>
<td>0.37439E-01</td>
<td>0.85965</td>
<td>1.48497</td>
<td>2.22740</td>
<td>0.0</td>
</tr>
<tr>
<td>0.205000</td>
<td>271.508</td>
<td>0.3371E+00</td>
<td>0.26637E+00</td>
<td>0.19050E+00</td>
<td>0.37649E-01</td>
<td>0.85813</td>
<td>1.49414</td>
<td>2.34382</td>
<td>0.0</td>
</tr>
<tr>
<td>0.197500</td>
<td>274.142</td>
<td>0.47312E+00</td>
<td>0.27219E+00</td>
<td>0.19347E+00</td>
<td>0.37777E-01</td>
<td>0.85042</td>
<td>1.50360</td>
<td>2.47637</td>
<td>0.0</td>
</tr>
<tr>
<td>0.190000</td>
<td>274.289</td>
<td>0.5751E+00</td>
<td>0.28629E+00</td>
<td>0.19636E+00</td>
<td>0.41347E-01</td>
<td>0.94569</td>
<td>1.51193</td>
<td>2.52145</td>
<td>2.57189</td>
</tr>
<tr>
<td>0.208750</td>
<td>276.384</td>
<td>0.24528E+00</td>
<td>0.26349E+00</td>
<td>0.18816E+00</td>
<td>0.37388E-01</td>
<td>0.85749</td>
<td>1.49462</td>
<td>2.27575</td>
<td>0.0</td>
</tr>
<tr>
<td>0.206750</td>
<td>276.937</td>
<td>0.23316E+00</td>
<td>0.26573E+00</td>
<td>0.19020E+00</td>
<td>0.37521E-01</td>
<td>0.85619</td>
<td>1.49359</td>
<td>2.31279</td>
<td>0.0</td>
</tr>
<tr>
<td>0.207812</td>
<td>276.665</td>
<td>0.26958E+00</td>
<td>0.26438E+00</td>
<td>0.18019E+00</td>
<td>0.37456E-01</td>
<td>0.85690</td>
<td>1.49074</td>
<td>2.29242</td>
<td>0.0</td>
</tr>
<tr>
<td>0.204281</td>
<td>276.498</td>
<td>0.25725E+00</td>
<td>0.26533E+00</td>
<td>0.18099E+00</td>
<td>0.37588E-01</td>
<td>0.85703</td>
<td>1.49105</td>
<td>2.29259</td>
<td>0.0</td>
</tr>
<tr>
<td>0.208047</td>
<td>276.832</td>
<td>0.26315E+00</td>
<td>0.26481E+00</td>
<td>0.18056E+00</td>
<td>0.37521E-01</td>
<td>0.85690</td>
<td>1.49089</td>
<td>2.29246</td>
<td>0.0</td>
</tr>
</tbody>
</table>

* * * SOLUTION HAS BEEN OBTAINED IN = 11 ITERATIONS * * *
** INTERMEDIATE RESULTS FOR FLOW RATE = 0.207929 (KG/SEC)

T    G    REYN    FISO

COLD LEG
1.540000E 02 1.058976E-02 2.966234E 04 2.344149E-02
EXCHANGER
2.141445E 02 1.103099E-02 1.774103E 04 2.671200E-02
RISER
2.742890E 02 1.058976E-02 5.580610E 04 2.344149E-02

** ALL LIQUID REGION

<table>
<thead>
<tr>
<th>ISCB</th>
<th>RO(TSCB)</th>
<th>RO-MEAN</th>
<th>T-MEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.4661210E-03</td>
<td>0.883809E-03</td>
<td></td>
</tr>
<tr>
<td>MU(TSCB)</td>
<td>0.127669E-03</td>
<td>0.152800E-05</td>
<td></td>
</tr>
<tr>
<td>CP(TSCB)</td>
<td>0.107874E-01</td>
<td>0.105142E 01</td>
<td></td>
</tr>
<tr>
<td>K(TSCB)</td>
<td>0.156252E-05</td>
<td>0.160384E-05</td>
<td></td>
</tr>
<tr>
<td>REYN-MEAN</td>
<td>0.711594E-06</td>
<td>0.160384E-05</td>
<td></td>
</tr>
<tr>
<td>H-MEAN</td>
<td>0.572769E-03</td>
<td>0.160384E-05</td>
<td></td>
</tr>
<tr>
<td>FISO</td>
<td>0.172498E-01</td>
<td>0.160384E-05</td>
<td></td>
</tr>
<tr>
<td>F/FISO</td>
<td>0.856672E 00</td>
<td>0.160384E-05</td>
<td></td>
</tr>
</tbody>
</table>

** HIGHLY SUBCOOLED BOILING REGION

<table>
<thead>
<tr>
<th>ISCB</th>
<th>RO(TSCB)</th>
<th>RO-MEAN</th>
<th>T-MEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.837010E-03</td>
<td>0.914911E-03</td>
<td></td>
</tr>
<tr>
<td>MU(TDI)</td>
<td>0.100146E-05</td>
<td>0.111090E-05</td>
<td></td>
</tr>
<tr>
<td>CP(TDI)</td>
<td>0.238271E-04</td>
<td>0.111090E-05</td>
<td></td>
</tr>
<tr>
<td>REYN-MEAN</td>
<td>0.149254E-02</td>
<td>0.111090E-05</td>
<td></td>
</tr>
<tr>
<td>H-MEAN</td>
<td>0.875471E-03</td>
<td>0.111090E-05</td>
<td></td>
</tr>
<tr>
<td>FISO</td>
<td>0.163647E-01</td>
<td>0.111090E-05</td>
<td></td>
</tr>
<tr>
<td>F/FISO</td>
<td>0.729589E 01</td>
<td>0.111090E-05</td>
<td></td>
</tr>
</tbody>
</table>

** SLIGHTLY SUBCOOLED BOILING REGION

<table>
<thead>
<tr>
<th>ISCB</th>
<th>RO(TDI)</th>
<th>RO-MEAN</th>
<th>T-MEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.237599E-01</td>
<td>0.161723E 00</td>
<td></td>
</tr>
<tr>
<td>ALFA-MEAN</td>
<td>0.161723E 00</td>
<td>0.161723E 00</td>
<td></td>
</tr>
<tr>
<td>RO-MEAN LIQUID</td>
<td>0.775471E-03</td>
<td>0.161723E 00</td>
<td></td>
</tr>
<tr>
<td>RO-MEAN FLUID</td>
<td>0.670194E-03</td>
<td>0.161723E 00</td>
<td></td>
</tr>
<tr>
<td>FISO</td>
<td>0.163647E-01</td>
<td>0.161723E 00</td>
<td></td>
</tr>
<tr>
<td>F/FISO</td>
<td>0.729589E 01</td>
<td>0.161723E 00</td>
<td></td>
</tr>
</tbody>
</table>
RESULTS OF CALCULATION FOR FLOW RATE = 0.297029 (KG/SFC)

