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IMPROVEMENT OF CORE MASS BALANCE CALCULATION IN REFLA-1D/MODE 1

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Improvement of Core Mass Balance Calculation in REFLA-1D/MODE1

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A computer code REFLA-1D/MODE1, which is used for an analysis of the reflood phase of LOCA, has been improved to eliminate unrealistic oscillations of the core mass balance calculation. In the improved core mass balance calculation, the void fraction at the quench front is evaluated and used explicitly in order to evaluate more precisely the mass balance above the quench front.

The improvement eliminated the unrealistic oscillations of the core mass balance calculation without making any significant changes in the rest of the calculated results. Therefore, this improvement has increased the validity of the calculated results of that code. This is an important point especially for the system calculations.

Keywords : REFLA-1D/MODE1, PWR, LOCA, Reflood, Core Mass Balance

REFLA－1D／MODE 1の炉心マスバランス計算の改良

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（1982年7月19日受理）

ＬＯＣＡ解析用計算コードＲＥＦＬＡ－１Ｄ／ＭＯＤＥ１の炉心マスバランス計算に現われる非現実的な振動を取り除くため，コードの改良を行った。改良後のマスバランス計算においては，クエンチ点でのボイド率を算出し，その値をマスバランス計算で用いることにより，クエンチ点上方のマスバランスをより精密に評価している。

この改良により，炉心マスバランス上の非現実的な振動を取り除くことができ，しかも，計算結果の他の部分には，目立った差は認められなかった。従って，この改良により，計算結果の信頼性が向上し，この事は，特にシステム計算において重要な点となる。

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1. Intorduction

REFLA-1D/MODE1[1] is a computer code being developed at the Japan Atomic Energy Research Institute (JAERI) for the thermo-hydrodynamic analysis of the reflood phase during a loss-of-coolant accident (LOCA) in a PWR. This code can calculate the phenomena of both forced flooding and gravity flooding of a system. The treated system is a simple one, such as the Small Scale Reflood Experiment at JAERI[2] and the PWR FLECHT-SET Phase A Experiment[3]. The core calculation is one-dimensional. The results calculated by the previous version of this code were in fairly good agreement[4],[5] with the data of the PWR-FLECHT Experiments[6], under the conditions of the flooding velocity of 1 to 10 in/sec and the system pressure of 60 psia (4.2 ata).

An assessment calculation on the core thermo-hydraulics of REFLA-1D/MODE1 was performed under the conditions of the relatively low system pressure (2 ata) and core inlet liquid flow rate (4 cm/sec). The comparisons of the calculational results with the experimental data showed some discrepancies and problems. One of the problems was the significant oscillations of core outlet mass flow rate. Although the oscillations did not seem to have significant effects on the core cooling behavior in that calculation, it will produce serious effects on both the core and the system behavior in a system calculation, which is planned to be performed in the future. Because, the large oscillations of the core outlet mass flow rate will induce the oscillations of the system behaviors and, hence, the oscillations of the core inlet liquid mass flow rate. Furthermore, the calculated oscillations looked unrealistic, because this kind of oscillations were not obseved in the experiment. Therefore, the oscillations were investigated carefully and eliminated by improving the mass balance calculation in the code.

In this report, the improvement and modification of the core mass balance calculation in REFLA-1D/MODE1 are presented.

2. Improvement and Modification

2.1 Results of previous calculation

As a sample of the previous results of the REFLA-1D/MODE1 core calculation, some of the calculational results for Run 6033 of the Small Scale Reflood Experiment[7] at JAERI are shown in Figs. 1 through 5. The main conditions of Run 6033 are summarized in Table I. The input deck is given in Table II. Figure 1 shows the rod surface temperature histories at six specified elevations. Figures 2 and 3 give the heat transfer coefficients and the void fractions, respectively, at the same six elevations as specified in Fig. 1. Figure 4 shows the movements of the flow regime boundaries. L1 and L2 are the bulk boiling point and the quench front, respectively. L3 is the bulk boiling point above the quench front (L2), when the liquid temperature is lower than the saturation temperature at the quench front. **In this calculation, L3 = 12. L4 and L5 are the froth level and the top quench front, respectively.** L7 is the liquid top *i.e.* the initiation of single phase steam flow. Figure 5 shows core mass balance. In the notations, G1 is the core inlet liquid mass flux. GLOUT and GN1 are the liquid and fluid mass fluxes at the core exit, respectively. MCDOT is the liquid accumulation rate in the core. These plots are the same as those given in Appendix of reference 1. However, in this report, they are plotted with the time interval of one second, which is one-fifth of that in reference 1, in order to show the oscillations more clearly.

As recognized from Figs. 4 and 5, there are some periodic oscillations after 180 sec. In Fig. 4, the liquid top (L7) drops down from the top of the core during the oscillations. Also in Fig. 5, the core outlet fluid and liquid mass flows approach zero during the oscillations.

Although there seems to be little effect of the oscillations on the rod surface temperature histories, as shown in Fig. 1, these oscillations will cause serious problems in the system calculations, which are planned to be performed in the future, because those oscillations are very large in magnitude. In the system calculations, the core inlet liquid flow rate is determined based on the system behaviors, mainly, the primary loop pressure loss. Thus, the oscillations of the core exit flow rate might result in the oscillations of the core inlet liquid flow rate and, hence, the core cooling behavior. On the other hand, this kind of oscillations were not observed in the experiment. Therefore, those oscillations are considered unrealistic and should be eliminated by improving the code.

The period of the oscillation was found to be 20 sec after 180 sec. A quench front propagation was also examined, because it is a key parameter of the core behavior. The calculated quench front velocity was found to be about 0.2 cm/sec, and the node increment was 4 cm in that calculation. Therefore, the time interval of travel of the quench front between nodes was estimated to be 20 sec. This time interval is the same as the oscillation period. Figure 6 shows the timings of the oscillations plotted on the quench front history. From this figure it was found that the oscillations occurred at the times just after the quench front passed the calculational nodes. In other words, when the quench front existed just above the calculational nodes, the oscillations occurred and the liquid top dropped.

In REFLA-1D/MODE 1, the liquid top level is determined based on the core mass balance calculation, as described in detial in the next section. Therefore, the core mass balance calculation was investigated as concerning the effect of the quench front position; that is, the logic and assumptions in the core mass balance calculation were examined, in order to eliminate unrealistic drops of the liquid top.

2.2 Improvement of mass balance calculation model

In REFLA-1D/MODE1, the mass balance calculation of the core is performed in a subroutine named MASBAL. In the subroutine MASBAL, several recurrence formulas are used in order to calculate a fluid mass flux, a vapor mass flux and so on. They are summarized in Table III. They are dervied from ordinary mass balance equations at the calculational node. A flow diagram of the subroutine MASBAL is given in Fig. 7.

The liquid top is determined based on the value of $M^*_{\ell,I+1}$, which is the liquid mass above the node I+1. The calculation procedes from node 1 to node N1(top node). If $M^*_{\ell,I+1}$ becomes a negative value first, the liquid top is assumed to exist between the nodes I and I+1. The exact position of the liquid top, which is denoted as L7, is obtained from Eq.(5) in Table III. Namely, replacing I+1 with L7 in Eq.(5),

$$M^*_{\ell,I} - \int_I^{L7} (1-\alpha_I)\rho_\ell dZ - \int_I^{L7} \dot{m} dZ \cdot \Delta t = 0 \qquad (9)$$

is the equation to obtain the liquid top L7. In the mass balance calculation (see Table III), the void fraction α_I is assumed to be constant between the nodes I and I+1 and is fixed at a value at the node I. This is illustrated in Fig. 8. In Fig. 8, broken lines show a void fraction distribution, and the width between two broken lines gives the void fraction. The hatched rectangles represent the assumed void fraction distribution, and the vaule of void fraction between the nodes I and I+1 is constant being fixed at the value of the node I. However, this assumption is not accurate enough when the quench front exists just above the calculational node.

The void fraction distribution near the quench front was investigated when the quench front just passed the calculational node. This is illustrated in Fig. 9 for the time about 240 sec. As recognized from Fig. 6, the oscillation was observed at about 240 sec. At 239.8 sec, the quench front is just below the node 47, 0.02 mm below as illustrated in Fig. 9(a). The void fraction at the node 47 is 0.9097, wheras at the node 46 the void fraction is 0.7777. This indicates that the difference of the void fraction is large between the positions above and below the quench front.

At the next time step (239.9 sec), as shown in Fig. 9(b), the quench front has progressed and exists just above the node 47, 0.2 mm above. The void fraction at the node 47 has decreased a lot from 0.9097 to 0.7939. Corresponding to this decrease of the void fraction, $M^*_{\ell,I+1=48}$ decreases and the water above the node 48 is calculated to decrease. Because $M^*_{\ell,I+1}$ is calculated based on the void fraction at the node I=47, as mentioned before. The sudden decrease of the water above the node I+1 results in the drop of the liquid top.

In about 2 sec after that time, however, the liquid top returns to the top of the core. The reason is as follows. When the liquid top does not exist at the top of the core, the liquid can not flow out and stays in the core. This increased amount of liquid decreases the void fractions and, hence, the liquid top returns to the top of the core. This process takes place in a short time, that is, in about 2 sec.

By the reason described above, the mass balance calculation has been improved. In the improvement, the void fraction at the quench front is calculated and used explicitly in the mass balance calculation in order to evaluate $M^*_{\ell,I+1}$ more precisely. Equation (5) in Table III is then rewritten as follows.

$$M^*_{\ell,I+1} = M^*_{\ell,I} - \int_I^{L2} (1-\alpha_I)\rho_\ell dZ - \int_{L2}^{I+1} (1-\alpha_{L2})\rho_\ell dZ - \int_I^{I+1} \dot{m} dZ \cdot \Delta t \qquad (10)$$

where, α_{L2}: void fraction at quench front

Corresponding to the changes described above, a subroutine named SATTPF, in which the thermo-hydrodynamics in the saturated two phase flow regime is calculated, and the subroutine MASBAL were improved. A flow diagram of subroutine SATTPF is given in Fig. 10.

As shown in Fig. 10, the fluid mass flux G_{I+1} at the node I+1 is calculated first by calling the subroutine MASBAL. Then, if the quench front exists between the nodes I and I+1 the vapor mass flux at the quench front, $G_{g,L2}$, is calculated by following the calculation of $\int_{I}^{L2} \dot{m}\, dZ$, which is the vapor mass changed from liquid between the node I and the quench front. The void fraction and the slip velocity at the quench front are calculated based on the value of $G_{g,L2}$, by calling a subroutine named VOIDCL. In this subroutine, the slip velocity is calculated first by using the void fraction evaluated with a Cunnigham-Yeh's correlation(8) for the vapor mass flux $G_{g,L2}$. Then, the void fraction α_{L2} is recalculated with the slip velocity obtained in the previous step. The variables at the node I+1, such as the fluid mass flux G_{I+1}, the liquid mass $M^{*}_{\ell,I+1}$, are calculated with the above void fraction α_{L2} and that at the node I.

