27
2-15-78
25 NTIS

LA-6994

NRC-4

MASTER

K-TIF: A Two-Fluid Computer Program for Downcomer Flow Dynamics

Issued: January 1978

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

An Affirmative Action/Equal Opportunity Employer

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

DISTRIBUTION OF THIS DOCUMENT IS UNLIMI

LA-6994
NRC-4

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

K-TIF: A Two-Fluid Computer Program for Downcomer Flow Dynamics

A. A. Amsden
F. H. Harlow

Manuscript completed: October 1977
Issued: January 1978

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared for the US Nuclear Regulatory Commission
Office of Nuclear Regulatory Research

DISTRIBUTION OF THIS DOCUMENT IS UNLIM

CONTENTS

Abstract 1

I. BASIC MODELING AND NUMERICAL SOLUTION 1

A. Introduction 1

B. The Physical and Mathematical Models 4

C. Scaling the Models 14

D. Summary of the Numerical Solution Technique 17

E. Boundary Conditions 32

F. Automatic Viscosity Calculation and Numerical Stability 35

II. THE K-TIF COMPUTER PROGRAM 38

A. General Structure 38

B. The Indexing Notation 43

C. The Input Data 44

D. Output - Plots, Prints, and Motion Pictures 48

E. Restart Dumps 51

F. LTSS Remote Terminal Operation: DROP and UNDROP 51

G. Microfilm Plots - Scaling and Subroutine CALLs 53

H. Miscellaneous System Library Subroutine CALLs 58

I. The Common Blocks KC1 and KC2 61

III. K-TIF CALCULATIONS 69

A. Examples 69

B. Input Data and Results from a Sample Calculation 86

IV. REFERENCES 102

Appendix: FORTRAN Listing of the K-TIF Program 103

K-TIF: A TWO-FLUID COMPUTER PROGRAM FOR DOWNCOMER FLOW DYNAMICS

by

A. A. Amsden and F. H. Harlow

ABSTRACT

The K-TIF computer program has been developed for numerical solution of the time-varying dynamics of steam and water in a pressurized water reactor downcomer. The current status of physical and mathematical modeling is presented in detail. The report also contains a complete description of the numerical solution technique, a full description and listing of the computer program, instructions for its use, with a sample printout for a specific test problem. A series of calculations, performed with no change in the modeling parameters, shows consistent agreement with the experimental trends over a wide range of conditions, which gives confidence to the calculations as a basis for investigating the complicated physics of steam-water flows in the downcomer.

I. BASIC MODELING AND NUMERICAL SOLUTION

A. Introduction

We have developed a computer model to describe the complicated countercurrent flow of steam and water in a pressurized water reactor (PWR). These flows have been studied experimentally at other laboratories. Typical examples are summarized in a recent Creare report,[1] which describes various circumstances of start up, steady state, and transient flow. We particularly have been concerned with the following.

1. For numerous variations in steam and emergency core coolant (ECC) water flow rate and ECC water temperature, the statistically steady countercurrent flow

rates have been measured and characterized in terms of useful nondimensional parameters and correlations.

2. Commencing from a state of complete flooding (bypass of the ECC water flow from the three intact inlet legs to the broken fourth leg), the flow configuration was altered to the state of complete dumping (downward water flow from all three inlet legs to the lower plenum) by a gradual reduction in the steam flow rate, during periods ranging from 3 to 175 sec.

3. Simultaneously the pressure in the lower plenum was varied (usually decreased) by amounts ranging from almost no variation to about 60 psia, with effects manifested predominantly in the corresponding changes of saturation temperature and steam density.

4. The initial temperature of the downcomer walls could be specified to within about ±10°F, and was chosen in each case to be either the initial saturation temperature of the steam or a superheated temperature of 350°F, followed by variations resulting from heat exchange with the water and steam.

Our goal is to describe these results theoretically, using physical and mathematical models that contain a minimum degree of uncertainty, that can be scaled with confidence to as wide a set of experimental configurations as possible, both steady and transient, and that can serve as effective guides to the study of an entire reactor flow circuit during both steady (normal) and transient (accidental disruption) circumstances.

For this purpose, we have started with the equations for two-phase flow which, even at this stage, imply a significant degree of simplification and idealization in several aspects. First, this model represents an average over the microscopic flow details of the contorted interactions of individual bubbles and droplets with films of water and channels of steam. These detailed interactions are ignored because of their great complexity. Second, the restriction to a pair

of field variables for each control volume and time ignores the spectrum of velocities that actually exists. Third, the formulation requires the introduction of effective mixture and exchange functions to describe mean transport and interaction processes for which little fundamental guidance is available. The choice and verification of these mixture and exchange functions lie at the heart of our theoretical investigations.

Even when the differential model is chosen, effective theoretical analysis is difficult. Except for the simplest problems, the equations are not amenable to analytical solution, therefore approximation techniques are required, which can be used effectively only by means of high-speed computers.

Thus the scope of our development and of this report covers multiple facets of a coordinated research effort to

1. formulate the differential equations for two-phase flow,

2. derive and/or propose appropriate exchange and mixture functions to represent the macroscopic effects of microscopic physical processes,

3. develop an effective numerical solution technique,

4. apply the calculations to a variety of specific problems to compare with experimental results,

5. continue improvement of all aspects of the mathematical and physical modeling to increase agreement with the experiments, to remove uncertainties and solidify the foundations of the models, and to enhance the "universality" of the representation,

6. extend the studies to circumstances for which experimental data are not yet available, to guide the planning of new experiments and the design of actual reactor installations, and

7. publish the entire project as a basis for further theoretical studies and for the incorporation of our findings into the more extensive systems codes that calculate steam-water dynamics in the entire flow loop.

Previous studies describe our multiphase flow calculations for the liquid metal fast breeder reactor (LMFBR),[2-4] for a system of compressible phases,[5] and for some preliminary parts of the downcomer studies.[6] Additional reports from LASL Group T-3[7,8] discuss related studies in steam-water flow dynamics. Here, we emphasize the detailed numerical technique for high-speed solution of the equations as embodied in the computer program called K-TIF and also present a summary of results, interpretations, and conclusions from this stage of the studies of the transient-flow experiments described in Ref. 1.

B. The Physical and Mathematical Models

In addition to assuming the validity of a two-field approach for the dynamics of the two phases, we assume that the material speeds are much smaller than the sound speed at each point, so that the microscopic material density for each phase is independent of position. Eventually, however, it may be necessary to account for compression and rarefaction waves that arise because of the greatly decreased sound speed in the mixture. In a more general K-TIF computer program, the density of each phase could be allowed to vary with time as a result of overall compression or expansion. For the present stages of development in the downcomer investigations, however, only the steam is treated in this manner, and the water density is held constant in both space and time. Accordingly, the mass-conservation equations

$$\frac{\partial \rho_1'}{\partial t} + \nabla \cdot (\rho_1' \vec{u}_1) = - J - \rho_1 S_{ABC1} \quad ,$$

and

$$\frac{\partial \rho_2'}{\partial t} + \nabla \cdot (\rho_2' \vec{u}_2) = + J - \rho_2 S_{ABC2}$$

become

$$\frac{\partial \theta_1}{\partial t} + \nabla \cdot (\theta_1 \vec{u}_1) = - J/\rho_1 - S_{ABC1} \quad , \tag{1}$$

and

$$\frac{\partial \theta_2}{\partial t} + \nabla \cdot (\theta_2 \vec{u}_2) = + J/\rho_2 - S_{ABC2} - S_{P2} \quad . \tag{2}$$

Here, ρ is microscopic material density; ρ' is total mass per unit volume; θ is volume fraction so that $\rho' \equiv \theta\rho$; $\vec{u}$ is material velocity; J is the mass per unit volume per unit time condensing ($J < 0$) or evaporating ($J > 0$); S_{ABC} is the volume per unit total volume per unit time lost or gained in the cold-leg source (A) cells, broken-leg sink (B) cells, and steam-insertion (C) cells; and S_{P2} denotes the effects of variable steam density,

$$S_{P2} = \frac{\theta_2}{\rho_2} \frac{d\rho_2}{dt} \quad .$$

Throughout, the subscripts 1 and 2 refer, respectively, to water and steam.

Our expression for the phase-transition rate is based on a mixing-limited model,[6] in which

$$J = J_L \, \theta_1 \, \theta_2 \, \frac{T_s - T_1}{T_s} \quad . \tag{3}$$

T_1 is local water temperature, J_L is a coefficient, and T_s is the (time-varying) saturation temperature calculated as a function of the overall pressure level in the system. In the Creare experiments[1] this pressure is a controlled quantity, which is, therefore, a specified function of time for the calculations. With p

given in psia, T_s in kelvins is obtained through the relationship

$$T_s = 117.8 \left(\frac{p}{14.7}\right)^{0.223} + 255.2 \quad ,$$

and the steam density in lbs/in.^{3} is given by

$$\rho_2 = 0.035p/[25060 + 6.67\ (T_s - 373.15)] \ .$$

With the flows assumed to occur at speeds much less than the sound speed, the dynamical contributions to the pressure variations are a negligible modification to the specified overall pressure insofar as determining T_s. In contrast, it is only the local dynamical pressure variation that enters the momentum equation, which senses nothing of the variations in overall pressure level.

The dependence of J on $(T_s - T_1)$ for all circumstances is based in part on the assumption that the steam is always at saturation temperature. The rationalization for this assumption has two parts. First, the steam cannot be subcooled because there is always sufficient nucleation for its immediate condensation and release of sufficient latent heat to increase the temperature of any remaining steam to T_s. Second, although it may be superheated, the energy of the superheat is very small compared to the latent heat and is considered negligible at this stage of development.

The formula for J also assumes that steam condenses only in the presence of sufficiently cool water, but ignores the possibility of condensation directly onto the wall wherever the wall temperature is less than T_s. This treatment is based on the idea that subcooled walls are likely to occur only where cold inlet water is flooding the wall, so that a cool wall becomes accessible to steam only if the water subsequently withdraws. Therefore, it is unlikely that much area of <u>dry</u> subcooled wall would be exposed. For a <u>wet</u> subcooled wall, the steam condenses onto the water, which then transfers released latent heat to the wall,

and brings the wall temperature to T_s before the surface dries.

The coefficient J_L is negative in magnitude and constant in all the calculations reported here. The magnitude of J_L can be estimated[6] in terms of fine-scale steam-water mixing rates describing, for example, the processes by which cool water away from the phase-transition interface is brought into contact with the steam, followed by almost instantaneous (equilibrium) condensation to the extent allowed by the release of latent heat and consequent warming of the water. Conversely, if the water is superheated from contact with hot walls or because of a drop in T_s, then J_L is an evaporation coefficient. A refinement for the phase-transition model will be the incorporation of more detailed physics into J_L as a variable in space and time, dependent on such flow properties as the relative velocity between phases and the dominant size scales of turbulence and of the bubble-droplet structure.