**TEMPERATURES (CELSIUS DEG.**)

<table>
<thead>
<tr>
<th>Description</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>INLET WALL TEMP.</td>
<td>0.234044E+03</td>
</tr>
<tr>
<td>TEMP. AT 7L9</td>
<td>0.217001E+03</td>
</tr>
<tr>
<td>TEMP. AT 7D</td>
<td>0.241021E+03</td>
</tr>
<tr>
<td>OUTLET TEMP.</td>
<td>0.270599E+03</td>
</tr>
</tbody>
</table>

**LENGTHS (CM)**

<table>
<thead>
<tr>
<th>Region</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL LIQUID FLOW REGION</td>
<td>0.103500E+03</td>
</tr>
<tr>
<td>HIGHLY SUBCOOLED BOILING REGION</td>
<td>0.710000E+02</td>
</tr>
<tr>
<td>SLIGHTLY SUBCOOLED REGION</td>
<td>0.255000E+02</td>
</tr>
</tbody>
</table>

**QUALITY AND VOID FRACTION**

- **EXIT QUALITY**: 0.175911E-01
- **VOID FRACTION AT ZRB**: 0.258685E+00
- **VOID FRACTION AT THE END OF BULK BOILING**: 0.0

**PRESSURE DROPS (KG/CM**²)

<table>
<thead>
<tr>
<th>Region</th>
<th>Pressure Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLD LEG</td>
<td>0.559836E-03</td>
</tr>
<tr>
<td>EXCHANGER</td>
<td>0.597336E-03</td>
</tr>
<tr>
<td>RISER</td>
<td>0.389600E-03</td>
</tr>
<tr>
<td>ALL LIQUID REGION</td>
<td>0.618090E-01</td>
</tr>
<tr>
<td>HIGHLY SUBCOOLED REGION</td>
<td>0.770654E+01</td>
</tr>
<tr>
<td>SLIGHTLY SUBCOOLED REGION</td>
<td>0.510485E+01</td>
</tr>
<tr>
<td>BULK BOILING REGION</td>
<td>0.0</td>
</tr>
<tr>
<td>TOTAL FRICTION PRESSURE DROP</td>
<td>0.191532E+00</td>
</tr>
</tbody>
</table>

**LOCAL PRESSURE DROP**

<table>
<thead>
<tr>
<th>Region</th>
<th>Pressure Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>INLET</td>
<td>0.128176E+01</td>
</tr>
<tr>
<td>COLD LEG</td>
<td>0.143479E+03</td>
</tr>
<tr>
<td>EXCHANGER</td>
<td>0.0</td>
</tr>
<tr>
<td>RISER</td>
<td>0.186996E+03</td>
</tr>
<tr>
<td>OUTLET</td>
<td>0.374886E+01</td>
</tr>
<tr>
<td>TOTAL LOCAL PRESSURE DROP</td>
<td>0.506615E+01</td>
</tr>
</tbody>
</table>

**ACCELERATION**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLUID PRESSURE RISE</td>
<td>0.0</td>
</tr>
<tr>
<td>ELEVATION HEAD</td>
<td>0.266390E+00</td>
</tr>
</tbody>
</table>

**TOTAL PRESSURE DROP**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL PRESSURE DROP</td>
<td>0.265153E+00</td>
</tr>
</tbody>
</table>

**TOTAL ELEVATION HEAD**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL ELEVATION HEAD</td>
<td>0.266390E+00</td>
</tr>
</tbody>
</table>

**RELATIVE ERROR**

-0.444638E-02
## TEST SECTION TEMPERATURES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>IMAX</td>
<td>XEQC</td>
<td>NZETA</td>
<td>INDLP</td>
<td>PRINT</td>
<td>IDT</td>
<td>KKK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>--------</td>
<td>--------</td>
<td>-------</td>
<td>-----</td>
<td>-----</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) If DPPUMP > 0 (constant or zero pump head) card 40 must not be supplied.

2) Supply as many cards of type C-12 as many problems to be run.
### 5.3.2 Input Data