After all, as described above, the mass balance calculation process has been divided into two parts at the quench front when the quench front exists between the concerned nodes. This new process has improved significantly the estimation of the liquid mass above the quench front and, hence, has eliminated the unrealistic oscillations of the core outlet mass flow rates. The effects of the improvement are recognized from Figs. 14 and 15 in comparison with Figs. 4 and 5, and are described in detail in Section 3.

2.3 Modification of mass balance calculation method

The improvement described above resulted in modification of the code. Subroutines modified are SATTPF, MASBAL and LIQTOP. Especially, subroutine MASBAL was modified extensively. A flow diagram of subroutine MASBAL is given in Fig. 7 and its FORTRAN list is attached in Appendix.

In subroutine MASBAL, JOB=7 and 8 were added newly. The former is a step for the mass balance calculation by taking into account the void fraction at the quench front. The latter is a step to store the values of GGS(I) and GLS(I) as the "old" (i.e. previous time step) values GGS1(I) and GLS1(I), respectively. Variables GGS(I) and GLS(I), which were also newly introduced, are given as follows;

$$GGS(I)=\int_{I}^{I+1} \alpha_I \rho_g \, dZ \quad \text{and} \quad GLS(I)=\int_{I}^{I+1} (1-\alpha_I)\rho_\ell \, dZ$$

Subroutine LIQTOP, in which the liquid top position is calculated by calling subroutine MASBAL, was also modified correspondingly to the improvement and modification of subroutine MASBAL. And besides, some minor formulation and coding errors were found and corrected.

3. Calculated Results with Improved Code and Discussion

Some results calculated with the improved code are shown in Figs. 11 through 15. The results are calculated with the same input deck as that for Figs. 1 through 5 (see Table II). In the following, the effects of the improvement on the core mass balance results are presented and discussed first. Next, the effects of the improvement on the other results, such as rod temperatures, heat transfer coefficients and void fractions, are presented and discussed.

3.1 Effects of improvement on core mass balance results

The core mass balance results are presented in Figs. 5 and 15. In these results, the large oscillations appeared in Fig. 5 after 180 sec are no larger observed in Fig. 15. The periodic drops of the liquid top level that appeared in Fig. 4 can neither be observed any more in the improved calculational results in Fig. 14. This means that the improvement more correctly calculates core mass balance and hence prevents the unrealistic oscillations. Therefore, the present improvement demonstrated that the explicit treatment of the void fraction at the quench front is necessary in the mass balance calculation.

The reason for the necessity of the treatment described above can be summarized as follows. In those calculations, as shown in Figs. 4 and 14, the transition flow regimes (between L2 and L4) disappear by 140 sec. It means the quench front is also the froth level, *i.e.* the initiation level of the dispersed flow regime after that time. In such a thermo-hydrodynamic situation, the void fractions which are a little above and below the quench front are calculated to be rather different from each other (Fig. 9). This difference is the reason of the explicit treatment of the void fraction at the quench front in the core mass balance calculation.

Although the oscillation of MCDOT/G1 is larger in Fig. 15 than in Fig. 5 before 30 sec, it is not considered to be a trouble by two reasons. One of them is that the rod temperatures, heat transfer coefficients and void fractions are nearly identical before and after the improvement, as is described in the next section. The other reason is that the oscillation does not induce the serious oscillation of the core outlet mass flow rate (see GN1/G1 in Fig. 15). This means that the oscillation will neither be trouble in the system calculations.

After all, the improvement increases the validity of the calculated results, because it eliminates the unrealistic oscillations of the core outlet mass flux. Especially this will be an important point for system calculations. As mentioned in Section 1, the oscillations of the core outlet mass flux will induce the oscillations of the system behaviors and hence the oscillations of the core inlet mass flux. Furthermore, in the system calculations, the calculated results tend to oscillate more than in the core calculation because of the U-tube type oscillatory behavior between the core and the downcomer, as sometimes observed in the experiments. Therefore, the present improvement will be able to make sure that the oscillations in the calculational results are not caused artificially, but are calculated correctly in reproducing the physical phenomena.

3.2 Effects of improvement on rod tmeperatures, heat transfer coefficients and void fractions

The comparison between Figs. 1 and 11 indicates that the rod temperatures are nearly identical before and after the improvement. The comparisons of the heat transfer coefficients (Figs. 2 and 12) and the void fractions (Figs. 3 and 13) also show the same trend; that is, the results before and after the improvement are nearly identical. Therefore, it can be said that the improvement did not change the calculated core thermo-hydrodynamic behaviors very much except for the elimination of the unrealistic oscillations.

As described above in detail, the improvement of the core mass balance calculation, which took into account the void fraction at the quench front, could eliminate the unrealistic oscillations. The calculated results such as rod temperatures and heat transfer coefficients were nearly indentical before nad after the improvement. Consequently, the improvement can eliminate the unrealistic oscillations of the mass balance calculation without making any significant changes in the rest of the calculated results. This improvement is important and meaningful especially in the system calculations, which are planned to be performed in the future as the next step of the analysis with REFLA-1D/MODE1.

4. Conclusions

A computer code REFLA-1D/MODE1 has been improved in order to eliminate the unrealistic oscillations from the core mass balance calculation. In the improved core mass balance calculation, the void fraction at the quench front is evaluated and used explicitly in order to evaluate more correctly the mass balance above the quench front. By the improvement, the oscillations of the core mass balance calculation were eliminated. This fact increases the validity of the mass balance calculation of that code. This is an important point especially for the system calculation.

Except for the elimination of the unrealistic oscillations, the calculated results were nearly identical bebore and after the improvement. Therefore, the improvement eliminates the unrealistic oscillations of the core mass balance calculation without making any significant changes in the rest of the calculated results.

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Table 1 Main initial conditions of Run 6033

Maximum linear power density	2.1	kW/m
System pressure	2.0	kg/cm^2a
Inlet water temperature	100	°C
Inlet water velocity	4.0	cm/sec
Initial rod surface temperature	400	°C

Table II Input data for Run 6033

Line No.												
1	TEST CALCULATION OF RUN 6033 (S6033)											
2		2.100		0.10		4.0		100.		2.000		2.000
3		100.0		4.000		4.00						0.0
4		1										
5		90				10.5		13.8		3.6		4
6		1.0						5.00				
7												
8												
9												
10				400.0								
11												
12		450.0										
13		450.0		1200.0								
14	181.0	181.0	181.0	181.0	181.0	181.0	181.0	181.0	181.0	181.0	181.0	181.0
15	181.0	250.5	250.5	250.5	250.5	250.5	250.5	250.5	250.5	250.5	250.5	250.5
16	318.0	318.0	318.0	318.0	318.0	318.0	318.0	318.0	318.0	318.0	318.0	400.0
17	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0
18	400.0	400.0	400.0	400.0	400.0	400.0	400.0	320.0	320.0	320.0	320.0	320.0
19	320.0	320.0	320.0	320.0	320.0	320.0	320.0	247.0	247.0	247.0	247.0	247.0
20	247.0	247.0	247.0	247.0	247.0	184.0	184.0	184.0	184.0	184.0	184.0	184.0
21	184.0	184.0	184.0	184.0	184.0	184.0	184.0					

Table III Recurrence formulas used for mass balance calculation

$$\begin{cases} G_{I+1} = G_I - \frac{\partial}{\partial t}\int_I^{I+1} \{\alpha_I \rho_g + (1-\alpha_I)\rho_\ell\} dZ & (1) \\ G_1 = \rho_\ell U_{\ell,1} & (2) \end{cases}$$

$$\begin{cases} G_{g,I+1} = G_{g,I} + \int_I^{I+1} \dot{m}\, dZ - \frac{\partial}{\partial t}\int_I^{I+1} \alpha_I \rho_g\, dZ & (3) \\ G_{g,1} = 0 & (4) \end{cases}$$

$$\begin{cases} M^*_{\ell,I+1} = M^*_{\ell,I} - \int_I^{I+1} (1-\alpha_I)\rho_\ell\, dZ - \int_I^{I+1} \dot{m}\, dz \cdot \Delta t & (5) \\ M^*_{\ell,1} = M^{old}_{\ell,N1} + \rho_\ell U_{\ell,1} \Delta t & (6) \end{cases}$$

$$\begin{cases} M_{\ell,I+1} = M_{\ell,I} + \int_I^{I+1} (1-\alpha_I)\rho_\ell\, dZ & (7) \\ M_{\ell,1} = 0 & (8) \end{cases}$$

Note:

G_I : fluid mass flux at node I

$G_{g,I}$: vapor mass flux at node I

$M^*_{\ell,I}$: liquid mass above node I

$M_{\ell,I}$: liquid mass below node I

α_I : void fraction at node I

ρ_g : vapor density

ρ_ℓ : liquid density

$U_{\ell,1}$: core inlet liquid velocity

$\dot{m}$: phase change rate from liquid to vapor

Δt : time mesh

N1 : top node

"old" means previous time step.

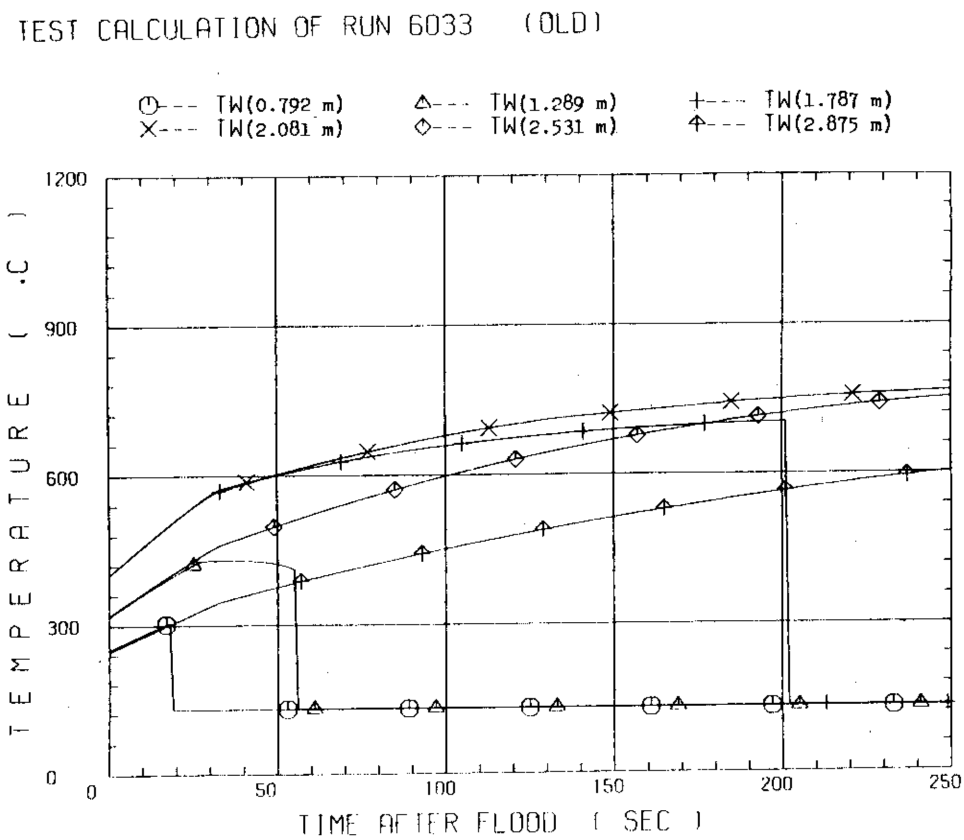

Fig.1 Temperature histories at six elevations (Old)