With constant microscopic water density, but allowing for time variation of the microscopic steam density, the momentum equations become

$$\rho_1 \left[\frac{\partial \theta_1 \vec{u}_1}{\partial t} + \nabla \cdot (\theta_1 \vec{u}_1 \vec{u}_1) \right] = - \theta_1 \nabla p + \rho_1 \theta_1 \vec{g} + K(\vec{u}_2 - \vec{u}_1) + \rho_1 \vec{V}_1 - J/2 \left[(1 + \text{sign } J) \vec{u}_1 + (1 - \text{sign } J) \vec{u}_2 \right] , \tag{4}$$

$$\rho_2 \left[\frac{\partial \theta_2 \vec{u}_2}{\partial t} + \nabla \cdot (\theta_2 \vec{u}_2 \vec{u}_2) \right] = - \theta_2 \nabla p + \rho_2 \theta_2 \vec{g} + K(\vec{u}_1 - \vec{u}_2) + \rho_2 \vec{V}_2 + J/2 \left[(1 + \text{sign } J) \vec{u}_1 + (1 - \text{sign } J) \vec{u}_2 \right] - \rho_2 \vec{u}_2 S_{P2}, \tag{5}$$

in which

$$\text{sign } J \equiv \begin{cases} +1 \text{ for } J > 0 \\ -1 \text{ for } J < 0 \end{cases} .$$

The pressure, p, is the same for both phases; $\vec{g}$ is the gravitational acceleration, $\rho\vec{V}$ describes the transport of momentum from viscosity; and K is a coefficient of momentum exchange resulting from the interfacial friction (drag) between the two phases.

The current simple model for $\vec{V}$ in our Cartesian downcomer studies can be expressed in the form

$$\vec{V}_1 = \nu_{s1} (\nabla \cdot \theta_1 \nabla) \vec{u}_1 \quad , \tag{6}$$

$$\vec{V}_2 = \nu_{s2} (\nabla \cdot \theta_2 \nabla) \vec{u}_2 \quad . \tag{7}$$

More elaborate representations can be envisioned with, for example, the kinematic viscosity coefficient, ν_s, moved inside the derivatives as a variable representation of eddy viscosity. Like the other mixing coefficients that depend on local turbulence levels, we might expect the variations of ν_s to be approximated by the product of relative speed between phases and the size scale of the eddies, which in turn may be related to the size scales of the droplets and/or bubbles.

The interfacial momentum exchange coefficient, K, is discussed in Ref. 6. Its magnitude is calculated in the present studies by the expression

$$K = \frac{3}{8} (r_1 + r_2)^2 \left(\frac{C_D \rho_1' \rho_2'}{r_1 \; r_2}\right)\left(\frac{|\vec{u}_1 - \vec{u}_2|}{r_2 \; \rho_1 + r_1 \; \rho_2}\right) \quad , \tag{8}$$

in which C_D is a "drag coefficient" of variable magnitude near unity chosen, however, to be a constant in the present series of calculations. The size scales, r_1 and r_2, represent the "effective radii" of the droplets and bubbles, respectively. For bubbles in a continuous fluid, r_2 is the bubble radius and r_1

becomes the scale of the overall flow region (essentially infinite); and for droplets in a continuous vapor, r_1 is the droplet radius and r_2 becomes the scale of the overall flow region. For $\theta_1 \approx \theta_2$, there are no well-defined droplets or bubbles; $r_1 \approx r_2$; and the momentum exchange cannot at this stage be predicted from first principles. Nevertheless, the postulated form can be given qualitative justification on the basis of "available-momentum" arguments,[6] and is also supported by means of comparison calculations for many circumstances. Daly[8] shows that a constant-Weber-number idea, proposed by Hirt, can be used to estimate the variations in r_1 and r_2 in the expression for K, with results that differ little from those obtained with constant r_1 and r_2. This further supports the concept of simple models for representing complicated fine-scale interactions. This and related matters are discussed in Sec. I.C.

In addition to the conservation equations for mass and momentum, we use an energy equation in which we sacrifice rigorous conservation in favor of other attributes useful for the numerical solution, as discussed in Sec. I.D. With an expression for phase-transition rate that depends on $(T_s - T_1)$ and with the assumption that the steam temperature can be equated to T_s, the required energy calculation reduces to finding T_1 as a function of position and time. For this purpose the energy equation becomes

$$\frac{\partial T_1 \theta_1}{\partial t} + \nabla \cdot (T_1 \theta_1 \vec{u}_1) + \frac{J T_s}{\rho_1} = - L_L J + \frac{z}{\rho_1 b_1 s} (WHF) . \tag{9}$$

L_L is the ratio of the latent heat per unit mass, L, to the product of density, ρ_1, and specific heat, b_1; s is the downcomer gap width; WHF is the wall heat flux, positive when from wall to water; and z is the number of walls adjacent to the water. We use z = 2 in the downcomer, and a z in the lower plenum that represents the ratio of actual surface area for heat transfer in the experimental

geometry to the fictitiously large area in the current model.

For a thermally thin wall, which responds throughout in short time compared to the overall time of interest, we would need a wall-temperature equation that responds according to the limited total heat capacity of the wall material. For our downcomer calculations, however, the wall is "thermally thick," corresponding to an effectively infinite heat reservoir within the time scale of our calculations, in which the temperature deep within the interior of the wall, T_w, remains constant in time. In this latter circumstance, it is necessary to account for the progress of cooling or heating in the wall near its contact with the water. Ideally, we would introduce enough finite-difference zones in the wall to resolve these temperature variations; in practice, such fine resolution uses too much computer time. We therefore use an approximation for the temperature variations in the wall based on a one-time-variable fit to the spatial profile.

$$T(x,y,\xi,t) = T_w + (T_{we} - T_w)\, e^{-\xi/\gamma} \quad ,$$

in which T_{we} is the temperature at the edge of the wall, ξ is the distance into the wall from the edge, and $\gamma(x,y,t)$ is the time variable for which we require an equation that can be solved simultaneously with Eq. (9). The physical interpretation of γ is that it represents the depth of heating or cooling penetration into the wall. T_{we} is also a function of x, y, and t, but the computer program does not need a separate storage matrix for this variable, as required for T_1 and γ, because we relate T_{we} directly to T_1 when the heat transfer is not critical-heat-flux limited, or indirectly to T_s when the heat transfer is critical-heat-flux limited.

Clearly, our chosen fit to the temperature variations in the wall is relatively crude. It precludes, for example, the possibility of an inflection in the temperature profile, which certainly can occur. Even in the simple case of a

self-similar temperature wave propagation into the wall, we have used a simpler representation than the known error-integral solution. The next order of approximation,

$$T = T_w + (T_{we} - T_w + \alpha\ \xi)\ e^{-\xi/\gamma} \quad ,$$

is potentially better, but requires significantly more complicated calculations together with an additional storage matrix in the computer for the variable $\alpha(x,y,t)$. Available information and the constraints on available computer time, however, both lead to experimentation with the simplest one-variable model, which we accordingly use for the calculations described in this report.

Within the wall, the temperature variations are described by the heat-diffusion equation

$$\frac{\partial\ \rho_w\ b_w\ T}{\partial t} = k_w \frac{\partial^2 T}{\partial \xi^2} \quad ,$$

in which ρ_w, b_w, and k_w are, respectively, the density, specific heat, and thermal conductivity of the wall material. Two types of thermometric conductivity are required for the analysis,

$$\kappa_w \equiv \frac{k_w}{\rho_w\ b_w}$$

and

$$\kappa_o \equiv \frac{k_w}{\rho_1\ b_1} \quad .$$

With this definition, the approximation solution inserted into the heat diffusion equation becomes

$$\frac{\partial}{\partial t}\ (T_{we} - T_w) + (T_{we} - T_w)\left(\frac{\xi}{\gamma^2}\frac{\partial\gamma}{\partial t} - \frac{\kappa_w}{\gamma^2}\right) = 0 \quad .$$

This equation cannot be an identity in ξ. To proceed, we must choose the value of ξ at which the equation should be satisfied, a technique equivalent to requiring that some particular moment equation be satisfied. For this purpose we choose the position $\xi = \gamma$ and accordingly derive the equation for γ,

$$\frac{\partial}{\partial t}\left[\gamma\,(T_{we} - T_w)\right] = \frac{\kappa_w}{\gamma}\,(T_{we} - T_w) \quad . \tag{10}$$

Note also that

$$\mathrm{WHF} \equiv k_w \left(\frac{\partial T}{\partial \xi}\right)_{\xi=0} = \frac{k_w}{\gamma}\,(T_w - T_{we}) \quad , \tag{11}$$

which is the appropriate expression to use in Eq. (9), as well as for testing to to see if the critical heat flux would be exceeded.

To complete the formulation, we specify $T_{we} = T_1$ for all circumstances in which the critical heat flux, CHF, is not exceeded. This choice is based on the assumption that the forced-convective mixing currents are so violent as to bring the water to an essentially uniform temperature across the gap, which is therefore the same temperature as the edge of the wall. This is especially the case if $T_1 < T_s$. For $T_1 \geqslant T_s$, however, we must also test to see if WHF > CHF. If so, then the simultaneous solution of Eqs. (9) and (10) can no longer be accomplished with the relation $T_{we} = T_1$. Instead, we replace this relation by

$$\mathrm{WHF} = \text{correlative function of } (T_{we} - T_s) \quad ,$$

in which the correlative function represents the postcritical-heat-flux heat transport rate as a function of wall-edge superheat above saturation. At this stage of the investigation, we take this correlative function to be a constant (MHF), evaluated as an average around the minimal heat flux (point E in Fig. 4.6

of Collier[9]), times the volume fraction of water, θ_1. In that case, the equation replacing $T_{we} = T_1$ becomes

$$\frac{k_w}{\gamma}(T_w - T_{we}) = (MHF)\,\theta_1 \quad ,$$

and Eqs. (9) and (10) become especially easy to solve simultaneously.

In the CHF-limited case, we note that Eq. (10) becomes

$$\frac{\partial\gamma^2}{\partial t} = \kappa_w \tag{12}$$

or

$$\gamma = (\text{constant} + \kappa_w t)^{\frac{1}{2}} \quad .$$

More generally, Eq. (10) can be formally solved to give

$$\gamma = \left[\frac{2\kappa_w}{(T_w - T_{we})^2}\int_{t_1}^{t}(T_w - T_{we})^2\,dt\right]^{\frac{1}{2}} \quad ,$$

in which $\gamma = 0$ at $t = t_1$. Thus we see that γ is not well-behaved when the water temperature nearly equals the wall temperature, but if the singularity is properly handled, then a brief excursion through the condition $T_{we} = T_w$ returns γ to essentially its previous value as soon as the temperature difference has returned to any previous value.

More realistically, however, we expect some recovery in the near-edge wall temperature during those intervals in which the water temperature has returned to nearly the deep wall temperature. To represent this effect, we therefore replace Eq. (10) with Eq. (12), together with the condition that whenever $|T_w - T_{we}|$ is sufficiently small, we set the value of γ back to a small value, γ_0. To do better than this procedure would probably require additional computer storage

and longer running time per problem, in which event the proper treatment would be to put a set of finite-difference zones in the wall and solve for the more detailed space and time variations of the temperature profile in the wall.

