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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

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

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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
WATER COOLANT
LIQUID FLOW
CONVECTION
PRESSURE

TEMPERATURE
MASS
HEAT TRANSFER
PROGRAMMING
COMPUTERS

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

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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 occuring in a system have been previously examined.

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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 Polytecnic 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 semplified 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:

$$\sum_{\text{loop}} \Delta P_{fr} + \sum_{\text{loop}} \Delta P_{acc} + \sum_{\text{loop}} \Delta P_{elev} + \Delta P_{pump} = 0 \qquad (1)$$

where:

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

$\sum_{\text{loop}} \Delta P_{acc}$ = acceleration pressure drop around the loop.

$\sum_{\text{loop}} \Delta P_{elev}$ = difference in the elevation head between hot and cold legs of the loop.

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

$$\beta = 62.745855\ e^{-0.0163(p-1)} \tag{2}$$

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

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

$$\Phi = \Phi_e + \Phi_a + \Phi_{sp} \quad .$$

By introducing the empirical parameter ε, defined as:

$$\varepsilon = \frac{\Phi_a}{\Phi_e}$$

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

$$\Phi_e = \frac{\Phi}{1 + \varepsilon} \quad .$$

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:

$$x = (P/\ \rho A V \lambda) \cdot \int_{ML}^{z} \Phi\, dz \qquad (3)$$

where P is the wetted perimeter and ML is the lenght 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:

$$x_b = (P/\ \rho A V \lambda) \int_{z_d}^{z} \frac{\Phi}{(1+\varepsilon)} dz \qquad (3')$$

Then the void fraction is expressed by following equation:

$$\alpha = \frac{x}{x + S_r \frac{\rho_g}{\rho_f}(1-x)} \qquad (4)$$

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:

$$\alpha_w = P \frac{\delta}{A} \qquad (5)$$

where δ is the effective thickness of the steam film and it is the lesser of:

$$\delta = 0.066\ R_d$$

$$\delta = \frac{Pr \cdot K \cdot V}{1.07 \cdot \eta \cdot \lambda^2}$$

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:

$$\sum_{loop} \Delta P_{elev} = \int_o^L \rho_{cl} dz - \int_o^L \rho_{hl} dz \qquad (6)$$

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

$$\rho = (1 - \alpha)\rho_f + \alpha\rho_g \qquad (7)$$

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

$$\rho = (1 - x_v)\rho_{fsat} + \rho_g x_v \qquad (8)$$

according to the energy equation.

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

α = void fraction or steam volume fraction
ρ_f = density of liquid
ρ_g = density of gas
ρ_{fsat} = density of liquid at saturation temperature
x_v = volumetric quality, defined as :

$$x_v = \frac{V_g A_g}{A_g V_g + A_f V_f} = \frac{S_r \alpha}{S_r \alpha + (1 - \alpha)} \qquad (9)$$

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:

$$\sum_{\text{loop}} \Delta P_{acc} = \frac{w^2}{2g\, A_{ts}^2} \left[\chi_{ts\text{-}ex} - \chi_{cl} \right] \cdot \left[1 - \frac{A_{ts}}{A_{exc}} \right]^2 \tag{10}$$

where:

$\chi = \frac{1}{\rho}$ for nonboiling regions

$$\chi = \left[\frac{(1-x)^2}{1-\alpha} + \frac{x^2}{\alpha} \frac{\rho_f}{\rho_g} \right] \frac{1}{\rho_f} \quad \text{for two-phase regions} \tag{11}$$

Subscripts "ts-ex", "cl" 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:

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

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_{exc} pipes in parallel, the following new relationship has been derived and introduced in the present model:

$$\sum_{loop} \Delta P_{acc} = \frac{G_{ts}^2}{2g} \left[\chi_{ts-ex} - \chi_{cl} \right] \bullet \left[1 - \frac{1}{n_{exc}^2} \left(\frac{D_{ts}}{D_{exc}} \right)^4 + \frac{n_{exc}^2 - 1}{n_{exc}^2} \left(\frac{D_{ts}}{D_{ris}} \right)^4 \right] \tag{13}$$

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:

$$\Delta P_f = f_{iso} \frac{L}{D} \frac{G^2}{2\rho g} \tag{14}$$

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

$$f_{iso} = 0.0055 \left[1 + \sqrt[3]{20000 \frac{\varepsilon}{D} + \frac{10^6}{Re}} \right] \tag{15}$$

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:

$$\Delta P_f = f_{iso} \cdot \left(\frac{f}{f_{iso}} \right) \cdot \frac{L}{D} \frac{G^2}{2\rho g} \tag{16}$$

where (f/f_{iso}) 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}):

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

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

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

where λ is calculated from Dittus-Boelter correlation:

$$\lambda = 0.023 \frac{K}{D} \; Re^{0.8} \cdot Pr^{1/3} \qquad (20)$$

Φ = heat flux expressed in units coherent with λ so that the ratio Φ/λ results a temperature measured in ^{o}C.

In the present model equation (19) has been adopted, which is valid for pressures in the range between 50 and 120 Kg/cm^2.

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 $(f/f_{iso})_{LB}$:

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

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

$$\left(\frac{f}{f_{iso}}\right)_{sat} = 19.579 \, p^{-0.5931697} \cdot \left[1 + 0.095868 \, G^{-0.919337} \right] \qquad (22)$$

t_{scb} is the temperature at which local boiling starts, and may be calculated as:

$$t_{scb} = t_{sat} + \Delta t_{sat} - \frac{\Phi}{\lambda} \qquad (23)$$

or, following Bowring:

$$t_{scb} = t_{sat} + \beta\Phi^{1/4} - \frac{\Phi}{\lambda} \qquad (23')$$

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

$$\Delta t_{sat} = 62.62096\ \Phi^{1/4}\ e^{-\frac{p}{61.2414}} \qquad (24)$$

$$\Delta t_{sat} = 145.7\ \Phi^{1/2}\ e^{-\frac{p}{87.89}} \qquad (25)$$

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 Δt_{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 $\left(\frac{f}{f_{iso}}\right)_{LB}$ has to be calculated in a different manner.

In the highly subcooled region, in which voidage is a wall effect, $(f/f_{iso})_{LB_1}$ is evaluated by means of relation (21). In the second region, where voidage is mainly a bulk effect, the multiplier $(f/f_{iso})_{LB_2}$ is evaluated by using the Lottes-Flinn relation (see Appendix 1), i.e.:

$$\left(\frac{f}{f_{iso}}\right)_{LB_2} = \frac{1}{3}\left[1 + \frac{1}{1 - \alpha_{ex}(1 - S_r\frac{\rho_g}{\rho_f})} + \frac{1}{\left[1 - \alpha_{ex}(1 - S_r\frac{\rho_g}{\rho_f})\right]^2}\right] \qquad (26)$$

where α_{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 $(f/f_{iso})_{LB_2} = 1$ and equation (21) gives

$$\left(\frac{f}{f_{iso}}\right)_{LB_1} = \left[\left(\frac{f}{f_{iso}}\right)_{sat} - 1\right]\frac{t_d - t_{scb}}{t_{sat} - t_{scb}}$$

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

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

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) 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:

$$\left(\frac{f}{f_{iso}}\right)_{bb} = \frac{(1-x)^{1.80}}{(1-\alpha)^2} \qquad (27)$$

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 (ρ_{fsat}/ρ_g), but not to mass flow rate.

Marchaterre proposes the expression (for vertical upflow):

$$\left(\frac{f}{f_{iso}}\right)_{bb} = \frac{(1-x)^2}{1-\alpha} + \alpha\,\frac{2g(\rho_f - \rho_g)\,\rho_f D}{f_{iso}\,.\,G^2} \qquad (28)$$

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

$$\left(\frac{f}{f_{iso}}\right)_{bb} = \frac{1-x}{1-\alpha} = 1 + x\left(\frac{\rho_f}{\rho_g}\,\bullet\,\frac{1}{S_r} - 1\right) \qquad (29)$$

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:

$$\left(\overline{\frac{f}{f_{iso}}}\right)_{bb} = \frac{1}{l_{ts} - z_{bb}} \int_{z_{bb}}^{l_{ts}} \left\{1 + \left(\frac{1}{S_r\,\frac{\rho_g}{\rho_{out}}} - 1\right)\left[x_{ex} - \frac{\pi D_{ts}}{W\,.\,r}\,\Phi(l_{ts}-z)\right]\right\}^2 dz \qquad (29')$$

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:

$$\Delta p_{loc} = K \frac{G^2}{2 \rho g_c} \tag{30}$$

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:

$$\Delta p_{loc,\,exit} = \frac{G_{ris}^2}{g_c(\rho_{out} + \rho_{ris})} \left[K_{out} - 2 \frac{D_{ts}}{D_{ris}} \left(1 - \frac{D_{ts}}{D_{ris}} \right) \right] + \\ + \frac{G_{ts}^2}{g_c \cdot \rho_{out}} \left(\frac{D_{ts}}{D_{ris}} \right)^2 \left[1 - \left(\frac{D_{ts}}{D_{ris}} \right)^2 \right] \left[x^2 \frac{\rho_g}{\rho_f \cdot \alpha} + \frac{(1 - x)^2}{1 -} \right] \tag{31}$$

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 througout every section of the loop.

b) Conservation of energy and heat balance:

for given inlet temperature (t_{in}), heat flux (Φ), heat transfer coefficient (λ_{in}), the wall temperature at the entrance of test section is:

$$t_{w,in} = t_{in} + \frac{\Phi}{\lambda_{in}} \tag{32}$$

For every lump of the test section the heat balance gives:

$$h^j_{out} = h^j_{in} + 4 \frac{\Phi \cdot \Delta z_j}{G_{ts} \cdot D_{ts}} \tag{33}$$

For every lump of the riser the heat balance gives:

$$h^j_{out} = h^j_{in} - \lambda_{ris} \cdot S_{ris} \cdot (\bar{t}^j - t_a) \frac{1}{W} \tag{34}$$

where subscript "a" refers to air, and λ_{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:

$$A = 1.6634 + 1.5323 \cdot 10^{-10} \cdot h^{4.4229448} \qquad (35)$$

which results from numerical interpolation of table values. Equation (35) is valid for pressures in the range between 20 and 100 Kg/cm^2 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 Δt_{cl} degrees. Δt_{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:

$$x = \frac{h - h_{sat}}{h_g - h_{sat}} \tag{36}$$

and, calling $\bar{x}$ the smooth value in every lump, the friction pressure drop two phase multiplier is given by:

$$R_{is} = \frac{1}{n_{ris}} \sum_{j=1}^{n_{ris}} \left(\frac{f}{f_{iso}} \right)_j \tag{37}$$

where $\left(\frac{f}{f_{iso}} \right)_j$ is given by the following equation:

$$\left(\frac{f}{f_{iso}} \right)_j = \left[1 + \left(\frac{1}{S_r \frac{\rho_g}{\rho_j}} - 1 \right) \right]^2 \bar{x}^2 \tag{38}$$

4.3 Flow rate calculation

The steady state flow rate calculation is done by solving the equation (1) of Section 3.1 implicitely, 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" $\varepsilon = (\Delta p_{mot} - \Delta p_{res}) / \Delta p_{mot}$, (where $\Delta p_{mot} = \Delta p_{elev} + \Delta p_{pump}$ and $\Delta p_{res} = \Delta p_{fr} + \Delta p_{acc}$), and a new flow rate value is chosen depending on the sign of ε. As many steps are performed as they are necessary to make ε less than a prescribed value.

Precisely an interval of flow rates is give, 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, 10and11 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 12there 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 tothe 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

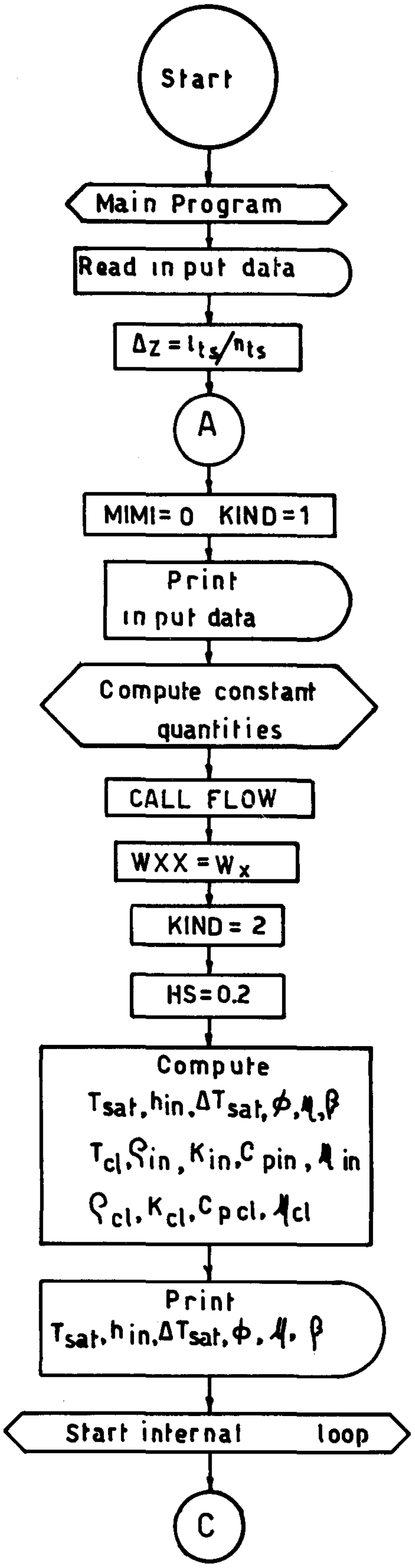
The FUNCTIONS: ENTALP, DENSIT, VISCOS, CSP, COND, SAT, ACCA compute the fluid enthalpy, density, viscosity, specific heat capacity, thermal conductivity, saturation temperature, heat transfer coefficient, respectively.

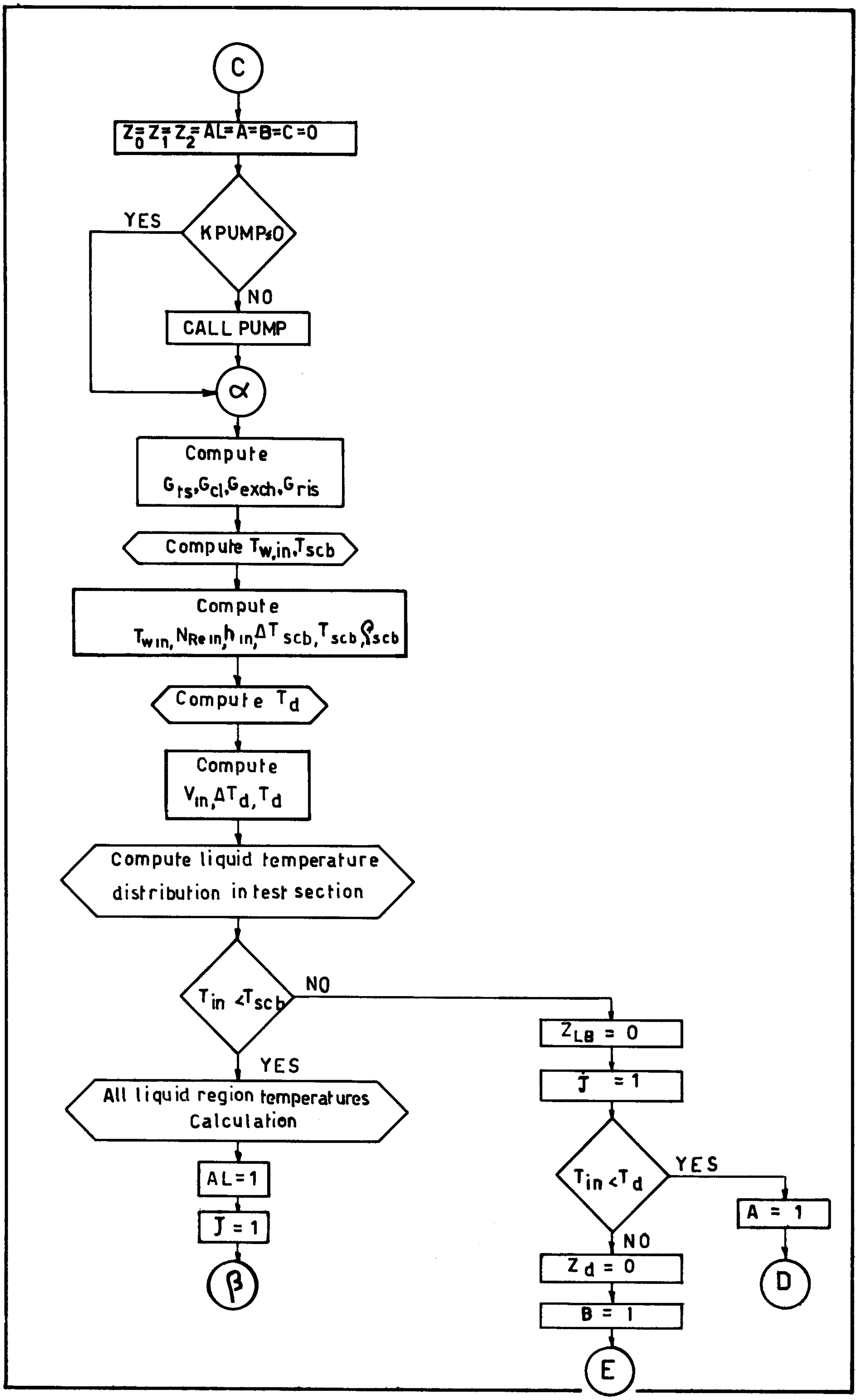
FUNCTIONS: DP, DPL, DPLU compute acceleration, local pressure drops and local two phase pressure drops at the exit of the test section, respectively.

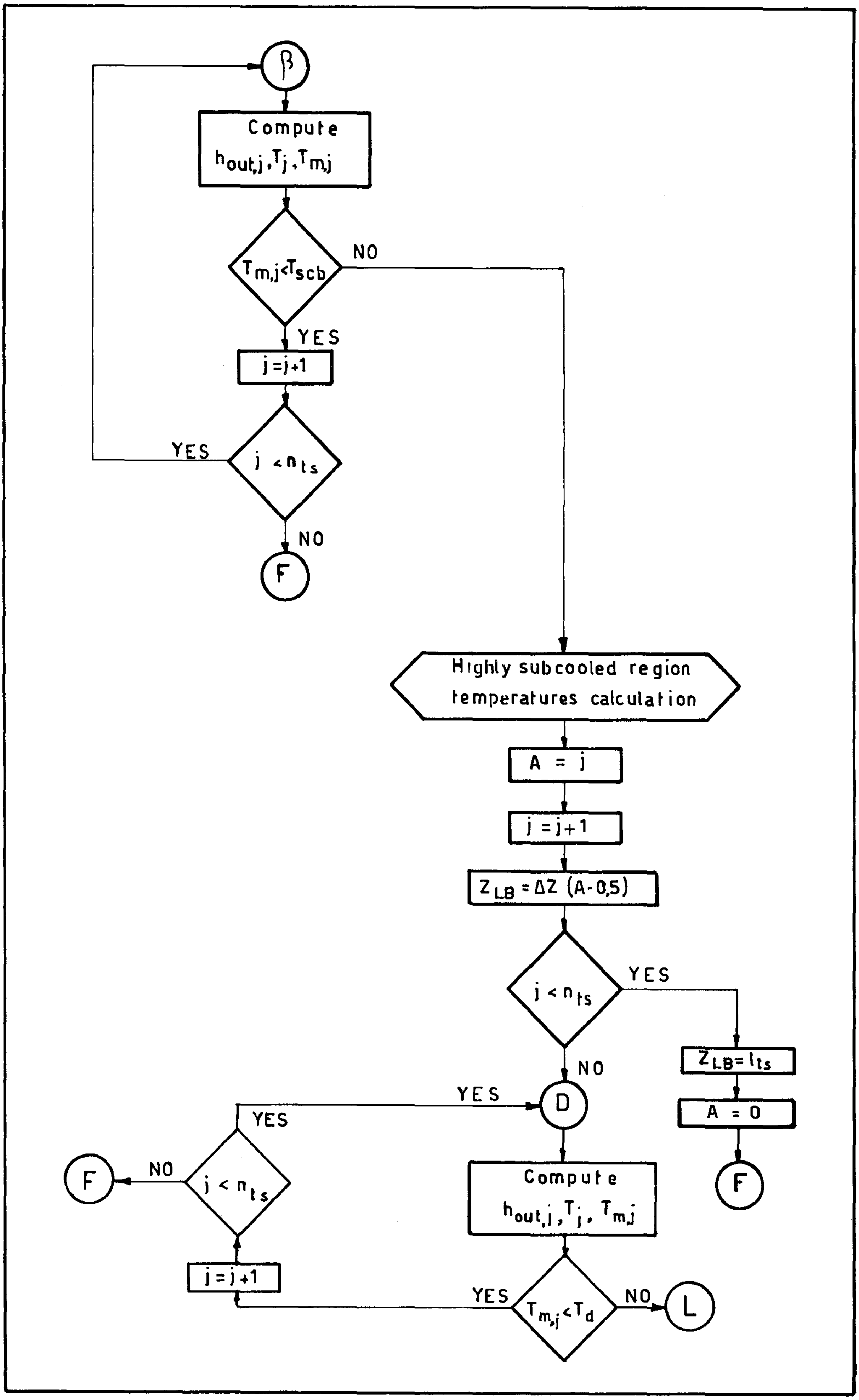
FUNCTION COMP computes the two phase multiplier, derived from the Lottes-Flinn model.