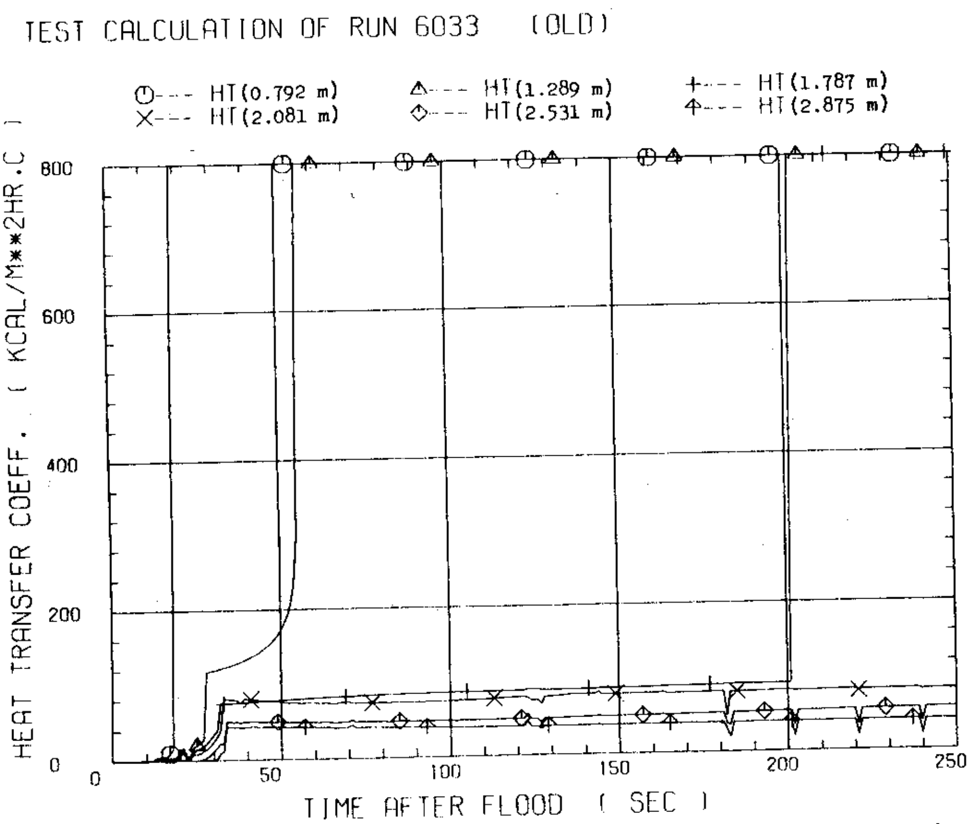

Fig.2 Heat transfer coefficients at six elevations (Old)

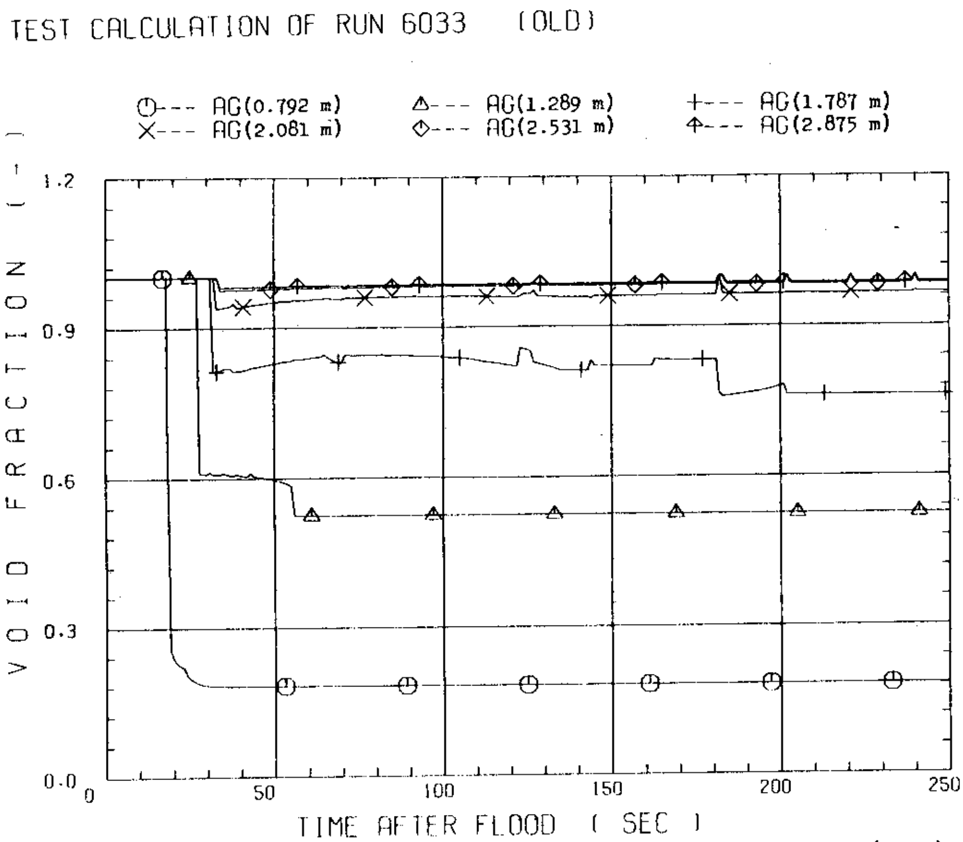

Fig.3 Void fraction histories at six elevations (Old)

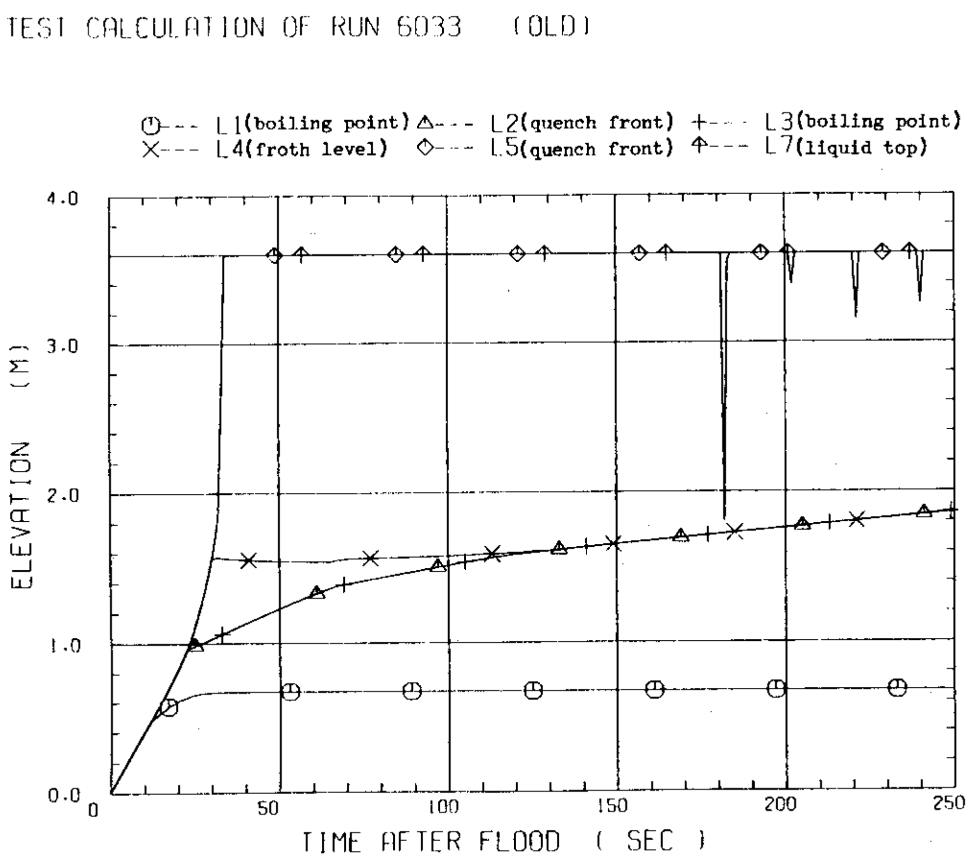

Fig.4 Movement of boundaries L1 through L7 (Old)

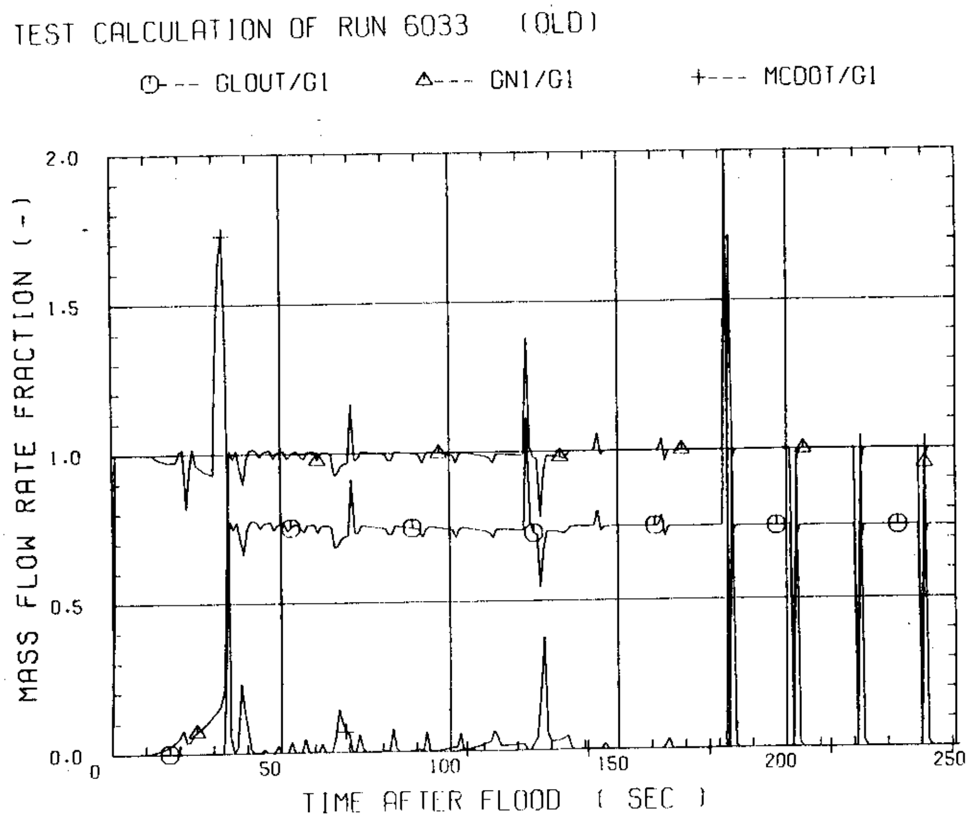

Fig.5 Core outlet liquid mass flux (GLOUT), core outlet fluid mass flux (GN1) and core liquid accumulation rate (MCDOT) divided by core inlet fluid mass flux (G1) (Old)