C. Scaling the Models

Because of the expense and difficulty involved in full-scale experimentation, it is important that the scaling properties of the calculation models be thoroughly understood and tested. Many approximations enter into our theoretical descriptions, and in some instances the basis for our mixture and exchange functions is more empirical and heuristic than rigorous. Nevertheless, there is a wealth of small-scale experimental data to guide our developments, and more are planned for the future. Careful use of this information, together with continuous upgrading of the fundamental aspects of our work and numerous comparisons at several different size scales, should increase confidence in the full-scale applications of the calculations.

In the absence of resolution in the radial (gap width) direction, our present two-dimensional scoping calculations give an efficient means for accomplishing much of the necessary developments. Fully three-dimensional calculations, with resolution in the radial direction and coupling to the lower plenum and core, consume more computer time, but may be crucial to the development. These calculations will enable the distinction between film flow and droplet-bubble flow to be sensed, and will also alleviate the necessity for an entrainment model, which will allow the important effects of reentrainment from the lower plenum to be represented. They will also permit the across-gap flow structure in the downcomer to be resolved.

Three-dimensional calculations will not, however, permit the resolution of the detailed flow structure, a cause for concern about the scaling properties of the calculations. The wave structure on the surface of a film, the size scales

of droplets or bubbles, and the eddy dimensions in the turbulence are some of the basic unknown features that enter strongly into the exchange and mixture functions and determine, in turn, the overall scaling of the large-scale flow properties of interest. Daly's study[8] exemplifies the relationship between microscale events and the mean-flow effects they cause, in his case relating to the momentum exchange (drag) between phases, as described in Sec. I.B.

For air-water flow in a downcomer, the knowledge of momentum exchange would be sufficient, but for steam-water flow, much more is required. For example, when there is rapid condensation, bubbles might be smaller and droplets larger than predicted by the balance-of-force argument. If the correction is sufficiently small, it might be expressed in the form

$$\left.\begin{aligned} r_1 &= r_1\ (\text{balance}) - r_1'\ J \\ r_2 &= r_2\ (\text{balance}) + r_2'\ J \end{aligned}\right\}$$

in which the coefficients, r_1' and r_2', are independent of J.

If experience shows that instantaneous equilibrium in bubble size is not a reasonable assumption, then a finite relaxation rate can be introduced through the transport of N_1 and N_2, representing the number of droplets and bubbles per unit volume, respectively. In a single-relaxation-time model, analogous to such models for the Boltzmann equation,[10] we would write, with relaxation rates ω_1 and ω_2,

$$\left.\begin{aligned} \frac{\partial N_1}{\partial t} + \nabla \cdot (\vec{u}_1\ N_1) &= \omega_1\ (N_{01} - N_1) \\ \frac{\partial N_2}{\partial t} + \nabla \cdot (\vec{u}_2\ N_2) &= \omega_2\ (N_{02} - N_2) \end{aligned}\right\} \qquad (13)$$

Because

$$\left.\begin{aligned} 4\pi r_1^3 N_1 &= 3\,\theta_1 \\ 4\pi r_2^3 N_2 &= 3\,\theta_2 \end{aligned}\right\} \tag{14}$$

for spherical droplets or bubbles, the magnitudes of r and N can be related directly to each other in terms of the (known) volume fraction for each phase. The functions N_{01} and N_{02} are the equilibrium values of N, determined by the balance-of-force concept as expressed by specified values of the Weber numbers for the two phases. Transport equations for N_1 and N_2 would be preferred to those for any other variables, as these represent the quantities actually transported, for which fundamental conservation principles apply when no fragmentation or coalescence is taking place.

In addition to the presence of r_1 and r_2 in the momentum exchange function, K, we expect the variations of those scales to be reflected in variations in the phase-transition coefficient, J_L. This coefficient is dependent on (perhaps proportional to) the mixing rate. Therefore, we must appeal to simple theories of turbulent diffusion, in which mixing rates are proportional to the product of eddy size scale and a measure of the departure of velocity from the mean, estimated by the relative velocity between phases. If eddy size were proportional to bubble or droplet size, we would be led to express J_L as a constant times $|\vec{u}_2 - \vec{u}_1| r_1$. Because the scale, r_1, may in turn depend on gap size, s, and various other local properties of the flow, we see the complicated manner in which the macroscopic properties of the flow can be affected in several ways by changes of downcomer gap size.

Thus, although the details of size scaling are not determined, helpful guidelines exist for developing appropriate models. One goal is to obtain results that will compare satisfactorily with experimental data over a wide range of size scales without requiring circumstance-dependent manipulation of coeffi-

cients. Another goal is to demonstrate that the resulting models are applicable to the realistic study of configurations at scales other than those for which experimental data are available.

D. Summary of the Numerical Solution Technique

The finite-difference numerical solution technique relates to a mesh of computational cells and finite time steps or cycles in the same way as in our previous multiphase computation procedures.[2-5] The cells are rectangular in a layout that extends in the azimuthal and vertical directions, but with no resolution in the radial (across-the-gap) direction. The top wall is a rigid free-slip boundary. Just below the top wall (Fig. 1) are the three cold-leg input ports (A), the broken cold-leg exit port (B), and the four hot-leg barriers (crossed). The left and right boundaries communicate so that whatever flows out of one flows into the other. Therefore, the system is an annulus connected to itself around the periphery of the vessel. Resolution of the full lower plenum is allowed by our model, and the cross-sectional drawing in Fig. 2 indicates how the two-dimensional computing mesh represents the actual geometry. The original volume of the lower plenum must be preserved when making this transformation. The steam-insertion (C) cells cover the entire lower plenum, with the steam distribution proportional to the local time-varying steam volume fraction. Despite the increase in computer time for full resolution of the lower plenum, there are several advantages over the representation of that region by a boundary condition at the bottom of the downcomer: (1) removal of ambiguity for the conditions to apply at the lower boundary, as it is simply a free-slip wall, (2) resolution of the splash details, which seem to have an appreciable effect on the downcomer flow dynamics, and (3) allowance for a physically reasonable model for the steam-insertion distribution.

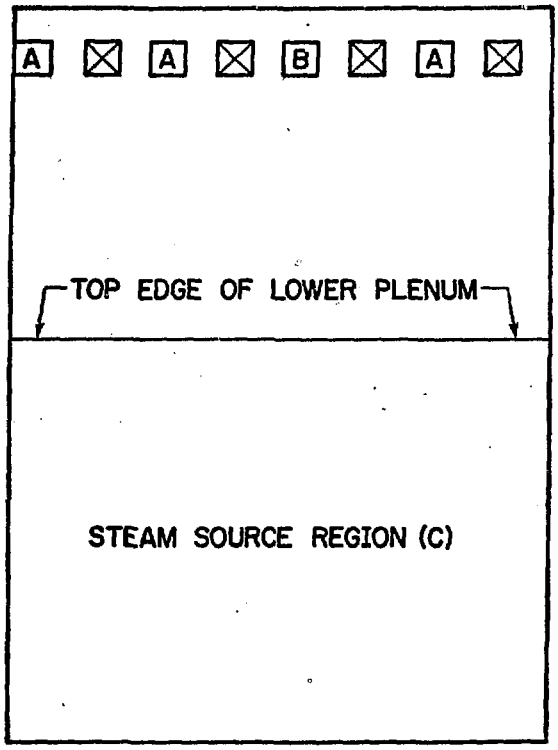

Fig. 1. A typical K-TIF downcomer computing region. The four crossed regions represent the hot-leg obstacles, A denotes the three unbroken cold-leg inlets, and B denotes the broken cold-leg exit.

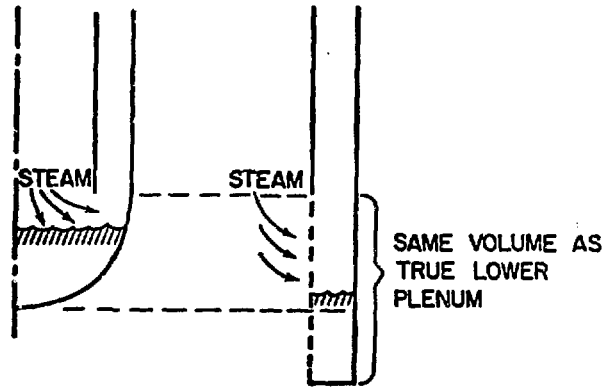

Fig. 2. The K-TIF two-dimensional volume-conservative approximation to the true lower plenum.

With rectangular cells to resolve the downcomer flow region, the cold-leg ports and hot-leg obstacles are represented by rectangles, but this idealization is probably not a source of significant error because the prescribed input flow rates are chosen carefully to agree with the experimental circumstances in each case.

The field variables for each calculation cell are located as shown in Fig. 3. The cell centers are labeled with indexes i and j, increasing, respectively, in the x (horizontal) and y (vertical) directions, for which the components of

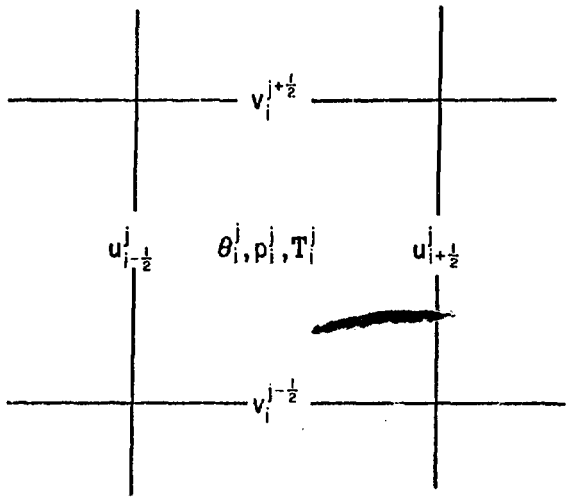

Fig. 3. Location of the principal variables about a K-TIF cell.

velocity are, respectively, u and v. In each case, except for the steam temperature, which is not specifically calculated, each field variable occurs twice at the locality shown, subscripted with 1 or 2 for water or steam.