<table>
<thead>
<tr>
<th>Card</th>
<th>Columns</th>
<th>Format</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 - 72</td>
<td>12 A6</td>
<td></td>
<td>Columns 2-72 are printed as a title.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18 A4</td>
<td>(for 7090)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 in Col. 1 causes an initial page skip.</td>
</tr>
<tr>
<td>2</td>
<td>1 - 5</td>
<td>15</td>
<td>IMAX</td>
<td>Maximum number of iterations to be performed by using the method of halving.</td>
</tr>
<tr>
<td>6</td>
<td>6 - 10</td>
<td>15</td>
<td>NEXC</td>
<td>Number of exchanger's pipes in parallel.</td>
</tr>
<tr>
<td>11</td>
<td>11 - 15</td>
<td>15</td>
<td>NZETA</td>
<td>Number of test section lumps.</td>
</tr>
<tr>
<td>16</td>
<td>16 - 20</td>
<td>15</td>
<td>INDL</td>
<td>Indicator for the riser temperature calculation. When ( \text{INDL} = 1 ) the main calls subroutine TRIST which computes the riser temperature by balances of enthalpy; when ( \text{INDL} = 0 ) the mean riser temperature is computed by subtracting an empirical value ( \text{XTRIS} ) to the outlet temperature.</td>
</tr>
<tr>
<td>21</td>
<td>21 - 25</td>
<td>15</td>
<td>IPRINT</td>
<td>Indicator for the results print. When ( \text{IPRINT} = 0 ) the code prints all results only of last iteration. When ( \text{IPRINT} = 1 ) the code prints all results in the output for each iteration.</td>
</tr>
<tr>
<td>26</td>
<td>26 - 30</td>
<td>15</td>
<td>IDT</td>
<td>Indicator for the calculation of ( \Delta T_{\text{sat}} ). For ( \text{IDT} = 0 ) the code uses the relation (25). For ( \text{IDT} = 1 ) it chooses the Jens and Lottes formula.</td>
</tr>
<tr>
<td>31</td>
<td>31 - 35</td>
<td>15</td>
<td>KKK</td>
<td>Indicator for the calculation of ( (f/f_{\text{iso}}) ) in the highly subcooled region. For ( \text{KKK} = 0 ) ( (f/f_{\text{iso}}) ) is computed in accordance with Mendler theory; for ( \text{KKK} = 1 ) ( (f/f_{\text{iso}}) ) is computed by the Lottes - Flinn relation for the two-phase fluid.</td>
</tr>
<tr>
<td>3</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>P</td>
<td>Pressure of the system.</td>
</tr>
<tr>
<td></td>
<td>13 - 24</td>
<td>E12.0</td>
<td>EMAX</td>
<td>Maximum relative error, ( \frac{\Delta p_{\text{mot}} - \Delta p_{\text{res}}}{\Delta p_{\text{res}}} ).</td>
</tr>
<tr>
<td></td>
<td>25-36</td>
<td>E12.0</td>
<td>DPPUM</td>
<td>Head of pump, if the circulation is forced. If ( \text{DPPUM} &lt; 0 ) is negative, the head is calculated by a polynomial whose coefficients are in card 10, which depends upon the flow rate.</td>
</tr>
<tr>
<td>Card</td>
<td>Column</td>
<td>Format</td>
<td>Name</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>--------</td>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>4</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>TSLT</td>
<td>Test section length.</td>
</tr>
<tr>
<td></td>
<td>13 - 24</td>
<td>E12.0</td>
<td>CLLT</td>
<td>Cold leg length.</td>
</tr>
<tr>
<td></td>
<td>25 - 36</td>
<td>E12.0</td>
<td>EXLT</td>
<td>Exchanger length.</td>
</tr>
<tr>
<td></td>
<td>37 - 48</td>
<td>E12.0</td>
<td>RILT</td>
<td>Riser length.</td>
</tr>
<tr>
<td></td>
<td>49 - 60</td>
<td>E12.0</td>
<td>FITLT</td>
<td>Fitting between test section and riser length.</td>
</tr>
<tr>
<td>5</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>TSD</td>
<td>Test section in. diameter.</td>
</tr>
<tr>
<td></td>
<td>13 - 24</td>
<td>E12.0</td>
<td>CLD</td>
<td>Cold leg in. diameter.</td>
</tr>
<tr>
<td></td>
<td>25 - 36</td>
<td>E12.0</td>
<td>EXD</td>
<td>Exchanger in. diameter.</td>
</tr>
<tr>
<td></td>
<td>37 - 48</td>
<td>E12.0</td>
<td>RID</td>
<td>Riser in. diameter.</td>
</tr>
<tr>
<td>6</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>RØUGTS</td>
<td>Test section roughness coefficient.</td>
</tr>
<tr>
<td></td>
<td>13 - 24</td>
<td>E12.0</td>
<td>RØUGL</td>
<td>Loop roughness coefficient.</td>
</tr>
<tr>
<td></td>
<td>25 - 36</td>
<td>E12.0</td>
<td>SLIPR</td>
<td>Slip ratio.</td>
</tr>
<tr>
<td></td>
<td>37 - 48</td>
<td>E12.0</td>
<td>DELTA</td>
<td>Angle of loop with respect to horizontal.</td>
</tr>
<tr>
<td>7</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>EPSI</td>
<td>Bowring's model parameter for the local quality (see Ref. 2)</td>
</tr>
<tr>
<td></td>
<td>13 - 24</td>
<td>E12.0</td>
<td>RD</td>
<td>Bowring's model parameter for ( \alpha ) ( w ) calculation. See pag. 11 and fig. 7 where RD is plotted versus pressure.</td>
</tr>
<tr>
<td></td>
<td>25 - 36</td>
<td>E12.0</td>
<td>RLANDA</td>
<td>Evaporation heat.</td>
</tr>
<tr>
<td></td>
<td>37 - 48</td>
<td>E12.0</td>
<td>RØG</td>
<td>Steam density.</td>
</tr>
<tr>
<td></td>
<td>49 - 60</td>
<td>E12.0</td>
<td>EØUTFS</td>
<td>Saturated water enthalpy.</td>
</tr>
<tr>
<td></td>
<td>61 - 72</td>
<td>E12.0</td>
<td>EØUTG</td>
<td>Saturated steam.</td>
</tr>
<tr>
<td>8</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>BKin</td>
<td>Loss coefficient at the test section inlet.</td>
</tr>
<tr>
<td></td>
<td>13 - 24</td>
<td>E12.0</td>
<td>BKC</td>
<td>Loss coefficient of the cold leg.</td>
</tr>
<tr>
<td></td>
<td>27 - 36</td>
<td>E12.0</td>
<td>BKE</td>
<td>Loss coefficient of the exchanger.</td>
</tr>
<tr>
<td></td>
<td>37 - 48</td>
<td>E12.0</td>
<td>BKRI</td>
<td>Loss coefficient of the riser.</td>
</tr>
<tr>
<td></td>
<td>49 - 60</td>
<td>E12.0</td>
<td>BKØUT</td>
<td>Loss coefficient at the exit of test section.</td>
</tr>
<tr>
<td></td>
<td>61 - 72</td>
<td>E12.0</td>
<td>BR</td>
<td>Two phase loss multiplier at the exit of test section, because the continuity of two regions, at the boundary between single phase and two phase regions. It is calculated when it is given zero in input.</td>
</tr>
<tr>
<td>Card</td>
<td>Columns</td>
<td>Format</td>
<td>Name</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
<td>--------</td>
<td>--------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>XTCL</td>
<td>Empirical value, which must be added to inlet temperature for the calculation of the cold leg mean temperature.</td>
</tr>
<tr>
<td>13</td>
<td>1 - 24</td>
<td>E12.0</td>
<td>XTRIS</td>
<td>Empirical value, which must be subtracted to outlet temperature for the calculation of the riser mean temperature, when INDL = 0.</td>
</tr>
<tr>
<td>10</td>
<td>1 - 72</td>
<td>E12.0</td>
<td>CC(1)</td>
<td>Coefficients of a polynomial, which represents analytically the characteristic of the pump in forced circulation. The card exists if DPPUMP is negative in input.</td>
</tr>
<tr>
<td>11</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>DD(1)</td>
<td>Number of riser axial meshes.</td>
</tr>
<tr>
<td></td>
<td>13 - 24</td>
<td>E12.0</td>
<td>DD(2)</td>
<td>Over-all heat transfer coefficient of the riser.</td>
</tr>
<tr>
<td>12</td>
<td>1 - 12</td>
<td>E12.0</td>
<td>DD(3)</td>
<td>Heat transfer surface of the riser.</td>
</tr>
<tr>
<td></td>
<td>25 - 36</td>
<td>E12.0</td>
<td>DD(4)</td>
<td>Air temperature.</td>
</tr>
<tr>
<td></td>
<td>37 - 48</td>
<td>E12.0</td>
<td>PØWKW</td>
<td>Thermal power supplied to the system.</td>
</tr>
<tr>
<td></td>
<td>1 - 12</td>
<td>E12.0</td>
<td>TIN</td>
<td>Inlet temperature.</td>
</tr>
<tr>
<td></td>
<td>25 - 36</td>
<td>E12.0</td>
<td>WMIN</td>
<td>Minimum value of flow rate interval, in which the solution exists certainly.</td>
</tr>
<tr>
<td></td>
<td>37 - 48</td>
<td>E12.0</td>
<td>WMAX</td>
<td>Maximum value of the flow rate interval in which the solution exists certainly.</td>
</tr>
</tbody>
</table>