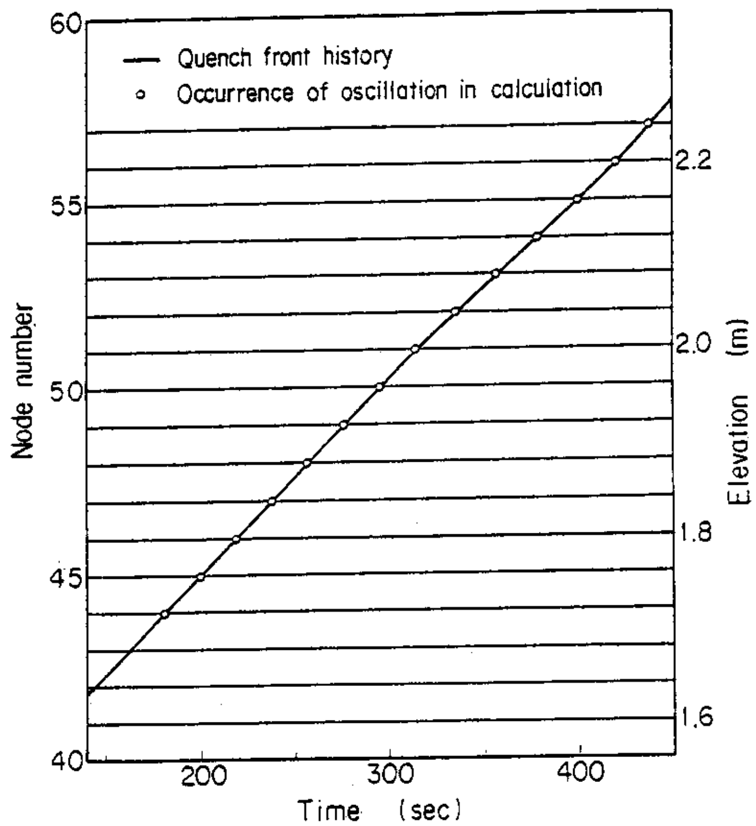

Fig.6 Timings of oscillations plotted on quench front history curve

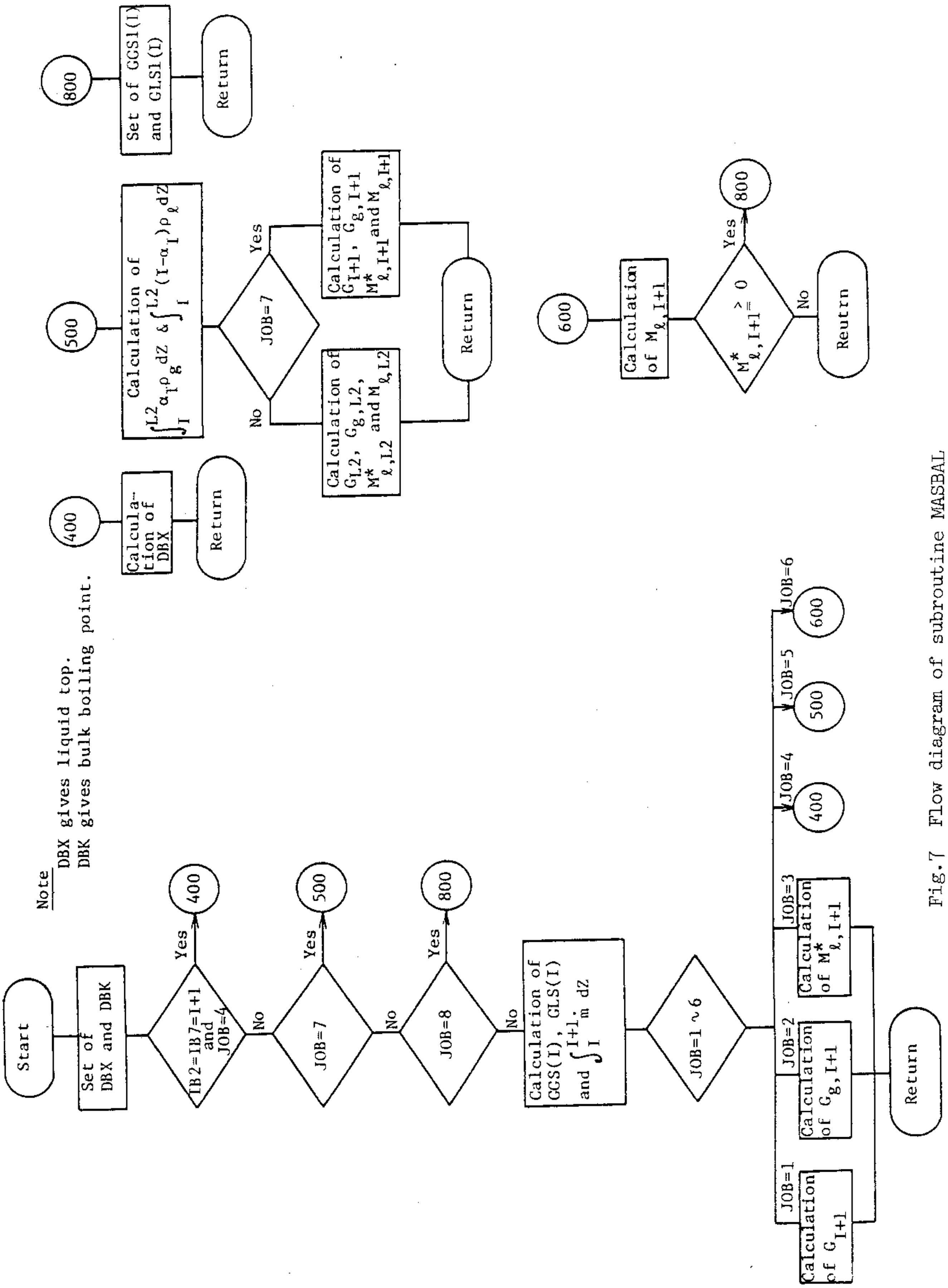

Fig.7 Flow diagram of subroutine MASBAL

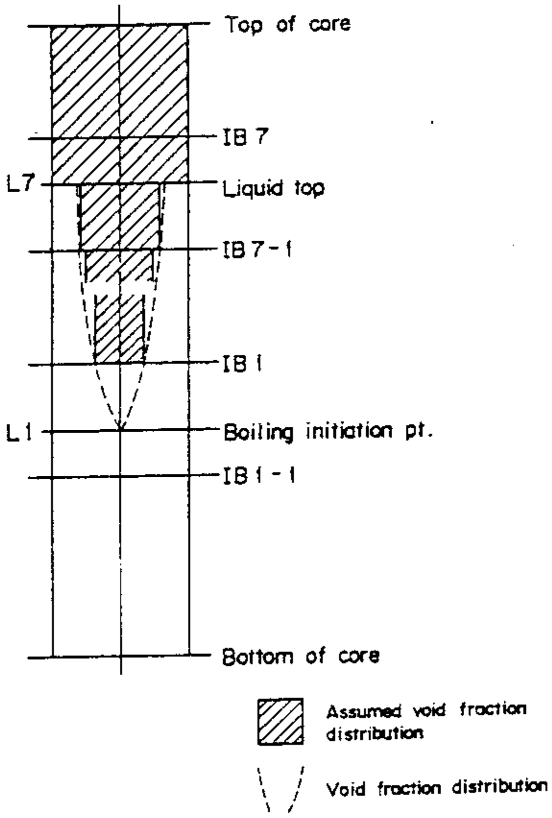

Fig.8 Assumed void fraction distribution

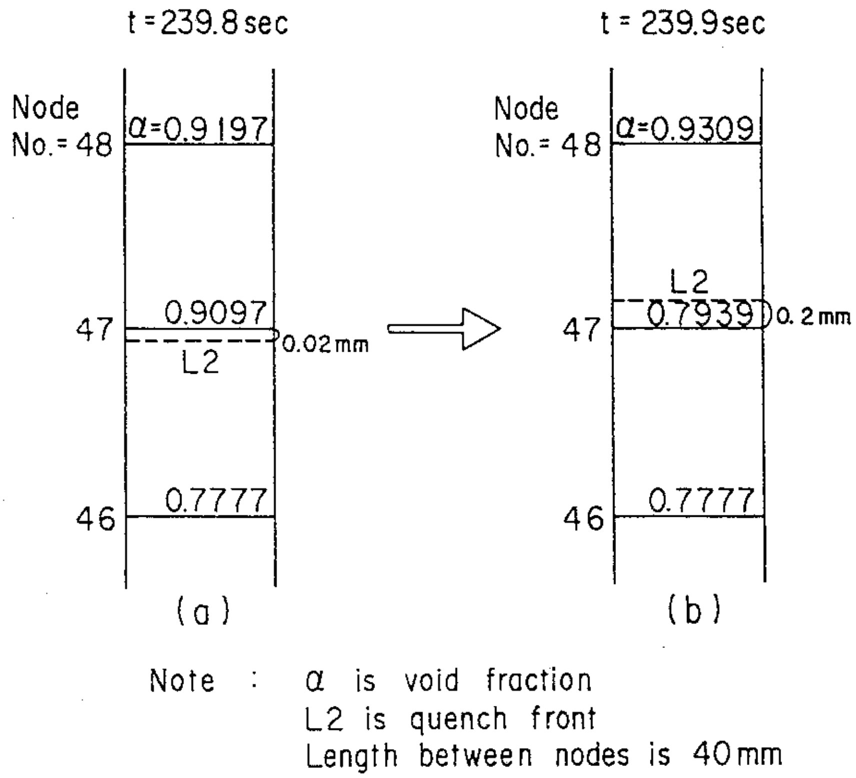

Fig.9 Calculated void fractions around quench front