In addition, each field variable may carry a left superscript n or n+1 that denotes the cycle number in the time-advancement sequence. If omitted, the implied cycle number is n. In the iterative solution within a cycle, through which some of the field variables advance in a converging sequence of values to their n+1 values, the intermediate levels are designated with an overhead tilde (~). Likewise, an overbar designates those n-cycle quantities that do not vary during the iteration. The following expressions represent those parts of the momentum equations.

$$(\overline{\theta_1 u_1})^j_{i+\frac{1}{2}} = {}^n(\theta_1 u_1)^j_{i+\frac{1}{2}} + \delta t \left\{ \frac{1}{\delta x}\left[{}^n\langle \theta_1 u_1^2 \rangle^j_i - {}^n\langle \theta_1 u_1^2 \rangle^j_{i+1} \right] \right.$$

$$\left. + \frac{1}{\delta y}\left[{}^n\langle \theta_1 u_1 v_1 \rangle^{j-\frac{1}{2}}_{i+\frac{1}{2}} - {}^n\langle \theta_1 u_1 v_1 \rangle^{j+\frac{1}{2}}_{i+\frac{1}{2}} \right] + \left(\frac{M_{x1}}{{}^n\rho_1} + V_{x1} \right)^j_{i+\frac{1}{2}} \right\} ,$$

$$(\overline{\theta_2 u_2})^j_{i+\frac{1}{2}} = {}^n(\theta_2 u_2)^j_{i+\frac{1}{2}} + \delta t \left\{ \frac{1}{\delta x}\left[{}^n\langle \theta_2 u_2^2 \rangle^j_i - {}^n\langle \theta_2 u_2^2 \rangle^j_{i+1} \right] \right.$$

$$+ \frac{1}{\delta y}\left[{}^n\langle \theta_2 u_2 v_2 \rangle^{j-\frac{1}{2}}_{i+\frac{1}{2}} - {}^n\langle \theta_2 u_2 v_2 \rangle^{j+\frac{1}{2}}_{i+\frac{1}{2}} \right] - {}^n(S_{p2}\, u_2)^j_{i+\frac{1}{2}}$$

$$\left. + \left(\frac{M_{x2}}{{}^n\rho_2} + V_{x2} \right)^j_{i+\frac{1}{2}} \right\} ,$$

$$(\overline{\theta_1 v_1})^{j+\frac{1}{2}}_i = {}^n(\theta_1 v_1)^{j+\frac{1}{2}}_i + \delta t \left\{ \frac{1}{\delta x}\left[{}^n\langle \theta_1 u_1 v_1 \rangle^{j+\frac{1}{2}}_{i-\frac{1}{2}} - {}^n\langle \theta_1 u_1 v_1 \rangle^{j+\frac{1}{2}}_{i+\frac{1}{2}} \right] \right.$$

$$\left. + \frac{1}{\delta y}\left[{}^n\langle \theta_1 v_1^2 \rangle^j_i - {}^n\langle \theta_1 v_1^2 \rangle^{j+1}_i \right] + \left(\frac{M_{y1}}{{}^n\rho_1} + V_{y1} \right)^{j+\frac{1}{2}}_i \right\} ,$$

$$(\overline{\theta_2 v_2})^{j+\frac{1}{2}}_i = {}^n(\theta_2 v_2)^{j+\frac{1}{2}}_i + \delta t \left\{ \frac{1}{\delta x}\left[{}^n\langle \theta_2 u_2 v_2 \rangle^{j+\frac{1}{2}}_{i-\frac{1}{2}} - {}^n\langle \theta_2 u_2 v_2 \rangle^{j+\frac{1}{2}}_{i+\frac{1}{2}} \right] \right.$$

$$+ \frac{1}{\delta y}\left[{}^n\langle \theta_2 v_2^2 \rangle^j_i - {}^n\langle \theta_2 v_2^2 \rangle^{j+1}_i \right] - {}^n(S_{p2}\, v_2)^{j+\frac{1}{2}}_i$$

$$\left. + \left(\frac{M_{y2}}{{}^n\rho_2} + V_{y2} \right)^{j+\frac{1}{2}}_i \right\} . \qquad (15)$$

The angular brackets < > indicate a donor-cell treatment of the convective flux of the enclosed quantity. The use of the donor-cell fluxing facilitates automatic partial mitigation of truncation-error effects[11] without requiring an

explicit artificial diffusion. In our formulation, the donor-cell convective flux of some cell-centered quantity, Q_i^j, at cell boundary $(i+\frac{1}{2},j)$ is given by

$$< u\ Q >^j_{i+\frac{1}{2}} = u^j_{i+\frac{1}{2}} \left[(1/2 + \xi)\ Q^j_i + (1/2 - \xi)\ Q^j_{i+1} \right] \quad ,$$

where $\xi = 1/2 \text{ sign } (u^j_{i+\frac{1}{2}})$. This formulation of ξ requires that $|u_{max}|\ \delta t/\delta x < 1/2$ everywhere, ordinarily a reasonable upper limit on δt for accuracy.

The $\vec{M}$ terms in Eqs. (15) are functions of the J from Eq. (3). We calculate $\vec{M}_1 = -\vec{M}_2$, where $\vec{M}_2 = J\vec{u}_1$ for $J > 0$, or $\vec{M}_2 = J\vec{u}_2$ for $J < 0$.

The $\vec{V}$ terms in Eqs. (15) are described below and defined in Eqs. (19).

For the mass convection terms, we use the abbreviations

$$\left.\begin{aligned} S_1 &\equiv S_{ABC1} + J/\rho_1 \\ &\text{and} \\ S_2 &\equiv S_{ABC2} - J/\rho_2 + S_{P2} \end{aligned}\right\} \tag{16}$$

in terms of which Eqs. (1) and (2) become

$$\begin{aligned} {}^{n+1}(\theta_1)^j_i = {}^n(\theta_1)^j_i + \delta t \Bigg\{ & \frac{1}{\delta x} \left[{}^{n+1}<\theta_1 u_1>^j_{i-\frac{1}{2}} - {}^{n+1}<\theta_1 u_1>^j_{i+\frac{1}{2}} \right] \\ & + \frac{1}{\delta y} \left[{}^{n+1}<\theta_1 v_1>^{j-\frac{1}{2}}_i - {}^{n+1}<\theta_1 v_1>^{j+\frac{1}{2}}_i \right] - S_{1_i}^j \Bigg\} \quad , \\ {}^{n+1}(\theta_2)^j_i = {}^n(\theta_2)^j_i + \delta t \Bigg\{ & \frac{1}{\delta x} \left[{}^{n+1}<\theta_2 u_2>^j_{i-\frac{1}{2}} - {}^{n+1}<\theta_2 u_2>^j_{i+\frac{1}{2}} \right] \\ & + \frac{1}{\delta y} \left[{}^{n+1}<\theta_2 v_2>^{j-\frac{1}{2}}_i - {}^{n+1}<\theta_2 v_2>^{j+\frac{1}{2}}_i \right] - S_{2_i}^j \Bigg\} \quad . \end{aligned} \tag{17}$$

Also, our momentum equations become

$$
\begin{aligned}
{}^{n+1}(\theta_1 u_1)^j_{i+\frac{1}{2}} &= (\overline{\theta_1 u_1})^j_{i+\frac{1}{2}} + \frac{{}^{n+1}(\theta_1)^j_{i+\frac{1}{2}}\,\delta t}{\rho_1\,\delta x}\left({}^{n+1}p^j_i - {}^{n+1}p^j_{i+1}\right) \\
&\quad + {}^{n}K^j_{i+\frac{1}{2}}\,\delta t\left[{}^{n+1}(u_2)^j_{i+\frac{1}{2}} - {}^{n+1}(u_1)^j_{i+\frac{1}{2}}\right]/\rho_1 \\
{}^{n+1}(\theta_1 v_1)^{j+\frac{1}{2}}_i &= (\overline{\theta_1 v_1})^{j+\frac{1}{2}}_i + \frac{{}^{n+1}(\theta_1)^{j+\frac{1}{2}}_i\,\delta t}{\rho_1\,\delta y}\left({}^{n+1}p^j_i - {}^{n+1}p^{j+1}_i\right) + {}^{n+1}(\theta_1)^{j+\frac{1}{2}}_i\, g\delta t \\
&\quad + {}^{n}K^{j+\frac{1}{2}}_i\,\delta t\left[{}^{n+1}(v_2)^{j+\frac{1}{2}}_i - {}^{n+1}(v_1)^{j+\frac{1}{2}}_i\right]/\rho_1 \\
{}^{n+1}(\theta_2 u_2)^j_{i+\frac{1}{2}} &= (\overline{\theta_2 u_2})^j_{i+\frac{1}{2}} + \frac{{}^{n+1}(\theta_2)^j_{i+\frac{1}{2}}\,\delta t}{\rho_2\,\delta x}\left({}^{n+1}p^j_i - {}^{n+1}p^j_{i+1}\right) \\
&\quad + {}^{n}K^j_{i+\frac{1}{2}}\,\delta t\left[{}^{n+1}(u_1)^j_{i+\frac{1}{2}} - {}^{n+1}(u_2)^j_{i+\frac{1}{2}}\right]/\rho_2 \\
{}^{n+1}(\theta_2 v_2)^{j+\frac{1}{2}}_i &= (\overline{\theta_2 v_2})^{j+\frac{1}{2}}_i + \frac{{}^{n+1}(\theta_2)^{j+\frac{1}{2}}_i\,\delta t}{\rho_2\,\delta y}\left({}^{n+1}p^j_i - {}^{n+1}p^{j+1}_i\right) + {}^{n+1}(\theta_2)^{j+\frac{1}{2}}_i\, g\delta t \\
&\quad + {}^{n}K^{j+\frac{1}{2}}_i\,\delta t\left[{}^{n+1}(v_1)^{j+\frac{1}{2}}_i - {}^{n+1}(v_2)^{j+\frac{1}{2}}_i\right]/\rho_2 \quad .
\end{aligned}
\tag{18}
$$

These finite-difference equations exhibit the basic, intercoupled implicitness in the solution technique. The new (n+1) values of quantities are expressed in terms of new values, which, as in the MAC[12] and ICE[13] methods enables the calculation of low speed ("incompressible," or low-Mach-number) flows, and also enables the momentum coupling between fields to be calculated without restricting the magnitude of K.

We discuss the solution of this part of the equations for each cycle, deferring consideration of the water-temperature equation, because it is not implicitly coupled to the mass and momentum equations.

The sequence of steps commences with an initialization that prepares for the iterative loop itself. Finite-difference expressions for K, J, and the components of V are calculated, the overbar terms for the momentum equation are evaluated [Eq. (15)], and the first tentative new values of the volume fractions are found by using Eq. (17). For the components of V, we use