If there are many values of power and inlet temperature, the card 12 will be followed by as many cards with new values of power or of inlet temperature, or of both. It could be opportune sometimes, for large variations of these values, to change the flow rate interval.

5.3.3 Operating Informations

LUPO Code runs on IBM 360/65 computer under O.S. control or on IBM 7090 computer under IBSYS control.

The running time for a typical problem is about:

20 seconds on IBM 7090
10 seconds on IBM 360/65

The LUPO Fortran deck is available at the CETIS EURATOM PROGRAM LIBRARY.
### 5.4 FORTRAN Nomenclature

#### Input Data

<table>
<thead>
<tr>
<th>FORTRAN Language</th>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BKCL</td>
<td>$K_{cl}$</td>
<td>Loss coefficient of the cold leg</td>
</tr>
<tr>
<td>BKEF</td>
<td>$K_{exc}$</td>
<td>&quot; of &quot; exchanger</td>
</tr>
<tr>
<td>BKIN</td>
<td>$K_{in}$</td>
<td>&quot; at test section inlet</td>
</tr>
<tr>
<td>BKOUT</td>
<td>$K_{out}$</td>
<td>&quot; &quot; outlet</td>
</tr>
<tr>
<td>BKRSI</td>
<td>$K_{ris}$</td>
<td>&quot; of the riser</td>
</tr>
<tr>
<td>BR</td>
<td>$K_{out, TPF}$</td>
<td>Two phase loss coefficient at test section outlet</td>
</tr>
<tr>
<td>CLD</td>
<td>$D_{cl}$</td>
<td>Cold leg inside diameter</td>
</tr>
<tr>
<td>CLLT</td>
<td>$l_{cl}$</td>
<td>&quot; &quot; length</td>
</tr>
<tr>
<td>DD(1)</td>
<td>$n_{ris}$</td>
<td>Number of riser lumps.</td>
</tr>
<tr>
<td>DD(2)</td>
<td>$\lambda_{ris}$</td>
<td>Over-all heat transfer coefficient of the riser</td>
</tr>
<tr>
<td>DD(3)</td>
<td>$S_{ris}$</td>
<td>Heat transfer surface of the riser</td>
</tr>
<tr>
<td>DD(4)</td>
<td>$t_{a}$</td>
<td>Air temperature</td>
</tr>
<tr>
<td>DELTA</td>
<td>$\delta$</td>
<td>Angle of loop with respect to horizontal</td>
</tr>
<tr>
<td>DPPUMP</td>
<td>$\Delta p_{pump}$</td>
<td>Head of pump</td>
</tr>
<tr>
<td>DMAX</td>
<td>$\varepsilon_{max}$</td>
<td>Maximum relative error</td>
</tr>
<tr>
<td>EOUTFS</td>
<td>$h_{l, sat}$</td>
<td>Saturated water enthalpy</td>
</tr>
<tr>
<td>EOUTG</td>
<td>$h_{g}$</td>
<td>Saturated steam</td>
</tr>
<tr>
<td>EPSI</td>
<td>$\bar{\theta}$</td>
<td>Bowring's model parameter for the local quality</td>
</tr>
<tr>
<td>EXD</td>
<td>$D_{exc}$</td>
<td>Exchanger inside diameter</td>
</tr>
<tr>
<td>EXLT</td>
<td>$l_{exc}$</td>
<td>Exchanger length</td>
</tr>
<tr>
<td>FITLT</td>
<td>$l_{fit}$</td>
<td>Test section fitting length</td>
</tr>
<tr>
<td>IMAX</td>
<td>$m$</td>
<td>Maximum number of iterations</td>
</tr>
<tr>
<td>IDT</td>
<td>/</td>
<td>Indicator for the $\Delta T_{sat}$ calculation</td>
</tr>
<tr>
<td>INDL</td>
<td>/</td>
<td>&quot; &quot; for the riser temperature calculation</td>
</tr>
<tr>
<td>IPRINT</td>
<td>/</td>
<td>Indicator for the results print</td>
</tr>
<tr>
<td>KKK</td>
<td>/</td>
<td>&quot; &quot; for the calculation of $\left(t/t_{iso}\right)$ in the highly subcooled region</td>
</tr>
<tr>
<td>NZETA</td>
<td>$n_{ts}$</td>
<td>Test section lumps number</td>
</tr>
<tr>
<td>NEXC</td>
<td>$n_{exc}$</td>
<td>Number of exchanger pipes in parallel.</td>
</tr>
<tr>
<td>FORTRAN Language</td>
<td>Symbol</td>
<td>Meaning</td>
</tr>
<tr>
<td>------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>P</td>
<td>p</td>
<td>Pressure</td>
</tr>
<tr>
<td>POWKW</td>
<td>P</td>
<td>Thermal power</td>
</tr>
<tr>
<td>RD</td>
<td>R&lt;sub&gt;d&lt;/sub&gt;</td>
<td>Bowring's model parameter for &lt;i&gt;α&lt;/i&gt;&lt;sub&gt;W&lt;/sub&gt; calculation</td>
</tr>
<tr>
<td>RID</td>
<td>D&lt;sub&gt;r&lt;/sub&gt;&lt;sub&gt;ris&lt;/sub&gt;</td>
<td>Riser's inside diameter</td>
</tr>
<tr>
<td>RILT</td>
<td>l&lt;sub&gt;r&lt;/sub&gt;&lt;sub&gt;ris&lt;/sub&gt;</td>
<td>Riser's length</td>
</tr>
<tr>
<td>RLANDA</td>
<td>r</td>
<td>Evaporation heat</td>
</tr>
<tr>
<td>ROG</td>
<td>ρ</td>
<td>Steam density</td>
</tr>
<tr>
<td>ROUGL</td>
<td>(ε/D)</td>
<td>Loop roughness coefficient</td>
</tr>
<tr>
<td>ROUGTS</td>
<td>(ε/D)&lt;sub&gt;ts&lt;/sub&gt;</td>
<td>Test section roughness coefficient</td>
</tr>
<tr>
<td>SLIPR</td>
<td>S&lt;sub&gt;r&lt;/sub&gt;</td>
<td>Slip ratio</td>
</tr>
<tr>
<td>TIN</td>
<td>t&lt;sub&gt;in&lt;/sub&gt;</td>
<td>Inlet temperature of test section</td>
</tr>
<tr>
<td>ZETA</td>
<td>n&lt;sub&gt;ts&lt;/sub&gt;</td>
<td>Test section lumps number</td>
</tr>
<tr>
<td>WMAX</td>
<td>W&lt;sub&gt;max&lt;/sub&gt;</td>
<td>Maximum value of the flow rate</td>
</tr>
<tr>
<td>WMIN</td>
<td>W&lt;sub&gt;min&lt;/sub&gt;</td>
<td>Minimum value of the flow rate</td>
</tr>
</tbody>
</table>