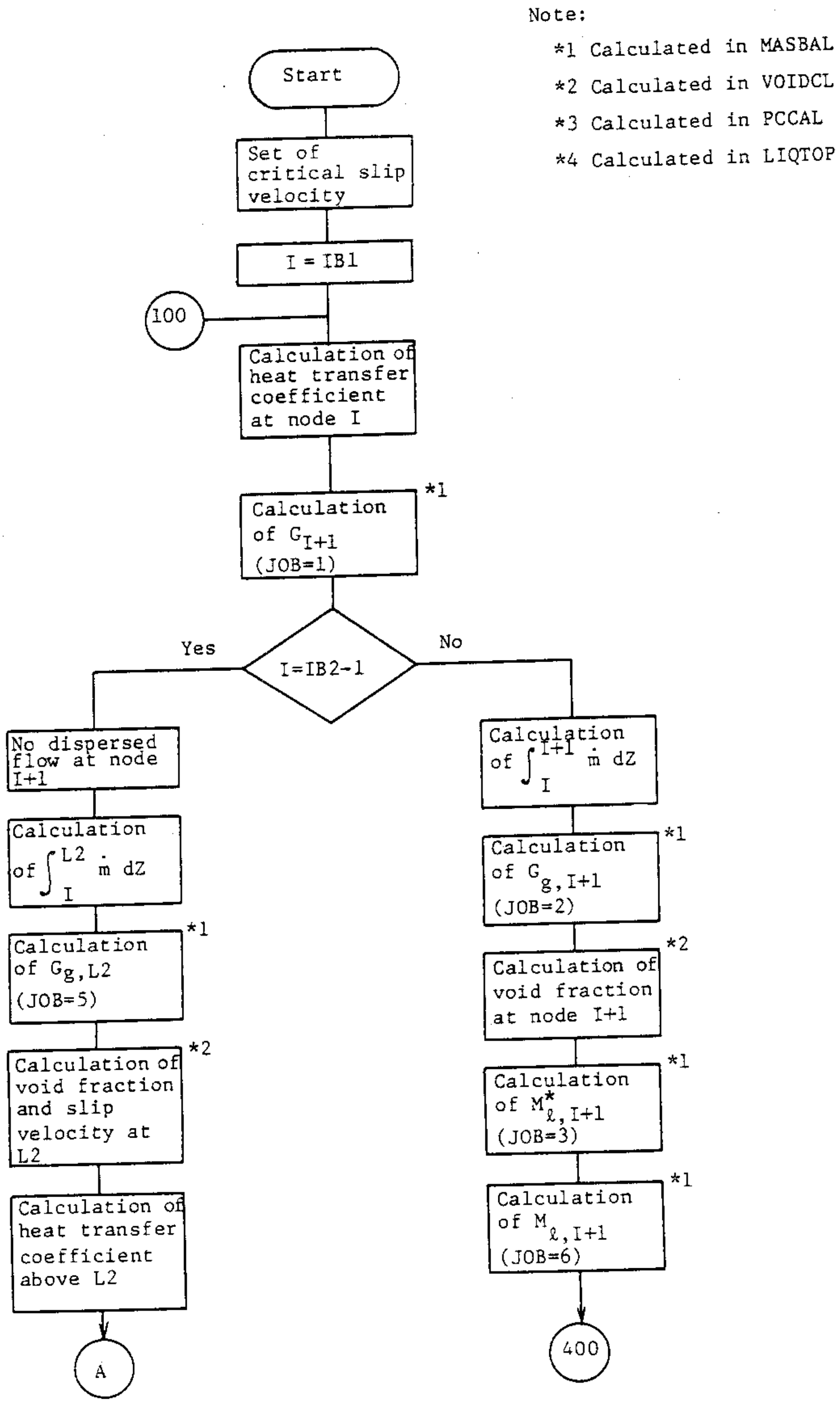

Fig.10 Flow diagram of subroutine SATTPF

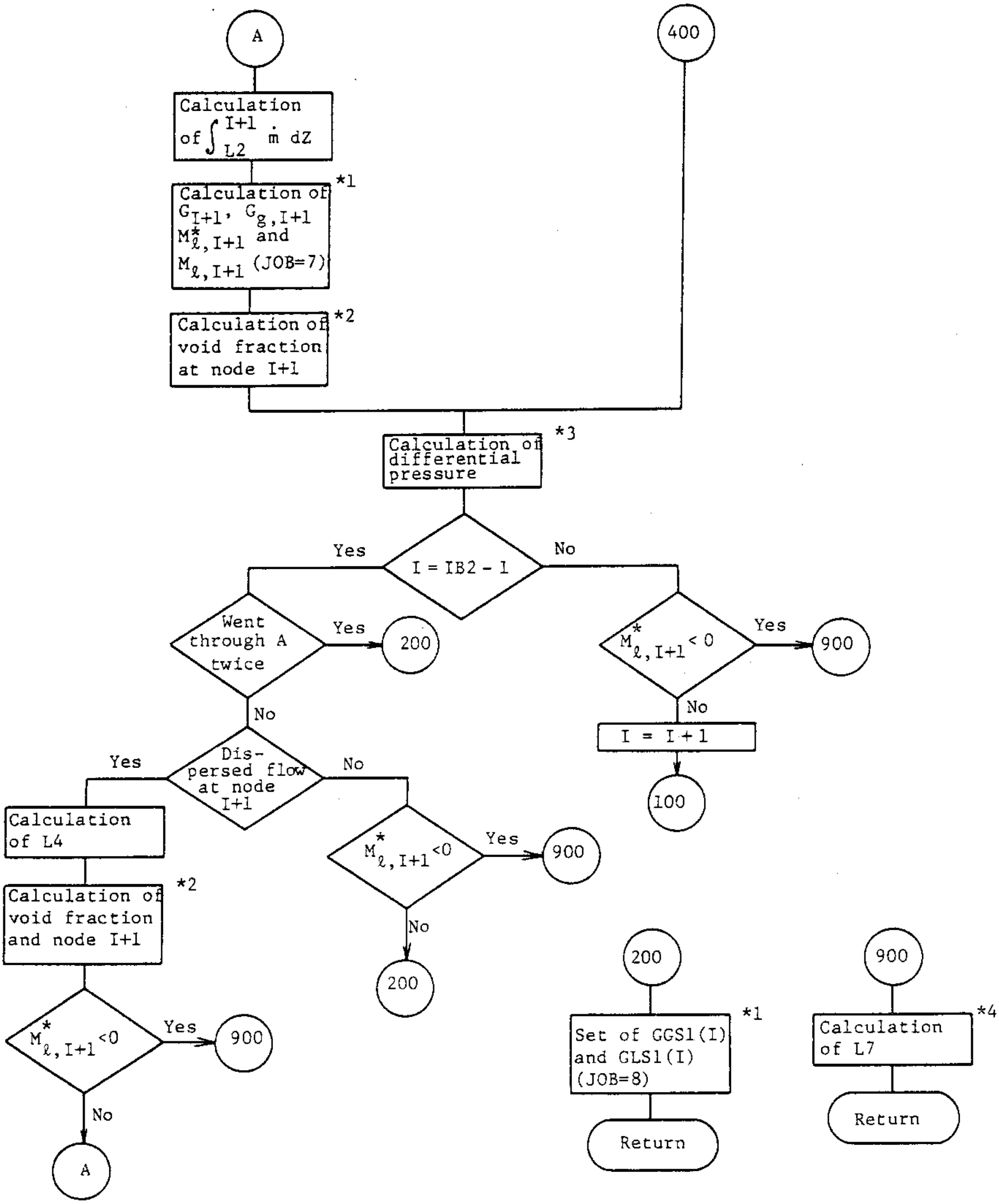

Fig.10 Flow diagram of subroutine SATTPF (cont'd)

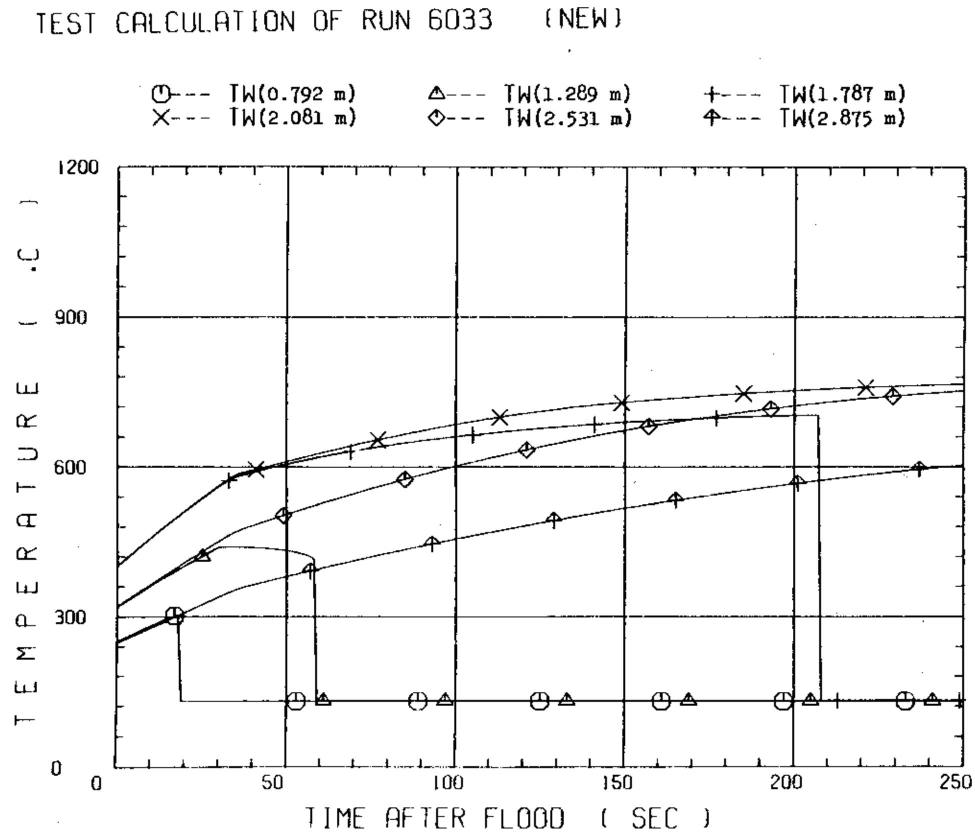

Fig.11 Temperature histories at six elevations (New)

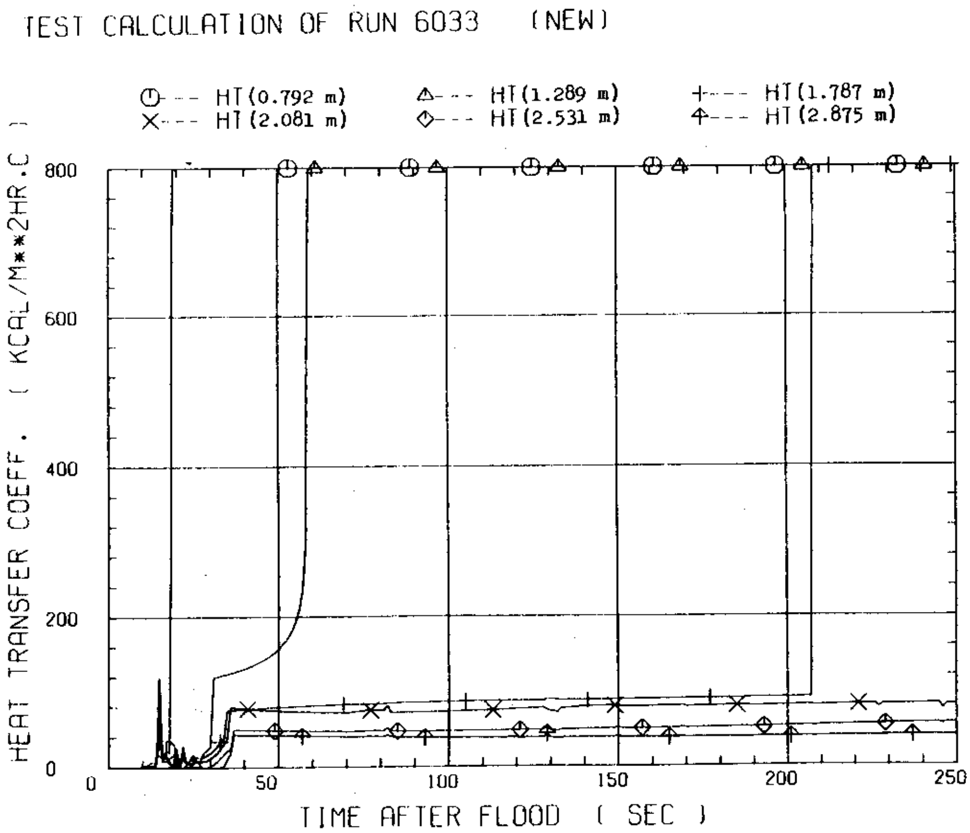

Fig.12 Heat transfer coefficients at six elevations (New)