$$
\begin{aligned}
(V_{x1})^{j}_{i+\frac{1}{2}} = {} & \frac{\nu_{s1}}{\delta x^2}\left\{(\theta_1)^{j}_{i+1}\left[(u_1)^{j}_{i+3/2} - (u_1)^{j}_{i+\frac{1}{2}}\right] - (\theta_1)^{j}_{i}\left[(u_1)^{j}_{i+\frac{1}{2}} - (u_1)^{j}_{i-\frac{1}{2}}\right]\right\} \\
& + \frac{\nu_{s1}}{\delta y^2}\left\{(\theta_1)^{j+\frac{1}{2}}_{i+\frac{1}{2}}\left[(u_1)^{j+1}_{i+\frac{1}{2}} - (u_1)^{j}_{i+\frac{1}{2}}\right] - (\theta_1)^{j-\frac{1}{2}}_{i+\frac{1}{2}}\left[(u_1)^{j}_{i+\frac{1}{2}} - (u_1)^{j-1}_{i+\frac{1}{2}}\right]\right\} \\
(V_{x2})^{j}_{i+\frac{1}{2}} = {} & \frac{\nu_{s2}}{\delta x^2}\left\{(\theta_2)^{j}_{i+1}\left[(u_2)^{j}_{i+3/2} - (u_2)^{j}_{i+\frac{1}{2}}\right] - (\theta_2)^{j}_{i}\left[(u_2)^{j}_{i+\frac{1}{2}} - (u_2)^{j}_{i-\frac{1}{2}}\right]\right\} \\
& + \frac{\nu_{s2}}{\delta y^2}\left\{(\theta_2)^{j+\frac{1}{2}}_{i+\frac{1}{2}}\left[(u_2)^{j+1}_{i+\frac{1}{2}} - (u_2)^{j}_{i+\frac{1}{2}}\right] - (\theta_2)^{j-\frac{1}{2}}_{i+\frac{1}{2}}\left[(u_2)^{j}_{i+\frac{1}{2}} - (u_2)^{j-1}_{i+\frac{1}{2}}\right]\right\} \\
(V_{y1})^{j+\frac{1}{2}}_{i} = {} & \frac{\nu_{s1}}{\delta x^2}\left\{(\theta_1)^{j+\frac{1}{2}}_{i+\frac{1}{2}}\left[(v_1)^{j+\frac{1}{2}}_{i+1} - (v_1)^{j+\frac{1}{2}}_{i}\right] - (\theta_1)^{j+\frac{1}{2}}_{i-\frac{1}{2}}\left[(v_1)^{j+\frac{1}{2}}_{i} - (v_1)^{j+\frac{1}{2}}_{i-1}\right]\right\} \\
& + \frac{\nu_{s1}}{\delta y^2}\left\{(\theta_1)^{j+1}_{i}\left[(v_1)^{j+3/2}_{i} - (v_1)^{j+\frac{1}{2}}_{i}\right] - (\theta_1)^{j}_{i}\left[(v_1)^{j+\frac{1}{2}}_{i} - (v_1)^{j-\frac{1}{2}}_{i}\right]\right\} \\
(V_{y2})^{j+\frac{1}{2}}_{i} = {} & \frac{\nu_{s2}}{\delta x^2}\left\{(\theta_2)^{j+\frac{1}{2}}_{i+\frac{1}{2}}\left[(v_2)^{j+\frac{1}{2}}_{i+1} - (v_2)^{j+\frac{1}{2}}_{i}\right] - (\theta_2)^{j+\frac{1}{2}}_{i-\frac{1}{2}}\left[(v_2)^{j+\frac{1}{2}}_{i} - (v_2)^{j+\frac{1}{2}}_{i-1}\right]\right\} \\
& + \frac{\nu_{s2}}{\delta y^2}\left\{(\theta_2)^{j+1}_{i}\left[(v_2)^{j+3/2}_{i} - (v_2)^{j+\frac{1}{2}}_{i}\right] - (\theta_2)^{j}_{i}\left[(v_2)^{j+\frac{1}{2}}_{i} - (v_2)^{j-\frac{1}{2}}_{i}\right]\right\} .
\end{aligned}
\tag{19}
$$

Special comment is required about the cell-corner values of the volume fractions. A momentum diffusion coefficient proportional to volume fraction is

necessary to represent the accessible area per unit volume through which the momentum is fluxed. Its presence is also beneficial in the numerical solution to help avoid excessive diffusion and numerical instability where the volume fraction is small. The cell-corner values, however, for example $(\theta_1)^{j+\frac{1}{2}}_{i+\frac{1}{2}}$, must be calculated carefully from the surrounding cell-centered values of θ_1. To see this, suppose that among the four θ_1 values surrounding a mesh vertex, only the lower left one is moderately large, and the rest are several orders of magnitude smaller. Then the flux of momentum upwards through the vertex, if proportional to a simple average of the four θ_1 values, would be far more than the $(u_1)^{j+1}_{i+\frac{1}{2}}$ calculation could absorb, because that calculation determines the new value of $(\theta_1 u_1)^{j+1}_{i+\frac{1}{2}}$ and converts this into a velocity through division by $(\theta_1)^{j+1}_{i+\frac{1}{2}}$. This last, by our premise, is very small, which would throw the resulting velocity magnitude into a grossly unrealistic range. Our remedy is to form $(\theta_1)^{j+\frac{1}{2}}_{i+\frac{1}{2}}$ as the lesser of a pair of two-cell averages, behind and in front of the fluxing direction.

The pressures and velocities left over from the previous cycle, or specified initially, together with the tentative new θ values, form the initial values of a sequence of iterative updates signified by tildes over the field variables. We carry through a Newton-Raphson solution procedure as follows. First, define

$$\beta^j_{i+\frac{1}{2}} = \rho_1 \overline{(\theta_1 u_1)}^j_{i+\frac{1}{2}} + \frac{(\tilde{\theta}_1)^j_{i+\frac{1}{2}} \delta t}{\delta x} (\tilde{p}^j_i - \tilde{p}^j_{i+1})$$

$$\gamma^j_{i+\frac{1}{2}} = \rho_2 \overline{(\theta_2 u_2)}^j_{i+\frac{1}{2}} + \frac{(\tilde{\theta}_2)^j_{i+\frac{1}{2}} \delta t}{\delta x} (\tilde{p}^j_i - \tilde{p}^j_{i+1})$$

$$\beta^{j+\frac{1}{2}}_i = \rho_1 \overline{(\theta_1 v_1)}^{j+\frac{1}{2}}_i + \frac{(\tilde{\theta}_1)^{j+\frac{1}{2}}_i \delta t}{\delta y} (\tilde{p}^j_i - \tilde{p}^{j+1}_i) + \rho_1 (\tilde{\theta}_1)^{j+\frac{1}{2}}_i g\delta t$$

$$\gamma^{j+\frac{1}{2}}_i = \rho_2 \overline{(\theta_2 v_2)}^{j+\frac{1}{2}}_i + \frac{(\tilde{\theta}_2)^{j+\frac{1}{2}}_i \delta t}{\delta y} (\tilde{p}^j_i - \tilde{p}^{j+1}_i) + \rho_2 (\tilde{\theta}_2)^{j+\frac{1}{2}}_i g\delta t$$

$$\mathcal{F}^{j}_{i+\frac{1}{2}} = (\tilde{\theta}_1\ \tilde{\theta}_2)^{j}_{i+\frac{1}{2}}\ \rho_1\ \rho_2 + K^{j}_{i+\frac{1}{2}}\ \delta t\ \left[(\tilde{\theta}_1)^{j}_{i+\frac{1}{2}}\ \rho_1 + (\tilde{\theta}_2)^{j}_{i+\frac{1}{2}}\ \rho_2\right]$$

$$\mathcal{B}^{j+\frac{1}{2}}_{i} = (\tilde{\theta}_1\ \tilde{\theta}_2)^{j+\frac{1}{2}}_{i}\ \rho_1\ \rho_2 + K^{j+\frac{1}{2}}_{i}\ \delta t\ \left[(\tilde{\theta}_1)^{j+\frac{1}{2}}_{i}\ \rho_1 + (\tilde{\theta}_2)^{j+\frac{1}{2}}_{i}\ \rho_2\right] \quad . \tag{20}$$

Then the simultaneous solution for Eq. (18) is

$$(\tilde{u}_1)^{j}_{i+\frac{1}{2}} = \frac{(\theta_2)^{j}_{i+\frac{1}{2}}\ \rho_2\ \mathcal{B}^{j}_{i+\frac{1}{2}} + K^{j}_{i+\frac{1}{2}}\ \delta t\ (\mathcal{B}^{j}_{i+\frac{1}{2}} + \mathcal{E}^{j}_{i+\frac{1}{2}})}{\mathcal{F}^{j}_{i+\frac{1}{2}}}$$

$$(\tilde{u}_2)^{j}_{i+\frac{1}{2}} = \frac{(\theta_1)^{j}_{i+\frac{1}{2}}\ \rho_1\ \mathcal{E}^{j}_{i+\frac{1}{2}} + K^{j}_{i+\frac{1}{2}}\ \delta t\ (\mathcal{F}^{j}_{i+\frac{1}{2}} + \mathcal{E}^{j}_{i+\frac{1}{2}})}{\mathcal{F}^{j}_{i+\frac{1}{2}}}$$

$$(\tilde{v}_1)^{j+\frac{1}{2}}_{i} = \frac{(\theta_2)^{j+\frac{1}{2}}_{i}\ \rho_2\ \mathcal{D}^{j+\frac{1}{2}}_{i} + K^{j+\frac{1}{2}}_{i}\ \delta t\ (\mathcal{D}^{j+\frac{1}{2}}_{i} + \mathcal{F}^{j+\frac{1}{2}}_{i})}{\mathcal{G}^{j+\frac{1}{2}}_{i}} \tag{21}$$

$$(\tilde{v}_2)^{j+\frac{1}{2}}_{i} = \frac{(\theta_1)^{j+\frac{1}{2}}_{i}\ \rho_1\ \mathcal{E}^{j+\frac{1}{2}}_{i} + K^{j+\frac{1}{2}}_{i}\ \delta t\ (\mathcal{D}^{j+\frac{1}{2}}_{i} + \mathcal{F}^{j+\frac{1}{2}}_{i})}{\mathcal{G}^{j+\frac{1}{2}}_{i}}$$

and the corresponding updates for the volume fractions are given by [see Eq. (17)]

$$(\tilde{\theta}_1)^{j}_{i} = {}^{n}(\theta_1)^{j}_{i} + \delta t \left\{\frac{1}{\delta x}\left[<\tilde{\theta}_1\tilde{u}_1>^{j}_{i-\frac{1}{2}} - <\tilde{\theta}_1\tilde{u}_1>^{j}_{i+\frac{1}{2}}\right] + \frac{1}{\delta y}\left[<\tilde{\theta}_1\tilde{v}_1>^{j-\frac{1}{2}}_{i} - <\tilde{\theta}_1\tilde{v}_1>^{j+\frac{1}{2}}_{i}\right] - (S_1)^{j}_{i}\right\} \quad ,$$

$$(\tilde{\theta}_2)^{j}_{i} = {}^{n}(\theta_2)^{j}_{i} + \delta t \left\{\frac{1}{\delta x}\left[<\tilde{\theta}_2\tilde{u}_2>^{j}_{i-\frac{1}{2}} - <\tilde{\theta}_2\tilde{u}_2>^{j}_{i+\frac{1}{2}}\right] + \frac{1}{\delta y}\left[<\tilde{\theta}_2\tilde{v}_2>^{j-\frac{1}{2}}_{i} - <\tilde{\theta}_2\tilde{v}_2>^{j+\frac{1}{2}}_{i}\right] - (S_2)^{j}_{i}\right\} \quad . \tag{22}$$

Next, repeat Eqs. (20) and (21) with

$$(p')_i^j = \tilde{p}_i^j \pm \varepsilon_p \quad , \tag{23}$$

in which ε_p is an appropriately small fraction of the mean dynamical pressure in the system, which is always normalized by an additive constant to show a minimum pressure of zero; and the sign is plus or minus in a checkerboard fashion throughout the mesh. Let the velocities formed with the p' substitution be denoted u' and v', which presumably differ slightly from the corresponding values of u and v. The next step, then, is to calculate

$$\tilde{D}_i^j = \frac{1}{\delta x}\left[< \tilde{\theta}_1\tilde{u}_1 + \tilde{\theta}_2\tilde{u}_2 >_{i+\frac{1}{2}}^j - < \tilde{\theta}_1\tilde{u}_1 + \tilde{\theta}_2\tilde{u}_2 >_{i-\frac{1}{2}}^j\right]$$

$$+ \frac{1}{\delta y}\left[< \tilde{\theta}_1\tilde{v}_1 + \tilde{\theta}_2\tilde{v}_2 >_i^{j+\frac{1}{2}} - < \tilde{\theta}_1\tilde{v}_1 + \tilde{\theta}_2\tilde{v}_2 >_i^{j-\frac{1}{2}}\right] + S_i^j \tag{24}$$

$$\tilde{D}'^j_i = \frac{1}{\delta x}\left[< \tilde{\theta}_1\tilde{u}_1' + \tilde{\theta}_2\tilde{u}_2' >_{i+\frac{1}{2}}^j - < \tilde{\theta}_1\tilde{u}_1' + \tilde{\theta}_2\tilde{u}_2' >_{i-\frac{1}{2}}^j\right]$$

$$+ \frac{1}{\delta y}\left[< \tilde{\theta}_1\tilde{v}_1' + \tilde{\theta}_2\tilde{v}_2' >_i^{j+\frac{1}{2}} - < \tilde{\theta}_1\tilde{v}_1' + \tilde{\theta}_2\tilde{v}_2' >_i^{j-\frac{1}{2}}\right] + S_i^j \quad . \tag{25}$$