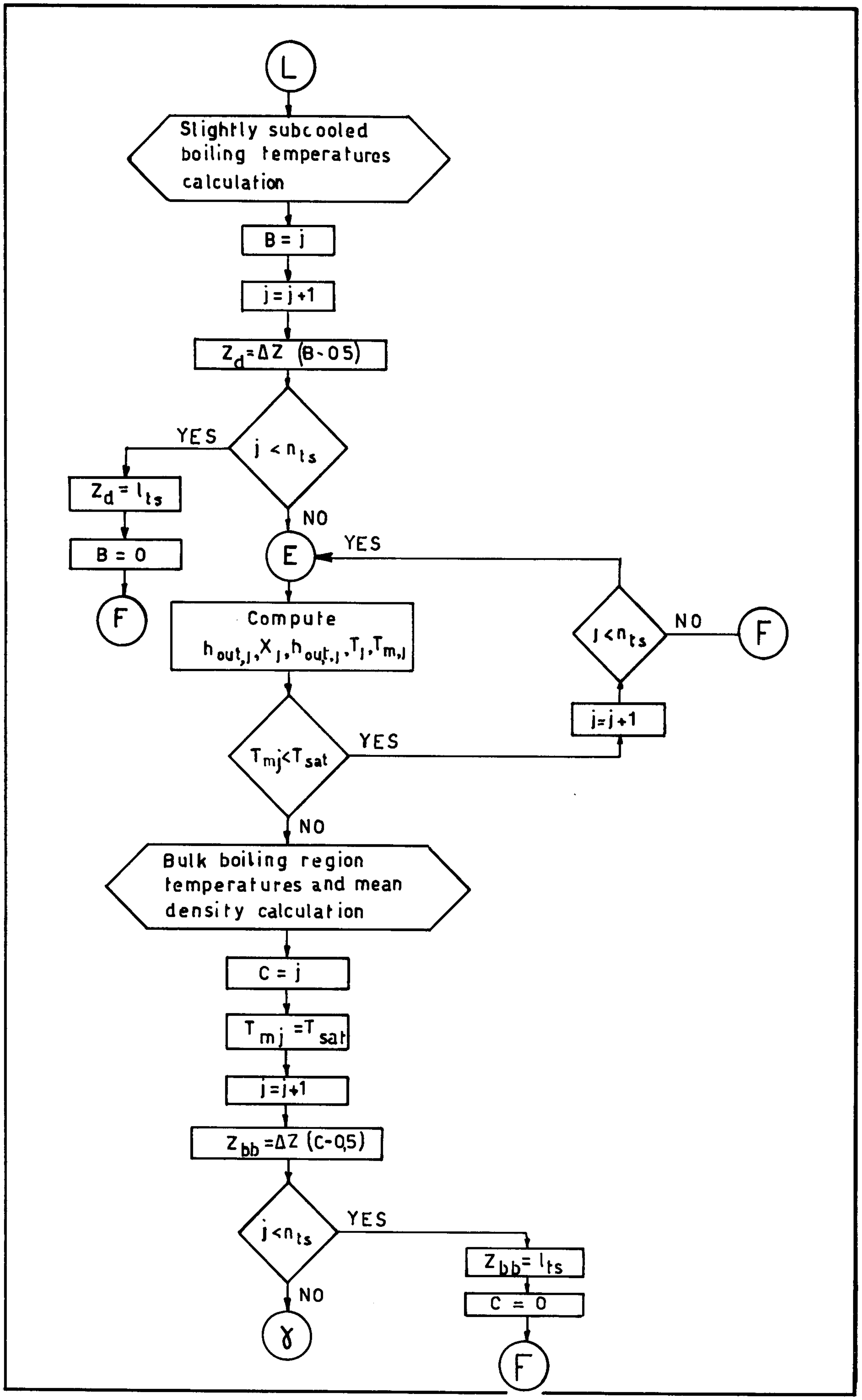
5. 2 Flow Chart

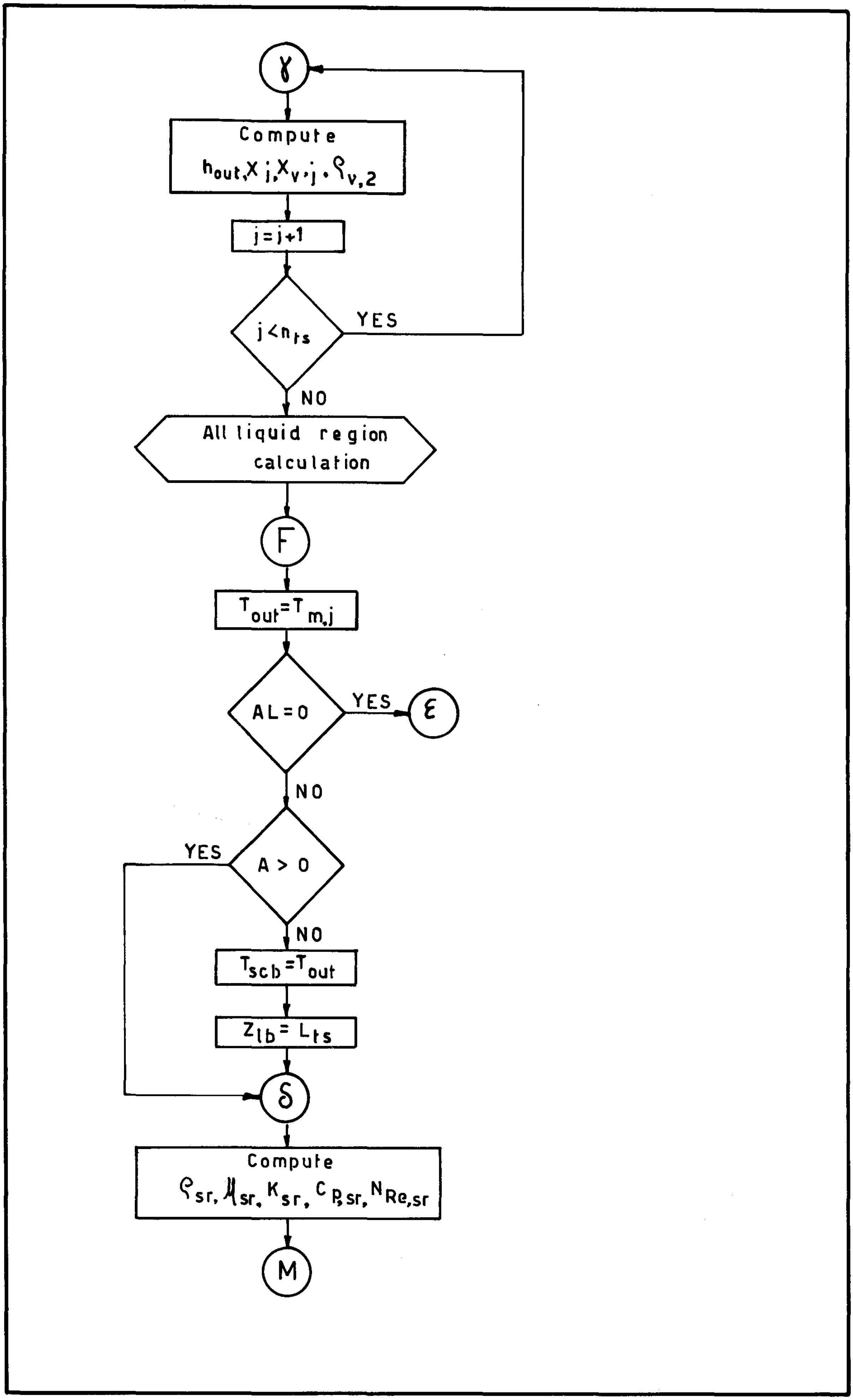
At following pages the flow chart of the program is shown. For symbols see the nomenclature at the end of report.

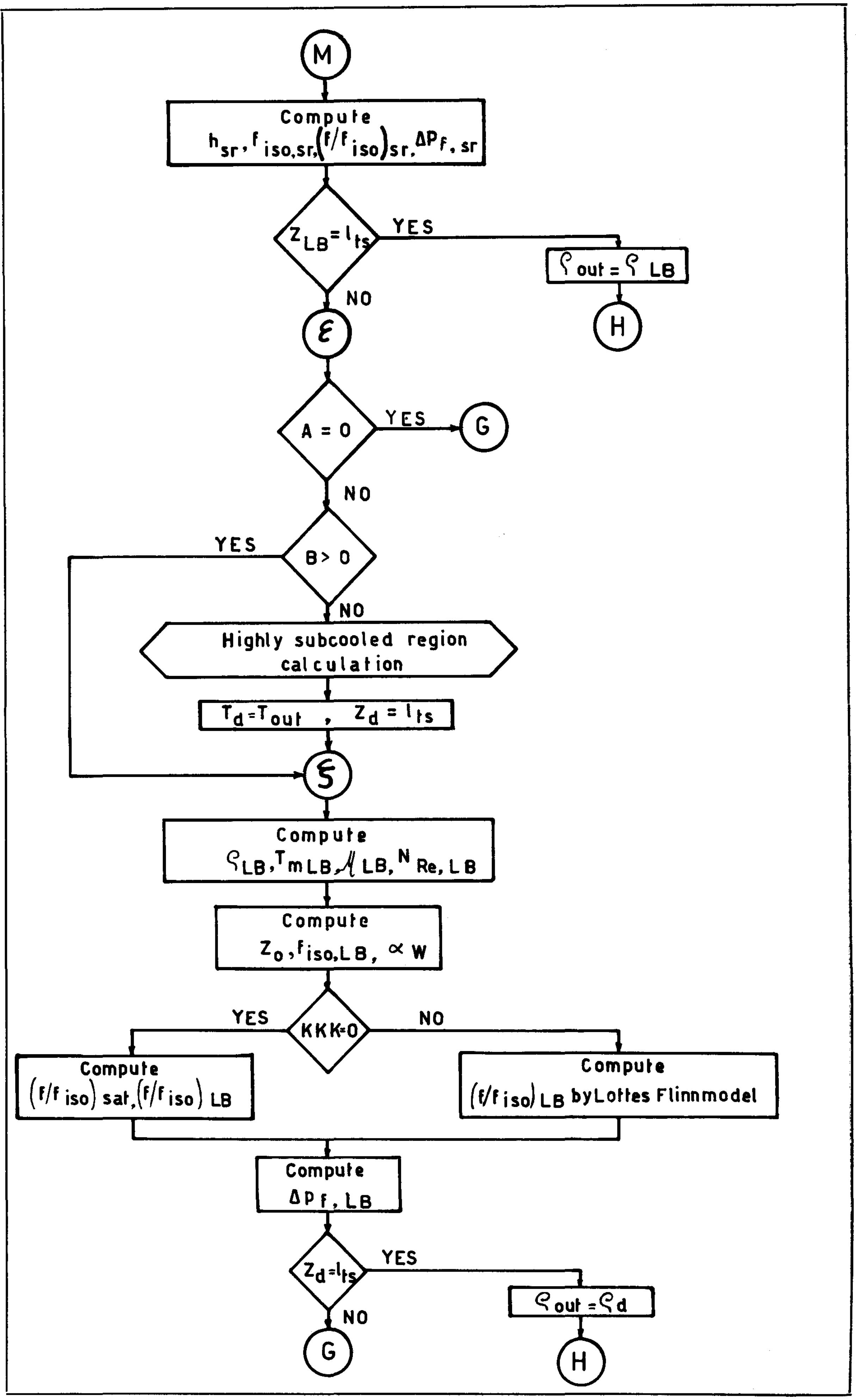

Start
Main Program
Read input data
$\Delta z = l_{ts}/n_{ts}$
A
MIMI= 0 KIND=1
Print input data
Compute constant quantities
CALL FLOW
$WXX = W_x$
KIND = 2
HS=0.2
Compute $T_{sat}, h_{in}, \Delta T_{sat}, \phi, \mu, \beta$ $T_{cl}, \rho_{in}, K_{in}, C_{pin}, \mu_{in}$ $\rho_{cl}, K_{cl}, C_{pcl}, \mu_{cl}$
Print $T_{sat}, h_{in}, \Delta T_{sat}, \phi, \mu, \beta$
Start internal loop
C


C
$Z_0=Z_1=Z_2=AL=A=B=C=0$
YES
KPUMP≠0
NO
CALL PUMP
α
Compute
$G_{ts}, G_{cl}, G_{exch}, G_{ris}$
Compute $T_{w,in}, T_{scb}$
Compute
$T_{w\,in}, N_{Re\,in}, h_{in}, \Delta T_{scb}, T_{scb}, \rho_{scb}$
Compute T_d
Compute
$V_{in}, \Delta T_d, T_d$
Compute liquid temperature distribution in test section
$T_{in} < T_{scb}$
NO
YES
All liquid region temperatures Calculation
AL=1
J=1
β
$Z_{LB}=0$
J =1
$T_{in} < T_d$
YES
NO
A = 1
D
$Z_d = 0$
B = 1
E

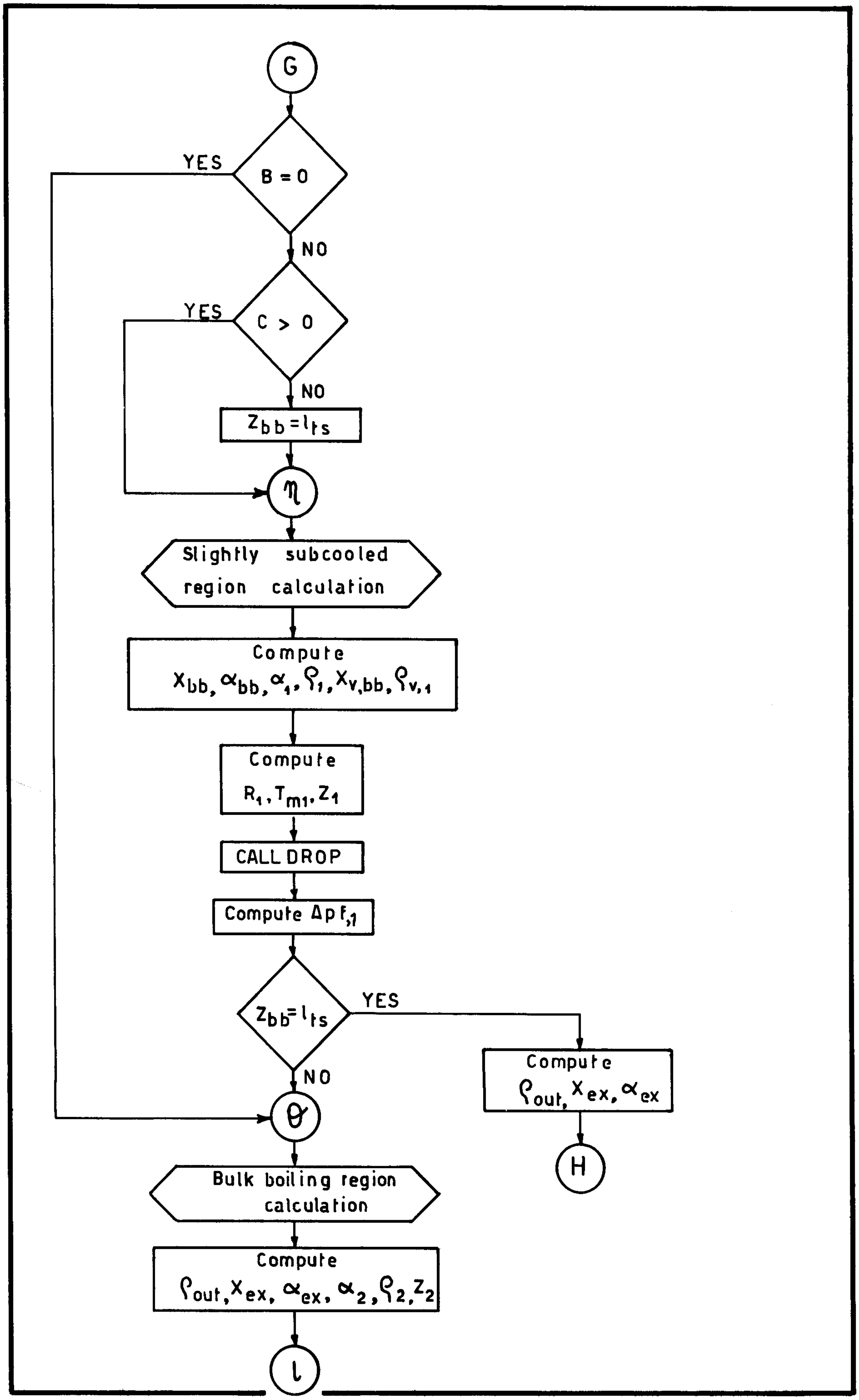

β
Compute
$h_{out,j}, T_j, T_{m,j}$
$T_{m,j} < T_{scb}$
NO
YES
$j = j+1$
YES
$j < n_{ts}$
NO
F
Highly subcooled region temperatures calculation
$A = j$
$j = j+1$
$Z_{LB} = \Delta Z\ (A-0,5)$
$j < n_{ts}$
YES
$Z_{LB} = l_{ts}$
$A = 0$
F
NO
D
YES
YES
$j < n_{ts}$
NO
F
Compute
$h_{out,j}, T_j, T_{m,j}$
$j = j+1$
YES
$T_{m,j} < T_d$
NO
L

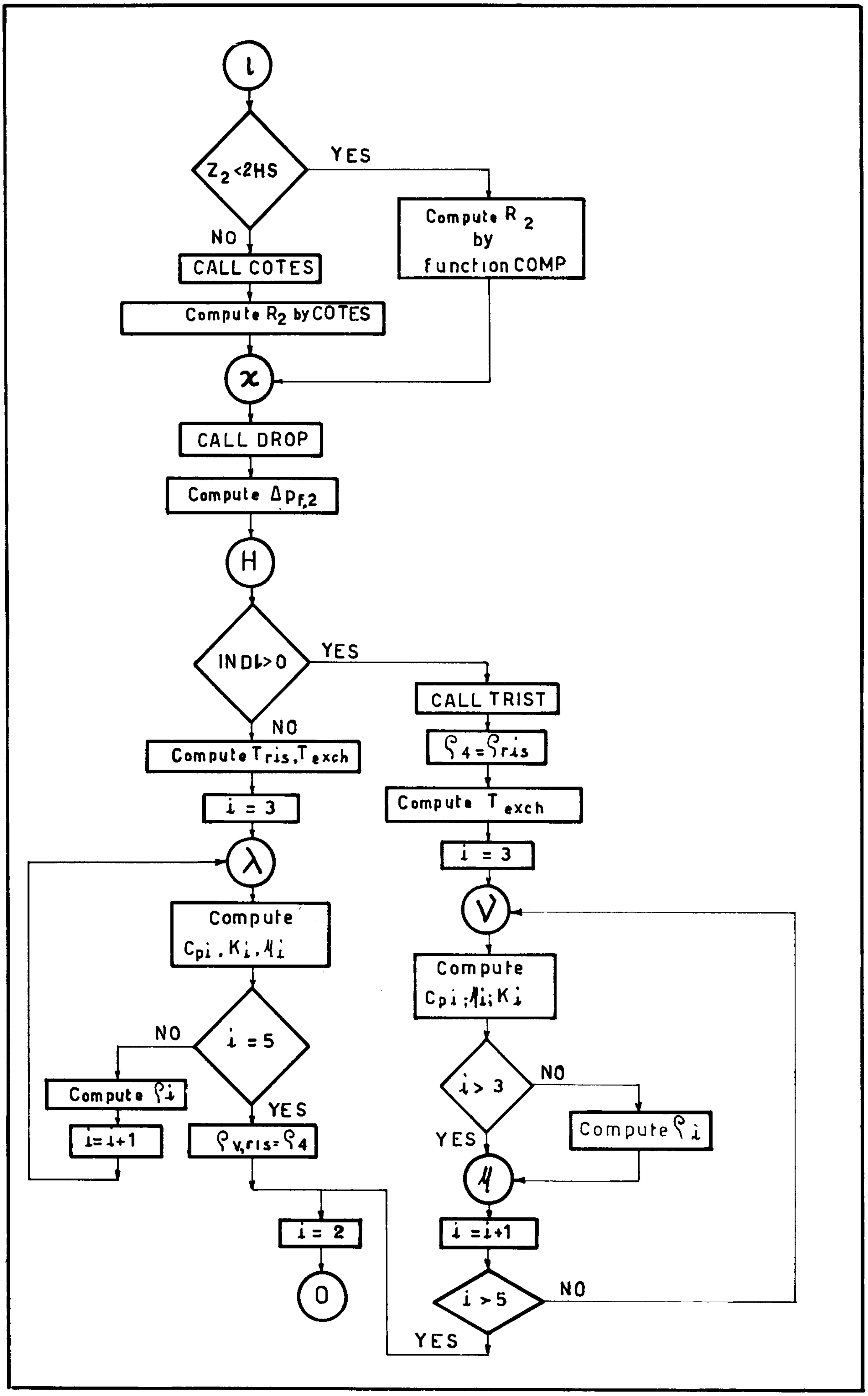

L
Slightly subcooled boiling temperatures calculation
B = j
j = j + 1
$Z_d = \Delta Z\ (B-0.5)$
$j < n_{ts}$
YES
NO
$Z_d = l_{ts}$
B = 0
F
E
YES
Compute $h_{out,j}, X_j, h_{out,j}, T_j, T_{m,j}$
$j < n_{ts}$
NO
F
j = j + 1
$T_{mj} < T_{sat}$
YES
NO
Bulk boiling region temperatures and mean density calculation
C = j
$T_{mj} = T_{sat}$
j = j + 1
$Z_{bb} = \Delta Z\ (C-0.5)$
$j < n_{ts}$
YES
NO
$Z_{bb} = l_{ts}$
C = 0
γ
F

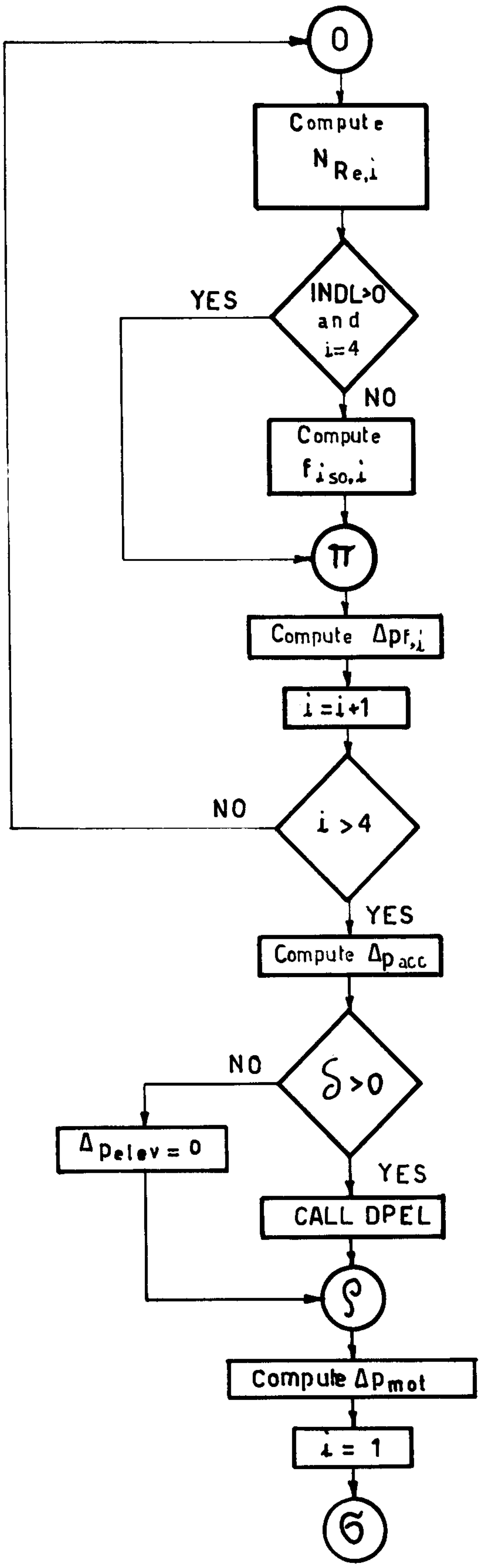

γ
Compute
$h_{out}, X_j, X_{v,j}, \rho_{v,2}$
$j = j+1$
$j < n_{ts}$
YES
NO
All liquid region calculation
F
$T_{out} = T_{m,j}$
$AL = 0$
YES
ε
NO
$A > 0$
YES
NO
$T_{scb} = T_{out}$
$Z_{lb} = L_{ts}$
δ
Compute
$\rho_{sr}, \mu_{sr}, K_{sr}, C_{p,sr}, N_{Re,sr}$
M