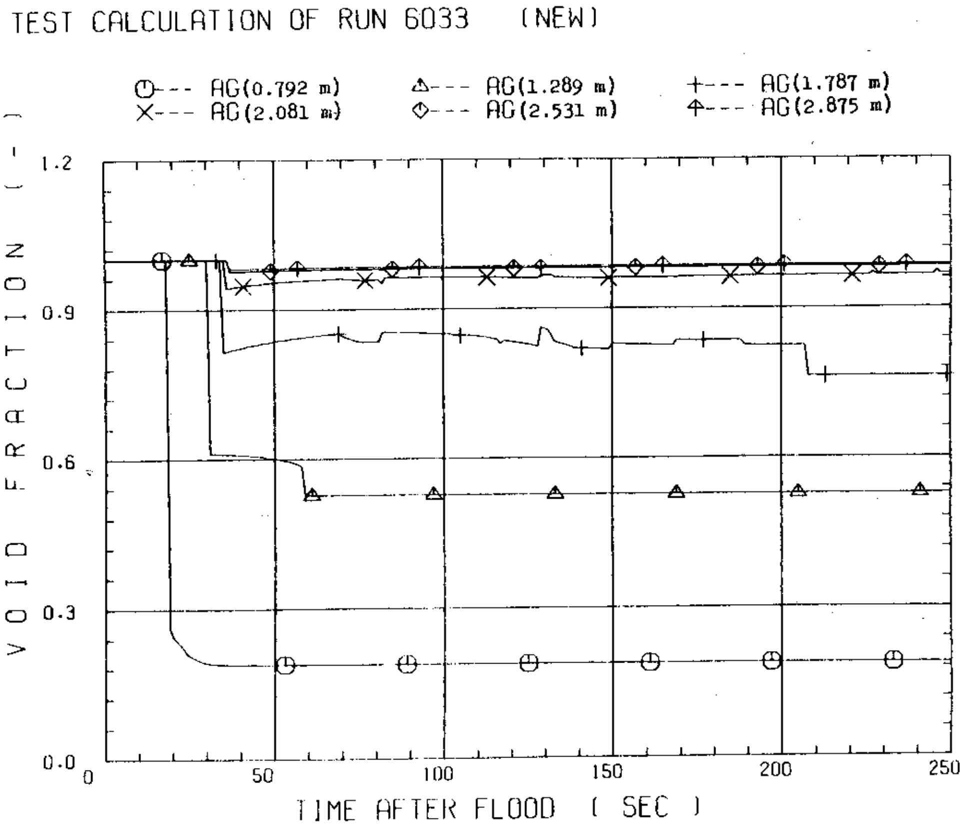

Fig.13 Void fraction histories at six elevations (New)

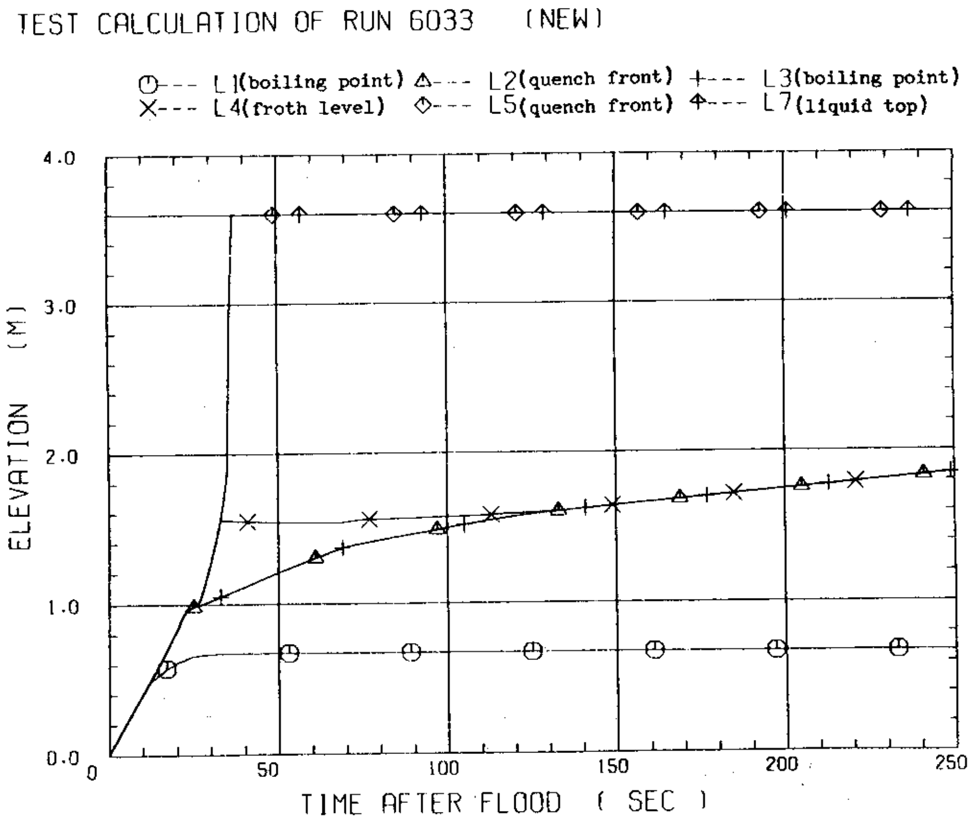

Fig.14 Movement of boundaries L1 through L7 (New)

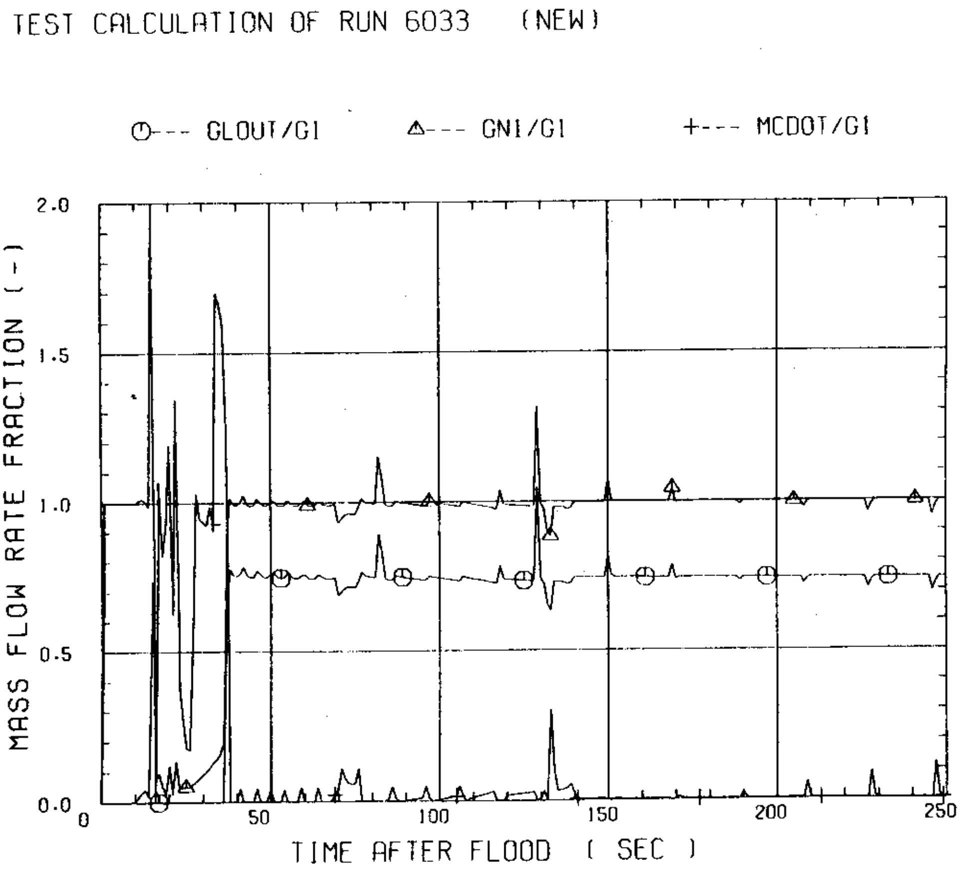

Fig.15 Core outlet liquid mass flux (GLOUT), core outlet fluid mass flux (GN1) and core liquid accumulation rate (MCDOT) divided by core inlet fluid mass flux (G1) (New)