The definition of $\tilde{D}_i^j$ is formed by adding the two parts of Eq. (22), assuming $^n(\theta_1 + \theta_2)_i^j \equiv 1$, setting $S \equiv S_1 + S_2$, and letting

$$\tilde{D}_i^j \equiv (\tilde{\theta}_1 + \tilde{\theta}_2)_i^j - 1 \ . \tag{26}$$

Then the significance of $\tilde{D}_i^j$ is that convergence of the iteration means $\tilde{D}_i^j$ has become sufficiently small for every cell in the mesh. With the proper choice of boundary conditions, perfect vanishing of $\tilde{D}_i^j$ for every cell means more than sim-

ply the achievement of ${}^{n+1}(\theta_1 + \theta_2)_i^j \equiv 1$. By summing separately each part of Eq. (22) over the entire mesh we see that convergence also means perfect response of each phase separately to the effects of S_1 and S_2, or alternatively to perfect conservation of each volume separately if $S_1 \equiv S_2 \equiv 0$. More important, Eq. (22) shows that the overall conservative property for the volume of each phase is ensured even if the convergence is not perfect. Without perfect convergence, however, Eq. (22) shows that ${}^{n+1}(\theta_1 + \theta_2)_i^j$ may differ from ${}^{n}(\theta_1 + \theta_2)_i^j$, and accordingly may depart from unity in each of the various cells. Because iteration to "perfect" convergence is costly in computer time, and has proved unnecessary for most purposes, we have devised an effective way to ensure that ${}^{n+1}(\theta_1 + \theta_2)_i^j$ is sufficiently close to unity, which is discussed below as a separate "corrective" procedure.

With the values of $\tilde{D}_i^j$ and $\tilde{D}'^j_i$ calculated for every cell, we may now proceed with the Newton-Raphson increment calculation, the incremented variable being the pressure for each cell. The fundamental idea is that we wish to solve simultaneously for the values of $\tilde{p}_i^j$ that make $\tilde{D}_i^j = 0$ for every cell. For each step, we determine the increment $\delta\tilde{p}_i^j$, by

$$\delta\tilde{p}_i^j = - \tilde{D}_i^j \Big/ \left(\frac{\partial\tilde{D}_i^j}{\partial\tilde{p}_i^j}\right) \quad . \tag{27}$$

The importance of D'^j_i can now be demonstrated. We use it to estimate the denominator in Eq. (27), by writing

$$\frac{1}{\beta_i^j} \equiv \frac{(\tilde{D}' - \tilde{D})_i^j}{\pm\, \epsilon_p} \tag{28}$$

so that

$$\delta\tilde{p}_i^j = -\,\omega\,\beta_i^j\,\tilde{D}_i^j \tag{29}$$

in which ω is an over/under relaxation constant with magnitude near unity. Thus the update value of $\tilde{p}_i^j$ is given by

$$^{new}(\tilde{p})_i^j = {}^{old}(\tilde{p})_i^j + \delta\tilde{p}_i^j \quad . \tag{30}$$

If, at this stage, the value of $\tilde{D}_i^j$ passes an appropriate convergence test for every cell, then the iteration is considered complete; if not, the calculation returns to Eq. (20) and is repeated.

When convergence is satisfactory, two additional modifications can be made to the fields of volume fractions, one corrective as mentioned above, the other diffusive to account for turbulence or perhaps to enhance numerical stability.

The turbulent diffusion is accomplished by a specified or calculated field of values for the coefficient, σ_i^j, according to the following equations.

$$\sigma_{i\pm\frac{1}{2}}^j = 1/2\ (\sigma_i^j + \sigma_{i\pm1}^j) \quad \text{and} \quad \sigma_i^{j\pm\frac{1}{2}} = 1/2\ (\sigma_i^j + \sigma_i^{j\pm1})\ ,$$

except at a rigid boundary, where $\sigma_{i\pm\frac{1}{2}}^j = 0$ and $\sigma_i^{j\pm\frac{1}{2}} = 0$ to ensure conservation. Then calculate

$$(\hat{\theta}_1)_i^j = (\theta_1)_i^j + \delta t\left(\frac{1}{\delta x^2}\left\{\sigma_{i+\frac{1}{2}}^j\left[(\theta_1)_{i+1}^j - (\theta_1)_i^j\right] - \sigma_{i-\frac{1}{2}}^j\left[(\theta_1)_i^j - (\theta_1)_{i-1}^j\right]\right\}\right.$$

$$\left. + \frac{1}{\delta y^2}\left\{\sigma_i^{j+\frac{1}{2}}\left[(\theta_1)_i^{j+1} - (\theta_1)_i^j\right] - \sigma_i^{j-\frac{1}{2}}\left[(\theta_1)_i^j - (\theta_1)_i^{j-1}\right]\right\}\right)$$

and

$$(\hat{\theta}_2)_i^j = (\theta_2)_i^j + \delta t \left(\frac{1}{\delta x^2} \left\{ \sigma_{i+\frac{1}{2}}^j \left[(\theta_2)_{i+1}^j - (\theta_2)_i^j \right] - \sigma_{i-\frac{1}{2}}^j \left[(\theta_2)_i^j - (\theta_2)_{i-1}^j \right] \right\} \right.$$

$$\left. + \frac{1}{\delta y^2} \left\{ \sigma_i^{j+\frac{1}{2}} \left[(\theta_2)_i^{j+1} - (\theta_2)_i^j \right] - \sigma_i^{j-\frac{1}{2}} \left[(\theta_2)_i^j - (\theta_2)_i^{j-1} \right] \right\} \right) \tag{31}$$

in which the modified values, $\hat{\theta}_1$ and $\hat{\theta}_2$, replace the new volume fractions in the computer storage.

The corrective procedure, to bring ${}^{n+1}(\theta_1 + \theta_2)_i^j$ to unity, is accomplished by an efficient and rapidly converging iteration. Let

$$\bar{\lambda}_o \equiv \frac{0.9}{2\delta t \left(\frac{1}{\delta x^2} + \frac{1}{\delta y^2} \right)} \quad , \tag{32}$$

which is 90% of the maximum value that could be chosen for the following purpose, according to the well-known stability properties of this process. Next,

$$(\bar{\lambda}_1)_{i\pm\frac{1}{2}}^j = 1/2\ \bar{\lambda}_o \left[(\theta_1)_i^j + (\theta_1)_{i\pm1}^j \right] \quad , \quad (\bar{\lambda}_1)_i^{j\pm\frac{1}{2}} = 1/2\ \bar{\lambda}_o \left[(\theta_1)_i^j + (\theta_1)_i^{j\pm1} \right] \quad ,$$

$$(\bar{\lambda}_2)_{i\pm\frac{1}{2}}^j = 1/2\ \bar{\lambda}_o \left[(\theta_2)_i^j + (\theta_2)_{i\pm1}^j \right] \quad , \quad (\bar{\lambda}_2)_i^{j\pm\frac{1}{2}} = 1/2\ \bar{\lambda}_o \left[(\theta_2)_i^j + (\theta_2)_i^{j\pm1} \right] \quad ,$$

except at a rigid boundary, where $\bar{\lambda}_1 = \bar{\lambda}_2 = 0$ to ensure conservation. Then calculate

$$(\check{\theta}_1)_i^j = (\theta_1)_i^j + \delta t \left(\frac{1}{\delta x^2} \left\{ (\bar{\lambda}_1)_{i+\frac{1}{2}}^j \left[(\theta_1 + \theta_2)_{i+1}^j - (\theta_1 + \theta_2)_i^j \right] \right. \right.$$

$$\left. - (\bar{\lambda}_1)_{i-\frac{1}{2}}^j \left[(\theta_1 + \theta_2)_i^j - (\theta_1 + \theta_2)_{i-1}^j \right] \right\}$$

$$+ \frac{1}{\delta y^2} \left\{ (\bar{\lambda}_1)_i^{j+\frac{1}{2}} \left[(\theta_1 + \theta_2)_i^{j+1} - (\theta_1 + \theta_2)_i^j \right] - (\bar{\lambda}_1)_i^{j-\frac{1}{2}} \left[(\theta_1 + \theta_2)_i^j \right. \right.$$

$$\left. \left. \left. - (\theta_1 + \theta_2)_i^{j-1} \right] \right\} \right) \tag{33}$$

and

$$(\check{\theta}_2)_i^j = (\theta_2)_i^j + \delta t \left(\frac{1}{\delta x^2} \left\{ (\bar{\lambda}_2)_{i+\frac{1}{2}}^j \left[(\theta_1 + \theta_2)_{i+1}^j - (\theta_1 + \theta_2)_i^j \right] \right.\right.$$

$$\left. - (\bar{\lambda}_2)_{i-\frac{1}{2}}^j \left[(\theta_1 + \theta_2)_i^j - (\theta_1 + \theta_2)_{i-1}^j \right] \right\}$$

$$+ \frac{1}{\delta y^2} \left\{ (\bar{\lambda}_2)_i^{j+\frac{1}{2}} \left[(\theta_1 + \theta_2)_i^{j+1} - (\theta_1 + \theta_2)_i^j \right] - (\bar{\lambda}_2)_i^{j-\frac{1}{2}} \left[(\theta_1 + \theta_2)_i^j \right.\right.$$

$$\left.\left.\left. - (\theta_1 + \theta_2)_i^{j-1} \right] \right\} \right) \quad ,$$

and replace each θ by $\check{\theta}$. This is repeated as many times as necessary to achieve a value of unity for $(\theta_1 + \theta_2)_i^j$ in every cell to within some desired degree, which, for most purposes is sufficiently accurate when the discrepancy is everywhere less than 2%.

The calculations of volume fractions, velocities, and pressures discussed so far are performed in each cycle with the water temperature remaining fixed. When that part of the calculation is complete, the new values of T_1 are determined using an implicitness that is not coupled to the advancement of the other field variables. This calculation needs no iterative procedure for its solution.