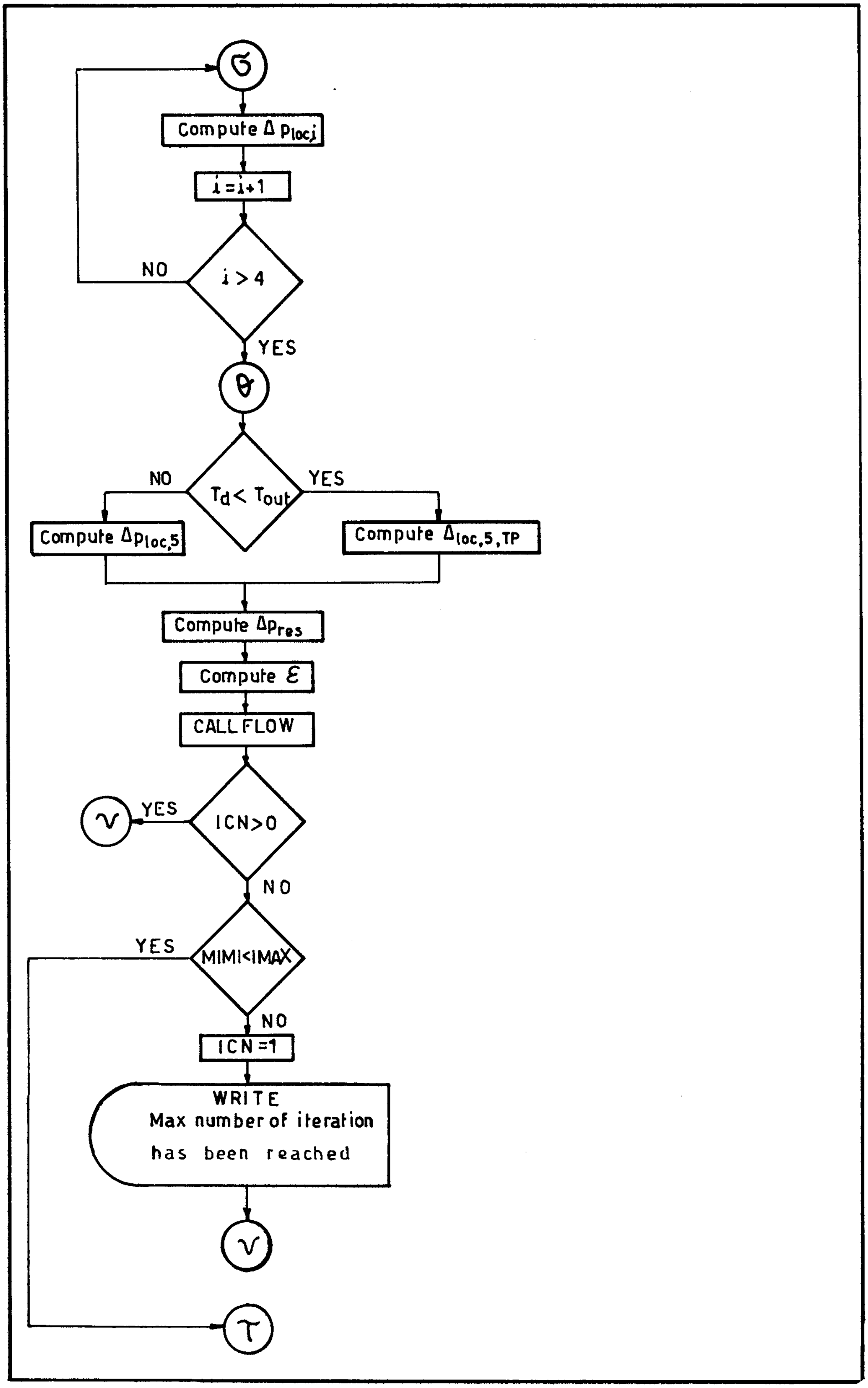


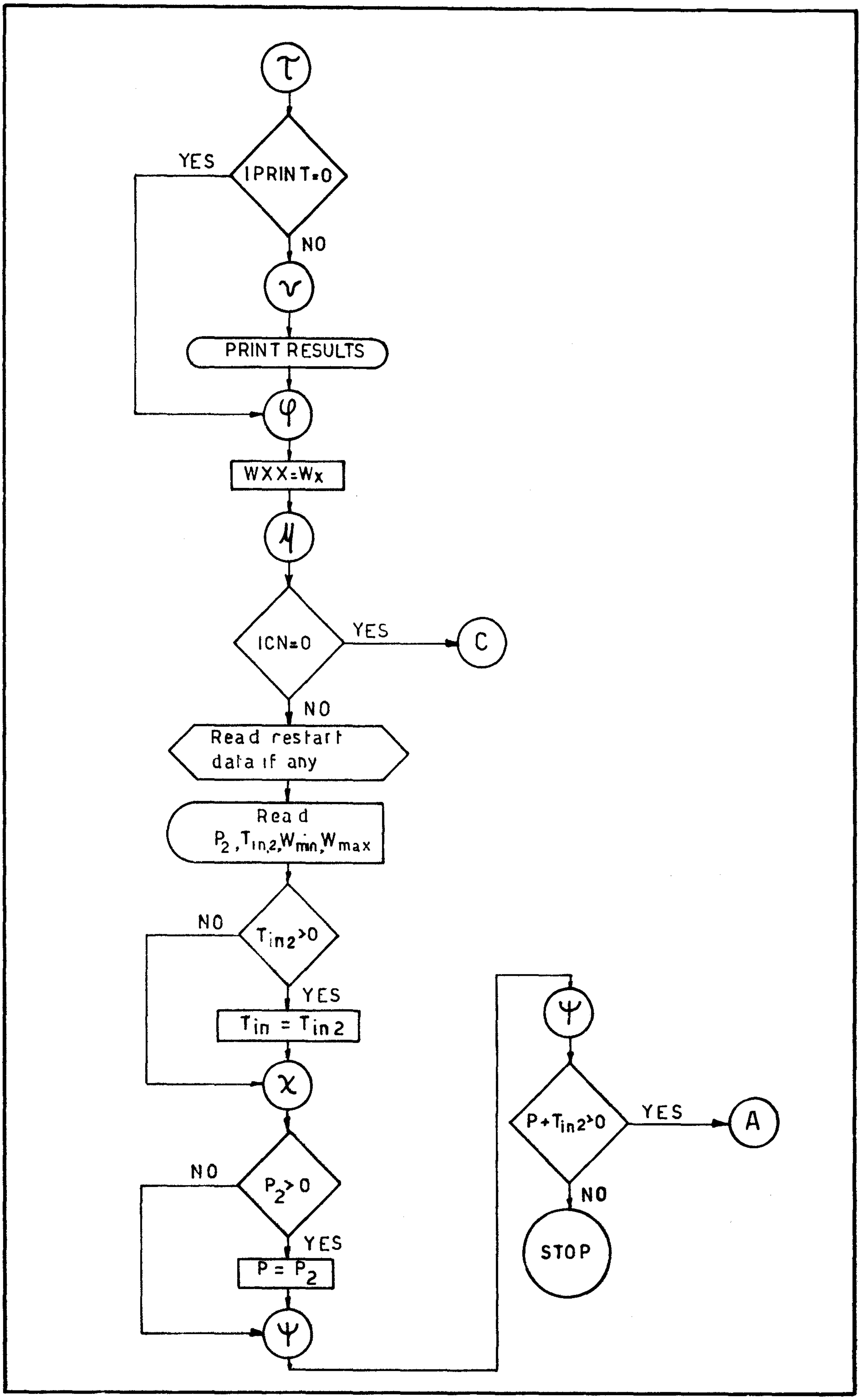
BAUDO - TORINO

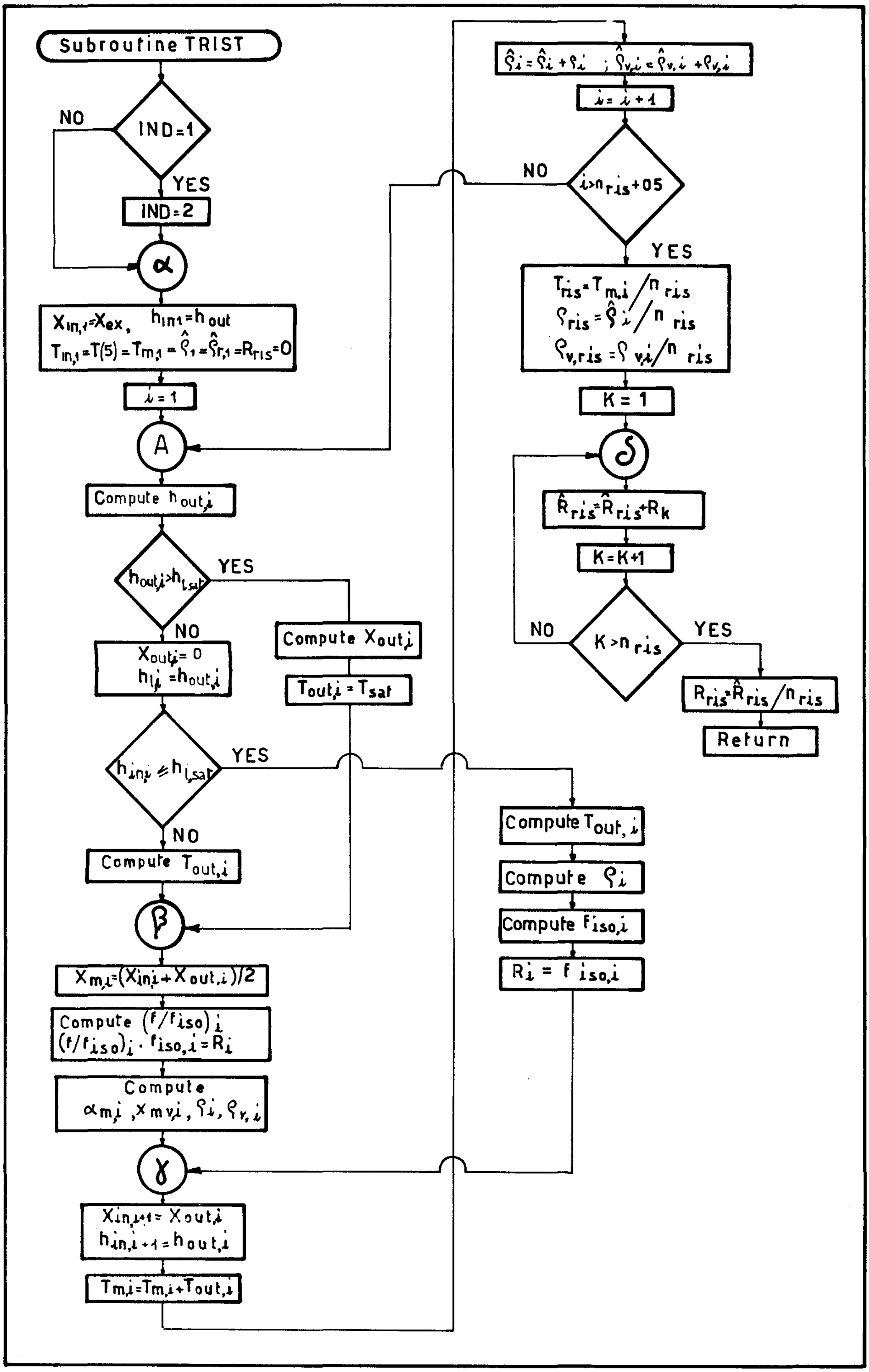

G
B = 0
YES
NO
C > 0
YES
NO
$Z_{bb} = l_{ts}$
η
Slightly subcooled region calculation
Compute $X_{bb}, \alpha_{bb}, \alpha_1, \rho_1, X_{v,bb}, \rho_{v,1}$
Compute R_1, T_{m1}, Z_1
CALL DROP
Compute $\Delta p_{f,1}$
$Z_{bb} = l_{ts}$
YES
NO
Compute $\rho_{out}, X_{ex}, \alpha_{ex}$
H
θ
Bulk boiling region calculation
Compute $\rho_{out}, X_{ex}, \alpha_{ex}, \alpha_2, \rho_2, Z_2$
ι

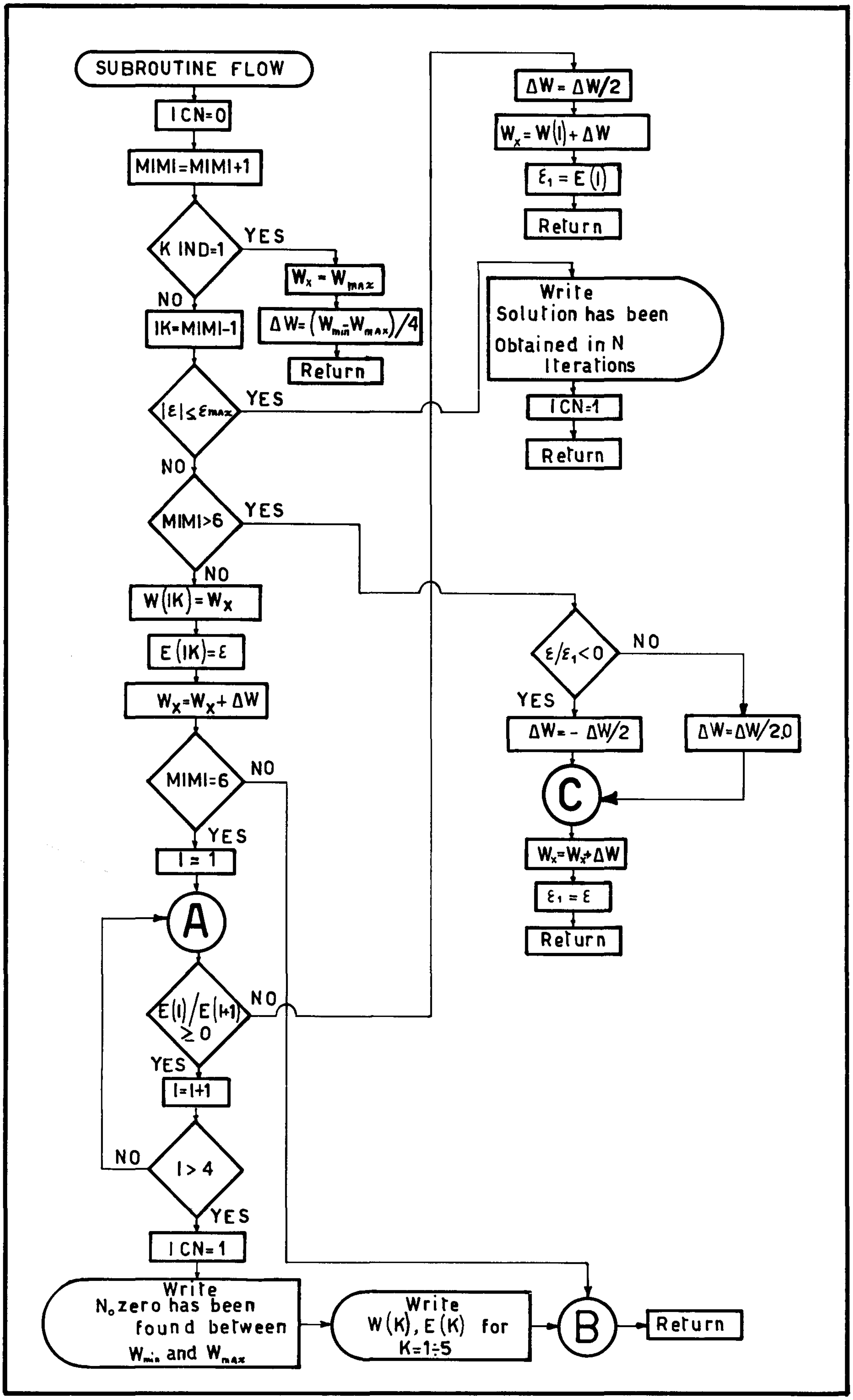

ι
$Z_2<2HS$
YES
Compute R_2 by function COMP
NO
CALL COTES
Compute R_2 by COTES
x
CALL DROP
Compute $\Delta p_{f,2}$
H
INDι>0
YES
CALL TRIST
$\rho_4=\rho_{ris}$
Compute T_{exch}
$i = 3$
V
Compute C_{pi}; μ_i; K_i
$i>3$
NO
Compute ρ_i
YES
μ
$i=i+1$
$i>5$
NO
YES
NO
Compute T_{ris}, T_{exch}
$i = 3$
λ
Compute C_{pi}, K_i, μ_i
$i=5$
NO
Compute ρ_i
$i=i+1$
YES
$\rho_{v,ris}=\rho_4$
$i = 2$
O


0
Compute $N_{Re,i}$
INDL>0 and $i=4$
YES
NO
Compute $f_{iso,i}$
π
Compute $\Delta p_{f,i}$
$i=i+1$
NO
$i>4$
YES
Compute Δp_{acc}
NO
$\delta>0$
$\Delta p_{elev}=0$
YES
CALL DPEL
ρ
Compute Δp_{mot}
$i=1$
σ


σ
Compute Δ $p_{loc,i}$
i = i+1
i > 4
NO
YES
θ
T_d < T_{out}
NO
YES
Compute $\Delta p_{loc,5}$
Compute $\Delta_{loc,5,TP}$
Compute Δp_{res}
Compute ε
CALL FLOW
ICN>0
YES
ν
NO
MIMI<IMAX
YES
NO
ICN =1
WRITE
Max number of iteration
has been reached
ν
τ


τ
IPRINT=0
YES
NO
ν
PRINT RESULTS
φ
WXX=Wx
μ
ICN=0
YES
C
NO
Read restart data if any
Read $P_2, T_{in,2}, W_{min}, W_{max}$
$T_{in2} > 0$
NO
YES
$T_{in} = T_{in2}$
χ
$P_2 > 0$
NO
YES
$P = P_2$
Ψ
Ψ
$P + T_{in2} > 0$
YES
A
NO
STOP


Subroutine TRIST
IND=1
NO
YES
IND=2
α
$X_{in,1}=X_{ex}$, $h_{in1}=h_{out}$
$T_{in,1}=T(5)=T_{m,1}=\hat{\rho}_1=\hat{\rho}_{r,1}=R_{ris}=0$
$i=1$
A
Compute $h_{out,i}$
$h_{out,i}>h_{l,sat}$
YES
NO
$X_{out,i}=0$
$h_{l,i}=h_{out,i}$
Compute $X_{out,i}$
$T_{out,i}=T_{sat}$
$h_{in,i}\leq h_{l,sat}$
YES
NO
Compute $T_{out,i}$
β
$X_{m,i}=(X_{in,i}+X_{out,i})/2$
Compute $(f/f_{iso})_i$
$(f/f_{iso})_i\cdot f_{iso,i}=R_i$
Compute
$\alpha_{m,i}$, $x_{mv,i}$, ρ_i, $\rho_{v,i}$
γ
$X_{in,i+1}=X_{out,i}$
$h_{in,i+1}=h_{out,i}$
$T_{m,i}=T_{m,i}+T_{out,i}$
$\hat{\rho}_i=\hat{\rho}_i+\rho_i$; $\hat{\rho}_{v,i}=\hat{\rho}_{v,i}+\rho_{v,i}$
$i=i+1$
NO
$i>n_{ris}+05$
YES
$T_{ris}=T_{m,i}/n_{ris}$
$\rho_{ris}=\hat{\rho}_i/n_{ris}$
$\rho_{v,ris}=\rho_{v,i}/n_{ris}$
$K=1$
δ
$\hat{R}_{ris}=\hat{R}_{ris}+R_k$
$K=K+1$
NO
$K>n_{ris}$
YES
$R_{ris}=\hat{R}_{ris}/n_{ris}$
Return
Compute $T_{out,i}$
Compute ρ_i
Compute $f_{iso,i}$
$R_i=f_{iso,i}$


SUBROUTINE FLOW
ICN=0
MIMI=MIMI+1
KIND=1
YES
$W_x = W_{max}$
$\Delta W = (W_{min} - W_{max})/4$
Return
NO
IK=MIMI-1
$|\varepsilon| \leq \varepsilon_{max}$
YES
NO
MIMI>6
YES
NO
$W(IK) = W_X$
$E(IK) = \varepsilon$
$W_X = W_X + \Delta W$
MIMI=6
NO
YES
I = 1
A
$E(I)/E(I+1) \geq 0$
NO
YES
I=I+1
I > 4
NO
YES
ICN=1
Write
N_o zero has been found between W_{min} and W_{max}
Write
W(K), E(K) for K=1÷5
B
Return
$\Delta W = \Delta W/2$
$W_x = W(I) + \Delta W$
$\varepsilon_1 = E(I)$
Return
Write
Solution has been Obtained in N Iterations
ICN=1
Return
$\varepsilon/\varepsilon_1 < 0$
NO
YES
$\Delta W = -\Delta W/2$
$\Delta W = \Delta W/2.0$
C
$W_x = W_x + \Delta W$
$\varepsilon_1 = \varepsilon$
Return