**Variables in the Program**

<p>| A, B, C          | /     | Number of the boundary lump |
| ALFABB           | α&lt;sub&gt;bb&lt;/sub&gt; | Void fraction at the end of the &quot;slight subcooled region&quot; |
| ALFAE            | ex    | Void fraction at the exit |
| ACCG             | g     | Gravity acceleration |
| AMU              | μ     | Dynamic viscosity |
| CP               | c&lt;sub&gt;p&lt;/sub&gt; | Heat specific capacity |
| CK               | K&lt;sub&gt;t&lt;/sub&gt; | Thermal conductivity |
| D                | D     | Diameter |
| DE               | Δε    | Relative error |
| DELTAZ           | ΔZ    | Length of test section lumps |
| DPACC            | Δ&lt;i&gt;p&lt;/i&gt;&lt;sub&gt;acc&lt;/sub&gt; | Spatial acceleration pressure drop |
| DPFRIC           | Δ&lt;i&gt;p&lt;/i&gt;&lt;sub&gt;fr&lt;/sub&gt; | Friction pressure drop in the loop |
| DPLOC            | Δ&lt;i&gt;p&lt;/i&gt;&lt;sub&gt;loc&lt;/sub&gt; | Local pressure drop |
| DPLOCT           | Δ&lt;i&gt;p&lt;/i&gt;&lt;sub&gt;loc, tot&lt;/sub&gt; | Total local pressure drop |
| DPRT             | Δ&lt;i&gt;p&lt;/i&gt;&lt;sub&gt;res&lt;/sub&gt; | Total resisting pressure drop |
| DPMOT            | Δ&lt;i&gt;p&lt;/i&gt;&lt;sub&gt;mot&lt;/sub&gt; | Driving force |</p>
<table>
<thead>
<tr>
<th>FORTRAN Language</th>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIN</td>
<td>$h_{in}$</td>
<td>Inlet enthalpy of test section</td>
</tr>
<tr>
<td>EOUT</td>
<td>$h_{out}$</td>
<td>Outlet enthalpy</td>
</tr>
<tr>
<td>FI</td>
<td>$\Phi$</td>
<td>Thermal flux</td>
</tr>
<tr>
<td>FFISLB</td>
<td>$(f/f_{iso})_{LB}$</td>
<td>Pressure drop multiplier in local boiling region</td>
</tr>
<tr>
<td>FISOLB</td>
<td>$(f_{iso})_{LB}$</td>
<td>Isothermal multiplier in local boiling region</td>
</tr>
<tr>
<td>FFISSR</td>
<td>$(f/f_{iso})_{sr}$</td>
<td>Pressure drop multiplier in the &quot;all liquid region&quot;</td>
</tr>
<tr>
<td>FISOSR</td>
<td>$(f_{iso})_{sr}$</td>
<td>Isothermal multiplier in the &quot;all liquid region&quot;</td>
</tr>
<tr>
<td>FISO</td>
<td>$f_{iso}$</td>
<td>&quot;&quot; in loop's components</td>
</tr>
<tr>
<td>G</td>
<td>$\rho V$</td>
<td>Mass velocity</td>
</tr>
<tr>
<td>ICN</td>
<td>/</td>
<td>Indicator for the cycle restart</td>
</tr>
<tr>
<td>KKK</td>
<td>/</td>
<td>Indicator for $(f/f_{iso})$ relation</td>
</tr>
<tr>
<td>KIND</td>
<td>/</td>
<td>&quot;&quot; for a new flow rate</td>
</tr>
<tr>
<td>KPUMP</td>
<td>/</td>
<td>Pump indicator</td>
</tr>
<tr>
<td>HX</td>
<td>$\lambda_{sr}$</td>
<td>Heat transfer coefficient in the all liquid region</td>
</tr>
<tr>
<td>PDROP1</td>
<td>$\Delta p_1$</td>
<td>Pressure drop in the &quot;slightly subcooled&quot; region</td>
</tr>
<tr>
<td>PDROP2</td>
<td>$\Delta p_2$</td>
<td>Pressure drop in the &quot;bulk boiling&quot; region</td>
</tr>
<tr>
<td>PFRICT</td>
<td>$\Delta p_{fr}$</td>
<td>Friction pressure drop</td>
</tr>
<tr>
<td>POWER</td>
<td>$P$</td>
<td>Thermal power</td>
</tr>
<tr>
<td>REYN</td>
<td>$N_{Re}$</td>
<td>Reynolds number</td>
</tr>
<tr>
<td>RMOLT1</td>
<td>$R_1$</td>
<td>Two phase multiplier in subcooled boiling</td>
</tr>
<tr>
<td>RMOLT2</td>
<td>$R_2$</td>
<td>&quot;&quot; &quot;&quot; in bulk boiling</td>
</tr>
<tr>
<td>RO</td>
<td>$\rho$</td>
<td>Density</td>
</tr>
<tr>
<td>ROLB</td>
<td>$\rho_{LB}$</td>
<td>Average density in the highly subcooled region</td>
</tr>
<tr>
<td>ROM1</td>
<td>$\rho_1$</td>
<td>Average density in the slightly subcooled region</td>
</tr>
<tr>
<td>ROM2</td>
<td>$\rho_2$</td>
<td>Average density in the bulk boiling region</td>
</tr>
<tr>
<td>ROMB</td>
<td>$\rho_{2,v}$</td>
<td>Average density in the bulk boiling region computed by volumetric quality</td>
</tr>
<tr>
<td>ROMS</td>
<td>$\rho_{1,v}$</td>
<td>Average density in the slightly subcooled region computed by volumetric quality</td>
</tr>
<tr>
<td>ROMR</td>
<td>$\rho_{ris}$</td>
<td>Average density in the riser</td>
</tr>
</tbody>
</table>
### FORTRAN Language