To accomplish the simultaneous solution of Eqs. (3), (9), and (12), we first assume that the critical heat flux is not exceeded. Let $T \equiv T_1 - T_s$. Then the combined equations become, for $|T_w - T_s - T| > \Delta T_o$,

$$\left.\begin{aligned} \frac{\partial T\theta_1}{\partial t} + \nabla \cdot (T\theta_1 \vec{u}_1) &= L_L J_L \theta_1 \theta_2 T/T_s + \frac{z\kappa_o}{\gamma_s} (T_w - T_s - T) \quad , \\ \frac{\partial \gamma^2}{\partial t} &= \kappa_w \quad , \end{aligned}\right\} \qquad (34)$$

in which Eq. (1) is used. For the solution of these equations, we define

$$\mathcal{L}_i^j \equiv L_L \, J_L \, \delta t \, (\theta_1 \, \theta_2)_i^j / T_s \, , \tag{35}$$

$$\mathcal{D}_i^j \equiv \frac{\delta t}{\delta x} \left[< u_1 \, \theta_1 \, T >_{i-\frac{1}{2}}^{j} - < u_1 \, \theta_1 \, T >_{i+\frac{1}{2}}^{j} \right] + \frac{\delta t}{\delta y} \left[< v_1 \, \theta_1 \, T >_{i}^{j-\frac{1}{2}} - < v_1 \, \theta_1 \, T >_{i}^{j+\frac{1}{2}} \right] \, . \tag{36}$$

Here, as a departure from the previously described convention, any value of u, v, and θ used in this water-temperature solution without a cycle-level superscript refers to the newly calculated (n+1) level. With these definitions, Eqs. (34) become, in finite-difference representation,

$$^{n+1}T_i^j \, {}^{n+1}(\theta_1)_i^j = {}^{n}T_i^j \, {}^{n}(\theta_1)_i^j + \mathcal{D}_i^j + \mathcal{L}_i^j \, {}^{n+1}T_i^j + \frac{z \, \kappa_o \, \delta t}{s \, {}^{n+1}\gamma_i^j} \left[T_w - T_s - {}^{n+1}T_i^j \right] \, ,$$

$$^{n+1}\gamma_i^j = \left[\left({}^{n}\gamma_i^j \right)^2 + \kappa_w \, \delta t \right]^{\frac{1}{2}} \, . \tag{37}$$

The implicitness, exhibited by the use of $^{n+1}T_i^j$ in both the phase-transition-rate term and the wall-heat-transfer term, removes any time-step restrictions on the magnitude of the coefficients for these effects. The equations are solved simultaneously for the advanced-time variables in each cell.

If $|T_w - T_s - T| < \Delta T_o$, then Eqs. (37) are replaced by $^{n+1}\gamma_i^j = \gamma_o$ and a T equation in which the wall heat term is set equal to zero. Thus, the calculations for advancing the water temperature take place in a three-step process.

1. Subtract T_s from every $^{n}(T_1)_i^j$, to form $^{n}T_i^j$.
2. Calculate $^{n+1}T_i^j$ and $^{n+1}\gamma_i^j$.
3. Add T_s to every $^{n+1}T_i^j$, to form $^{n+1}(T_1)_i^j$.

Although steps 1 and 3 are not required in principle, we find in practice that the accuracy is significantly enhanced by this procedure. The reason is that

Eq. (17) is not precisely satisfied by the iteration solution, because practical considerations force cessation of iteration before convergence is complete. The resultant discrepancy would serve as a source or sink for T_1, but it is almost completely removed by solving for T in Eq. (34), from which most of the source and sink terms have been removed by Eq. (1).

In the critical-heat-flux limited case, the procedure is nearly the same as above, except that Eqs. (37) are modified by the assumption that

$$\frac{k_w}{{}^{n+1}\gamma_i^j}\left[T_w - T_s - {}^{n+1}\ell_i^j\right] = (\mathrm{MHF})\,{}^{n+1}(\theta_1)_i^j \quad ,$$

so that the two equations to be solved for ${}^{n+1}T_i^j$ and ${}^{n+1}\gamma_i^j$ are

$$\left.\begin{aligned} {}^{n+1}T_i^j\,{}^{n+1}(\theta_1)_i^j &= {}^{n}T_i^j\,{}^{n}(\theta_1)_i^j + \mathcal{D}_i^j + \mathcal{L}_i^j\,{}^{n+1}T_i^j + \frac{z\delta t}{s\,\rho_1\,b_1}(\mathrm{MHF})\,{}^{n+1}(\theta_1)_i^j \,, \\ {}^{n+1}\gamma_i^j &= \left[\left({}^{n}\gamma_i^j\right)^2 + \kappa_w\,\delta t\right]^{1/2} \quad . \end{aligned}\right\} \quad (38)$$

Note that our equation for water temperature excludes S_{ABC1} of Eq. (1). That term is active only in the cold-leg inlet and outlet cells, where the water temperature is not calculated. In the cold-leg inlet (A) cells, the water temperature is the prescribed ECC temperature. In the broken-cold-leg outlet (B) cells, the water temperature is taken to be T_s, although the value is irrelevant because we allow water flow only <u>into</u> those cells.

E. Boundary Conditions

The boundary conditions presented in this version of K-TIF are tailored specifically for the geometry described in Fig. 1, where the walls that surround the computing region are typical representations of free-slip rigid walls along the top and bottom, and periodic boundaries along the left and right. The free-slip walls are insulated, nonadhering surfaces that exert no drag onto the fluid.

The normal component of velocity and the gradient of any scalar variable vanishes at the wall. The periodic boundaries simply connect the two sides of the computing mesh. Along the left boundary, for example, the neighbor to the left of a given cell is the cell lying adjacent to the right boundary in the same row of cells, and vice versa.

The boundary conditions applied to certain cells within the mesh merit a more extensive discussion. One condition concerns the flux of steam into the lower plenum, which is mentioned in Sec. I.D in relation to Fig. 2. The flux is based on data for a specific experiment, in particular the dimensionless parameter J^*_{gc}, a measure of the variable steam flux, which may, for example, ramp down to zero over some number of seconds. In K-TIF, J^*_{gc} appears in our expression for the quantity F_{B2}, which is the total volume of steam per unit time per gap width entering the system. Then

$$J^*_{gc} = \frac{-F_{B2}}{L} \sqrt{\frac{\rho_2}{gL\,(\rho_1 - \rho_2)}} \quad , \tag{39}$$

where L is the length of the system, equal to downcomer circumference. In all cases, our sign convention is that every volumetric flow rate is positive for a flow <u>out</u> of the system. F_{B2} is then converted to the volumetric source-sink function, S_{C2}, subject to the constraint

$$\sum_{LP} (S_{C2})^j_i \, \delta x \delta y = F_{B2} \quad ,$$

with the sum taken over all cells in the lower plenum. The distribution is θ_2 weighted, so that for every cell (i,j) in the lower plenum

$$(S_{C2})^j_i = \frac{F_{B2}}{\delta x \; \delta y} \left[\frac{(\theta_2)^j_i}{\sum_{LP} (\theta_2)^j_i} \right] . \tag{40}$$

In addition to having a steam source feature, the only other unusual treatment in the lower plenum is that the wall-heat transfer rate is half as large as in the downcomer region above, as there is only one heated wall in the plenum but two in the downcomer. This is described in Sec. I.B.

Also taken from the experimental data is $J^*_{f,in}$, the influx of ECC water through the three intact cold legs, which is related to the quantity S'_{A1}, the total inlet volumetric flow of water through these three legs per gap width. Again using the Creare system of nondimensionalization,

$$J^*_{f,in} \equiv \frac{-S'_{A1}}{L}\sqrt{\frac{\rho_1}{gL\,(\rho_1 - \rho_2)}} \quad . \tag{41}$$

S'_{A1} is then divided evenly among all the individual A-type cells that comprise the three intact legs.

$$S_{A1}\ (\text{individual cell}) = \frac{S'_{A1}}{\tau_A} \quad , \tag{42}$$

with τ_A denoting the total volume per unit gap width of the inlet-pipe source regions.

In addition to the steam source S_{C2} and the ECC source S_{A1}, there are two other volumetric sources to the system. One of these arises from the effects of variable steam density, S_{P2} of Eq. (2), and the other arises from phase transitions. For this latter, the total volumetric change rate over the entire system is

$$F_p = \left(\frac{1}{\rho_1} - \frac{1}{\rho_2}\right) \sum_{ij} (J^j_i)\ \delta x \delta y \quad . \tag{43}$$

With four of the volumetric sources known at any given instant, we impose the condition that the <u>net</u> volumetric loss rate over the entire system is zero. The necessary adjustment to achieve this balance is made at the broken cold leg (B). Combining the sources and following our sign convention, we declare

$$F_{B2} + S_{A1}\,\tau_A + \sum_{ij} (S_{P2})_i^j\,\delta x\delta y + F_p + (S_{B1} + S_{B2})\,\tau_B \equiv 0 \quad , \tag{44}$$

in which τ_B denotes the total volume per unit gap width of the outlet pipe sink region. To calculate S_{B1} and S_{B2}, we specify

$$\left.\begin{aligned} S_{B1} &= H(\theta_1)_B \\ S_{B2} &= H(\theta_2)_B \end{aligned}\right\} \tag{45}$$

and substitute these expressions into Eq. (44) to determine H.

$$H = -\frac{F_{B2} + S_{A1}\,\tau_A + \sum_{ij} (S_{p2})_i^j\,\delta x\delta y + F_p}{(\theta_1 + \theta_2)_B \tau_B} \quad . \tag{46}$$

Because the removal of water and steam is in proportion to the local θ's, the velocities could be subject to large accelerations for extremely small θ values at the outlet. Accordingly, we have found it helpful to set the S_B term for either of Eqs. (45) to zero if the corresponding ∂ value is less than 0.01. The procedure thus delays drainage until material buildup is appreciable, avoiding accelerations that would reduce δt, but at the same time it has a negligible effect on the overall dynamics of interest. If the calculation gives $H < 0$, indicating flow back into the downcomer from the broken leg, then we take $S_{B1} = 0$ and $S_{B2} = H(\theta_1 + \theta_2)_B$, thus allowing only steam to reenter.

F. Automatic Viscosity Calculation and Numerical Stability

Donor-cell convection contributes an effective viscosity to the flow. The magnitude of this contribution can be estimated in the following way,[11] which we discuss for brevity under the assumption that $\delta x = \delta y$,

$$\nu_s = \omega_s(U^2\,\delta t + 1/2\,U\,\delta x) \quad , \tag{47}$$

in which $\omega_s \approx 0.5$, and U is an appropriate estimate of the maximum speed in the system. If this donor-cell contribution is deemed insufficient, then we may add more by explicitly incorporating Eq. (47) into Eqs. (6) and (7), with some appropriate choice for the magnitude of ω_s. More accurately, we could endeavor to cancel from the calculations the (positive or negative) lowest order diffusive effects by a truncation-error subtraction procedure,[14] but this is not attempted in the present version of the code.

Because the convection terms are solved explicitly, the calculations are subject to a stability condition of the form

$$\frac{U\delta t}{\delta x} < 1 \quad .$$

This condition forces a restriction on the efficiency of the present K-TIF code. Because of the relatively high speeds attained by the steam flow, the time step per cycle must be smaller than would be required if the steam convection were calculated implicitly. Production versions of the code, planned as developments from the present research version, may be expected to run faster on the computer if they incorporate this additional implicitness, but other considerations may keep this improvement from being appreciable.