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.

```
C
C      *** L U P O *** A PROGRAM FOR SINGLE AND TWO-PHASE PRESSURE DROPS
C      CALCULATION IN PRESSURIZED WATER CLOSED LOOPS.
C      (JUNE,28,1967)  G.GAGGERO,B.PANELLA
C
C      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C      * * INPUT DATA
C
C      TITLE     PROBLEM TITLE (ANY ALPHAMERIC CHARACTER STRING)
C      IMAX      MAXIMUM NUMBER OF ITERATIONS
C      NEXC      NUMBER OF EXCHANGER PIPES IN PARALLEL
C      NZETA     NUMBER OF TEST SECTION LUMPS
C      INDL      RISER TEMPERATURE CALCULATION PARAMETER
C                INDL=1 RISER TEMPERATURE COMPUTED BY SUBROUTINE TRIST
C                INDL=0 RISER TEMPERATURE = TOUT-XTRIS
C      IPRINT    PRINTING PARAMETER
C                IPRINT=0 SHORT OUTPUT (LAST ITERATION RESULTS ONLY)
C                IPRINT=1 FULL OUTPUT
C      IDT       DELTAT-SAT CALCULATION PARAMETER
C                IDT=0 FORMULA (25) IS USED
C                IDT=1 JENS-LOTTES FORMULA IS USED
C      KKK       HIGHLY SUBCOOLED REGION CALCULATION PARAMETER
C                KKK=0 (F/FISO) COMPUTED ACCORDING TO MENDLER THEORY
C                KKK=1 (F/FISO) COMPUTED ACCORDING TO LOTTES-FLINN METHOD
C      P         PRESSURE OF THE SYSTEM (KG/CM**2)
C      EMAX      MAXIMUM RELATIVE ERROR
C      DPPUMP    PUMP HEAD (KG/CM**2)
C                IF DPPUMP LESS THAN ZERO IS SPECIFIED ,DPPUMP IS
C                EVALUATED BY SUBROUTINE PUMP
C      TSLT      TEST SECTION LENGTH     (CM)
C      CLLT      COLD LEG LENGTH         (CM)
C      EXLT      EXCHANGER LENGTH        (CM)
C      RILT      RISER LENGTH            (CM)
C      FITLT     OUTLET FITTING LENGTH   (CM)
C      TSD       TEST SECTION INTERNAL DIAMETER  (CM)
C      CLD       COLD LEG INTERNAL DIAMETER      (CM)
C      EXD       EXCHANGER INTERNAL DIAMETER     (CM)
C      RID       RISER INTERNAL DIAMETER         (CM)
C      ROUGTS    TEST SECTION ROUGHNESS COEFFICIENT
C      ROUGL     LOOP ROUGHNESS COEFFICIENT
C      SLIPR     SLIP RATIO
C      DELTA     ANGLE OF LOOP WITH RESPECT TO HORIZONTAL   RADIANT)
C      EPSI      BOWRING PARAMETER FOR LOCAL QUALITY CALCULATION
C      RD        BUBBLE AVERAGE RADIUS AT DETACHMENT
C      RLANDA    EVAPORATION HEAT  KCAL/KG)
C      ROG       SATURATED STEAM DENSITY (KG/CM**3)
C      EOUTES    SATURATED WATER ENTHALPY (KCAL/KG)
```

```
FORTRAN IV G LEVEL 0, MOD 0              MAIN                 DATE = 67233            15/28/49
                 C      EOUTG      SATURATED STEAM ENTHALPY (KCAL/KG)
                 C      BKIN       TEST SECTION INLET LOSS COEFFICIENT
                 C      BKCL       COLD LEG LOSS COEFFICIENT
                 C      BKEX       EXCHANGER LOSS COEFFICIENT
                 C      BKRI       RISER LOSS COEFFICIENT
                 C      BKOUT      TEST SECTION OUTLET SINGLE PHASE LOSS COEFFICIENT
                 C      BR         TEST SECTION OUTLET TWO PHASE LOSS COEFFICIENT
                 C                 IF BR=0 TWO PHASE LOSS COEFFICIENT IS EVALUATED BY USING
                 C                 ROMIE CORRELATION
                 C      XTCL       DIFFERENCE BETWEEN COLD LEG MEAN TEMPERATURE AND INLET
                 C                 TEMPERATURE,TIN  (CELSIUS DEGR.)
                 C      XTRIS      DIFFERENCE BETWEEN OUTLET TEMPERATURE AND RISER MEAN
                 C                 TEMPERATURE   CELSIUS DEGR.)
                 C      CC(I)      PUMP CHARACTERISTIC COEFFICIENTS
                 C      DD(1)      NUMBER OF RISER AXIAL LUMPS
                 C      DD(2)      RISER OVERALL HEAT TRANSFER COEFFICIENT  (KCAL/CM**2 SEC
                 C                  DEGR)
                 C      DD(3)      RISER SURFACE  (CM**2)
                 C      DD 4)      AIR TEMPERATURE  (CELSIUS DEGR)
                 C      POWKW      THERMAL POWER SUPPLIED TO SYSTEM  (KW)
                 C      WMIN       MINIMUM VALUE OF FLOW RATE  (KG/SEC)
                 C      WMAX       MAXIMUM VALUE OF FLOW RATE  (KG/SEC)
                 C
                 C      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                 C
0001                    COMMON P,G,ROUGTS,CR,ACCG,DPPUMP,DELTA,RO
0002                    COMMON /DAT1/PSI1,HFI,XE
C003                    COMMON/DAT2/D,EXCN,BR
0004                    COMMON /DAT3/XL,ZLB,ZD,ROSR,ROLB
0005                    COMMON/FLOWC/WMIN,WMAX,DE,EMAX,MIMI,KIND,ICN
0006                    COMMON/TRISTE/T,DD(6),XEX,EOUT,EOUTG,EOUTFS,ROG,WX,TSAT,PST1,ROSAT
                       *,ROUGL
                 C
0007                    DIMENSION TITLE(18),T(5),D(4),XL(4),RO(5),CK(5),CP(5),AMU(5),CC(6)
                       1,G(4),REYN(4),FISO(4),DPFRIC(4),DPLOC(5),LABEL(12),BK(5),TT(250),T
                       1M(250)
                 C
0008                    EQUIVALENCE(T(1),TIN),(T(2),TCL),(T(3),TEXC),(T(4),TRIS),(T(5),TOU
                       1T),(D(1),TSD),(D(2),CLD),(D(3),EXD),(D(4),RID),(XL(1),TSLT),(XL(2)
                       2,CLLT), XL 3),EXLT),(XL(4),RILT),(BK(1),BKIN),(BK(2),BKCL).(BK(3),
                       3BKEX),(BK(4),BKRI),(BK(5),BKOUT)
0009                    DATA LUPC/4HLUPO/
0010                    DATA LABEL/4HTEST,4H SEC,4HTION,4HCOLD,4H LEG,4H    ,4HEXCH,
                       *           4HANGE,4HR   ,4HRISE,4HR   ,4H    /
                 C
                 C
                 C      READ INPUT DATA
                 C
```

```
      READ  5,1001) (TITLE(I),I=1,18)
      READ (5,999) IMAX,NEXC,NZETA,INDL,IPRINT,IDT,KKK
      READ (5,1002) P,EMAX,DPPUMP
      READ  5,1002) TSLT,CLLT,EXLT,RILT,FITLT
      READ (5,1002) TSD,CLD,EXD,RID
      READ (5,1002) ROUGTS,ROUGL,SLIPR,DELTA
      READ  5,1002) EPSI,RD,RLANDA,ROG,EOUTFS,EOUTG
      READ (5,1002) BKIN,BKCL,BKEX,BKRI,BKOUT,BR
      READ (5,1002) XTCL,XTRIS
      KPUMP=0
      IF(DPPUMP)1,2,2
    1 READ (5,1002) (CC(I),I=1,6)
      KPUMP=1
    2 CONTINUE
      IF(INDL.EQ.0) GO TO 11
      READ (5,1002) (DD(I),I=1,6)
   11 CONTINUE
      READ (5,1002) POWKW,TIN,WMIN,WMAX
      POWER=POWKW*0.2388
      EXCN=NEXC
      ZETA=NZETA
      DELTAZ=TSLT/ZETA
      NRR=NZETA/5
      NSS=NZETA-NRR*5
      IF(BR.GT.0.0)GO TO 1400
      SIGMA=(TSD/RID)
      SIGMA=SIGMA*SIGMA
      BR=BKOUT-2.0*SIGMA*(1.0-SIGMA)
C
 1400 CONTINUE
      KIND=1
      MIMI=0
C
C     PRINT INPUT DATA
C
      WRITE (6,2001)
      WRITE  6,2002) (TITLE(I),I=1,18)
      WRITE (6,2003)
      IF(IMAX.LE.1) GO TO 6
    5 WRITE (6,2004)
      GO TO 7
    6 WRITE (6,2005)
    7 CONTINUE
      WRITE (6,2013) NZETA,NEXC,IMAX,IPRINT,INDL,IDT,KKK
      WRITE (6,2006)
      N=1
      DO 8 K=1,4
      WRITE (6,2007)  LABEL(N),LABEL(N+1),LABEL N+2),XL K),D K)
```

```
 0055                 8 N=N+3
 C056                   WRITE (6,2008) DELTA
 0057                   WRITE (6,2009) P,POWKW,TIN,WMIN,WMAX
 0058                   WRITE  6,2010) ROUGTS,ROUGL
 0059                   WRITE (6,2011) (BK(I),I=1,5),BR
 C06C                   WRITE (6,2012) SLIPR,EPSI,RD,RLANDA,ROG,XTCL,XTRIS,EQUTES,EQUTG
                  C
                  C     COMPUTE CONSTANT QUANTITIES
                  C
 0061                   CALL FLOW WX)
 0062                   WXX = WX
 C063                   KIND=2
 0064                   PGRK=3.1415926
 0065                   HS=0.2
 0066                   ACCG=981.0
 0067                   CR=1.0/3.0
 0068                   ALFAW=0.264*RD/TSD
 0069                   ETA=(14.0+0.1*P)*4.187E+3
 0070                   FI=POWER/(PGRK*TSLT*TSD)
 0071                   TSAT=SAT(DUMMY)
 0072                   ROSAT=DENSIT(TSAT)
 0073                   GAMSAT=ROG/ROSAT
 0074                   DROS=ROSAT-ROG
 0075                   DTIN=TSAT-TIN
 0076                   IF(IDT.EQ.0) GO TO 33
 0077                   DTSAT=62.620957*(FI**0.25)*EXP(-P/61.2414)
 0078                   BETA=62.745855*EXP(- P-1.0)/61.3497)
 0079                   GO TO 34
 0080                33 DTSAT=145.7*(FI**0.5)*EXP(-P/87.89)
 0081                   BETA=145.7*EXP(-P/87.89)*FI**0.25
 0082                34 CONTINUE
 0083                   TWSCB=TSAT+DTSAT
 0084                   TCL=TIN+XTCL
 0085                   EIN=ENTALP(TIN)
 0086                   WRITE (6,2030) TSAT,EIN,DTSAT,FI,ETA,BETA
 0087                   DO 10 I=1,2
 C088                   RO(I)=DENSIT(T(I))
 0089                   CK(I)=COND(T(I))
 0090                   CP I)=CSP T I))
 0091                   AMU(I)=VISCOS(T(I))
 0092                10 CONTINUE
 C093                   IF IPRINT.NE.0) GO TO 100
 0094                   WRITE (6,2045)
                  C
                  C     START INTERNAL LOOP
                  C
 0095               100 CONTINUE
 0096                   FFISSR=0.0
```

```
0097              FFISLB=0.0
0098              RMOLT1=0.0
0099              ZC=0.0
0100              RMOLT2=0.0
0101              Z1=0.0
0102              Z2=0.0
0103              ALFABB=0.0
0104              ALFAE=0.0
0105              XEX=0.0
0106              DROPSR=0.0
0107              DROPLB=0.0
0108              PDROP1=0.0
0109              PDROP2=0.0
0110              PFRICT=0.0
0111              ROM1=0.0
0112              ROM2=0.0
0113              ROLB=0.0
0114              ROMS=0.0
0115              ROMB=0.0
0116              AL=0.0
0117              A=0.0
0118              B=0.0
0119              C=0.0
0120              IF(KPUMP)4,4,3
0121            3 CALL PUMP(WX,CC,DPPUMP)
0122            4 CONTINUE
0123              DO 20 I=1,4
0124              G(I)=WX/(PGRK*D(I)**2)*4.0
0125              IF(I.EQ.3)G(I)=G(I)/EXCN
0126           20 CONTINUE
            C
            C     COMPUTE TWIN
            C
0127              REYN 1)=G 1)*D(1)/AMU(1)
0128              HIN=ACCA(REYN(1),AMU(1),CP(1),CK(1),TSD)
0129              TWIN=TIN+FI/HIN
0130              IF(TWIN.GT.TWSCB) TWIN=TWSCB
            C
            C     COMPUTE TD
            C
0131              V=G(1)/RO(1)
0132              DTD=ETA*FI/V
0133              TD=TSAT-DTD
            C
            C     COMPUTE LIQUID TEMPERATURE DISTRIBUTION IN TEST-SECTION
            C
0134              EINT1=EIN
0135              TT(1)=TIN
```

```
      BP=FI*DELTAZ/(G(1)*TSD)*4.0
      IF(TWIN.LT.TWSCB) GO TO 16
      J1=1
      ZLB=0.0
      TSCB=TWSCB-FI/HIN
      DTSCB=TSAT-TSCB
      ROTB=RO(1)
      TB=TIN
      IF(TIN.LT.TD)GO TO 49
      B=1.0
      ZD=0.0
      KKK=1
      ROTD=RO(1)
      TD=TIN
      GO TO 18
   49 A=1.0
      GO TO 19
   16 CONTINUE
C
C     ALL LIQUID REGION TEMPERATURES CALCULATION
C
      AL=1.0
      DO 40 J=1,NZETA
      EOUT1=EINT1+BP
      TT(J+1)=EOUT1-(1.6634E+0+1.5323E-10*(EOUT1**4.4229448))
      TM(J)=(TT J)+TT(J+1))/2.0
      EINT1=EOUT1
      CKZ=COND(TM(J))
      CPZ=CSP TM J))
      AMUZ=VISCOS(TM(J))
      REYNZ=G(1)*D(1)/AMUZ
      TWALL=TM J)+FI/ACCA(REYNZ,AMUZ,CPZ,CKZ,TSD)
      IF(TWALL.GE.TWSCB) GO TO 46
   40 CONTINUE
      GO TO 60
C
C     HIGHLY SUBCOOLED LOCAL BOILING REGION TEMPERATURES CALCULATION
C
   46 A=J
      TSCB=TM(J)
      DTSCB=TSAT-TSCB
      TB=TSCB
      ROTB=DENSIT(TSCB)
      J1=J+1
      ZLB=DELTAZ*(A-0.5)
      IF(J1.LE.NZETA) GO TO 19
      ZLB=TSLT
      A=0.0
```

```
            GO TO 60
       19   CONTINUE
            DO 48 J=J1,NZETA
            EOUT1=EINT1+BP
            TT(J+1)=EOUT1-(1.6634E+0+1.5323E-10*(EOUT1**4.4229448))
            TM(J)=(TT(J)+TT(J+1))/2.0
            EINT1=EOUT1
            IF(TM(J)-TD)48,51,51
       48   CONTINUE
            GO TO 60
C
C           SLIGHTLY SUBCOOLED LOCAL BOILING REGION TEMPERATURES CALCULATION
C
       51   B=J
            J1=J+1
            ZD=DELTAZ*(B-0.5)
            IF(J1.LE.NZETA) GO TO 18
            ZD=TSLT
            B=0.0
            GO TO 60
       18   CONTINUE
            Z=ZD
            DO 52 J=J1,NZETA
            EOUT1=EINT1+BP
            Z=Z+DELTAZ
            XX=PGRK*TSD/(WX*RLANDA*(1.0+EPSI))*FI*(Z-ZD)
            EOUTF= EOUT1-EOUTG*XX)/(1.0-XX)
            TT(J+1)=EOUTF-(1.6634+1.5323E-10*(EOUTF**4.4229448))
            TM(J)=(TT(J)+TT(J+1))/2.0
            EINT1=EOUT1
            IF(TM(J)-TSAT)52,54,54
       52   CONTINUE
            ZBB=TSLT
            GO TO 60
C
C           BULK BOILING REGION TEMPERATURES AND MEAN DENSITY CALCULATION
C
       54   C=J
            TM J)=TSAT
            AJ=NZETA-J
            J1=J+1
            ZBB=DELTAZ* C-0.5)
            IF(J1.LE.NZETA) GO TO 35
            ZBB=TSLT
            C=0.0
            GO TO 60
       35   CONTINUE
            DENT=EOUTG-EOUTFS
```

```
 0220              DO 55 J=J1,NZETA
 0221              EOUT1=EINT1+BP
 0222              XXB= EOUT1-EOUTFS)/DENT
 0223              XXV=XXB/(XXB*(1.0-GAMSAT)+GAMSAT)
 0224              TM(J)=TSAT
 0225              ROMB=ROMB+ROSAT-XXV*DROS
 0226              EINT1=EOUT1
 0227           55 CONTINUE
 0228              ROMB=ROMB/AJ
            C
            C
            C      ALL LIQUID REGION CALCULATION
            C
 0229           60 TOUT=TM(J)
 0230              RO 5)=DENSIT TOUT)
 0231              EOUT=EOUT1
 0232              IF(AL.EQ.0.0) GO TO 27
 0233              IF A.GT.0.0) GO TO 61
 0234           62 TSCB=TOUT
 0235              ROTB=DENSIT(TSCB)
 0236              ZLB=TSLT
 0237           61 TMM=(TSCB+TIN)/2.0
 0238              ROTM=DENSIT(TMM)
 0239              ROSR=(RO(1)+ROTM+ROTB)/3.0
 0240              AMTB=VISCOS(TSCB)
 0241              AMSR=(AMU(1)+AMTB)/2.0
 0242              CPTB=CSP(TSCB)
 0243              CPSR=(CP(1)+CPTB)/2.0
 0244              CKTB=COND TSCB)
 0245              CKSR=(CK(1)+CKTB)/2.0
 0246              REYSR=G(1)*D(1)/AMSR
 0247              HSR=ACCA REYSR,AMSR,CPSR,CKSR,TSD)
 0248              FISOSR=5.5E-3*(1.0+(ROUGTS*2.0E+4+1.0E+6/REYSR)**CR)
 0249              FFISSR=1.0-1.8E-3*FI/HSR
 0250              DROPSR=(FISOSR*FFISSR*G(1)**2*ZLB/TSD)/(2.0*ACCG*ROSR)
 0251              PFRICT=PFRICT+DROPSR
 0252              IF(ZLB.EQ.TSLT) GO TO 600
 0253           27 IF(A.EQ.0.0) GO TO 28
 0254              IF(B.GT.0.0) GO TO 190
            C
            C      HIGHLY SUBCOOLED BOILING REGION CALCULATION
            C
 0255          300 TD=TOUT
 0256              ZD=TSLT
 0257          190 ROTD=DENSIT(TD)
 0258              TMLB=(TD+TB)/2.0
 0259              ROLB= ROTB+ROTD)/2.0
 0260              AMTD=VISCOS(TD)
```

```
      AMLB=(AMTB+AMTD)/2.0
      REYLB=G 1)*D 1)/AMLB
      FISOLB=5.5E-3*(1.0+(ROUGTS*2.0E+4+1.0E+6/REYLB)**CR)
      IF(KKK.EQ.0) GO TO 770
      GAMMAO=ROG/ROTD
      PSIO=SLIPR*GAMMAO
      PP=1.0/(1.0-ALFAW*(1.0-PSIO))
      FFISLB=CR* 1.0+PP+PP**2)
      GO TO 771
  770 FFISAT=19.579*(P**(-0.5931697))*(1.0+0.95868E-1*G(1)**(-0.919337))
      FFISLB=1.0+ FFISAT-1.0)*(TMLB-TSCB)/DTSCB
      XFSLB=(FFISAT-1.0)*(TD-TSCB)/DTSCB
  771 CONTINUE
      ZO=ZD-ZLB
      DROPLB=(FISOLB*FFISLB*G(1)**2* ZO /TSD)/(2.0*ACCG*ROLB)
      PFRICT=PFRICT+DROPLB
      IF(ZD .EQ.TSLT) GO TO 500
   28 IF(B.EQ.0.0) GO TO 29
      IF(C.GT.0.0) GO TO 21
C
C     SLIGHTLY SUBCOOLED BOILING REGION CALCULATION
C
   22 ZBB=TSLT
   21 XBB=PGRK*TSD/(WX*RLANDA*(1.0+EPSI))*FI*(ZBB-ZD)
      GAMMA1=ROG/RO(5)
      PSI1=SLIPR*GAMMA1
      ALFABB=XBB/(XBB+PSI1*(1.0-XBB))
      ALFABB=ALFABB+ALFAW
      ALFAM1= ALFABB+ALFAW)/2.0
      RO1=(ROTD+RO(5))/2.0
      ROM1=(1.0-ALFAM1)*RO1+ALFAM1*ROG
      XBM=XBB/2.0
      XBV=XBM/(XBM*(1.0-GAMMA1)+GAMMA1)
      ROMS=RO1-XBV*(RO1-ROG)
      IF(KKK.EQ.0) GO TO 772
      PP=1.0/(1.0-ALFABB*(1.0-PSI1))
      RMOLT1=CR*(1.0+PP+PP**2)
      GO TO 773
  772 PP=1.0/(1.0-(ALFABB-ALFAW)*(1.0-PSI1))
      RMOLT1=XFSLB+CR*(1.0+PP+PP*PP)
  773 CONTINUE
      TM1=(TOUT+TD)/2.0
      Z1=ZBB-ZD
      CALL DROP(TM1,Z1,RMOLT1,ROM1,TSD,PDROP1,FIS1)
      PFRICT=PFRICT+PDROP1
      IF(ZBB.EQ.TSLT) GO TO 400
C
C     BULK BOILING REGION CALCULATION
```

```
C
   29 CONTINUE
   23 Z2=TSLT-ZBB
      HFI=PGRK*TSD*FI/(WX*RLANDA)
      XE=(EOUT-EOUTFS)/(EOUTG-EOUTFS)
      XEX=XE
      RO2=RO(5)
      ALFAE=XE/(XE+PSI1*(1.0-XE))
      ROOUT=(1.0-ALFAE)*RO2+ALFAE*ROG
      ALFAM2=(ALFAE+ALFABB)/2.0
      ROM2=(1.0-ALFAM2)*RO2+ALFAM2*ROG
      ALFAEX=ALFAE
      IF(Z2-2.0*HS)24,24,25
   24 RMOLT2=(COMP(ZBB)+COMP(TSLT))/2.0
      GO TO 26
   25 CALL COTFS(ZBB,TSLT,HS,RMOLT2)
      RMOLT2=RMOLT2/Z2
   26 CALL DROP(TSAT,Z2,RMOLT2,ROM2,TSD,PDROP2,FIS2)
      PFRICT=PFRICT+PDROP2
      GO TO 700
  400 ROOUT= 1.0-ALFABB)*RO(5)+ALFABB*ROG
      XEX=XBB
      ALFAEX=ALFABB
      GO TO 700
  500 ROOUT=ROTD
      GO TO 700
  600 ROOUT=ROTB
  700 CONTINUE
      IF(INDL.GT.0) GO TO 12
      TRIS=TOUT-XTRIS
      TEXC=(TRIS+TCL)/2.0
      DO 820 I=3,5
      CK(I)=COND(T(I))
      CP(I)=CSP(T(I))
      AMU(I)=VISCOS(T(I))
      IF(I.EQ.5) GO TO 820
      RO(I)=DENSIT(T(I))
  820 CONTINUE
      ROMR=RO 4)
      GO TO 13
   12 CONTINUE
      PST1=ROG/RO(5)*SLIPR
      CALL TRIST(INDL,RORIS,ROMR,FISO(4))
      RO(4)=RORIS
      TEXC=(TRIS+TCL)/2.0
      DO 15 I=3,5
      CK(I)=COND(T(I))
      CP(I)=CSP(T(I))
```

```
      AMU(I)=VISCOS(T(I))
      IF(I.GT.3) GO TO 15
      RO I)=DENSIT T(I))
   15 CONTINUE
   13 CONTINUE
      DO 30 I=2,4
      REYN(I)=G(I)*D(I)/AMU(I)
      IF(INDL.GT.0.AND.I.EQ.4) GO TO 14
      FISO(I)=5.5E-3*(1.0+(ROUGL*2.0E+4+1.0E+6/REYN(I))**CR)
   14 DPFRIC(I)=FISO(I)*(XL(I)/D(I))*(G(I)**2)/(2.0*ACCG*RO(I))
      PFRICT=PFRICT+DPFRIC(I)
   30 CONTINUE
      DPACC=DP(ROOUT)
      IF(DELTA)710,710,720
  710 DPELEV=0.0
      GO TO 730
C     COMPUTE DPELEV ACCORDING TO THE ENERGY CONSERVATION THEOREM
  720 CONTINUE
      CALL DPEL(Z0,Z1,Z2,FITLT,RCMS,ROMB,ROMR,DPELEV)
  730 DPMOT=DPPUMP+DPELEV
      DO 50 I=1,4
      DPLOC(I)=DPL(BK(I),I)
   50 CONTINUE
      IF(TD-TOUT)750,800,300
  750 CONTINUE
      DPLOC 5)=DPLU XEX,ALFAEX,GAMMA1,ROOUT)
      GO TO 900
  800 DPLOC(5)=DPL(BK(5),5)
  900 DPLOCT=DPLOC 1)+DPLOC(2)+DPLOC(3)+DPLOC(4)+DPLOC(5)
      DPRT=DPACC+PFRICT+DPLOCT
      DE=(DPRT-DPMOT)/DPMOT
      CALL FLOW WX)
      IF(ICN.GT.0) GO TO 1100
      IF(MIMI.LE.IMAX) GO TO 1180
      ICN=1
      WRITE (6,2043)
      GO TO 1100
 1180 CONTINUE
      IF(IPRINT.NE.0) GO TO 1100
      DROPTS=DROPSR+DROPLB+PDROP1+PDROP2
      WRITE (6,2044) WXX,TOUT,DPMOT,DPRT,DROPTS,DPLOC(5),FFISSR,FFISLB,R
     1MOLT1,RMOLT2
      GO TO 1150
C
C
C     PRINT RESULTS
C
 1100 CONTINUE
```

```
      WRITE (6,2031) WXX
      WRITE (6,2032)
      N=4
      DO 222 K=2,4
      WRITE (6,2033)  LABEL(N),LABEL(N+1),LABEL(N+2),T(K),G K),REYN K),F
     1ISO(K)
  222 N=N+3
      IF(AL.EQ.0.0) GO TO 1251
      WRITE (6,2034)        TSCB,ROTB,ROSR,AMTB,AMSR,CPTB,CPSR,CKTB,CKSR
      WRITE (6,2035) REYSR,HSR,FISOSR,FFISSR
 1251 IF(A.EQ.0.0) GO TO 1252
      WRITE (6,2036) TD,TMLB,ROTD,ROLB,AMTD,AMLB,REYLB,FISOLB,FFISLB
 1252 IF(B.EQ.0.0) GO TO 1253
      WRITE (6,2037) ALFAW,TM1,ALFAM1,RO1,ROM1,FIS1,RMOLT1
 1253 IF(C.EQ.0.0) GO TO 1260
      WRITE (6,2038) ALFAM2,RO2,ROM2,FIS2,RMOLT2
 1260 CONTINUE
      WRITE (6,2014)WXX
      WRITE (6,2015)
      WRITE (6,2016)TWIN,TSCB,TD,TOUT
      WRITE (6,2017)
      WRITE (6,2018)ZLB,Z0,Z1,Z2
      WRITE  6,2019)
      WRITE (6,2020)XEX,ALFABB,ALFAE
      WRITE (6,2021)
      WRITE (6,2022)
      WRITE (6,2023) DPFRIC(2),DPFRIC(3),DPFRIC(4),DROPSR,DROPLB,PDROP1,
     1PDROP2,PFRICT
      WRITE (6,2024)
      WRITE (6,2025) (DPLOC(I),I=1,5),DPLOCT
      WRITE (6,2026)DPACC
      WRITE (6,2028) DPPUMP,DPELEV
      WRITE (6,2027)DPRT
      WRITE (6,2029) DPMOT
      WRITE (6,2039) DE
      WRITE (6,2040)
      DO 3315 K=1,NRR
      NR1=K+NRR
      NR2=NR1+NRR
      NR3=NR2+NRR
      NR4=NR3+NRR
 3315 WRITE (6,2041) TM(K),TM(NR1),TM(NR2),TM(NR3),TM(NR4)
      IF(NSS.EQ.0)GO TO 3316
      NR4=NR4+1
      WRITE (6,2042) (TM(I),I=NR4,NZETA)
 3316 CONTINUE
 1150 WXX = WX
      IF(ICN.EQ.0) GO TO 100
```

```
FORTRAN IV G LEVEL 0, MOD 0                MAIN               DATE = 67233           15/28/49
                     C
                     C          READ RESTART DATA IF ANY
                     C
 0439                 1200 READ (5,1002) POWER2,TIN2,WMIN,WMAX
 0440                      IF TIN2)1250,1250,1262
 0441                 1262 TIN=TIN2
 0442                 1250 IF(POWER2)1270,1270,1280
 0443                 1280 POWER=POWER2*0.2388
 0444                      POWKW=POWER2
 0445                 1270 IF(TIN2+POWER2)1300,1300,1400
 0446                 1300 STOP
                     C
                     C          INPUT-OUTPUT FORMATS
                     C
 0447                  999 FORMAT (10I5)
 0448                 1001 FORMAT (18A4)
 0449                 1002 FORMAT  6E12.0)
 0450                 2001 FORMAT (1H1,30X,23H* * *  L U P O  * * *   )
 0451                 2002 FORMAT (1H0,18A4/)
 0452                 2003 FORMAT (1H0,17HTYPE OF PROBLEM  )
 0453                 2004 FORMAT (1H+,19X,54HSTEADY STATE FLOW RATE AND PRESSURE DROPS CALCU
                          1LATION    )
 0454                 2005 FORMAT (1H+,19X,29HPRESSURE DROPS CALCULATION    )
 0455                 2006 FORMAT (1H0,14H* * INPUT DATA //22X,11HLENGTH (CM),13X,13HDIAMETER
                          1 (CM)//)
 0456                 2007 FORMAT  2X,3A4,6X,F11.3,13X,F9.3)
 0457                 2008 FORMAT (1H0,10H ANGLE    =F10.5,7H  (RAD))
 0458                 2009 FORMAT (1H0,9H PRESSURE,9X,F16.5,12H  (KG/CM**2)/2X,5HPOWER,13X,F1
                          15.5,12H   KW)       /2X,17HINLET TEMPERATURE,1X,F15.5,17H  (CELSIUS
                          2 DEGR.)/2X,9HMIN. FLOW,9X,F15.5,10H  (KG/SEC)/2X,9HMAX. FLOW,9X,F1
                          35.5,10H  (KG/SEC))
 0459                 2010 FORMAT (1H0,29H TEST SECTION ROUGNESS COEF. ,3X,F10.6/2X,26HLOOP P
                          1IPES ROUGNESS COEF.  ,5X,F10.6/)
 0460                 2011 FORMAT (1H0,27H LOCAL PRESSURE LOSS COEFF.//2X,21HK-TEST SECT. ENT
                          1RANCE,1X,F10.5/2X,10HK-COLD LEG,12X,F10.5/2X,11HK-EXCHANGER,11X,F1
                          20.5/2X,7HK-RISER,15X,F10.5/2X,17HK-TEST SECT. EXIT,5X,F10.5/2X,18H
                          3BK-TEST SECT. EXIT,4X,F10.5//)
 0461                 2012 FORMAT (1H0,11H SLIP RATIO,18X,F10.5/2X,7HEPSILON,21X,F10.5/2X,27H
                          1BUBBLE RADIUS AT DETACHMENT ,1X,F10.5,6H  (CM)/2X,17HHEAT EVAPORAT
                          2ION ,11X,F10.5,11H   KCAL/KG)/1X,15H STEAM DENSITY ,14X,F10.5,12H
                          3 (KG/CM**3)/1X,9H DELTATCL ,20X,F10.5,17H  (CELSIUS DEGR.)/1X,11H
                          4DELTATRIS ,18X,F10.5,17H  (CELSIUS DEGR.)/2X,24HSATURATED WATER EN
                          5THALPY,4X,F10.5,11H  (KCAL/KG)/2X,14HSTEAM ENTHALPY,14X,F10.5,11H
                          6 (KCAL/KG))
 0462                 2013 FORMAT (1H0,7HNZETA =I4,2X,6HNEXC =I3,2X,6HIMAX =I3,2X,8HIPRINT =I
                          12,2X,6HINDL =I2,2X,5HIDT =I2,2X,5HKKK =I2)
 0463                 2014 FORMAT (1H1,10X,39HRESULTS OF CALCULATION FOR FLOW RATE  =F10.6,10
                          1H  (KG/SEC)//)
```

```
 0464              2015 FORMAT  4H0* *,13H TEMPERATURES,17H  (CELSIUS DEGR.))
 0465              2016 FORMAT (1H0,17H INLET WALL TEMP.,7X,E13.6/2X,12HTEMP. AT ZLB,11X,E
                       113.6/2X,11HTEMP. AT ZD,12X,E13.6/2X,12HOUTLET TEMP.,11X,E13.6/)
 0466              2017 FORMAT (5H0* * , 7HLENGTHS,6H  (CM))
 0467              2018 FORMAT(2H0 ,22HALL LIQUID FLOW REGION,12X,E13.6/2X,31HHIGHLY SUBCO
                       1OLED BOILING REGION, 3X,E13.6/2X,33HSLIGHTLY SUBCOOLED BOILING REG
                       2ION, 1X,E13.6/2X,19HBULK BOILING REGION,15X,E13.6/)
 0468              2019 FORMAT (5H0* * ,27HQUALITY AND VOID FRACTION  )
 0469              2020 FORMAT(2H0 ,12HEXIT QUALITY,29X,E13.6/2X,20HVOID FRACTION AT ZBB,2
                       11X,E13.6/2X,40HVOID FRACTION AT THE END OF BULK BOILING, 1X,E13.6/
                       2)
 0470              2021 FORMAT (5H0* * ,14HPRESSURE DROPS,12H   KG/CM**2)/)
 0471              2022 FORMAT(2H0 ,10HFRICTION   )
 0472              2023 FORMAT (1H0,9H COLD LEG,21X,E13.6/2X, 9HEXCHANGER,20X,E13.6/2X, 5H
                       1RISER,24X,E13.6/2X,17HALL LIQUID REGION,12X,E13.6/2X,23HHIGHLY SUB
                       2COOLED REGION, 6X,E13.6/2X,25HSLIGHTLY SUBCOOLED REGION, 4X,E13.6/
                       32X,19HBULK BOILING REGION,10X,E13.6/2X,28HTOTAL FRICTION PRESSURE
                       4DROP, 1X,E13.6/)
 0473              2024 FORMAT (1H0,8H LOCAL   )
 0474              2025 FORMAT (1H0,6H INLET, 24X,E13.6/2X, 8HCOLD LEG, 21X,E13.6/2X, 9HEX
                       1CHANGER,20X,E13.6/2X, 5HRISER,24X,E13.6/2X, 6HOUTLET,23X,E13.6/2X,
                       225HTOTAL LOCAL PRESSURE DROP, 4X,E13.6/)
 0475              2026 FORMAT (1H0,14H ACCELERATION   ,16X,E13.6)
 0476              2027 FORMAT (1H0,20H TOTAL PRESSURE DROP,9X,E14.6/)
 0477              2028 FORMAT (1H0,20H FLUID PRESSURE RISE,9X,E14.6/2X, 14HELEVATION HEAD
                       1,15X,E13.6/)
 0478              2029 FORMAT (1H0,21H TOTAL ELEVATION HEAD,9X,E13.6/)
 0479              2030 FORMAT (/// 32H ***  CONSTANT QUANTITIES VALUES //1H ,5H TSAT,15X,
                       *1PE13.6/1H ,15H INLET ENTHALPY  ,5X,E13.6/1H ,13H (DELTA-T)SAT ,7X
                       *,E13.6/1H ,10H HEAT FLUX ,10X,E13.6/1H ,4H ETA ,16X,E13.6/1H ,5H B
                       *ETA ,15X,E13.6)
 0480              2031 FORMAT (1H1,45H  * * * INTERMEDIATE RESULTS FOR FLOW RATE  =F13.6,
                       *2X,8H(KG/SEC)//)
 0481              2032 FORMAT (//23X,1HT,14X,1HG,11X,4HREYN,10X,4HFISO//)
 0482              2033 FORMAT (2X,3A4,2X,1P4E14.7)
 0483              2034 FORMAT (//22H * * ALL LIQUID REGION //                 2X,4HTSCB
                       *,18X,F14.7/2X,20HRO(TSCB) , RO-MEAN  ,2X,E14.7,5X,E14.7/2X,20HMU(T
                       *SCB) , MU-MEAN  ,2X,E14.7,5X,E14.7/2X,20HCP(TSCB) , CP-MEAN  ,2X,E
                       *14.7,5X,E14.7/2X,20HK(TSCB)   , K-MEAN   ,2X,E14.7,5X,E14.7)
 0484              2035 FORMAT (2X,10HREYN-MEAN ,12X,E14.7/2X,6HH-MEAN,16X,E14.7/2X,5HFISO
                       * ,17X,E14.7/2X,6HF/FISO,16X,F14.7)
 0485              2036 FORMAT  //36H *.* HIGHLY SUBCOOLED BOILING REGION //2X,2HTD,20X,F1
                       *4.7/2X,6HT-MEAN,16X,F14.7/2X,16HRO(TD) , RO-MEAN,6X,E14.7,5X,E14.7
                       */2X,16HMU(TD) , MU-MEAN,6X,E14.7,5X,E14.7/2X,10HREYN-MEAN ,12X,E14
                       *.7/2X,5HFISO ,17X,E14.7/2X,6HF/FISO,16X,E14.7)
 0486              2037 FORMAT (//38H * * SLIGHTLY SUBCOOLED BOILING REGION //2X,5HALFAW,1
                       *7X,E14.7/2X,6HT-MEAN,16X,F14.7/2X,9HALFA-MEAN,13X,E14.7/2X,14HRO-M
                       *EAN LIQUID,8X,E14.7/2X,13HRO-MEAN FLUID,9X,E14.7/2X,4HFISO,18X,E14
```

```
            *.7/2X,6HF/FISO,16X,E14.7)
      2038 FORMAT (//24H * * BULK BOILING REGION //2X,9HALFA-MEAN,13X,E14.7/2
          *X,14HRO-MEAN LIQUID,8X,E14.7/2X,13HRO-MEAN FLUID,9X,F14.7/2X,4HFIS
          *0,18X,E14.7/2X,6HF/FISO,16X,E14.7)
      2039 FORMAT (1H0,15H RELATIVE ERROR,15X,E13.6)
      2040 FORMAT (1H1,30X,26H TEST SECTION TEMPERATURES  //)
      2041 FORMAT (5X,5F15.3)
      2042 FORMAT (65X,F15.3)
      2043 FORMAT (1H0,37H** MAX.ITER.NUMBER HAS BEEN REACHED**)
      2044 FORMAT (1H0,F10.6,5X,F7.3,3X,4E13.5,F9.5,3(2X,F9.5))
      2045 FORMAT (1H1,2X,9HFLOW RATE,3X,10HEXIT TEMP.,4X,9HDELTAPMOT,4X,9HDE
          1LTAPRES,4X,9HDELTAPETS,3X,10HDELTAPEXIT,2X,9HF/FISO-SR,2X,9HF/FISO
          2-HS,2X,9HF/FISO-SS,2X,9HF/FISO-BB//)
 C
           END
```