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho_{sr}$</td>
<td>Average density in the all liquid region</td>
</tr>
<tr>
<td>$\rho_{f,sat}$</td>
<td>Saturate water density</td>
</tr>
<tr>
<td>$t$</td>
<td>Temperature</td>
</tr>
<tr>
<td>$t_{sat}$</td>
<td>Saturation temperature</td>
</tr>
<tr>
<td>$t_d$</td>
<td>Temperature at which slightly subcooled boiling starts</td>
</tr>
<tr>
<td>$t_w$</td>
<td>Wall temperature</td>
</tr>
<tr>
<td>$t_{w,in}$</td>
<td>Wall inlet temperature</td>
</tr>
<tr>
<td>$t_{w,scb}$</td>
<td>$t_{sat} + \Delta t_{sat}$</td>
</tr>
<tr>
<td>$t_{scb}$</td>
<td>Temperature at which highly subcooled boiling starts</td>
</tr>
<tr>
<td>$V$</td>
<td>Velocity</td>
</tr>
<tr>
<td>$W_x$</td>
<td>Flow rate</td>
</tr>
<tr>
<td>$X_v$</td>
<td>Volumetric quality</td>
</tr>
<tr>
<td>$X_{ex}$</td>
<td>Outlet quality</td>
</tr>
<tr>
<td>$/ \text{FSLB}$</td>
<td>Term of the two phase multiplier in the slightly subcooled boiling</td>
</tr>
<tr>
<td>$l$</td>
<td>Loop components length</td>
</tr>
<tr>
<td>$Z_o$</td>
<td>All liquid region length</td>
</tr>
<tr>
<td>$Z_1$</td>
<td>Highly subcooled region length</td>
</tr>
<tr>
<td>$Z_2$</td>
<td>Slightly subcooled region length</td>
</tr>
<tr>
<td>$Z_d$</td>
<td>Test section length up to the end of highly subcooled region</td>
</tr>
<tr>
<td>$Z_{LB}$</td>
<td>Test section length up to the end of all liquid region</td>
</tr>
</tbody>
</table>

### 5.5 Possible Future Developments of the Program

Possible developments may consist in the usage of some relations expressing the variability, versus input data, of some quantities, assumed constant in the code. Among these slip ratio and parameter $\varepsilon$ are important. The slip is variable versus the void fraction and the pressure; $\varepsilon$ varies versus the subcooling.
Moreover some equations can be substituted by other equations, if the last ones were in best accordance with experimental results. Another future development may be the extension of the calculation until to regions near critical point; in that case the program must use other relations for the properties calculation.

### Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_p$</td>
<td>Specific heat capacity</td>
<td>$[H/M, T], (Kcal/Kg_m \cdot ^\circ C)$</td>
</tr>
<tr>
<td>$D$</td>
<td>Diameter</td>
<td>$[L], (cm)$</td>
</tr>
<tr>
<td>$f_{iso}$</td>
<td>Isothermal pressure drop multiplier</td>
<td>/</td>
</tr>
<tr>
<td>$(f/f_{iso})$</td>
<td>Local boiling pressure drop multiplier</td>
<td>/</td>
</tr>
<tr>
<td>$g$</td>
<td>Gravity acceleration</td>
<td>$[L/\theta^2], (cm/sec^2)$</td>
</tr>
<tr>
<td>$G$</td>
<td>Mass velocity</td>
<td>$[M/\theta, L^2], (Kg_m/sec.cm^2)$</td>
</tr>
<tr>
<td>$h$</td>
<td>Enthalpy</td>
<td>$[H/M], (Kcal/Kg_m)$</td>
</tr>
<tr>
<td>$K$</td>
<td>Loss coefficient</td>
<td>/</td>
</tr>
<tr>
<td>$K_b$</td>
<td>Thermal conductivity</td>
<td>$[M/\theta, T, L], (Kcal/cm \cdot sec \cdot ^\circ C)$</td>
</tr>
<tr>
<td>$l$</td>
<td>Length of loop's components</td>
<td>$[L], (cm)$</td>
</tr>
<tr>
<td>$N_{Re}$</td>
<td>Reynold's number</td>
<td>/</td>
</tr>
<tr>
<td>$p$</td>
<td>Pressure</td>
<td>$[F/L^2], (Kg_p/cm^2)$</td>
</tr>
<tr>
<td>$P$</td>
<td>Thermal power</td>
<td>$[H/\theta], (Kcal/sec)$</td>
</tr>
<tr>
<td>$r$</td>
<td>Evaporation heat</td>
<td>$[H/M], (Kcal/Kg_m)$</td>
</tr>
<tr>
<td>$R$</td>
<td>Two phase multiplier</td>
<td>/</td>
</tr>
<tr>
<td>$S_r$</td>
<td>Slip ratio</td>
<td>/</td>
</tr>
<tr>
<td>$S$</td>
<td>Area</td>
<td>$[L^2], (cm^2)$</td>
</tr>
<tr>
<td>$t$</td>
<td>Temperature</td>
<td>$[T], (^\circ C)$</td>
</tr>
<tr>
<td>$V$</td>
<td>Velocity</td>
<td>$[L/\theta], (cm/sec)$</td>
</tr>
<tr>
<td>$x$</td>
<td>Steam quality</td>
<td>/</td>
</tr>
<tr>
<td>$Z$</td>
<td>Length from the test section inlet</td>
<td>$[L], (cm)$</td>
</tr>
</tbody>
</table>
Greek letters

\( \alpha \)  
Void fraction  
/

\( \beta, \gamma, \delta \)  
Bowring's model parameters  
/

\( \delta \)  
Angle of loop  
radiant

\( \Delta p \)  
Pressure drop  
\([F/L^2], (Kg_p/cm^2)\)