Appendix

In this appendix, FORTRAN lists of subroutines SATTPF and MASBAL are given.

```
      SUBROUTINE SATTPF(IB1,IB2,IB3,IB4,IB5,IB6,IB7,
     1           IB01,IB02,IB03,IB04,IB05,IB06,IB07,DB1,DB2,DB3,DB4,DB5,
     2           DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     3           X,G,FCPR,QTIME,AG,AG1,RG,TW1,TW,UGO,HR,UL,
     4           CREST,CTOTAL,PC,DU,CN,TG,HG,TL,DV,DD,
     5           HCV,TF2,HT,UG,TL1,TG1,
     6           GGS,DDU,EK,DOTM,UULO,RG1,
     7           TS,HFG,RGST,DYL,RL,DYV,GA,WEC,ST,QMAX,DIA,
     8           PAI,P,DE,HTCV,SO,CL,ULXO,ASTORE,QTAW,QNT2,
     9           QNT5,TLQN2,TLQN5,TWQN2,TWQN5,ULIB7,CSAVE,CNHEAT,
     A           CLENG,PRNL,RAML,SIGM,EMIS,AGMAX,ULX,
     B           TIMES,IS,IE,N51,DZ,DT,N1,EPS,ID,IAXMOD,ITO,
     C           N,TIME,VOUTO2,NCH)
C
C        *** MODE 1 *** 3,APRIL,1980  BY Y.MURAO
C
C      CALCULATION OF THERMO-HYDRAULIC BEHAVIOR ON SATURATED TWO PHASE
C    1   FLOW DURING REFLOOD PHASE
C
C
      DIMENSION X(N1),G(N1),FCPR(N1),QTIME(N1),AG(N1),AG1(N1),RG(N1),
     *           TW1(N1),TW(N1),UGO(N1),HR(N1),UL(N1),CREST(N1),
     *           CTOTAL(N1),PC(N1),DU(3),CN(N1),TG(N1),HG(N1),TL(N1),
     *           DV(N1),DD(N1),HCV(N1),TF2(10,N1),HT(N1),UG(N1),TL1(N1),
     *           VOUTO2(1),GGS(N1),DDU(N1),EK(N1),DOTM(N1),
     *           UULO(N1),RG1(N1),TG1(N1)
C
C   * TO SET THE CRITICAL SLIP VELOCITY IN DU(2)   *
      DU1=0.53713*(GA*RL)**0.2066*(WEC*ST)**0.3801/RGST**0.5868
     1/DYV**0.1736
      DU2=1.3512*(WEC*ST*GA*RL/RGST**2)**0.25
      IF(DU2.LT.DU1) DU1=DU2
      DU(2)=DU1
C
      DO 100 I=IS,IE
C
      ID=I
C
      PX1=PX(I,DZ,IAXMOD,CSAVE,CNHEAT,CLENG,PAI)
      QX=QMAX*DIA**2*PAI/4.0*PX1
      QFLUX=QX/(DIA*PAI)
      TWBOIL=(QFLUX/(2.197*EXP(1.54E-06*P)))**0.25+TS
      REDE=DE*UL(1)/DYL
      REDE=ABS(REDE)
      HR(I)=0.0
      CALL SBHCL(DZ,REDE,PRNL,DE,I,CL,SO,RAML,TW,TL1,HCV,HTCV)
      IF(HTCV.NE.0.0) TW(I)=QFLUX*CL/(HTCV*SO)+TS
      IF(HTCV.EQ.0.0) TW(I)=TW1(I)
      HCVB=QFLUX*CL/SO
C     IF(TWBOIL.LT.TW(I)) HCV(I)=HCVB
C     IF(TWBOIL.LT.TW(I)) TW(I)=TWBOIL
      HCV(I)=HCVB
      TW(I)=TWBOIL
      QBOIL=QFLUX
  630 CONTINUE
      DO 620 J=1,N51
      TF2(J,I)=TW(I)
  620 CONTINUE
```

```
C
C   DETERMINE THE HEAT TRANSFER COEFFICIENT
C
      IF(TW(I).GT.TS+0.0001) HT(I)=QFLUX/(TW(I)-TS)
      IF(TW(I).LE.TS+0.0001) HT(I)=0.0
      IF(TW(I).LE.TS+0.0001) HCV(I)=0.0
      IF(TW(I).LT.TS) TW(I)=TS
  300 CONTINUE
C
      FCPRV=FCPR(I)*ASTORE
C
      QX=QX+(1-ASTORE)/QTAW*FCPR(I)*EXP(-QTIME(I)/QTAW)
      IF(I.GE.N1) ULIB7=UL(N1)
      IF(I.GE.N1) GO TO 200
C
C  ***   CALCULATION OF SLIP VEL. DU(1) AND VOID FRACTION AG(I+1)   ***
C
      DDBX=0.0
C
C       DETERMINE THE MASS VELOCITY AND THE VOID CHANGE RATE
C
C       G(I+1)
C
      CALL MASBAL(I,TIMES,DT,QDOT,GGAS,1,DBX,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *   DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *   AG,AG1,G,RG,TG1,TL,UGO,CTOTAL,CREST,
     *   RL,RGST,TS,DZ)
C
      TG(I+1)=TS
      TL(I+1)=TS
      RG(I+1)=RGST
      IF(I.NE.IB2-1) GO TO 650
C
C  IDISP  - IF=1, ABOVE SATTPF THERE IS DISPERSED FLOW
C  DDX    - DISTANCE FROM IB2 TO L4 ( TOP OF TRANSITION FLOW )
C
C   * TO INITIALIZE IDISP AND DDX
C
      IDISP=0
      DDX=0.0
C
C
      DDB2=(IB2-IB02)*DZ+DB02-DB2
      DDB5=(IB05-IB5)*DZ+DB5-DB05
      DDBK=DDB2
      IF(I.EQ.IB5-1   ) DDBK5=DDB5
      IF(DDBK5.LT.0.0.AND.I+1.EQ.IB5) DDBK5=0.0
      FTX=1.0-DB2/DZ
      IF(I.EQ.IB5-1)FTX5=DB5/DZ
C
C   **  CALCULATION OF MASS VELOCITY OF GAS AT THE QUENCH POINT  ***
C
      TQO=321.05+0.237*P/10000.0
      IF(IB2.EQ.1) QNT2=0.0
      IF(IB2.NE.IB5) TWQC=(TW(IB2)+TW(IB5-1))/2
      IF(IB02.NE.IB2) QNT2=(TW1(IB2-1)-TW1(IB2))/DZ
      TWQN2=TW(IB2)+QNT2*DB2
      IF(TWQN2.LT.TQO.AND.TW(I+1).LT.TQO) TWQN2=TW(I+1)
      IF(IB5.EQ.N1) QNT5=0.0
```

```
      IF(IB05.NE.IB5-1.AND.I.EQ.IB5-1) QNT5=(TW1(IB5)-TW1(IB5-1))/DZ
      IF(I.EQ.IB5-1) TWQN5=TW(IB5-1)+QNT5*(DZ-DB5)
      IF((TWQN5.LT.TQ0.AND.TW(I).LT.TQ0).AND.I.EQ.IB5-1) TWQN5=TW(I)
      TK=TWQN2
      IF(I.EQ.IB5-1) TK5=TWQN5
      IF(IB2.EQ.IB5) TK=TWQC
      IF(IB2.EQ.IB5) TK5=TWQC
      IF(DDB2.LE.0.0) GO TO 650
      IF(TK.LT.TW(I)) TK=TW(I)
      IF(TK5.LT.TW(I).AND.I.EQ.IB5-1) TK5=TW(I)
      DBK=DZ
      IF(I+1.EQ.IB1) DBK=DB1
      QTOTLU=(DDBK*(TK-TW(I))*FCPRV/DT+QX*(DBK-DB2))/SO
      QDOT1=QTOTLU/(HFG*GA)
C
C       GGASU
C
      CALL MASBAL(I,TIMES,DT,QDOT1,GGASU,5,DBX,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *   DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *   AG,AG1,G,RG,TG1,TL,UGO,CTOTAL,CREST,
     *   RL,RGST,TS,DZ)
C
C
C    ***   FIND SLIP VELOCITY AT QUENCH PT.   ***
C
      DUX=DU(3)
C
C       AG(I+1) AND DU(1) AT QUENCH POINT
C
      CALL VOIDCL(I,TIMES,DT,GGASU,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,DB1,DB2,DB3,DB4,DB5,DB6,DB7,
     *   AG,G,RG,UG,UGO,UL,CN,DD,DU,
     *   RL,RGST,GA,ST,DYV,WEC,PAI)
      DUXU=DU(1)
      DU(1)=DU(3)
      DU(3)=DUX
      AGU=AG(I+1)
C
C
      REDE=DE*UG(I+1)/DYV
      REDE=ABS(REDE)
      TH=TWQN2
      ZL=DB2
      ZL7=DB2-DB7
      ZL5=DB2-DB5
      SRAG=SQRT(1.0-AG(I+1))
C
      HIA1=HIA(TH,I+1,TS,RGST,GA,PAI,ST,RL,HFG)
      HCVX=SQRT(SRAG)*HIA1*(TH-TS)*CL/SO
      IF(ZL.GT.1.0E-04) HCV(I+1)=HCVX*ZL**(-0.25)
      IF(ZL.LE.1.0E-04) HCV(I+1)=HCVX*10.0
      IF(I+1.LT.IB3) HR(I+1)=0.0
      TDUM=TW(I+1)
      TW(I+1)=TH
      IF(I+1.GE.IB3) CALL SBHR(I+1,TW,TS,DD,AG,CL,SO,SIGM,N1,HR,EMIS)
      TW(I+1)=TDUM
C
  340 CONTINUE
      QTOTAL=HR(I+1)*(DB2-DDX)+4.0/3.0*(DB2-DDX)**0.75*HCVX
```

```
     1    + QX/SO*DDX
      IF(I.EQ.IB5-1) QTOTAL=HR(I+1)*(DB2-DB5)+4.0/3.0*ZL5**0.75*HCVX
     1+(DDBK5*(TK5-TW(I))*FCPRV/DT+QX*FTX5*DZ)/SO
      IF(I.EQ.IB7-1) QTOTAL=HR(I+1)*(DB2-DB7)+
     14.0/3.0*ZL7**0.75*HCVX
      QDOT2=QTOTAL/(HFG*GA)
      AG(I+1)=AGU
C
C         GGAS
C
      CALL MASBAL(I,TIMES,DT,QDOT2,GGAS,7,DBX,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *   DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *   AG,AG1,G,RG,TG1,TL,UGO,CTOTAL,CREST,
     *   RL,RGST,TS,DZ)
C
      IF(IDISP.EQ.1) DU(1)=DU(3)
C
C
C         AG(I+1)
C
      CALL VOIDCL(I,TIMES,DT,GGAS,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,DB1,DB2,DB3,DB4,DB5,DB6,DB7,
     *   AG,G,RG,UG,UGO,UL,CN,DD,DU,
     *   RL,RGST,GA,ST,DYV,WEC,PAI)
C
      GO TO 400
  650 CONTINUE
      DBK=DZ
      IF(I+1.EQ.IB1) DBK=DB1
      QTOTAL=(DZ*(TW1(I)-TW(I))*FCPRV/DT+QX*DBK)/SO
      QDOT=QTOTAL/(HFG*GA)
C
C         GGAS
C
      CALL MASBAL(I,TIMES,DT,QDOT,GGAS,2,DBX,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *   DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *   AG,AG1,G,RG,TG1,TL,UGO,CTOTAL,CREST,
     *   RL,RGST,TS,DZ)
  600 CONTINUE
C
C         AG(I+1)
C
      CALL VOIDCL(I,TIMES,DT,GGAS,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,DB1,DB2,DB3,DB4,DB5,DB6,DB7,
     *   AG,G,RG,UG,UGO,UL,CN,DD,DU,
     *   RL,RGST,GA,ST,DYV,WEC,PAI)
C
C        CREST(I+1)
C
      CALL MASBAL(I,TIMES,DT,QDOT,GGAS,3,DBX,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *   DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *   AG,AG1,G,RG,TG1,TL,UGO,CTOTAL,CREST,