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LEVEL 2 FEB 67                                OS/360  FORTRAN H                                DATE  67.233/15.32.27
          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
    ISN 0002                   SUBROUTINE FLOW(WX)
                     C
                     C         SUBROUTINE FLOW
                     C         COMPUTES AT EACH ITERATION STEP THE NEW VALUE OF FLOW RATE
                     C         BY USING THE METHOD OF HALVING
                     C         ICN     CONVERGENCE INDICATOR
                     C                 ICN=1  WHEN CONVERGENCE TEST IS SATISFIED
                     C
    ISN 0003                   DIMENSION W(5),ERR(5)
    ISN 0004                   COMMON/FLOWC/WMIN,WMAX,DE,EMAX,MIMI,KIND,ICN
    ISN 0005                   ICN=0
    ISN 0006                   MIMI=MIMI&1
    ISN 0007                   GO TO  1,2),KIND
    ISN 0008                 1 WX=WMAX
    ISN 0009                   DW=-(WMAX-WMIN)*0.25
    ISN 0010                   RETURN
    ISN 0011                 2 CONTINUE
    ISN 0012                   IK=MIMI-1
    ISN 0013                   IF(ABS(DE).LE.EMAX)GO TO 100
    ISN 0015                   IF(MIMI.GT.6)GO TO 7
    ISN 0017                   W(IK)=WX
    ISN 0018                   ERR(IK)=DE
    ISN 0019                   WX=WX&DW
    ISN 0020                   IF(MIMI.LT.6)GO TO 3
    ISN 0022                   DO 4 I=1,4
    ISN 0023                   II=I
    ISN 0024                   IF(ERR(I)/ERR(I&1))5,4,4
    ISN 0025                 4 CONTINUE
    ISN 0026                   ICN=1
    ISN 0027                   WRITE (6,1100)
    ISN 0028              1100 FORMAT (1H1,2X,52H* * NO ZERO HAS BEEN FOUND BETWEEN  WMIN - WMAX
                             1 **     ///)
    ISN 0029                   WRITE (6,1200) (W(K),ERR(K),K=1,5)
    ISN 0030              1200 FORMAT (10X,E15.7,5X,E15.7)
    ISN 0031                 3 CONTINUE
    ISN 0032                   RETURN
    ISN 0033                 5 CONTINUE
    ISN 0034                   DW=DW/2.0
    ISN 0035                   WX=W(II)&DW
    ISN 0036                   E1=ERR(II)
    ISN 0037                   RETURN
    ISN 0038                 7 CONTINUE
    ISN 0039                   IF DE/E1)11,12,12
    ISN 0040                11 DW=-DW/2.0
    ISN 0041                   GO TO 13
    ISN 0042                12 DW=DW/2.0
    ISN 0043                13 WX=WX&DW
    ISN 0044                   E1=DE
    ISN 0045                   RETURN
```

EURATOM - C.C.R. ISPRA - CETIS

```
ISN 0046         100 WRITE (6,1000) IK
ISN 0047        1000 FORMAT (1H0,38H* * * SOLUTION HAS BEEN OBTAINED IN  =,I5,2X,18HITE
                    1RATIONS  * * *  )
ISN 0048             ICN=1
ISN 0049             RETURN
ISN 0050             END
```

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LEVEL 2 FEB 67                                   OS/360  FORTRAN H                                    DATE  67.233/15.32.39

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
    ISN 0002                  SUBROUTINE TRIST(IND,RS,RR,FFRS)
                        C
                        C     SUBROUTINE TRIST
                        C     COMPUTES TEMPERATURE DISTRIBUTION AND FRICTION MULTIPLIER IN RISER
                        C     WHEN INDL=1
                        C
                        C
                        C     DD 1) = RISER LUMPS NUMBER
                        C     DD(2) = OVERALL HEAT TRANSFER COEFFICIENT (KCAL/(CM**2.SEC.DEGR.))
                        C     DD(3) = TOTAL SURFACE (CM**2)
                        C     DD(4) = AIR TEMPERATURE (C DEGR.)
                        C
    ISN 0003                  COMMON P,G,ROUGTS,CR,ACCG,DPPUMP,DELTA,RO
    ISN 0004                  COMMON/DAT2/D,EXCN,BR
    ISN 0005                  COMMON/TRISTE/T(5),DD(6),XEX,EOUT,EOUTG,EFSAT,ROG,WX,TSAT,PST1,ROS
                             1AT,ROUGL
    ISN 0006                  DIMENSION G 4),D(4),RO(5),FR(100)
    ISN 0007                  DATA C1,C2,C3/1.6634,1.5323E-10,4.4229448/
    ISN 0008                  GO TO (10,20),IND
    ISN 0009               10 CONTINUE
    ISN 0010                  IND=2
    ISN 0011                  GAM=ROG/ROSAT
    ISN 0012                  S=DD 3)/DD 1)
    ISN 0013                  DEN=EOUTG-EFSAT
    ISN 0014                  NLUMP=DD(1)&0.5
    ISN 0015               20 CONTINUE
    ISN 0016                  X1=XEX
    ISN 0017                  E1=EOUT
    ISN 0018                  T1=T 5)
    ISN 0019                  T2M=0.0
    ISN 0020                  FFRS=0.0
    ISN 0021                  RS=0.0
    ISN 0022                  RR=0.0
    ISN 0023                  DO 1 I=1,NLUMP
    ISN 0024                  E2=E1-DD(2)*S*(T1-DD(4))/WX
    ISN 0025                  IF(E2.GT.EFSAT) GO TO 2
    ISN 0027                  X2=0.0
    ISN 0028                  EL=E2
    ISN 0029                  IF(E1.LE.EFSAT) GO TO 3
    ISN 0031                  T2=EL-(C1&C2*(EL**C3))
    ISN 0032                5 XM=(X1&X2)/2.0
    ISN 0033                  FR(I)=(1.0&(1.0-PST1)/PST1*XM)**2
    ISN 0034                  REYN=G(4)*D(4)/VISCOS(T2)
    ISN 0035                  FR(I)=FR(I)*5.5E-3*(1.0&(ROUGL*2.0E&4&1.0E&6/REYN)**CR)
    ISN 0036                  ALFAM=XM/(XM&PST1*(1.0-XM))
    ISN 0037                  RRS=(1.0-ALFAM)*ROSAT&ALFAM*ROG
    ISN 0038                  XMV=XM/(XM*(1.0-GAM)&GAM)
    ISN 0039                  RRR=ROSAT-XMV*(ROSAT-ROG)
    ISN 0040                  GO TO 4
```

```
  2 CONTINUE
    X2=(E2-EFSAT)/DEN
    T2=TSAT
    GO TO 5
  3 CONTINUE
    T2=EL-(C1&C2*(EL**C3))
    RRS=DENSIT(T2)
    RRR=RRS
    REYN=G(4)*D(4)/VISCOS(T2)
    FR(I)=5.5E-3*(1.0&(ROUGL*2.0E&4&1.0E&6/REYN)**CR)
  4 CONTINUE
    T1=T2
    X1=X2
    E1=E2
    T2M=T2M&T2
    RS=RS&RRS
    RR=RR&RRR
  1 CONTINUE
    T(4)=T2M/DD(1)
    RS=RS/DD 1)
    RR=RR/DD(1)
    DO 30 K=1,NLUMP
    FFRS=FFRS&FR K)
 30 CONTINUE
    FFRS=FFRS/DD(1)
    RETURN
    END
```

```
LEVEL 2 FEB 67                                    OS/360  FORTRAN H                                      DATE  67.233/15.29.41
         COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
  ISN 0002                  REAL FUNCTION VISCOS(T)
                  C
                  C         FUNCTION VISCOS(T)
                  C         COMPUTES VISCOSITY OF LIQUID WATER AS A FUNCTION OF PRESSURE,P
                  C         AND TEMPERATURE,T
                  C         P     IN UNITS (KG/CM**2)
                  C         T     IN UNITS (CELSIUS DEGR.)
                  C         VISCOS IN UNITS (KG*SEC/CM**2)
                  C
  ISN 0003                  COMMON P
  ISN 0004                  DIMENSION B 4)
  ISN 0005                  DATA B          /8.0784E&3,1.650E-6,1.369E-8,2.7316E&2/
  ISN 0006                  AMU0=1.0/(-120.0&2.1482*((T-8.435)&SQRT(B(1)&(T-8.435)**2)))
  ISN 0007                  TA=B(4)&T
  ISN 0008                  VISCOS=AMU0*10.0**(B(2)*P/TA&B(3)*P*ALOG10(TA))*1.0E-3
  ISN 0009                  RETURN
  ISN 0010                  END
```

```
LEVEL 2 FEB 67                                     OS/360  FORTRAN H                                       DATE  67.233/15.30.1
          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
    ISN 0002                  REAL FUNCTION DENSIT(T)
                     C
                     C        FUNCTION DENSIT(T)
                     C
                     C        COMPUTES DENSITY OF LIQUID WATER AS A FUNCTION OF PRESSURE,P
                     C        AND TEMPERATURE,T
                     C        P     IN UNITS (KG/CM**2)
                     C        T     IN UNITS (CELSIUS DEGR.)
                     C        DENSIT  IN UNITS (KG/CM**3)
                     C
    ISN 0003                  COMMON P
    ISN 0004                  DIMENSION C(15)
    ISN 0005                  DATA C          /3.122199E&8,1.999850E&5,1.362926E&16,1.500705E&0
                             1,-2.9411764E-1,1.139706E-4,9.949927E-5,6.537134E-1,7.241165E-5,7.6
                             276621E-1,1.052358E-11,1.310268E&1,1.5108E-5,-6.244398E&8,1.19991E&
                             36/
    ISN 0006                  SIGMA=P/225.65
    ISN 0007                  TAU=(T&273.16)/647.3
    ISN 0008                  STAU=TAU**2
    ISN 0009                  ETAU=TAU**6
    ISN 0010                  UTAU=3.7E&8-C(1)*STAU-C(2)/ETAU
    ISN 0011                  W=UTAU&SQRT(1.72*UTAU**2&C(3)*(SIGMA-C(4)*TAU))
    ISN 0012                  RRO=(0.417*W**(&C(5))-C(6)&TAU*C(7)&((C(8)-TAU)**2)*(C(9)&C(10)*(C
                             1(8)-TAU)**8)-C(11)*(62.5&C(12)*SIGMA&SIGMA**2)/ C 13)&TAU**11))*1.
                             20E&6
    ISN 0013                  DENSIT=1.0/RRO
    ISN 0014                  RETURN
    ISN 0015                  END
```

```
LEVEL 2 FEB 67                                OS/360  FORTRAN H                                DATE  67.233/15.30.34
          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
  ISN 0002              REAL FUNCTION SAT(DUMMY)
                C
                C       FUNCTION SAT
                C       COMPUTES SATURATION TEMPERATURE OF WATER AS A FUNCTION
                C       OF PRESSURE,P
                C       P     IN UNITS (KG/CM**2)
                C       SAT   IN UNITS (CELSIUS DEGR.)
                C
  ISN 0003              COMMON P
  ISN 0004              DIMENSION E(6)
  ISN 0005              DATA E          /2.4878413E&00,-1.9500182E-2,1.1430815E-4,-4.12447
                       117E-7,8.0614939E-10,-6.4499527E-13/,EE/175.2781/
  ISN 0006              SAT=EE
  ISN 0007              DO 1 I=1,6
  ISN 0008              IE=I
  ISN 0009              SAT=SAT&E(I)*P**IE
  ISN 0010            1 CONTINUE
  ISN 0011              RETURN
  ISN 0012              END
```

```
LEVEL 2 FEB 67                          OS/360  FORTRAN H                                    DATE  67.233/15.
          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
    ISN 0002               REAL FUNCTION COND(T)
                    C
                    C      FUNCTION COND(T)
                    C      COMPUTES THERMAL CONDUCTIVITY OF LIQUID WATER AS A FUNCTION
                    C      OF PRESSURE,P AND TEMPERATURE,T
                    C      P     IN UNITS (KG/CM**2)
                    C      T     IN UNITS (CELSIUS DEGR.)
                    C      COND  IN UNITS (KCAL/SEC*CM*CELSIUS DEGR.)
                    C
    ISN 0003               COMMON P
    ISN 0004               DIMENSION A 5,6)
    ISN 0005               DATA A                 /1.6806856E-6,-2.450802E-8,3.3679544E-10
                          1,-1.608719E-12,2.5338636E-15,5.8667508E-9,-9.6963733E-10,1.3521684
                          2E-11,-6.5034530E-14,1.0285862E-16,1.0325614E-10,-1.3922641E-11,1.9
                          3871537E-13,-9.6757872E-16,1.5458723E-18,5.5015828E-13,-8.911722E-1
                          44,1.3140626E-15,-6.4968997E-18,1.0494531E-20,6.1230411E-16,-2.5432
                          5297E-16,3.9380525E-18,-1.9851484E-20,3.2450692E-23,1.0776624E-18,2
                          6.5778153E-19,-4.3069694E-21,2.2279553E-23,-3.6928275E-26/
    ISN 0006               COND=0.0
    ISN 0007               DO 1 I=1,6
    ISN 0008               IE=I-1
    ISN 0009               CAPPA=A(1,I)
    ISN 0010               DO 2 J=2,5
    ISN 0011               JE=J-1
    ISN 0012               CAPPA=CAPPA&A(J,I)*P**JE
    ISN 0013             2 CONTINUE
    ISN 0014               GO TO (3,4,3,4,3,3),I
    ISN 0015             3 COND=COND&CAPPA*T**IE
    ISN 0016               GO TO 1
    ISN 0017             4 COND=COND-CAPPA*T**IE
    ISN 0018             1 CONTINUE
    ISN 0019               RETURN
    ISN 0020               END
```

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LEVEL 2 FEB 67                               OS/360  FORTRAN H                                     DATE  67.233/15.30.55
           COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
  ISN 0002              REAL FUNCTION CSP(T)
                 C
                 C      FUNCTION CSP(T)
                 C      COMPUTES HEAT SPECIFIC CAPACITY OF WATER AS A FUNCTION
                 C      OF PRESSURE,P AND TEMPERATURE,T
                 C      P     IN UNITS (KG/CM**2)
                 C      T     IN UNITS (CELSIUS DEGR.)
                 C      CSP   IN UNITS (KCAL/KG*DEGR.)
                 C
  ISN 0003              COMMON P
  ISN 0004              DIMENSION F(30),C(2)
  ISN 0005              DATA F          /-1.9680907E&00,9.9961839E&00,-2.9178681E&1,5.340
                       19602E&1,-6.2676143E&1,4.5998995E&1,-1.9289733E&1,3.53740874E&0,-6.
                       2244398E&8,1.19991E&6,-1.2488796E&9,7.19946E&6,1.0226742E&16,1.3629
                       326E&16,1.500705E&00,8.16522474E&00,-1.7997608E-17,-1.2941176E&00,0
                       4.58620689E&00,0.41666667E&00,6.1191876E-17,-0.2941176E&00,-7.24116
                       55E-5,0.6537154E&00,0.7676621E&00,6.1412968E&00,6.9089589E&00,1.052
                       6358E-11,6.55134E&00,1.5108E-5/,C                /3.122199E&8,1.99985E&5
                       7/,FF/1.7211567E-1/
  ISN 0006              SIGMA=P/225.65
  ISN 0007              TAU=(T&273.16)/647.3
  ISN 0008              STAU=TAU**2
  ISN 0009              ETAU=TAU**6
  ISN 0010              DTAU=TAU**10
  ISN 0011              PTAU=TAU**11
  ISN 0012              UTAU=3.7E&8-C(1)*STAU-C(2)/ETAU
  ISN 0013              W=UTAU&SQRT(1.72*UTAU**2&F(14)*(SIGMA-F(15)*TAU))
  ISN 0014              VTAU=F 9)*STAU&F(10)/ETAU
  ISN 0015              SIGMI=FF
  ISN 0016              DO 1 I=1,8
  ISN 0017              IE=I
  ISN 0018              SIGMI=SIGMI&F(I)*TAU**IE
  ISN 0019            1 CONTINUE
  ISN 0020              DUTAU=F(9)*TAU&F(10)*TAU**(-7)
  ISN 0021              DVTAU=F(11)*TAU-F(12)*TAU**(-7)
  ISN 0022              DWST=1.72*UTAU*DUTAU-F(13)
  ISN 0023              DWT=1.72*UTAU**2&F(14)*(SIGMA-F(15)*TAU)
  ISN 0024              DW=DUTAU&DWST/SQRT(DWT)
  ISN 0025              CSPP=W*(F(19)*W-F(20)*(3.4*UTAU-VTAU))&F(13)*TAU-0.72*UTAU*VTAU
  ISN 0026              CSPA=DW*(F(19)*W-F(20)*(3.4*UTAU-VTAU))&W*(F(19)*DW-F(20)*(3.4*DUT
                       1AU-DVTAU))&F(13)-0.72*(UTAU*DVTAU&VTAU*DUTAU)
  ISN 0027              CSPN=F(23)*(F(24)&TAU)-F(25)*(F(24)-TAU)**8* F 24)&9.0*TAU)& F 24)
                       1-TAU)*(-F(23)-F(26)*(F(24)-TAU)**7*(F(24)&9.0*TAU)&F(27)*(F(24)-TA
                       2U)**8)
  ISN 0028              CSPE=62.5& F 29)&SIGMA/3.0)*SIGMA
  ISN 0029              CSPL=(132.0*(F(30)&PTAU)-22.0*(F(30)&12.0*PTAU))*(F(30)&PTAU)**(-3
                       1)
  ISN 0030              CSP=F 16)* F 17)*W**F(18)*DW*CSPP&F(21)*W**F(22)*CSPA&SIGMA*CSPN-F
                       1(28)*CSPE*SIGMA*DTAU*CSPL)&SIGMI*1.0E&3
```