\( \Delta \varepsilon \)  
Relative error  
/

\( \varepsilon/D \)  
Roughness coefficient  
/

\( \lambda \)  
Heat transfer coefficient  
\([H/L^2 \cdot \theta \cdot T], (Kcal/cm^2 \cdot \circ\cdot \sec)\)

\( \mu \)  
Dynamic viscosity  
\([M/L \cdot \theta], (Kg_m/cm \cdot \sec)\)

\( \rho \)  
Density  
\([M/L^3], (Kg_m/cm^3)\)

\( \Phi \)  
Heat flux  
\([M/ \theta \cdot L^2], (Kcal/sec \cdot cm^2)\)

Subscripts

\( a \)  
Air  
/

\( acc \)  
Acceleration  
/

\( bb \)  
At the end of "slightly subcooled"  
/

\( cl \)  
Cold leg  
/

\( d \)  
At the end of "highly subcooled"  
/

\( elev \)  
Elevation  
/

\( ex \)  
At the exit of test section  
/

\( exc \)  
Exchanger  
/

\( fr \)  
Friction  
/

\( fit \)  
Fitting  
/

\( g \)  
Steam  
/

\( in \)  
Test section inlet  
/

\( iso \)  
Isothermal, single phase  
/

\( f \)  
Liquid  
/

\( LB \)  
Local boiling  
/

\( loc \)  
Local  
/

\( mot \)  
Driving  
/

\( res \)  
Resisting  
/

\( ris \)  
Riser  
/

\( sat \)  
Saturated  
/

\( scb \)  
At the beginning of "highly subcooled"  
/

\( sr \)  
Only heated region  
/

\( t \)  
Thermal  
/
Symbol | Meaning
---|---
tot | Total
ts | Test section
T.P.F. | Two phase flow
v | Volumetric
w | Wall
O | Highly subcooled region
x | Unknown value
1 | Slightly subcooled region
2 | Bulk boiling region

Acknowledgements

The authors wish to thank Prof. C.A. Arneodo for his precious suggestions in the model discussion. The authors are also grateful to Ing. P. Gregorio for his help in the pressure drops calculation, and to Mr. L. Magnone for the drawing of flow chart.
References

[1] C. Arneodo, G. Gaggero, P. Gregorio "Mauro-2 A Program for Temporal Analysis in a Closed Pressurized Water Loop" PTIN 23 (oct. 64)


CISE Report R-43 (May 1962)


Politecnico di Torino, Report PTIN 25 (Ottobre 1965)

ASME Trans. 71, n. 7, p. 805

ASME Paper n. 63 - WA - 98


Nuclear Science and Engineering : 9, 26-31 (1961)

[10] "VDI - Wasserdampftabellen"
Sechste überarbeitete und erweiterte Auflage von Ernst Schmidt VDI
Springer - Verlag, R. Oldenburg, 1963

WAPD-TH-300 (March 1957)


Appendix 1

The Lattes-Flinn Model

Lattes and Flinn model for annular two phase flow in uniformly heated channels supposes the pressure losses increase is due to the liquid velocity increase. By giving the subscript "in" to the inlet and the subscript "f" to a generic section, the respective velocities are defined by:

\[
\begin{align*}
v_{\text{in}} &= \frac{W}{\rho_{\text{in}} \cdot A}, \\
v_f &= \frac{W_f}{\rho_f \cdot A_f} = \frac{(1-x) \cdot w}{\rho_f(1-\alpha) \cdot A}
\end{align*}
\]

and by supposing \( \rho_{\text{in}} = \rho_f \) (rigorously true in bulk boiling):

\[
\frac{v_f}{v_{\text{in}}} = \frac{1-x}{1-\alpha} = 1 + \left(\frac{\rho_f}{\rho \cdot g} \frac{v_f}{g} - 1\right) x
\]

The mean value of pressure drop multiplier \( R \) is given in general by the relation:

\[
\bar{R} = \frac{1}{L_2 - L_1} \int_{L_1}^{L_2} \frac{(dp/dz)_{\text{FFP}}}{(dp/dz)_0} dz = \frac{1}{L_2 - L_1} \int_{L_1}^{L_2} \left(\frac{v_f}{v_{\text{in}}}\right)^2 dz
\]

By using the eq. (2):

\[
\bar{R} = \frac{1}{L_2 - L_1} \int_{X_1}^{X_2} \left[ 1 + \left(\frac{\rho_f}{\rho \cdot g} \frac{v_f}{g} - 1\right) x \right]^2 dx
\]

In the slightly subcooled boiling \( (X_1 = 0) \), by introducing the void fraction:

\[
\bar{R} = \frac{1}{3} \left[ 1 + \frac{1}{1 - \alpha_e(1-\psi)} \cdot \frac{1}{[1 - \alpha_e(1-\psi)]^2} \right]
\]

where \( \frac{v}{v_f} = \frac{\rho_f}{\rho} \)

In the bulk boiling \( (X_1 = X_{bb}) \), the integral (4) has been solved by Cotes formula, or by arithmetic average, when the integration length is less than 0.4 cm.
Appendix 2

Expansion Losses in Two-phase Flow

When a flowing mixture of vapor and liquid expands because of a change in flow area, a static pressure change may be observed across the expansion.

Since the pressure losses are proportional to the square of the local liquid velocities, it seems that regions of highest losses are the regions of highest void fraction and liquid velocity.

Romie calculated this loss by writing an equation for the momentum balance across an abrupt expansion as follows: (see fig. 1)

\[ p_1 A_2 + \frac{w_{f_1} v_{f_1}}{g} + \frac{w_{g_1} v_{g_1}}{g} = p_2 A_2 + \frac{w_{f_2} v_{f_2}}{g} + \frac{w_{g_2} v_{g_2}}{g} \]  

This equation assumes that pressure \( p_1 \) also acts on area \( A_2 \), just after the expansion.