     *   RL,RGST,TS,DZ)
C
C        CTOTAL(I+1)
C
      CALL MASBAL(I,TIMES,DT,QDOT,GGAS,6,DBX,N1,
```

```
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *   DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *   AG,AG1,G,RG,TG1,TL,UGO,CTOTAL,CREST,
     *   RL,RGST,TS,DZ)
  400 CONTINUE
      V=0.0
C
C       PC(I+1)
C
      CALL PCCAL(I,TIMES,DT,V,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,DB1,DB2,DB3,DB4,DB5,DB6,DB7,
     *   AG,G,RG,TG1,UGO,UL,DV,PC,
     *   RL,RGST,TS,GA,DZ)
C
      IF(I.NE.IB2-1) GO TO 90
C
C   * IF IDISP=1 ( I.E. DISPERSED FLOW ABOVE SATTPF, ALREADY RECALCULATED
C
      IF(IDISP.EQ.1) GO TO 200
C
      IB3=IB2
      DB3=DB2
C
 1000 CONTINUE
      IF((DU(1).LT. DU(2) .OR. UL(ID+1).LE.0.0).AND.CREST(I+1).LT.0.0)
     1GO TO 900
      IF((DU(1).LT. DU(2) .OR. UL(ID+1).LE.0.0).AND.CREST(I+1).GE.0.0)
     1GO TO 200
C
C   *  FIRST WE SET THE BOUNDARY OF L4  *
      IB4=ID+1
      IF(TIME.NE.DT.AND.DUXU.LE.DU(2)) DB4=(DU(1)-DU(2))/(DU(1)-DUXU)*
     1DB2
      IF(TIME.NE.DT.AND.DUXU.GT.DU(2)) DB4=DB2
      IF(TIME.EQ.DT) DB4=0.0
C
C       AG(I+1) OF DISPERSED FLOW
C
      DUX=DU(3)
      CALL VOIDCL(I,TIMES,DT,GGAS,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,DB1,DB2,DB3,DB4,DB5,DB6,DB7,
     *   AG,G,RG,UG,UGO,UL,CN,DD,DU,
     *   RL,RGST,GA,ST,DYV,WEC,PAI)
      DU(3)=DUX
C
      IF(CREST(ID+1).LT.0.0) GO TO 900
C
C   * DISPERSED FLOW ABOVE SATTPF, SO TO SET IDISP AND DDX
C
      IDISP=1
      DDX=DB4
C
C   * TO RECALCULATE QTOTAL AND GGAS BASED ON L4 BOUNDARY
C
      GO TO 340
C
C        END OF CALCULATION OF DISPERSED FLOW BOUNDARY CONDITION
C
   90 CONTINUE
C
```

```
      IF(CREST(I+1).LT.0.0) GO TO 900
C
  100 CONTINUE
      RETURN
C
  900 CONTINUE
C        CALCULATION OF BOUNDARY CONDITION OF STEAM FLOW REGION
      V=0.0
      AG(I+1)=AGU
C
C       FIND LIQ TOP
      CALL LIQTOP(ID,TIMES,DT,QDOT,GGAS,V,NLIQ,DBX,ULX,ULIB7,N1,
     *    IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *    DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *    AG,AG1,G,RG,TG,TG1,TL,UG,UG0,UL,CTOTAL,CREST,DV,CN,DD,PC,DU,
     *    RL,RGST,TS,DZ,GA,ST,DYV,WEC,PAI)
C
C
      RETURN
C
C
  200 CONTINUE
C
C       SET OF GGS1(I) AND GLS1(I)
C
      CALL MASBAL(I,TIMES,DT,QDOT,GGAS,8,DBX,N1,
     *    IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *    DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *    AG,AG1,G,RG,TG1,TL,UG0,CTOTAL,CREST,
     *    RL,RGST,TS,DZ)
C
      RETURN
      END
```

```
      SUBROUTINE MASBAL(I,TIMES,DT,QDOT,GGAS,JOB,DBX,N1,
     *   IB1,IB2,IB3,IB4,IB5,IB6,IB7,IB01,IB02,IB03,IB04,IB05,IB06,IB07,
     *   DB1,DB2,DB3,DB4,DB5,DB6,DB7,DB01,DB02,DB03,DB04,DB05,DB06,DB07,
     *   AG,AG1,G,RG,TG1,TL,UGO,CTOTAL,CREST,
     *   RL,RGST,TS,DZ)
C
C
C        *** MODE 1 *** 3,APRIL,1980  BY Y.MURAO
C
C
C       JOB=1   **** G(I+1)
C       JOB=2   **** GGAS
C       JOB=3   **** CREST(I+1)
C       JOB=4   **** DBX
C       JOB=5   **** GGASU
C       JOB=6   **** CTOTAL
C       JOB=7   **** ALL AT I+1=IB2
C       JOB=8   **** GGS1(I) AND GLS1(I)
C
C       DBX  **** POSITION OF LIQUID TOP
C       DBK  **** POSITION OF INITIATION OF VOIDING
C
      DIMENSION AG(N1),AG1(N1),G(N1),RG(N1),TG1(N1),TL(N1),UGO(N1),
     *          CTOTAL(N1),CREST(N1),GGS(100),GLS(100),QDS(100),
     *          GGS1(100),GLS1(100)
C
      RGO=RGST*(TS+273.16)/(TG1(I)+273.16)
      IF(TIMES.NE.0.0) GO TO 20
      GGS1(I)=RGO*DZ
      GLS1(I)=0.0
   20 CONTINUE
      IF(I.EQ.1) QDSU=0.0
      DBX=0.0
      DBOX=0.0
      DBK=DZ
C
C     WRITE(6,2000) TIMES,I,IB7,JOB,G(I),G(I+1),GGAS,QDOT,DBX,
C    1DBOX,AG(I),AG1(I),RG(I),UGO(I),CREST(I+1),CREST(I)
C
      IF(I+1.EQ.IB7) DBX=DB7
      IF(I+1.EQ.IB07) DBOX=DB07
      IF(IB7.EQ.1.AND.I.EQ.1) DBX=DZ
      IF(IB07.EQ.1.AND.I.EQ.1) DBOX=DZ
      XL1=IB1*DZ-DB1
      XL2=IB2*DZ-DB2
      XL3=IB3*DZ-DB3
      IF(I+1.EQ.IB3.AND.XL3.GE.XL2) DBK=DB3
      IF(I+1.EQ.IB1.AND.XL1.LE.XL2) DBK=DB1
      IF(DBK.LT.DBX) DBK=DBX
      IF(JOB.GE.9) GO TO 1000
      IF((IB2.EQ.I+1.AND.IB7.EQ.I+1).AND.JOB.EQ.4) GO TO 450
      IF(JOB.EQ.7) GO TO 500
      IF(JOB.EQ.8) GO TO 800
C
      GGS(I)=AG(I)*RG(I)*(DZ-DBX)+RG(I)*DBX
      GLS(I)=(1-AG(I))*RL*(DZ-DBX)
      QDS(I)=QDOT*(DBK-DBX)/DBK
      IF(QDS(I).EQ.0.0) QDOT=0.0
```

```
      GGSS=0.0
      GLSS=0.0
C
C
      GO TO(100,200,300,400,500,600),JOB
C
C
  100 G(I+1)=G(I)-(GGS(I)+GLS(I)-GGS1(I)-GLS1(I))/DT
      GO TO 1000
C
C
  200 CONTINUE
      GGAS=UGO(I)*RG(I)+QDS(I)-(GGS(I)-GGS1(I))/DT
      IF(IB7.EQ.I+1) G(I+1)=GGAS
      IF(I+1.LT.IB7.AND.TL(I+1).LT.TS) GGAS=0.0
      GO TO 1000
C
C
  300 CREST(I+1)=CREST(I)-GLS(I)-QDS(I)*DT
      GO TO 1000
C
C
  400 DBX=(RL*(1-AG(I))*DZ+QDOT*DT-CREST(I))/(RL*(1-AG(I))+QDOT/DBK*DT)
      IF(DBX.GE.DBK) DBX=DZ-CREST(I)/(RL*(1-AG(I)))
      GO TO 1000
C
  450 CONTINUE
      GO TO 400
C     DBX=(GLS(I)+(1-AG(I+1))*RL*DB2+QDS(I)*DT+QDOT*DT-CREST(I))/
C    *     ((1-AG(I+1))*RL+QDOT/DB2*DT)
C     GO TO 1000
C
C
  500 CONTINUE
      DBOX=DBOX-DB2
      IF(DBOX.LT.0.0) DBOX=0.0
C
      GGS(I)=AG(I)*RG(I)*(DZ-DB2)
      GLS(I)=(1-AG(I))*RL*(DZ-DB2)
      QDS(I)=QDOT
      IF(JOB.EQ.7.AND.QDSU.NE.0.0) QDS(I)=QDSU
      IF(JOB.EQ.7) GO TO 700
      QDSU=QDOT
      GGS1U=AG1(I)*RGO*(DZ-DB2-DBOX)+RGO*DBOX
      GLS1U=(1-AG1(I)) RL*(DZ-DB2)
      IF(I+1.EQ.IBO2.AND.DB2.LT.DBO2)
     *   GGS1U=AG1(I)*RGO*(DZ-DBO2)+AG1U*RGST*(DBO2-DB2-DBOX)+RGST*DBOX
      IF(I+1.EQ.IBO2.AND.DB2.LT.DBO2)
     *   GLS1U=(1-AG1(I))*RL*(DZ-DBO2)+(1-AG1U)*RL*(DBO2-DB2-DBOX)
C
      G(I+1)=G(I)-(GGS(I)+GLS(I)-GGS1U-GLS1U)/DT
      GGAS=UGO(I)*RG(I)+QDS(I)-(GGS(I)-GGS1U)/DT
      CREST(I+1)=CREST(I)-GLS(I)-QDS(I)*DT
      CTOTAL(I+1)=CTOTAL(I)+GLS(I)
      GO TO 1000
C
C
  600 CTOTAL(I+1)=CTOTAL(I)+GLS(I)
      IF(CREST(I+1).GE.0.0) GO TO 800
      GO TO 1000
```

```
C
C
  700 CONTINUE
      GGSS=AG(I+1)*RGST*(DB2-DBX)+RGST*DBX
      GLSS=(1-AG(I+1))*RL*(DB2-DBX)
      QDSS=QDOT
      AG1U=AG(I+1)
C
      G(I+1)=G(I)-(GGS(I)+GGSS+GLS(I)+GLSS-GGS1(I)-GLS1(I))/DT
      GGAS=UGO(I)*RG(I)+QDS(I)+QDSS-(GGS(I)+GGSS-GGS1(I))/DT
      CREST(I+1)=CREST(I)-GLS(I)-GLSS-(QDS(I)+QDSS)*DT
      CTOTAL(I+1)=CTOTAL(I)+GLS(I)+GLSS
      IF(IB7.EQ.I+1) G(I+1)=GGAS
C
C
 1000 CONTINUE
C
C
      IF(TIMES.LT.0.0.OR.TIMES.GE.0.0) GO TO 3000
      WRITE(6,2000) TIMES,I,IB7,JOB,G(I),G(I+1),GGAS,QDOT,DBX,DBOX,DB07,
     *  AG(I+1),AG(I),AG1(I),RG(I),UGO(I),CREST(I+1),CREST(I),
     *  GGS(I),GLS(I),QDS(I),GGSS,GLSS,GGS1(I),GLS1(I),
     *  IB1,IB2,IB3,IB4,IB5,IB6,IB7,DB1,DB2,DB3,DB4,DB5,DB6,DB7,DBK
 2000 FORMAT(//5X'MASBAL LIST'/7X,G15.5,3I3,6G15.5,F10.4,2(/7X,7G15.5)/
     *       5X7(I2,3X),10X8F10.4)
 3000 CONTINUE
C
      RETURN
C
C
  800 CONTINUE
      GGS1(I)=GGS(I)+GGSS
      GLS1(I)=GLS(I)+GLSS
C
      IF(TIMES.LT.0.0.OR.TIMES.GE.0.0) RETURN
      WRITE(6,2000) TIMES,I,IB7,JOB,G(I),G(I+1),GGAS,QDOT,DBX,DBOX,DB07,
     *  AG(I+1),AG(I),AG1(I),RG(I),UGO(I),CREST(I+1),CREST(I),
     *  GGS(I),GLS(I),QDS(I),GGSS,GLSS,GGS1(I),GLS1(I),
     *  IB1,IB2,IB3,IB4,IB5,IB6,IB7,DB1,DB2,DB3,DB4,DB5,DB6,DB7,DBK
      RETURN
C
C
      END
```