```
ISN 0031          RETURN
ISN 0032          END
```

```
LEVEL 2 FEB 67                                   OS/360  FORTRAN H                                          DATE  67.233/15.31.41
           COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP.NOEDIT,NOID
   ISN 0002                   REAL FUNCTION ENTALP(T)
                     C
                     C        FUNCTION ENTALP(T)
                     C        COMPUTES ENTHALPY OF LIQUID AS A FUNCTION OF PRESSURE,P
                     C        AND TEMPERATURE,T
                     C        ENTALP  IN UNITS (KCAL/KG)
                     C
   ISN 0003                   COMMON P
   ISN 0004                   DIMENSION D 25),C(4)
   ISN 0005                   DATA D          /-8.943553F&3,1.1141047E&5,-6.3697257E&5,2.156843
                             13E&6,-4.721840E&6,6.91440715E&6,-6.76171126E&6,4.25359285E&6,-1.56
                             2078055F&6,2.54418298E&5,5.28535F&3,6.1191876E-17,0.294117E&00,5.86
                             320689E-1,4.1666667E-1,1.0226748F&16,-1.139706E-4,-6.244398F&8,1.19
                             49910E&6,0.6537154E&00,7.241165F-5,0.7676621E&00,-1.052358F-11,1.51
                             508E-5,6.55134E&00/,C                 /3.122199E&8,1.999850E&5,1.362926F&
                             616,1.500705E&00/
   ISN 0006                   SIGMA=P/225.65
   ISN 0007                   TAU=(T&273.16)/647.3
   ISN 0008                   STAU=TAU**2
   ISN 0009                   ETAU=TAU**6
   ISN 0010                   PTAU=TAU**11
   ISN 0011                   UTAU=3.7E&8-C(1)*STAU-C(2)/ETAU
   ISN 0012                   VTAU=D(18)*STAU&D(19)/ETAU
   ISN 0013                   W=UTAU&SQRT(1.72*UTAU**2&C(3)*(SIGMA-C(4)*TAU))
   ISN 0014                   TTAU=D(1)
   ISN 0015                   DO 1 I=1,9
   ISN 0016                   II=I&1
   ISN 0017                   TTAU=TTAU&D(II)*TAU**I
   ISN 0018                 1 CONTINUE
   ISN 0019                   TT1=W*(D(14)*W-D(15)*(3.4*UTAU-VTAU))&D(16)*TAU-0.72*UTAU*VTAU
   ISN 0020                   TT2=D(17)&(D(20)-TAU)*(D(21)*(D(20)&TAU)&D(22)*((D(20)-TAU)**8)*(D
                             1(20)&9.0*TAU))
   ISN 0021                   ENTALP=TTAU&D(11)*(D(12)/(W**D(13))*TT1&TT2*SIGMA&D(23)*(D(24)&12.
                             10*PTAU)/((D(24)&PTAU)**2)*(62.5&SIGMA*(D(25)&SIGMA/3.0))*SIGMA)
   ISN 0022                   RETURN
   ISN 0023                   END
```

```
LEVEL 2 FEB 67                                OS/360  FORTRAN H                                      DATE  67.233/15.32.15
           COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
    ISN 0002                 SUBROUTINE COTES(XA,XB,HS,TOT)
                      C
                      C      SUBROUTINE COTES
                      C      COTES-SIMPSON INTEGRATION SUBROUTINE
                      C
    ISN 0003                 TOT=0.0
    ISN 0004                 NL=ABS XB-XA)/HS
    ISN 0005                 NSTEP=NL&1
    ISN 0006                 STEP=NSTEP
    ISN 0007                 HSTEP=ABS(XB-XA)/STEP
    ISN 0008                 N3=NSTEP/3
    ISN 0009                 N4=NSTEP-3*N3
    ISN 0010                 X=XA
    ISN 0011                 A=3.0*HSTEP/8.0
    ISN 0012                 DELTA=HSTEP
    ISN 0013                 FY=COMP(X)
    ISN 0014                 DO 1 I=1,N3
    ISN 0015                 SUM=FY
    ISN 0016                 DO 2 K=1,3
    ISN 0017                 X=X&DELTA
    ISN 0018                 FY=COMP(X)
    ISN 0019                 GO TO  4,4,3),K
    ISN 0020               3 SUM=SUM&FY
    ISN 0021                 GO TO 2
    ISN 0022               4 SUM=SUM&FY*3.0
    ISN 0023               2 CONTINUE
    ISN 0024                 ENT=A*SUM
    ISN 0025                 TOT=TOT&ENT
    ISN 0026               1 CONTINUE
    ISN 0027                 IF(N4)10,10,5
    ISN 0028               5 HSTEP=ABS XB-X)/2.0
    ISN 0029                 A=HSTEP/3.0
    ISN 0030                 DELTA=HSTEP
    ISN 0031                 SUM=FY
    ISN 0032                 DO 7 I=1,2
    ISN 0033                 X=X&DELTA
    ISN 0034                 FY=COMP X)
    ISN 0035                 GO TO (9,8),I
    ISN 0036               8 SUM=SUM&FY
    ISN 0037                 GO TO 7
    ISN 0038               9 SUM=SUM&FY*4.0
    ISN 0039               7 CONTINUE
    ISN 0040                 ENT=A*SUM
    ISN 0041                 TOT=TOT&ENT
    ISN 0042              10 RETURN
    ISN 0043                 END
```

```
LEVEL 2 FEB 67                                OS/360  FORTRAN H                                DATE  67.233/15.30.02
        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
  ISN 0002              REAL FUNCTION COMP(Z)
                  C
                  C     FUNCTION COMP(Z)
                  C     COMPUTES LOCAL VALUE OF THE TWO-PHASE MULTIPLIER
                  C     ACCORDING TO LOTTES-FLINN CORRELATION
                  C
  ISN 0003              DIMENSION XL(4)
  ISN 0004              COMMON /DAT1/PSI1,HFI,XE
  ISN 0005              COMMON /DAT3/XL,ZLB,ZD,ROSR,ROLB
  ISN 0006              EQUIVALENCE (XL(1),TSLT)
  ISN 0007              COMP=(1.0&(1.0-PSI1)/PSI1*(XE-HFI*(TSLT-Z)))**2
  ISN 0008              RETURN
  ISN 0009              END
```

```
LEVEL 2 FEB 67                                   OS/360  FORTRAN H                                    DATE  67.233/15.29.52
          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
   ISN 0002              REAL FUNCTION DP(ROOUT)
                   C
                   C     FUNCTION DP
                   C     COMPUTES THE ACCELERATION PRESSURE DROP AROUND THE LOOP
                   C     ACCORDING TO EQUATION(13)
                   C
   ISN 0003              COMMON P,G,ROOUGT ,CR,ACCG,DPPUMP,DELTA,RO
   ISN 0004              COMMON/DAT2/D,EXCN,BR
   ISN 0005              DIMENSION G(4),RO(5),D(4)
   ISN 0006              EQUIVALENCE(D(1),TSD),(D(2),CLD),(D(3),EXD),(D(4),RID)
   ISN 0007              DP= 1.0/ROOUT-1.0/RO(2))*(1.0-1.0/EXCN**2*(TSD/EXD)**4&(EXCN**2-1.
                        10)/EXCN**2*(TSD/RID)**4)*G(1)**2/(2.0*ACCG)
   ISN 0008              RETURN
   ISN 0009              END
```

```
LEVEL 2 FEB 67                                   OS/360  FORTRAN H                                        DATE  67.234/11.37.38
         COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
   ISN 0002                 SUBROUTINE PUMP(W,C,DPPUMP)
                  C
                  C         SUBROUTINE PUMP(W,C,DPPUMP)
                  C         COMPUTES THE HEAD OF PUMP,DPPUMP AS A FUNCTION OF
                  C         FLOW RATE,W
                  C         W    IN UNITS (KG/SEC)
                  C         DPPUMP IN UNITS (KG/CM**2)
                  C
   ISN 0003                 DIMENSION C(6)
   ISN 0004                 DPPUMP=C(6)*W
   ISN 0005                 DO 1 I=1,4
   ISN 0006               1 DPPUMP=(DPPUMP&C(6-I))*W
   ISN 0007                 DPPUMP=DPPUMP&C(1)
   ISN 0008                 RETURN
   ISN 0009                 END
```

```
LEVEL 2 FEB 67                                 OS/360  FORTRAN H                                     DATE  67.233/15.31.10
              COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
   ISN 0002                REAL FUNCTION ACCA(RE,BMU,BCP,BK,BD)
                   C
                   C       FUNCTION ACCA
                   C       COMPUTES HEAT TRANSFER COEFFICIENT BETWEEN THE WALL AND THE LIQUID
                   C       AS A FUNCTION OF REYNOLDS NUNBER(REYN),VISCOSITY(AMU),HEAT
                   C       SPECIFIC CAPACITY(CP),CONTUCTIVITY(CK),DIAMETER(TSD)
                   C       P    IN UNITS (KG/CM**2)
                   C       T    IN UNITS (CELSIUS DEGR.)
                   C       ACCA  IN UNITS (KCAL/SEC*CM**2*CELSIUS DEGR.)
                   C
   ISN 0003                DATA AA/0.33333333/,BB/2.3E-2/
   ISN 0004                PRAND=BMU*BCP/BK
   ISN 0005                ACCA=BB*BK/BD*(RE**0.8)*(PRAND**AA)
   ISN 0006                RETURN
   ISN 0007                END
```

```
LEVEL 2 FEB 67                                         OS/360  FORTRAN H                                             DATE  67.233/15.31.20
             COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
   ISN 0002               REAL FUNCTION DPL(BR,I)
                 C
                 C        FUNCTION DPL
                 C        COMPUTES SINGLE PHASE LOCAL PRESSURE DROP AT THE EXIT
                 C        ACCORDING TO EQUATION(30)
                 C
   ISN 0003               DIMENSION G(4),RO(5)
   ISN 0004               COMMON P,G,ROUGTS,CR,ACCG,DPPUMP,DELTA,RO
   ISN 0005               I=I
   ISN 0006               GO TO (1,1,1,1,2),I
   ISN 0007             1 DPL=BR*G(I)**2/(2.0*ACCG*RO(I))
   ISN 0008               GO TO 3
   ISN 0009             2 DPL=BR*G(1)**2/(2.0*ACCG*RO(I))
   ISN 0010             3 RETURN
   ISN 0011               END
```

```
LEVEL 2 FEB 67                          OS/360  FORTRAN H                                DATE  67.233/15.31.31
          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
  ISN 0002                   SUBROUTINE DROP(TX,ZL,R,RO,D,PDR,FIS)
                   C
                   C         SUBROUTINE DROP
                   C         COMPUTES TWO PHASE PRESSURE DROP
                   C
  ISN 0003                   COMMON P,G,ROUGTS,CR,ACCG
  ISN 0004                   DIMENSION G(4)
  ISN 0005                   REN=G(1)*D/VISCOS(TX)
  ISN 0006                   FIS=5.5E-3*(1.0S(ROUGTS*2.0ES4&1.0E&6/REN)**CR)
  ISN 0007                   PDR=P*FIS*ZL*(G(1)**2)/(2.0*RO*ACCG*D)
  ISN 0008                   RETURN
  ISN 0009                   END
```

```
LEVEL 2 FEB 67                                    OS/360  FORTRAN H                                      DATE  67.233/15.31.53
        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
  ISN 0002                REAL FUNCTION DPLU(X,ALFA,GAMMA,ROT)
                    C
                    C     FUNCTION DPLU
                    C     COMPUTES EXIT LOCAL PRESSURE DROP ACCORDING TO EQUATION(31)
                    C
  ISN 0003                DIMENSION G(4),RO(5),D(4)
  ISN 0004                COMMON P,G,ROUGTS,CR,ACCG,DPPUMP,DELTA,RO
  ISN 0005                COMMON/DAT2/D,EXCN,BR
  ISN 0006                EQUIVALENCE (D(1),TSD),(D(2),CLD),(D(3),EXD),(D(4),RID)
  ISN 0007                DPLU=BR* X**2/(ALFA*GAMMA)&(1.0-X)**2/(1.0-ALFA))*G(1)**2/(2.0*ACC
                         1G*RO(5))
  ISN 0008                RETURN
  ISN 0009                END
```

```
LEVEL 2 FEB 67                                  OS/360  FORTRAN H                                       DATE  67.233/15.32.04
             COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=50,SOURCE,BCD,NOLIST,DECK,LOAD,MAP,NOEDIT,NOID
    ISN 0002                   SUBROUTINE DPEL(Z0,Z1,Z2,FITLT,ROMS,ROMB,ROMR,DPELEV)
                     C
                     C         SUBROUTINE DPEL
                     C         COMPUTES THE ELEVATION HEAD AROUND THE LOOP
                     C         ACCORDING TO EQUATION(6)
                     C
    ISN 0003                   COMMON P,G,ROUGTS,CR,ACCG,DPPUMP,DELTA,RO
    ISN 0004                   COMMON /DAT3/XL,ZLB,ZD,ROSR,ROLB
    ISN 0005                   DIMENSION RO(5),XL(4),G(4)
    ISN 0006                   DP1=RO(2)*(XL(4)&XL(1)&FITLT)
    ISN 0007                   FIT=FITLT
    ISN 0008                   DP2=XL(4)*ROMR
    ISN 0009                   IF(Z2.EQ.0.0) GO TO 1
    ISN 0011                   DP2=DP2& FIT&Z2)*ROMB
    ISN 0012                   FIT=0.0
    ISN 0013                 1 IF(Z1.EQ.0.0) GO TO 2
    ISN 0015                   DP2=DP2& FIT&Z1)*ROMS
    ISN 0016                   FIT=0.0
    ISN 0017                 2 DP2=DP2&ZLB*ROSR&Z0*ROLB&FIT*RO(5)
    ISN 0018                   DPELEV=(DP1-DP2)*SIN(DELTA)
    ISN 0019                   RETURN
    ISN 0020                   END
```

```
   F-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED--MAP
IEW0000   PUN        NOW ADDED TO DATA SET

                                                                ----  MODULE MAP  ----

  CONTROL SECTION                                   ENTRY

    NAME      ORIGIN  LENGTH                          NAME    LOCATION      NAME    LOCATION      NAME    LOCATION      NAME    LOCATION

   IHCFRXPR*      00      D4                        FRXPR=         00
   IHCFDXPD*      D8      D0                        FDXPD=         D8
   IHCSEXP *     1A8     11E                        EXP           1A8
   IHCSSQRT*     2C8      AC                        SQRT          2C8
   IHCSLOG *     378     10C                        ALOG10        378       ALOG         394
   IHCFRXPI*     488      94                        FRXPI=        488
   IHCSSCN *     520     104                        COS           520       SIN          53C
   IHCUOPT *     628       8
   IHCTRCH *     630     258
   IHCLLOG *     888     178                        DLOG10        888       DLOG         8A4
   IHCLEXP *     A00     1CC                        DEXP          A00
   IHCUATBL*     8D0     638
   MAIN=        1208    44DC                        MAIN         1208
   VISCOS=      56E8     1E4                        VISCOS       5730
   DENSIT=      58D0     320                        DENSIT       5988
   SAT=         5BF0     18A                        SAT          5C28
   COND=        5D80     2C4                        COND         5E30
   CSP=         6048     6EC                        CSP          61E0
   ENTALP=      6738     48A                        ENTALP       6870
   FLOW=        6BC8     3C4                        FLOW         6CC0
   TRIST=       6F90     6FC                        TRIST        71C8
   COTES=       769C     386                        COTES        7700
   COMP=        7A18     12E                        COMP         7A30
   PUMP=        7B48      02                        PUMP         7B50
```

```
  NAME      ORIGIN  LENGTH        NAME    LOCATION      NAME    LOCATION      NAME    LOCATION      NAME    LOCATION
 ACCA=        7C20    100
                                 ACCA       7C50
 DPL=         7DF0    192
                                 DPL        7F10
 DROP=        7F88    240
                                 DROP       7FC8
 DPLU=        81C8    1A6
                                 DPLU       81E8
 DPEL=        8370    29C
                                 DPEL       8388
 DP=          861C    18E
                                 DP         8630
 IHCFCOMH*    87A0    FFD
                                 IBCOM=     87A0        FDIOCS=     885C
 IHCFCVTH*    97AC    FF3
                                 ADCON=     97A0        FCVZO       98EC        FCVAO       9992        FCVLO       9A1A
                                 FCVIO      9D28        FCVEO       A1CC        FCVCO       A3C6
 IHCFIOSH*    A798    CF2
                                 FIOCS=     A798
$BLANKCOM     B490     3C
 DAT1         B4D0      C
 DAT2         B4E0     18
 DAT3         B4F8     20
 FLOWC        B518     1C
 TRISTE       B538     54
ENTRY ADDRESS      1208
TOTAL LENGTH       858C
```

EURATOM - CETIS

DATA (Zones de 6 colonnes)

PROBLEM SAMPLE INPUT | DATE 8/22/1967 | PAGE 1 OF LUPO

```
        * * TEST CASE FØR LUPØ , NATURAL CIRCULATIØN   (8TH,22,1967)        C-01
   20    6  200    1    0    0    0                                         C-02
        60.0       0.005         0.0                                        C-03
       200.0      1914.0       614.0      1012.0        32.5                C-04
         1.0         5.0         2.0         5.0                            C-05
      0.0002     0.00005         1.5      1.5708                            C-06
        1.66        0.09       373.4     0.00003       286.1       659.5    C-07
        0.33         2.7         0.0         2.3       0.681         0.0    C-08
         4.0         3.0                                                    C-09
        20.0       1.5-7     20000.0        30.0                            C-11
       120.0        80.0       0.180       0.200                            C-12
                   150.0       0.190       0.220                            C-12
                                                                           BLANK
```

CET - 004

```
                              * * *  L U P O  * * *

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

      TYPE OF PROBLEM    STEADY STATE FLOW RATE AND PRESSURE DROPS CALCULATION

      NZETA = 200  NEXC =  6  IMAX = 20  IPRINT = 0  INDL = 1  IDT = 0  KKK = 0

      * * INPUT DATA

                                   LENGTH (CM)                 DIAMETER (CM)


       TEST SECTION            200.000                    1.000
       COLD LEG               1914.000                    5.000
       EXCHANGER               614.000                    2.000
       RISER                  1012.000                    5.000

       ANGLE    =    1.57080  (RAD)

       PRESSURE                    60.00000  (KG/CM**2)
       POWER                      120.00000  (KW)
       INLET TEMPERATURE           80.00000  (CELSIUS DEGR.)
       MIN. FLOW                    0.18000  (KG/SEC)
       MAX. FLOW                    0.20000  (KG/SEC)

       TEST SECTION ROUGNESS COEF.       0.000200
       LOOP PIPES ROUGNESS COEF.         0.000050


       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                             1.66000
       BUBBLE RADIUS AT DETACHMENT         0.09000  (CM)
       HEAT EVAPORATION                  373.39990  (KCAL/KG)
       STEAM DENSITY                       0.00003  (KG/CM**3)
       DELTATCL                            4.00000  (CELSIUS DEGR.)
       DELTATRIS                           3.00000  (CELSIUS DEGR.)
       SATURATED WATER ENTHALPY          286.09985  (KCAL/KG)
       STEAM ENTHALPY                    659.50000  (KCAL/KG)


      ***  CONSTANT QUANTITIES VALUES

       TSAT                 2.742891E 02
       INLET ENTHALPY       8.113780E 01
       (DELTA-T)SAT         1.572160E 01
       HEAT FLUX            4.560744E-02
       ETA                  8.373988E 04
       BETA                 3.402028E 01
```

```
FLOW RATE   EXIT TEMP.    DELTAPMOT    DELTAPRES    DELTAPFTS    DELTAPEXIT  F/FISO-SR  F/FISO-HS  F/FISO-SS  F/FISO-BB

0.200000     218.587    0.14249E 00  0.15484E 00  0.11021E 00  0.26632E-01  0.81600    1.03678    0.0        0.0
0.195000     221.965    0.14729E 00  0.14881E 00  0.10605E 00  0.25449E-01  0.81257    1.08916    0.0        0.0
0.190000     225.510    0.15242E 00  0.14324E 00  0.10230E 00  0.24295E-01  0.80822    1.14263    0.0        0.0
0.185000     229.221    0.15788E 00  0.13846E 00  0.99294E-01  0.23170E-01  0.80371    1.20261    0.0        0.0
0.180000     233.117    0.16375E 00  0.13392E 00  0.96482E-01  0.22077E-01  0.79923    1.25789    0.0        0.0
0.192500     223.717    0.14981E 00  0.14603E 00  0.10418E 00  0.24868E-01  0.81011    1.11885    0.0        0.0
0.193750     222.836    0.14854E 00  0.14737E 00  0.10507E 00  0.25157E-01  0.81110    1.10401    0.0        0.0
* * * SOLUTION HAS BEEN OBTAINED IN  =    8  ITERATIONS  * * *
```

```
* * * INTERMEDIATE RESULTS FOR FLOW RATE  =      0.194375  (KG/SEC)


                          T              G             REYN          FISO


 COLD LEG        8.4000000E 01 9.8994263E-03 1.4580750E 04 2.8122000E-02
 EXCHANGER       1.5265356E 02 1.0311902E-02 1.1443273E 04 2.9999629E-02
 RISER           2.2130722E 02 9.8994263E-03 4.1264273E 04 2.1632127E-02

* * ALL LIQUID REGION

 TSCB                          213.5308838
 RO(TSCB) , RO-MEAN          0.8514938E-03        0.9161232E-03
 MU(TSCB) , MU-MEAN          0.1247475E-05        0.2405995E-05
 CP(TSCB) , CP-MEAN          0.1088243E 01        0.1043219E 01
 K(TSCB)  , K-MEAN           0.1571943E-05        0.1597055E-05
 REYN-MEAN                   0.1028621E 06
 H-MEAN                      0.4368189E-03
 FISO                        0.1866737E-01
 F/FISO                      0.8120655E 00

* * HIGHLY SUBCOOLED BOILING REGION

 TD                            222.3996582
 T-MEAN                        217.9652100
 RO(TD) , RO-MEAN            0.8401994E-03        0.8458465E-03
 MU(TD) , MU-MEAN            0.1193062E-05        0.1220268E-05
 REYN-MEAN                   0.2028125E 06
 FISO                        0.1691100E-01
 F/FISO                      0.1096585E 01
```

```
        RESULTS OF CALCULATION FOR FLOW RATE  =  0.194375  (KG/SEC)


 * * TEMPERATURES  (CELSIUS DEGR.)