From material balances and the continuity equation, it can be shown that \( \sigma = A_1 / A_2 \) and \( W_o \) the total flow rate flowing as liquid)

\[ w_{f_2} = w_{f_1} = w_o (1-x) = \rho_f v_o A_1 (1-x) = \rho_f v_o \sigma A_2 (1-x) \]  

\[ w_{g_2} = w_{g_1} = x W_o = v_o A_1 x = \rho_f v_o \sigma A_2 x \]  

\[ v_{f_1} = \frac{v_o (1-x)}{1 - \alpha_1}, \quad v_{f_2} = \frac{\sigma v_o (1-x)}{1 - \alpha_2} \]  

\[ v_{g_1} = \frac{v_o x \rho_f}{\alpha_1 \rho_g}, \quad v_{g_2} = \frac{\sigma v_o x \rho_f}{\alpha_2 \rho_g} \]  

By combining eqs. (1) through (5) the static pressure change is found to be:

\[ p_2 - p_1 = \frac{G_f^2}{2 g \rho_f} \cdot 2 \sigma \left[ x^2 \frac{1}{\alpha_1} \left( 1 - \frac{\sigma}{\alpha_2} \right) + (1-x)^2 \left( \frac{1}{1 - \alpha_1} - \frac{\sigma}{1 - \alpha_2} \right) \right] \]
Because Richardson found no change in \( \alpha \) across the expansion, in eq. (6) \( \alpha_1 = \alpha_2. \)

In the LUPO there is in addition the following term because of the continuity between the single phase and two-phase pressure losses:

\[
K_{\text{out}} - 2 \frac{D_{\text{ts}}}{D_{\text{ris}}} \left( 1 - \frac{D_{\text{ts}}}{D_{\text{ris}}} \right) g \frac{G^2}{\left( \rho_{\text{out}} - \rho_{\text{ris}} \right)} = \left[ K_{\text{out}} - 2 \sigma (1 - \sigma) \right] g \frac{G^2}{\left( \rho_{\text{out}} - \rho_{\text{ris}} \right)}
\]

(7)

Therefore the two-phase exit pressure drop is given by:

\[
\Delta p_{\text{out, TPF}} = \frac{\sigma (1 - \sigma)}{\rho_{\text{out}} g} \cdot G^2 \left[ \frac{x}{\alpha} \frac{\rho_f}{\rho_g} + \frac{(1-x)^2}{1 - \alpha} \right] + \left[ K_{\text{out}} - 2 \sigma (1 - \sigma) \right] g \frac{G^2}{\left( \rho_{\text{out}} - \rho_{\text{ris}} \right)}
\]

(8)

Appendix 3

Comparison between calculations and experiments

The calculation results have been composed with experimental results of natural circulation loops built at the Polytechnic School of Turin. A description of the loop (fig. 6) and the experimental results obtained up to date, have already been published in many reports. Here we show several points, obtained in various tests, with pressure \( p = 60 \text{ Kg/cm}^2 \) and thermal power \( P = 80\text{ KW} \). Truly the thermal power is kept constant hardly, during the test.

However, there is a fairly good correspondence between calculations and experiments (fig. 5), for large void fraction also.

Appendix 4

Analytical formulation of Martinelli-Nelson multiplier

In their famous work of 1948 Martinelli and Nelson gave a plot (p. 698, fig. 4 of Ref. 16) of the two-phase multiplier \( R \) versus the pressure \( p \); the steam quality \( x \) is the parameter of the various curves.

A numerical table also is given.
In his thesis at Polytechnic of Turin in 1966 (Ref. 21) B. Panella derived a formula from this table, by the least squares method.

Using the following relation:

\[ R = 1 + a \times b \]

and by iterating the least squares method, the following expression for \( a \) and \( b \) have been computed:

\[ a = 44.38 \times e^{-0.01688p} \]
\[ b = 0.7878 - 0.4762 \times 10^{-3} p \]

where the pressure \( p \) must be given in Kg/cm\(^2\). The range of validity (with errors less than 5%) is between 40 and 140 Kg/cm\(^2\).
Fig. 1  Hydraulic loop scheme
Fig. 2  Section of the heated channel of the loop at Polytechnical School of Turin
CHANGE IN VOID FRACTION
TRANSITION POINTS BETWEEN THE TWO SUBCOOLED REGIONS

Single phase | Subcooled boiling | Bulk boiling
---|---|---
Region I (highly scb) | Region II (slightly scb) | 

![Diagram showing transition points between single phase, subcooled boiling, and bulk boiling with labels A, B', C, D, E']

![Graph showing void fraction versus channel length and bubble radius at detachment versus pressure from Ref. 2.]

**Fig. 3** Void fraction versus channel length and bubble radius at detachment versus pressure from Ref. 2.
Fig. 4  Parameter \( \beta \) versus pressure from Ref. [2] and Shape of curves representing the elevation head and the total pressure drop versus flow rate.
Comparison between results of the calculation and experimental

Fig. 5

W [gr/sec]

$P_{th} = 80 \text{ KW}$
$p = 60 \text{ ata}$
Fig. 6  Schematic representation of the loop at Polytechnical School of Turin
NOTICE TO THE READER

All Euratom reports are announced, as and when they are issued, in the monthly periodical EURATOM INFORMATION, edited by the Centre for Information and Documentation (CID). For subscription (1 year: US$ 15, £ 5.7) or free specimen copies please write to:

Handelsblatt GmbH
"Euratom Information"
Postfach 1102
D-4 Düsseldorf (Germany)

or

Office central de vente des publications des Communautés européennes
Z, Place de Metz
Luxembourg

To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel
SALES OFFICES

All Euratom reports are on sale at the offices listed below, at the prices given on the back of the front cover (when ordering, specify clearly the EUR number and the title of the report, which are shown on the front cover).

OFFICE CENTRAL DE VENTE DES PUBLICATIONS DES COMMUNAUTES EUROPEENNES
2, place de Metz, Luxembourg (Compte chèque postal No 191-90)

BELGIQUE — BELGIË
MONITEUR BELGE
40-42, rue de Louvain - Bruxelles
BELGISCHE STAATSBLAD
Leuvenseweg 40-42, - Brussel

DEUTSCHLAND
BUNDESANZEIGER
Postfach - Köln 1

FRANCE
SERVICE DE VENTE EN FRANCE DES PUBLICATIONS DES COMMUNAUTES EUROPEENNES
26, rue Desaix - Paris 15e

ITALIA
LIBRERIA DELLO STATO
Piazza G. Verdi, 10 - Roma

LUXEMBOURG
OFFICE CENTRAL DE VENTE DES PUBLICATIONS DES COMMUNAUTES EUROPEENNES
9, rue Goethe - Luxembourg

NEDERLAND
STAATSDRUKKERIJ
Christoffel Plantijnstraat - Den Haag

UNITED KINGDOM
H. M. STATIONERY OFFICE
P. O. Box 569 - London S.E.1

EURATOM — C.I.D.
51-53, rue Belliard
Bruxelles (Belgique)