  INLET WALL TEMP.            0.205970E 03
  TEMP. AT ZLB                0.213531E 03
  TEMP. AT ZD                 0.222400E 03
  OUTLET TEMP.                0.222400E 03

 * * LENGTHS  (CM)

  ALL LIQUID FLOW REGION                0.186500E 03
  HIGHLY SUBCOOLED BOILING REGION       0.135000E 02
  SLIGHTLY SUBCOOLED BOILING REGION     0.0
  BULK BOILING REGION                   0.0

 * * QUALITY AND VOID FRACTION

  EXIT QUALITY                                 0.0
  VOID FRACTION AT ZBB                         0.0
  VOID FRACTION AT THE END OF BULK BOILING     0.0

 * * PRESSURE DROPS  (KG/CM**2)

  FRICTION

  COLD LEG                      0.553391E-03
  EXCHANGER                     0.544179E-03
  RISER                         0.259847E-03
  ALL LIQUID REGION             0.963386E-01
  HIGHLY SUBCOOLED REGION       0.923964E-02
  SLIGHTLY SUBCOOLED REGION     0.0
  BULK BOILING REGION           0.0
  TOTAL FRICTION PRESSURE DROP  0.106936E 00

  LOCAL

  INLET                         0.105749E-01
  COLD LEG                      0.138796E-03
  EXCHANGER                     0.0
  RISER                         0.136501E-03
  OUTLET                        0.253026E-01
  TOTAL LOCAL PRESSURE DROP     0.361528E-01

  ACCELERATION                  0.502542E-02

  FLUID PRESSURE RISE           0.0
  ELEVATION HEAD                0.147914E 00

  TOTAL PRESSURE DROP           0.148114E 00

  TOTAL ELEVATION HEAD          0.147914E 00

  RELATIVE ERROR                0.135035E-02
```

TEST SECTION TEMPERATURES

```
  80.084       109.157       138.329       167.175       195.505
  80.535       109.889       139.055       167.891       196.205
  81.270       110.621       139.781       168.606       196.904
  82.005       111.353       140.506       169.321       197.603
  82.741       112.085       141.231       170.035       198.301
  83.476       112.816       141.956       170.749       198.999
  84.211       113.548       142.681       171.463       199.696
  84.946       114.279       143.406       172.176       200.393
  85.681       115.010       144.130       172.890       201.089
  86.416       115.742       144.854       173.602       201.785
  87.150       116.473       145.578       174.315       202.480
  87.885       117.203       146.302       175.027       203.175
  88.620       117.934       147.025       175.738       203.869
  89.354       118.665       147.748       176.450       204.563
  90.089       119.395       148.471       177.161       205.256
  90.823       120.125       149.194       177.871       205.948
  91.558       120.855       149.916       178.582       206.641
  92.292       121.585       150.639       179.291       207.332
  93.026       122.315       151.361       180.001       208.023
  93.761       123.045       152.082       180.710       208.714
  94.495       123.774       152.804       181.419       209.403
  95.229       124.504       153.525       182.127       210.093
  95.963       125.233       154.246       182.835       210.782
  96.696       125.962       154.967       183.542       211.470
  97.430       126.691       155.687       184.250       212.157
  98.164       127.420       156.407       184.956       212.844
  98.897       128.148       157.127       185.662       213.531
  99.631       128.877       157.847       186.368       214.217
 100.364       129.605       158.566       187.074       214.902
 101.098       130.333       159.285       187.779       215.587
 101.831       131.061       160.004       188.484       216.271
 102.564       131.788       160.722       189.188       216.954
 103.297       132.516       161.441       189.891       217.637
 104.030       133.243       162.158       190.595       218.319
 104.763       133.970       162.876       191.298       219.001
 105.495       134.698       163.593       192.000       219.682
 106.228       135.424       164.310       192.702       220.362
 106.961       136.151       165.027       193.404       221.042
 107.693       136.877       165.743       194.105       221.721
 108.425       137.604       166.460       194.805       222.400
```

```
                              * * *  L U P O  * * *
          * * TEST CASE FOR LUPO , NATURAL CIRCULATION   (8TH,22,1967)

TYPE OF PRCBLEM    STEADY STATE FLOW RATE AND PRESSURE DROPS CALCULATION
NZETA = 200  NEXC =  6  IMAX = 20  IPRINT = 0  INDL = 2  IDT = 0  KKK = 0
* * INPUT DATA
                           LENGTH (CM)              DIAMETER (CM)

 TEST SECTION              200.000                     1.000
 COLD LEG                 1914.000                     5.000
 EXCHANGER                 614.000                     2.000
 RISER                    1012.000                     5.000

 ANGLE    =    1.57080  (RAD)

 PRESSURE                          60.00000  (KG/CM**2)
 POWER                            120.00000  (KW)
 INLET TEMPERATURE                150.00000  (CELSIUS DEGR.)
 MIN. FLOW                          0.19000  (KG/SEC)
 MAX. FLOW                          0.22000  (KG/SEC)

 TEST SECTION ROUGNESS COEF.          0.000200
 LCOP PIPES ROUGNESS COFF.            0.000050

 LCCAL PRESSURE LCSS 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                             1.66000
 BUBBLE RADIUS AT DETACHMENT         0.09000   (CM)
 HEAT EVAPORATION                  373.39990   (KCAL/KG)
 STEAM DENSITY                       0.00003   (KG/CM**3)
 DELTATCL                            4.00000   (CELSIUS DEGR.)
 DELTATRIS                           3.00000   (CELSIUS DEGR.)
 SATURATED WATER ENTHALPY          286.09985   (KCAL/KG)
 STEAM ENTHALPY                    659.50000   (KCAL/KG)


***  CONSTANT QUANTITIES VALUES

 TSAT                  2.742891E 02
 INLET ENTHALPY        1.518917E 02
 (DELTA-T)SAT          1.572160E 01
 HEAT FLUX             4.560744E-02
 ETA                   8.373988E 04
 BETA                  3.402028E 01
```

```
FLOW RATE   EXIT TEMP.    DELTAPMOT     DELTAPRES     DELTAPETS     DELTAPEXIT   F/FISO-SR   F/FISO-HS   F/FISO-SS   F/FISO-BR

0.220000     266.816     0.16833E 00   0.26042E 00   0.18915E 00   0.37144E-01   0.86354     1.47856     2.11903     0.0
0.212500     269.075     0.18638E 00   0.26333E 00   0.18946E 00   0.37438E-01   0.85965     1.48697     2.22749     0.0
0.205000     271.508     0.33713E 00   0.26687E 00   0.19050E 00   0.37649E-01   0.85513     1.49414     2.34382     0.0
0.197500     274.142     0.47312E 00   0.27218E 00   0.19347E 00   0.37777E-01   0.85042     1.50360     2.47637     0.0
0.190000     274.289     0.57511E 00   0.28629E 00   0.19636E 00   0.41347E-01   0.84549     1.51193     2.52145     2.57180
0.208750     270.384     0.24528E 00   0.26349E 00   0.18881E 00   0.37388E-01   0.85740     1.48962     2.27575     0.0
0.206875     270.937     0.29316E 00   0.26573E 00   0.19020E 00   0.37521E-01   0.85618     1.49359     2.31279     0.0
0.207812     270.665     0.26958E 00   0.26430E 00   0.18919E 00   0.37456E-01   0.85690     1.49074     2.29242     0.0
0.208281     270.408     0.25725E 00   0.26533E 00   0.18999E 00   0.37588E-01   0.85703     1.49105     2.29250     0.0
0.208047     270.532     0.26315E 00   0.26481E 00   0.18959E 00   0.37521E-01   0.85690     1.49089     2.29246     0.0
* * * SOLUTION HAS BEEN OBTAINED IN  =   11  ITERATIONS  * * *
```

```
* * * INTERMEDIATE RESULTS FOR FLOW RATE  =      0.207929  (KG/SEC)


                          T                G              REYN            FISO

COLD LEG        1.5400000E 02 1.0589760E-02 2.9662348E 04 2.3441497E-02
EXCHANGER       2.1414453E 02 1.1030991E-02 1.7741031E 04 2.6712004E-02
RISER           2.7428906E 02 1.0589760E-02 5.5806102E 04 2.3663830E-02

* * ALL LIQUID REGION

TSCB                             217.8010254
RO(TSCB) , RO-MEAN             0.8461210E-03          0.8838917E-03
MU(TSCB) , MU-MEAN             0.1220691E-05          0.1528902E-05
CP(TSCB) , CP-MEAN             0.1078742E 01          0.1051428E 01
K(TSCB)  , K-MEAN              0.1562520E-05          0.1603848E-05
REYN-MEAN                      0.1731594E 06
H-MEAN                         0.5727692E-03
FISO                           0.1725985E-01
F/FISO                         0.8566729E 00

* * HIGHLY SUBCOOLED BOILING REGION

TD                               261.0209961
T-MEAN                           239.4110107
RO(TD) , RO-MEAN               0.7837010E-03          0.8149110E-03
MU(TD) , MU-MEAN               0.1001468E-05          0.1111080E-05
REYN-MEAN                      0.2382761E 06
FISO                           0.1658947E-01
F/FISO                         0.1492542E 01

* * SLIGHTLY SUBCOOLED BOILING REGION

ALFAW                          0.2375999E-01
T-MEAN                           265.8093262
ALFA-MEAN                      0.1412225E 00
RO-MEAN LIQUID                 0.7754713E-03
RO-MEAN FLUID                  0.6701937E-03
FISO                           0.1636476E-01
F/FISO                         0.2295896E 01
```

```
          RESULTS OF CALCULATION FOR FLOW RATE  =  0.207929  (KG/SEC)


  * * TEMPERATURES  (CELSIUS DEGR.)

   INLET WALL TEMP.          0.236044E 03
   TEMP. AT ZLB              0.217801E 03
   TEMP. AT ZD               0.261021E 03
   OUTLET TEMP.              0.270598E 03

  * * LENGTHS  (CM)

   ALL LIQUID FLOW REGION                0.103500E 03
   HIGHLY SUBCOOLED BOILING REGION       0.710000E 02
   SLIGHTLY SUBCOOLED BOILING REGION     0.255000E 02
   BULK BOILING REGION                   0.0

  * * QUALITY AND VOID FRACTION

   EXIT QUALITY                                      0.176911E-01
   VOID FRACTION AT ZBB                              0.258685E 00
   VOID FRACTION AT THE END OF BULK BOILING          0.0

  * * PRESSURE DROPS  (KG/CM**2)

   FRICTION

   COLD LEG                         0.559936E-03
   EXCHANGER                        0.597838E-03
   RISER                            0.389400E-03
   ALL LIQUID REGION                0.618509E-01
   HIGHLY SUBCOOLED REGION          0.770654E-01
   SLIGHTLY SUBCOOLED REGION        0.510686E-01
   BULK BOILING REGION              0.0
   TOTAL FRICTION PRESSURE DROP     0.191532E 00

   LOCAL

   INLET                            0.128176E-01
   COLD LEG                         0.168479E-03
   EXCHANGER                        0.0
   RISER                            0.186994E-03
   OUTLET                           0.374884E-01
   TOTAL LOCAL PRESSURE DROP        0.506615E-01

   ACCELERATION                     0.229592E-01

   FLUID PRESSURE RISE              0.0
   ELEVATION HEAD                   0.266390E 00

   TOTAL PRESSURE DROP              0.265153E 00

   TOTAL ELEVATION HEAD             0.266390E 00

   RELATIVE ERROR                  -0.464638E-02
```

TEST SECTION TEMPERATURES

```
150.110   176.696   202.994   228.564   253.151
150.558   177.361   203.643   229.192   253.750
151.233   178.025   204.292   229.819   254.349
151.908   178.689   204.940   230.446   254.947
152.583   179.352   205.587   231.072   255.544
153.257   180.016   206.235   231.697   256.140
153.931   180.678   206.881   232.322   256.736
154.605   181.341   207.528   232.946   257.330
155.278   182.003   208.174   233.569   257.924
155.952   182.665   208.819   234.192   258.517
156.625   183.327   209.464   234.814   259.109
157.298   183.988   210.108   235.436   259.700
157.970   184.649   210.752   236.057   260.291
158.643   185.309   211.395   236.677   260.880
159.315   185.969   212.038   237.296   261.469
159.987   186.629   212.681   237.915   261.942
160.659   187.288   213.323   238.533   262.301
161.330   187.947   213.964   239.151   262.660
162.001   188.606   214.605   239.767   263.019
162.672   189.264   215.245   240.383   263.378
163.343   189.922   215.885   240.999   263.738
164.013   190.579   216.524   241.613   264.098
164.683   191.236   217.163   242.227   264.458
165.353   191.893   217.801   242.840   264.817
166.023   192.549   218.439   243.453   265.178
166.692   193.205   219.076   244.065   265.538
167.361   193.861   219.712   244.676   265.898
168.030   194.516   220.348   245.286   266.259
168.698   195.171   220.984   245.896   266.620
169.366   195.825   221.619   246.505   266.981
170.034   196.479   222.253   247.113   267.342
170.702   197.132   222.887   247.720   267.703
171.369   197.785   223.520   248.327   268.064
172.036   198.438   224.152   248.932   268.426
172.703   199.090   224.785   249.537   268.788
173.369   199.742   225.416   250.142   269.149
174.035   200.393   226.047   250.745   269.511
174.701   201.044   226.677   251.348   269.873
175.366   201.694   227.307   251.950   270.236
176.031   202.344   227.936   252.551   270.598
```

EURATOM - CETIS

1	TITLE							C-01
2	IMAX	NEXC	NZETA	INDL	IPRINT	IDT	KKK	C-02
3	P	EMAX	DPPUMP					C-03
4	TSLT	CLLT	EXLT	RILT	FITLT			C-04
5	TSD	CLD	EXD	RID				C-05
6	RQUGTS	RØUGL	SLIPR	DELTA				C-06
7	EPSI	RD	RLANDA	RØG	EØUTFS	EØUTG		C-07
8	BKIN	BKCL	BKEX	BKRI	BKØUT	BR		C-08
9	XTCL	XTRIS						C-09
10	CC(1)	CC(2)	CC(3)	CC(4)	CC(5)	CC(6)		C-10
11	DD(1)	DD(2)	DD(3)	DD(4)				C-11
12	PØWKW	TIN	WMIN	WMAX				C-12
13	BLANK CARD							C-13

NB.

1) IF DPPUMP ≥ 0 (CØNSTANT ØR ZERØ PUMP HEAD) CARD 10 MUST NØT BE SUPPLIED.

2) SUPPLY AS MANY CARDS ØF TYPE C-12 AS MANY PRØBLEMS TØ BE RUN.

5.3.2 Input Data

Card	Columns	Format	Name	Description
1	1 - 72	12 A6 (for 7090)		Columns 2-72 are printed as a title.
		18 A4 (for 360)		1 in Col. 1 causes an initial page skip.
2	1 - 5	I5	IMAX	Maximum number of iterations to be performed by using the method of halving.
	6 - 10	I5	NEXC	Number of exchanger's pipes in parallel.
	11 - 15	I5	NZETA	Number of test section lumps.
	16 - 20	I5	INDL	Indicator for the riser temperature calculation. When INDL = 1 the main calls subroutine TRIST which computes the riser temperature by balances of enthalpy; when INDL = 0 the mean riser temperature is computed by subtracting an empirical value XTRIS to the outlet temperature.
	21 - 25	I5	IPRINT	Indicator for the results print. When IPRINT = 0 the code prints all results only of last iteration. When IPRINT = 1 the code prints all results in the output for each iteration.
	26 - 30	I5	IDT	Indicator for the calculation of ΔT_{sat} For IDT = 0 the code uses the relation (25). For IDT = 1 it choices the Jens and Lottes formula.
	31 - 35	I5	KKK	Indicator for the calculation of (f/f_{iso}) in the highly subcooled region. For KKK = 0 (f/f_{iso}) is computed in accordance with Mendler theory; for KKK = 1 (f/f_{iso}) is computed by the Lottes - Flinn relation for the two-phase fluid.
3	1 - 12	E12.0	P	Pressure of the system.
	13 - 24	E12.0	EMAX	Maximum relative error, $(\Delta p_{mot} - \Delta p_{res})/\Delta p_{res}$.
	25-36	E12.0	DPPUM	Head of pump, if the circulation is forced. If DPPUMP is negatif, the head is calculated by a polinomial whose coefficients are in card 10, which depends upon the flow rate.

Card	Column	Format	N Name	Description
4	1 - 12	E12.0	TSLT	Test section length.
	13 - 24	E12.0	CLLT	Cold leg length.
	25 - 36	E12.0	EXLT	Exchanger length.
	37 - 48	E12.0	RILT	Riser length.
	49 - 60	E12.0	FITLT	Fitting between test section and riser length.
5	1 - 12	E12.0	TSD	Test section in. diameter.
	13 - 24	E12.0	CLD	Cold leg in.diameter.
	25 - 36	E12.0	EXD	Exchanger in.diameter.
	37 - 48	E12.0	RID	Riser in.diameter.
6	1 - 12	E12.0	RØUGTS	Test section roughness coefficient.
	13 - 24	E12.0	RØUGL	Loop roughness coefficient.
	25 - 36	E12.0	SLIPR	Slip ratio.
	37 - 48	E12.0	DELTA	Angle of loop with respect to horizontal.
7	1 - 12	E12.0	EPSI	Bowring's model parameter for the local quality (see Ref. 2)
	13 - 24	E12.0	RD	Bowring's model parameter for α_w calculation . See pag.11 and fig. 7 where RD is plotted versus pressure.
	25 - 36	E12.0	RLANDA	Evaporation heat.
	37 - 48	E12.0	RØG	Steam density.
	49 - 60	E12.0	EØUTFS	Saturated water enthalpy.
	61 - 72	E12.0	EØUTG	Saturated steam.
8	1 - 12	E12.0	BKIN	Loss coefficient at the test section inlet.
	13 - 24	E12.0	BKCL	Loss coefficient of the cold leg.
	27 - 36	E12.0	BKEX	Loss coefficient of the exchanger.
	37 - 48	E12.0	BKRI	Loss coefficient of the riser.
	49 - 60	E12.0	BKØUT	Loss coefficient at the exit of test section.
	61 - 72	E12.0	BR	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.

Card	Columns	Format	Name	Description
9	1 - 12	E12.0	XTCL	Empirical value, which must be added to inlet temperature for the calculation of the cold leg mean temperature.
	13 - 24	E12.0	XTRIS	Empirical value, which must be subtracted to outlet temperature for the calculation of the riser mean temperature, when INDL = 0.
10	1 - 72	E12.0 I = 1, 6	CC(I)	Coefficients of a polynomial, which represents analytically the characteristic of the pump in forced circulation. The card exists if DPPUMP is negative in input.
11	1 - 12	E12.0	DD(1)	Number of riser axial meshes.
	13 - 24	E12.0	DD(2)	Over-all heat transfer coefficient of the riser.
	25 - 36	E12.0	DD(3)	Heat transfer surface of the riser.
	37 - 48	E12.0	DD(4)	Air temperature.
12	1 - 12	E12.0	P0WKW	Thermal power supplied to the system.
	13 - 24	E12.0	TIN	Inlet temperature.
	25 - 36	E12.0	WMIN	Minimum value of flow rate interval, in which the solution exists certainly.
	37 - 48	E12.0	WMAX	Maximum value of the flow rate interval in which the solution exists certainly.

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

FORTRAN Language	Symbol	Meaning
BKCL	K_{cl}	Loss coefficient of the cold leg
BKEX	K_{exc}	" of " exchanger
BKIN	K_{in}	" at test section inlet
BKOUT	K_{out}	" " outlet
BKRIS	K_{ris}	" of the riser
BR	$K_{out, TPF}$	Two phase loss coefficient at test section outlet
CLD	D_{cl}	Cold leg inside diameter
CLLT	l_{cl}	" " lenght
DD(1)	n_{ris}	Number of riser lumps.
DD(2)	λ_{ris}	Over-all heat transfer coefficient of the riser
DD(3)	S_{ris}	Heat transfer surface of the riser
DD(4)	t_a	Air temperature
DELTA	δ	Angle of loop with respect to horizontal
DPPUMP	Δp_{pump}	Head of pump
EMAX	ε_{max}	Maximum relative error
EOUTFS	$h_{l, sat}$	Saturated water enthalpy
EOUTG	h_g	Saturated steam "
EPSI	$\hat{\varepsilon}$	Bowring's model parameter for the local quality
EXD	D_{exc}	Exchanger inside diameter
EXLT	l_{exc}	Exchanger length
FITLT	l_{fit}	Test section fitting length
IMAX	m	Maximum number of iterations
IDT	/	Indicator for the ΔT_{sat} calculation
INDL	/	" for the riser temperature calculation
IPRINT	/	Indicator for the results print
KKK	/	" for the calculation of (f/f_{iso}) in the highly subcooled region
NZETA	n_{ts}	Test section lumps number
NEXC	n_{exc}	Number of exchanger pipes in parallel.

FORTRAN Language	Symbol	Meaning
P	p	Pressure
POWKW	P	Thermal power
RD	R_d	Bowring's model parameter for α_w calculation
RID	D_{ris}	Riser's inside diameter
RILT	l_{ris}	Riser's length
RLANDA	r	Evaporation heat
ROG	ρ_g	Steam density
ROUGL	(ε/D)	Loop roughness coefficient
ROUGTS	$(\varepsilon/D)_{ts}$	Test section roughness coefficient
SLIPR	S_r	Slip ratio
TIN	t_{in}	Inlet temperature of test section
ZETA	n_{ts}	Test section lumps number
WMAX	W_{max}	Maximum value of the flow rate
WMIN	W_{min}	Minimum value of the flow rate

Variables in the Program

A, B, C	/	Number of the boundary lump
ALFABB	α_{bb}	Void fraction at the end of the "slight subcooled region"
ALFAE	$_{ex}$	Void fraction at the exit
ACCG	g	Gravity acceleration
AMU	μ	Dynamic viscosity
CP	c_p	Heat specific capacity
CK	K_t	Thermal conductivity
D	D	Diameter
DE	$\Delta\varepsilon$	Relative error
DELTAZ	ΔZ	Length of test section lumps
DPACC	Δp_{acc}	Spatial acceleration pressure drop
DPFRIC	Δp_{fr}	Friction pressure drop in the loop
DPLOC	Δp_{loc}	Local pressure drop
DPLOCT	$\Delta p_{loc, tot}$	Total local pressure drop
DPRT	Δp_{res}	Total resisting pressure drop
DPMOT	Δp_{mot}	Driving force

FORTRAN Language	Symbol	Meaning
EIN	h_{in}	Inlet enthalpy of test section
EOUT	h_{out}	Outlet enthalpy "
FI	Φ	Thermal flux
FFISLB	$(f/f_{iso})_{LB}$	Pressure drop multiplier in local boiling region
FISOLB	$(f_{iso})_{LB}$	Isothermal multiplier in local boiling region
FFISSR	$(f/f_{iso})_{sr}$	Pressure drop multiplier in the "all liquid region"
FISOSR	$(f_{iso})_{sr}$	Isothermal multiplier in the "all liquid region"
FISO	f_{iso}	" " in loop's components
G	ρV	Mass velccity
ICN	/	Indicator for the cycle restart
KKK	/	Indicator for (f/f_{iso}) relation
KIND	/	" for a new flow rate
KPUMP	/	Pump indicator
HX	λ_{sr}	Heat transfer coefficient in the all liquid region
PDROP1	Δp_1	Pressure drop in the "slightly subcooled" region
PDROP2	Δp_2	Pressure drop in the "bulk boiling" region
PFRICT	Δp_{fr}	Friction pressure drop
POWER	P	Thermal power
REYN	N_{Re}	Reynolds number
RMOLT1	R_1	Two phase multiplier in subcooled boiling
RMOLT2	R_2	" " " in bulk boiling
RO	ρ	Density
ROLB	ρ_{LB}	Average density in the highly subcooled region
ROM1	ρ_1	Average density in the slightly subcooled region
ROM2	ρ_2	Average density in the bulk boiling region
ROMB	$\rho_{2,v}$	Average density in the bulk boilong region computed by volumetric quality
ROMS	$\rho_{1,v}$	Average density in the slightly subcooled region computed by volumetric quality
ROMR	ρ_{ris}	Average density in the riser

FORTRAN Language	Symbol	Meaning
ROSR	ρ_{sr}	Average density in the all liquid region
ROSAT	$\rho_{f, sat}$	Saturate water density
T	t	Temperature
TSAT	t_{sat}	Saturation temperature
TD	t_d	Temperature at which slightly subcooled boiling starts
TWALL	t_w	Wall temperature
TWIN	$t_{w, in}$	Wall inlet temperature
TWSCB	$t_{w, scb}$	$t_{sat} + \Delta t_{sat}$
TSCB	t_{scb}	Temperature at which highly subcooled boiling starts
V	V	Velocity
WX	W_x	Flow rate
XBV	X_v	Volumetric quality
XE, XEX	X_{ex}	Outlet quality
XFSLB	/	Term of the two phase multiplier in the slightly subcooled boiling
XL	l	Loop components length
ZO	Z_o	All liquid region length
Z1	Z_1	Highly subcooled region length
Z2	Z_2	Slightly subcooled region length
ZD	Z_d	Test section length up to the end of highly subcooled region
ZLB	Z_{LB}	Test section length up to the end of all liquid region

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 ε are important. The slip is variable versus the void fraction and the pressure; ε 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

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

Greak letters

α	Void fraction	/
β , η , $\hat{\varepsilon}$	Bowring's model parameters	/
δ	Angle of loop	radiant
Δp	Pressure drop	$[F/L^{2}]$, (Kg_{p}/cm^{2})
$\Delta\varepsilon$	Relative error	/
ε/D	Roughness coefficient	/
λ	Heat transfer coefficient	$[H/L^{2}.\vartheta.T]$, $(Kcal/cm^{2}.{}^{o}C.sec)$
μ	Dynamic viscosity	$[M/L\vartheta]$, $(Kg_{m}/cm.sec)$
ρ	Density	$[M/L^{3}]$, (Kg_{m}/cm^{3})
Φ	Heat flux	$[M/\vartheta.L^{2}]$, $(Kcal/sec.cm^{2})$

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	Unkwown value
1	Slightly subcooled region
2	Bulk boiling region

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Appendix 1

The Lottes-Flinn Model

Lottes and Flinn model for annular two phase flow in uniformely 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:

$$v_{in} = \frac{W}{\rho_{in} \cdot A} \quad , \qquad v_f = \frac{w_f}{\rho_f \cdot A_f} = \frac{(1-x) \cdot w}{\rho_f (1-\alpha) \cdot A} \tag{1}$$

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

$$\frac{v_f}{v_{in}} = \frac{1-x}{1-\alpha} = 1 + \left(\frac{\rho_f}{\rho_g} \frac{v_f}{v_g} - 1 \right) x \tag{2}$$

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

$$\overline{R} = \frac{1}{L_2 - L_1} \int_{L_1}^{L_2} \frac{(dp/dz)_{TPF}}{(dp/dz)_0} dz = \frac{1}{L_2 - L_1} \int_{L_1}^{L_2} \left(\frac{v_f}{v_{in}} \right)^2 dz \tag{3}$$

By using the eq. (2):

$$\overline{R} = \frac{1}{L_2 - L_1} \int_{X_1}^{X_2} \left[1 + \left(\frac{\rho_f}{\rho_g} \frac{v_f}{v_g} - 1 \right) x \right]^2 dx \tag{4}$$

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

$$\overline{R} = \frac{1}{3} \left[1 + \frac{1}{1 - \alpha_e (1-\psi)} + \frac{1}{[1 - \alpha_e (1-\psi)]^2} \right] \tag{5}$$

where $= \frac{v_g}{v_f} \frac{\rho_g}{\rho_f}$

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)

$$p_1 A_2 + \frac{w_{f_1} v_{f_1}}{g} + \frac{w_{g_1} v_{g_1}}{g} = p_2 A_2 + \frac{w_{f_2} v_{f_2}}{g} + + \frac{w_{g_2} v_{g_2}}{g} \qquad (1)$$

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)

$$w_{f_2} = w_{f_1} = w_o(1-x) = \rho_f V_o A_1 (1-x) = \rho_f V_o \sigma A_2 (1-x) \qquad (2)$$

$$w_{g_2} = w_{g_1} = xW_o = {}_f V_o A_1 x = \rho_f V_o \sigma A_2 x \qquad (3)$$

$$v_{f_1} = \frac{v_o(1-x)}{1-\alpha_1}, \qquad v_{f_2} = \frac{\sigma v_o (1-x)}{1-\alpha_2} \qquad (4)$$

$$v_{g_1} = \frac{v_o \cdot x}{\alpha_1} \frac{\rho_f}{\rho_g}, \qquad v_{g_2} = \frac{\sigma v_o x}{\alpha_2} \frac{\rho_f}{\rho_g} \qquad (5)$$

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

$$p_2 - p_1 = \frac{G^2}{2g\rho_f} \cdot 2\sigma \cdot \left[x^2 \frac{f}{\rho_g} \left(\frac{1}{\alpha_1} - \frac{\sigma}{\alpha_2} \right) + (1-x)^2 \left(\frac{1}{1-\alpha_1} - \frac{\sigma}{1-\alpha_2} \right) \right] \qquad (6)$$

Because Richardson found no change in α 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:

$$\left[K_{out} - 2\frac{D_{ts}}{D_{ris}}\left(1 - \frac{D_{ts}}{D_{ris}}\right)\right]\frac{G^2}{g_c(\rho_{out} - \rho_{ris})} = \left[K_{out} - 2\sigma(1-\sigma)\right]\frac{G^2}{g_c(\rho_{out} - \rho_{ris})} \tag{7}$$

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

$$\Delta p_{out,\,TPF} = \frac{\sigma(1-\sigma)}{\rho_{out}\cdot g_c}\cdot G^2\left[\frac{x^2}{\alpha}\frac{\rho_f}{\rho_g} + \frac{(1-x)^2}{1-\alpha}\right] + \left[K_{out} - 2\sigma(1-\sigma)\right]\frac{G^2}{g_c(\rho_{out} - \rho_{ris})} \tag{8}$$

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 Kg/cm^2 and thermal power P = 80KW. 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 last squares method.
Using the following relation:

$$R = 1 + a\,x^{b}$$

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

$$a = 44.38 \cdot e^{-0.01688p}$$

$$b = 0.7878 - 0.4762 \cdot 10^{-3}p$$

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.

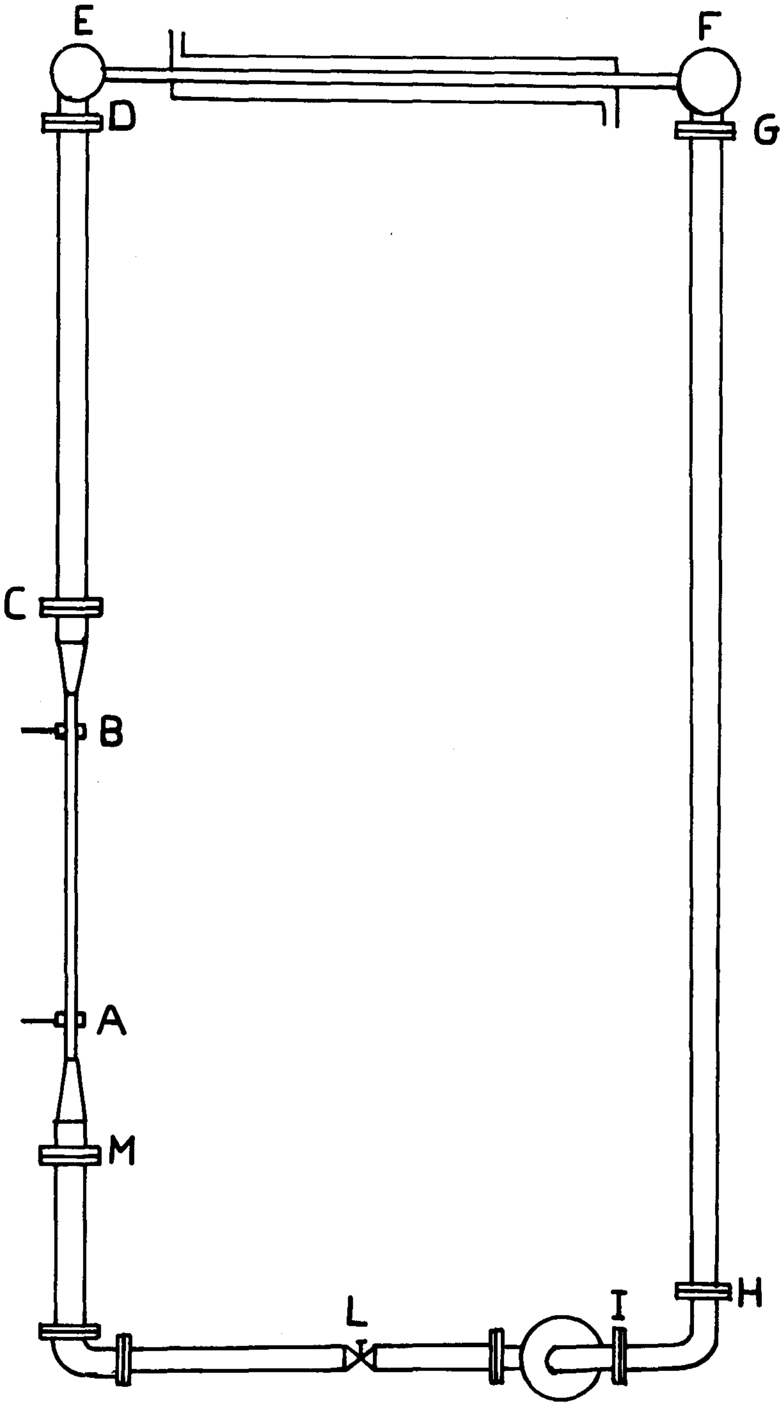

Fig. 1 Hydraulic loop scheme

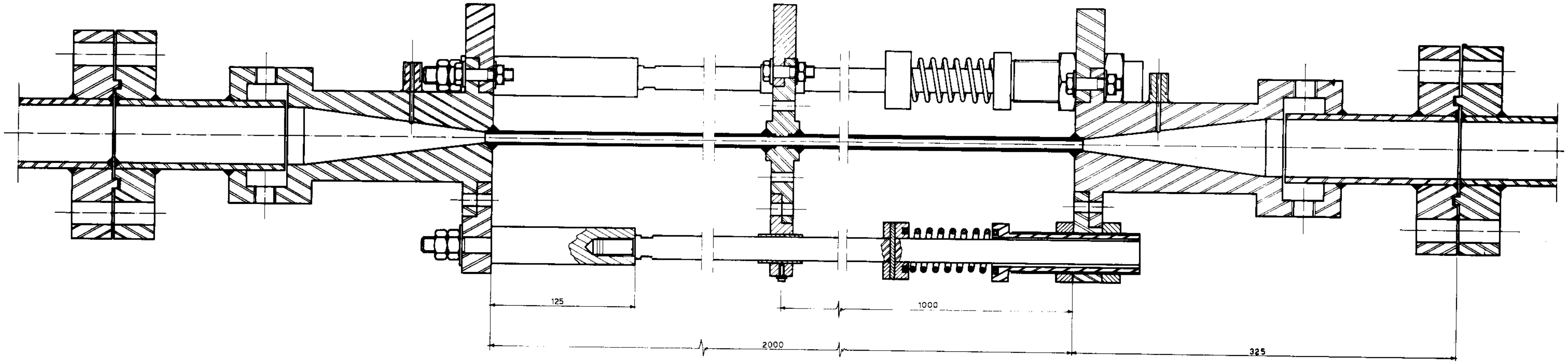

Fig. 2 Section of the heated channel of the loop at Polytechnical School of Turin

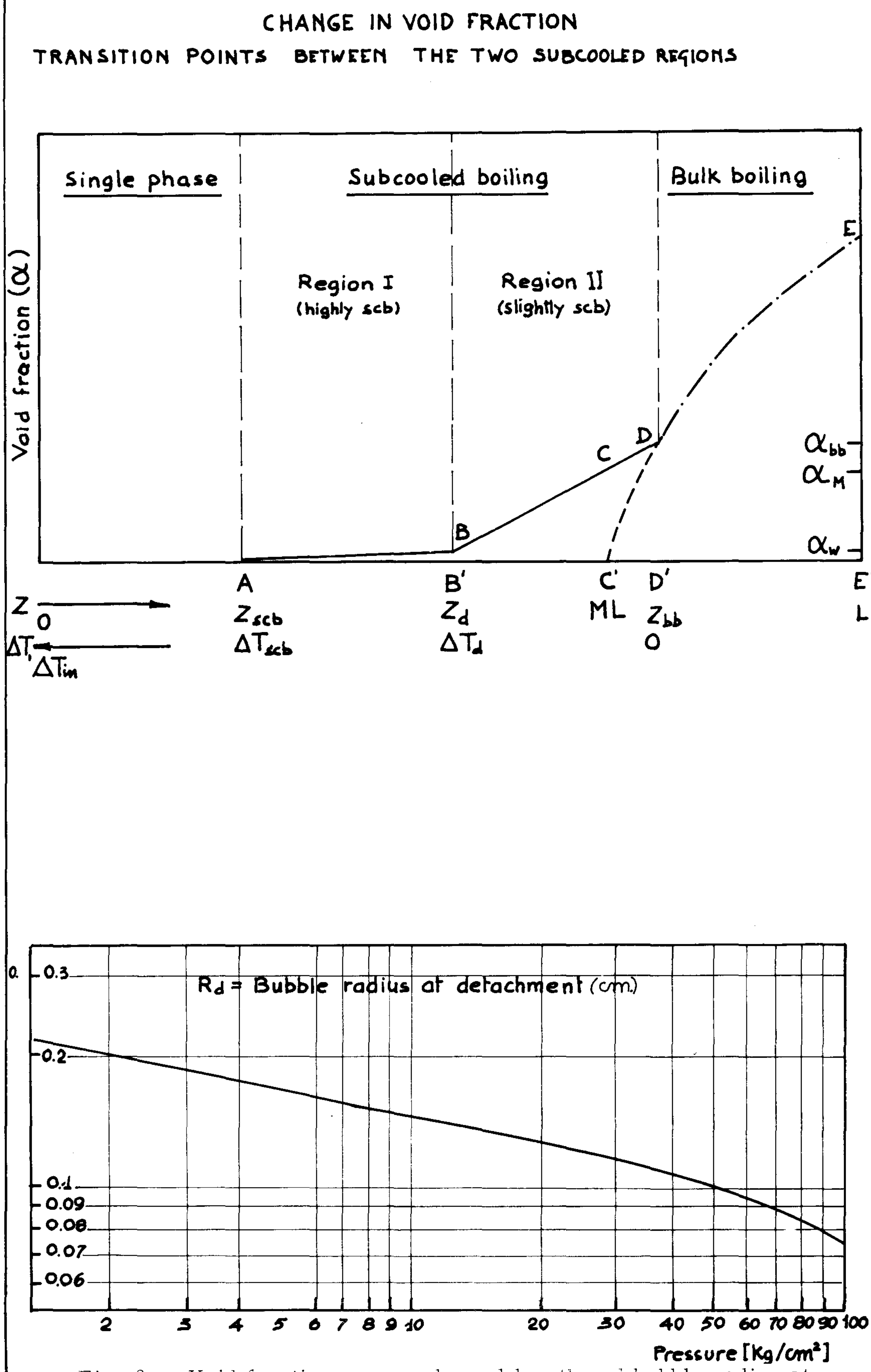

Fig. 3 Void fraction versus channel length and bubble radius at detachment versus pressure from Ref. [2]

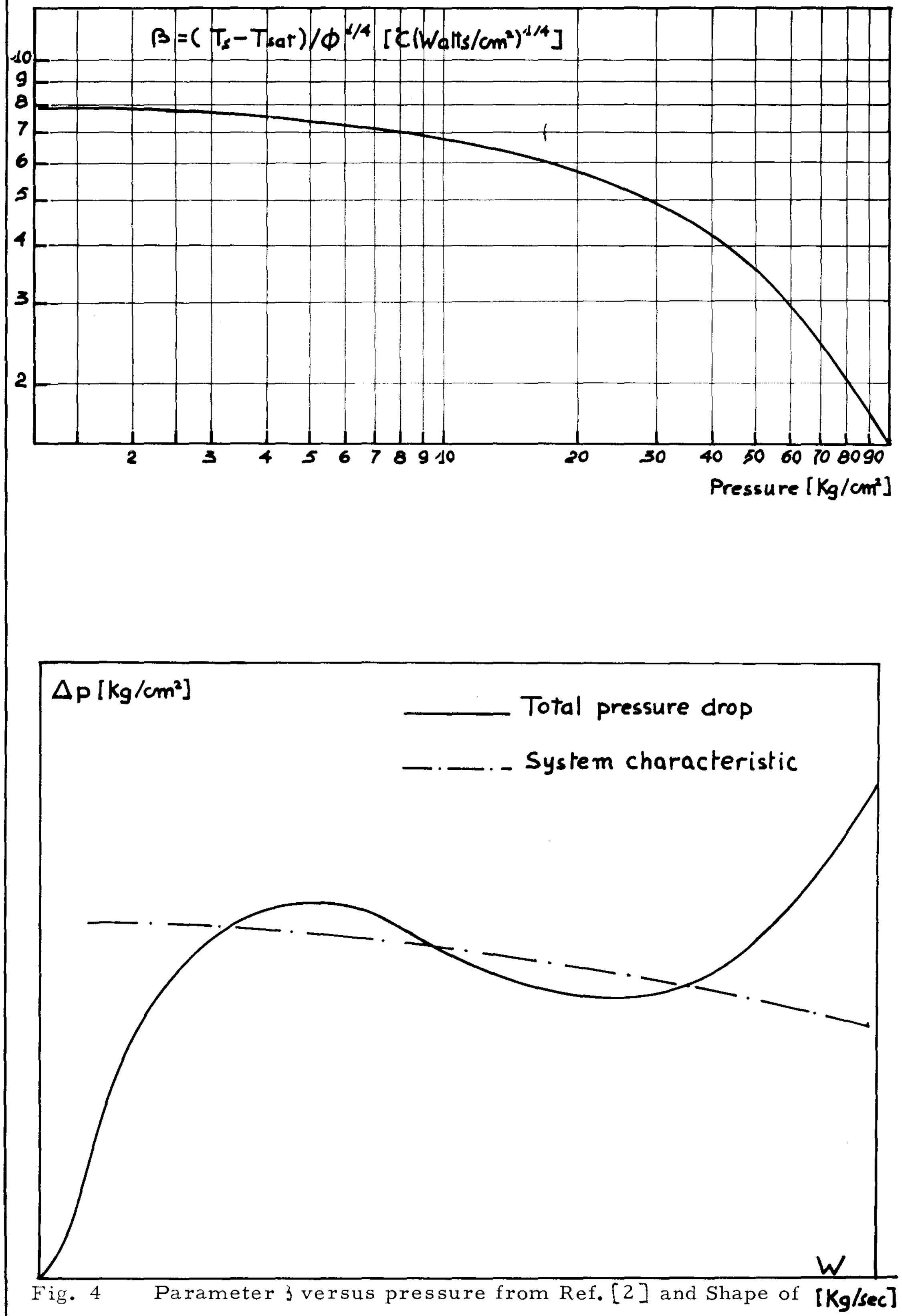

Fig. 4 Parameter β versus pressure from Ref. [2] and Shape of curves representing the elevation head and the total pressure drop versus flow rate

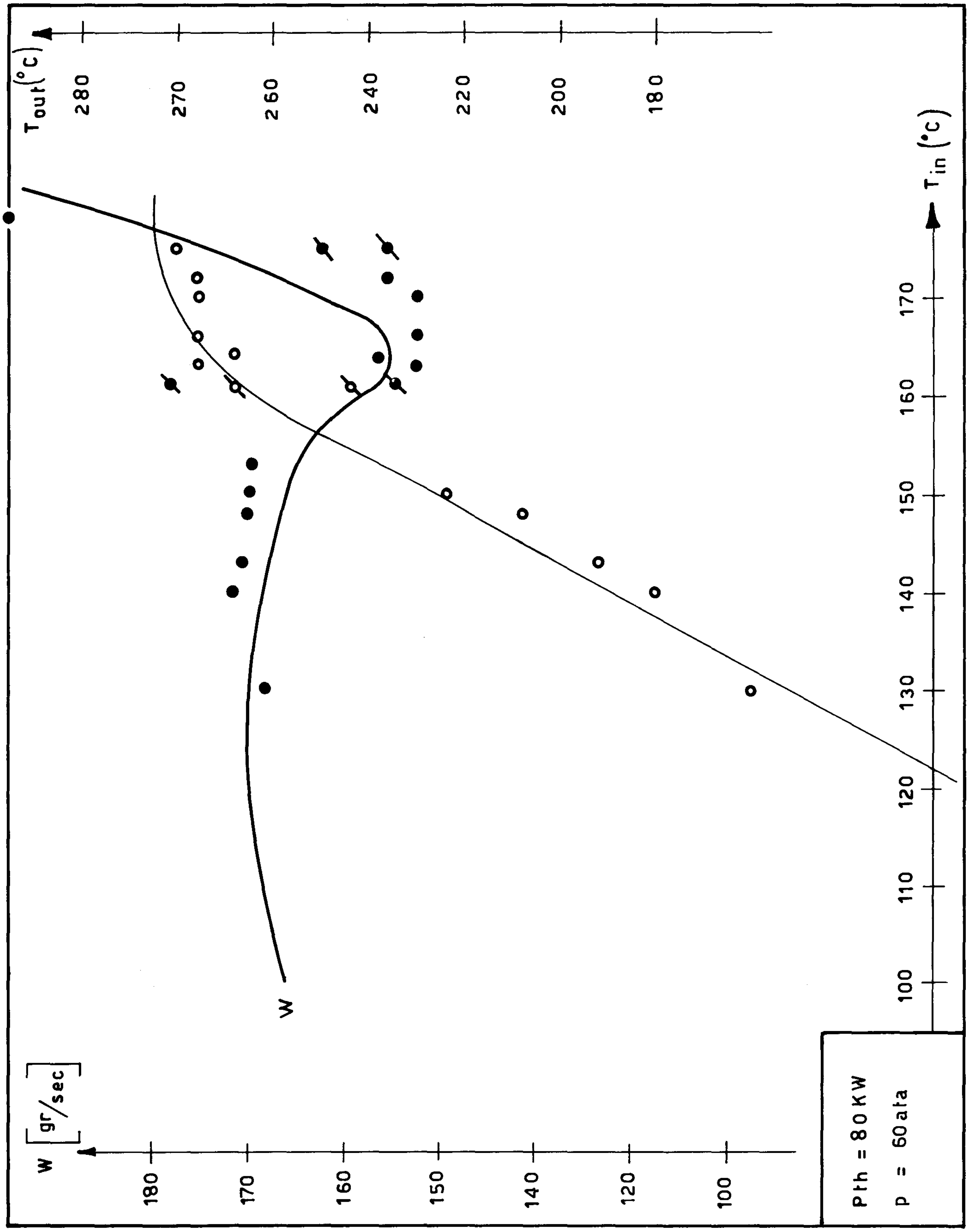

Fig. 5 Comparison between results of the calculation and experimental

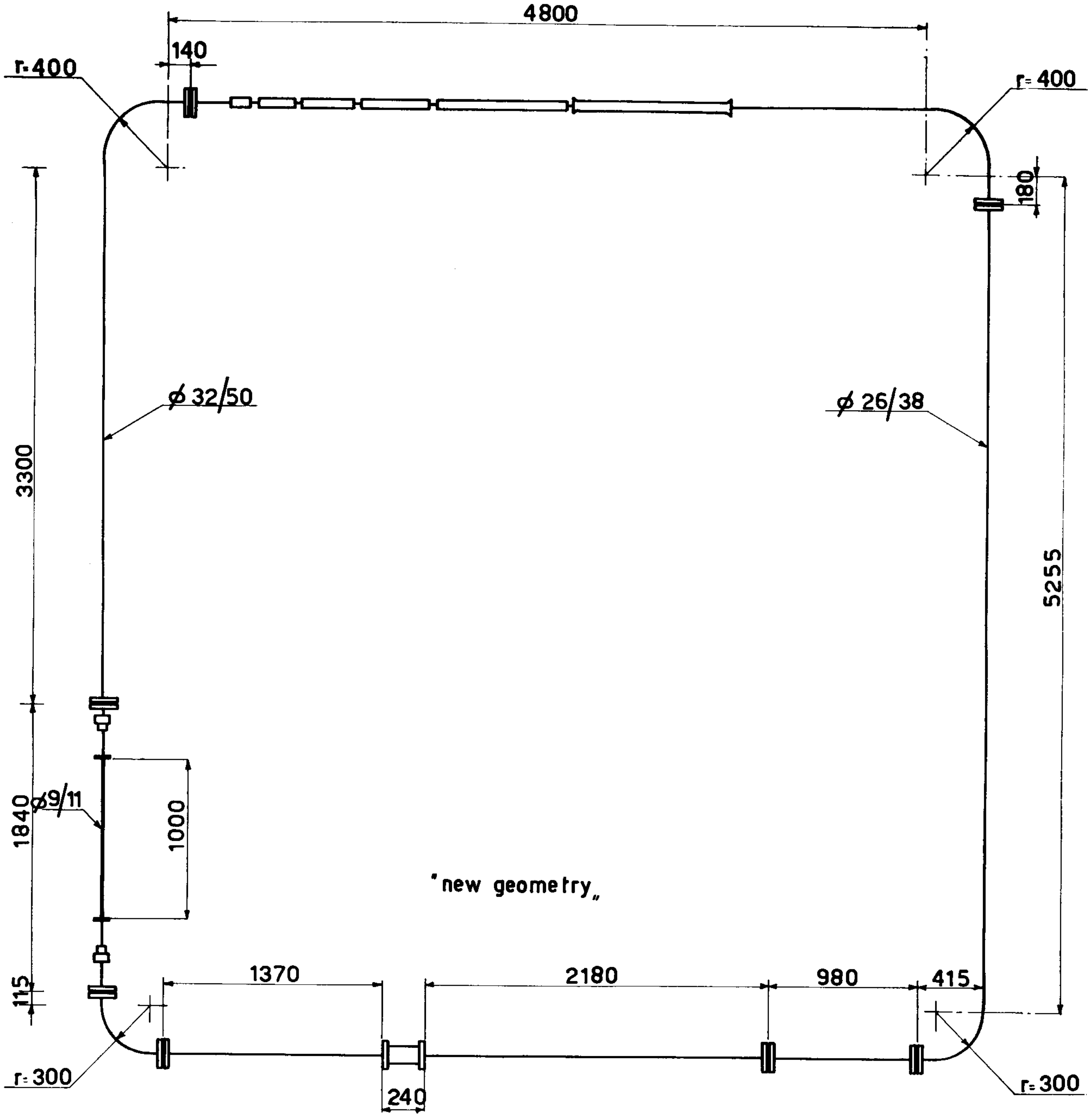

Fig. 6 Schematic representation of the loop at Polytechnical School of Turin

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Alfred Nobel

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