Note that if a calculation is performed with the restriction

$$\frac{U\delta t}{\delta x} = f \quad , \tag{48}$$

where $0 < f < 1$, then Eq. (47) shows that

$$\nu_s = \omega_s \; f \; (f + 1/2) \; \frac{\delta x^2}{\delta t} \quad . \tag{49}$$

Now the ensurance of diffusional stability requires $4\nu_s \; \delta t < \delta x^2$, which, with Eq. (49) can be written

$$\omega_s < \frac{1}{2f(2f + 1)} \quad . \tag{50}$$

This result shows the consistency among Eqs. (47), (48), and the diffusional stability condition. For example, if f = 0.5, then $\omega_s < 0.5$ is required, and this restriction is closely related to the donor-cell and/or explicit diffusion that would in any case be expected or appropriate.

Another stability condition, associated with the phase transition rate, can be illustrated by considering parts of the second half of Eq. (17),

$$^{n+1}\theta_2 = {}^{n}\theta_2 \left(1 + {}^{n}\theta_1 \, J_L \, \delta t \, \frac{T_s - T_1}{T_s \, \rho_2}\right) \quad ,$$

which shows that we must require, in the worst case ($^{n}\theta_1 \approx 1.0$),

$$\left| J_L \, \delta t \, \frac{T_s - T_1}{T_s \, \rho_2} \right| < 1 \; .$$

This stability condition restricts the time step, δt, in a manner that is independent of finite-difference cell size. In case this restriction should become severe, it is easily mitigated by an additional degree of implicitness in the J terms of Eqs. (17).

II. THE K-TIF COMPUTER PROGRAM

A. General Structure

K-TIF is intended for use on the CDC-7600, operating under the Livermore Time-Sharing System (LTSS). To optimize computing resources in a time-sharing mode, we decided to write the program as a short main program that drives 15 subroutines of short-to-medium length. By forming a binary library of the entire routine collection, generally only one or two subroutines require recompilation to set up any particular problem, thereby minimizing compilation time.

Figure 4 illustrates the 16-routine structure, which begins with the main routine KTIF. From this point, control can pass any one of three possible ways, depending on the disposition of the variable $\overline{I}$, located in the input file.

1. If $\overline{I} > 0$, it is assumed that a calculation is to be set up from data supplied in the input file, with $\overline{I}$ taken to be the number of mesh zones in the azimuthal (x) direction. Thus, control is passed to subroutine SETUP, which creates the computing mesh with its initial cell quantities and determines all parameters necessary to the cyclic solution of the problem.

2. If $\overline{I} = 0$, it is assumed that a calculation is to be continued that was previously set up and running, and that was terminated with a data dump.

3. If $\overline{I} < 0$, the input file is exhausted and the problem ends.

As shown in Fig. 4, both the paths $\overline{I} > 0$ and $\overline{I} = 0$ enter subroutine CONTROL. All the remaining subroutines and the logic directing them are subservient to CONTROL. The first task of CONTROL is to sense the $\overline{I} = 0$ condition and, if it exists, to read the data dump and continue the calculation. The basic K-TIF calculation cycle is the top-to-bottom logic path below the CONTROL box in Fig. 4. CONTROL performs the calls and makes the tests just as indicated in the figure. Note that several of the called subroutines call other subroutines, indicated by boxes, to the right with double-headed arrows.

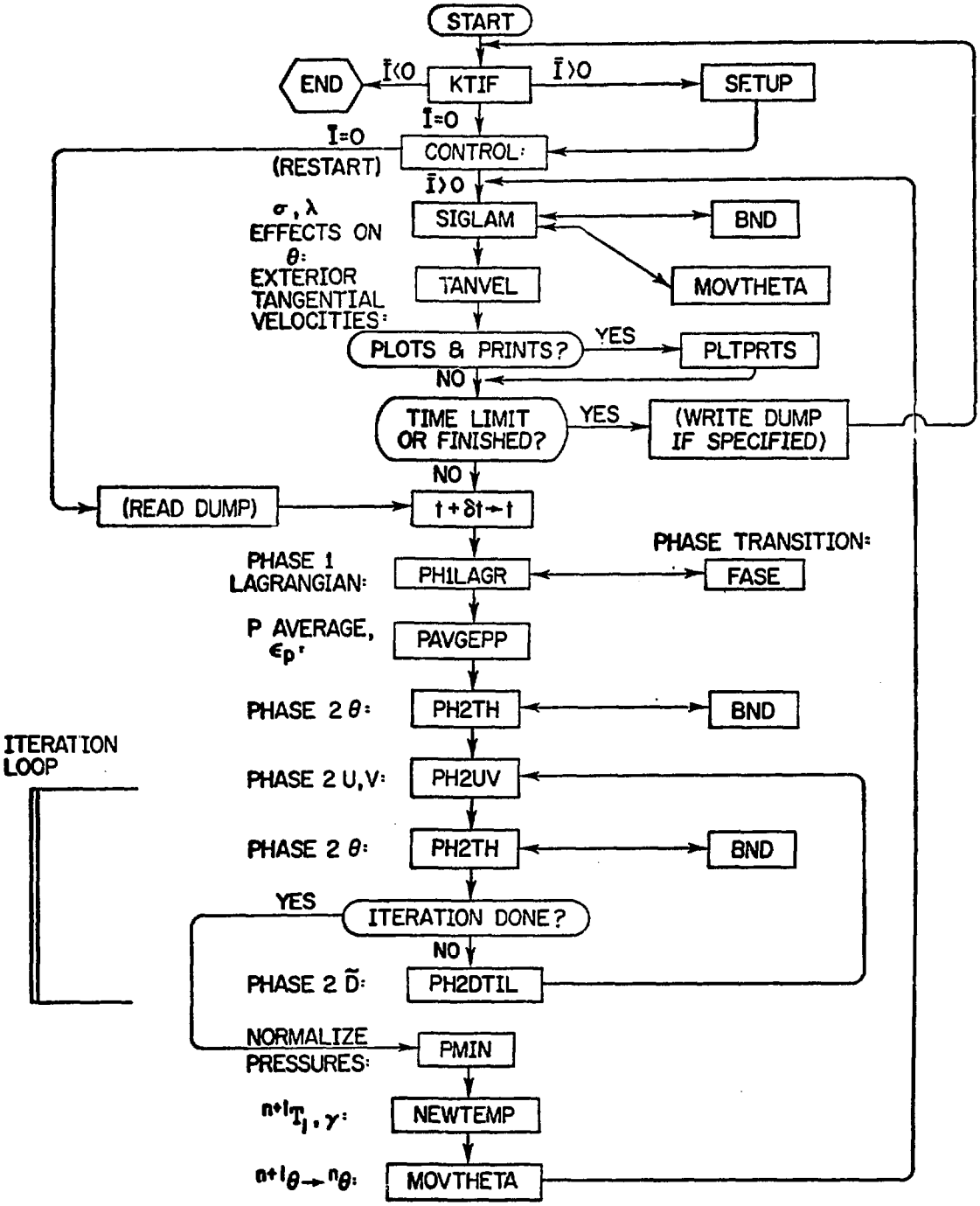

Fig. 4. The K-TIF program structure, in which the main routine KTIF drives 15 subroutines.

The tasks of the subroutines referenced in this cyclic loop are as follows.

SIGLAM makes two modifications to the volume fraction fields. The first is the incorporation of the turbulent diffusion (σ) of Eqs. (31), and the second is the corrective (λ) procedure that brings $(\theta_1 + \theta_2) \rightarrow (1 \pm \varepsilon_\theta)$ in every cell, by using Eqs. (33).

BND sets boundary conditions for θ's and velocities in the fictitious cells surrounding the mesh. It is necessary to CALL BND whenever the inside values of any of these variables are updated.

MOVTHETA moves the contents of $\tilde{\theta}_1$ and $\tilde{\theta}_2$ storage to ${}^n\theta_1$ and ${}^n\theta_2$. In K-TIF, several levels of θ storage must be maintained. Note that the water temperature equation requires both ${}^n\theta$ and ${}^{n+1}\theta$. The $\tilde{\theta}$ evolves from ${}^n\theta$ during the course of the Phase 2 iteration and emerges as ${}^{n+1}\theta$. The multilevel θ storage is also required in SIGLAM, where the $\hat{\theta}$ and $\check{\theta}$ equations require current θ values from the neighboring cells.

TANVEL sets the exterior tangential velocities on the bottom, top, left, and right sides of the mesh.

The SIGLAM-TANVEL duo are placed at the <u>beginning</u> of the cycle rather than at the end, where the discussion of Sec. I.D logically placed them. The purpose here is to accommodate a more general setup that (1) may have generated θ's that did not sum to unity in every cell, or (2) had an initial velocity field, immediately requiring the exterior tangential velocities.

Upon completion of the SIGLAM-TANVEL duo, the code has either the complete problem setup or the complete results of a calculation cycle. At this point, therefore, we make the tests for output plots and prints, calling PLTPRTS to create the desired output (Sec. II.D) if the tests are satisfied. Also at this point, checks are made to see if the problem either has run to the specified finish time or is about to exhaust the computer time assigned to the run. In

either case, CONTROL will write a dump for restart purposes if specified by the input data. If the run survives these two tests that can force its termination, t is incremented by δt, and the logic sequence begins that performs the next cycle.

PH1LAGR performs the Phase 1 explicit Lagrangian calculations. A call is made to subroutine FASE to obtain new arrays of J [Eq. (3)], the J contributions to S_1 and S_2 [Eqs. (16)], and the new value of F_p, the flux due to phase transitions [Eq. (43)]. In PH1LAGR, the r_1 and r_2 arrays are calculated, or alternatively, set to a prescribed constant value. The various contributions to the sources and sinks of the A, B, and C cells are calculated: variable steam density [Eq. (2)], ECC water flux in the A cells [Eq. (42)], removal of water and steam from the broken cold leg [Eqs. (45)] or influx of steam only if there is a net inflow [$H < 0$ in Eq. (46)]. Throughout the lower plenum, which is comprised entirely of C cells, the present steam flux, F_{B2} [Eq. (39)], is distributed in proportion to the local θ_2 of each cell [Eq. (40)]. At this point, the S_1 and S_2 fields of all cells contain all the contributions for the cycle.

$$(S_1)_i^j = (S_{1,ABC})_i^j + J_i^j/\rho_1 \ ,$$

and

$$(S_2)_i^j = (S_{2,ABC})_i^j - J_i^j/\rho_2 + S_{P2} \ .$$

The remaining tasks of PH1LAGR include the calculation of K [Eq. (8)], the $\tilde{D}$ convergence test for later use in the Phase 2 iteration, and the $(\overline{\theta u})$ and $(\overline{\theta v})$ fields [Eqs. (15)].

PAVGEPP determines the average pressure in the system and, from it, the ε_p that will be used in the tilde prime and β equations in the Phase 2 iteration.

PH2TH calculates the new $\tilde{\theta}_1$ and $\tilde{\theta}_2$ arrays [Eqs. (22)]. The first entry is to initialize their values before the iteration loop.

The Phase 2 iteration loop begins at this point.

PH2UV is called to obtain the tilde and tilde prime velocities [Eqs. (21)]. A perturbation may be applied for some number of cycles at the beginning of the calculation by a slight acceleration added to the $\tilde{u}$ and $\tilde{u}'$ of the cell just below the ECC inlet cell lying furthest from the broken leg. This ensures that the calculation will allow growth of the instabilities that are present in the physical model.

PH2TH is called to obtain updated $\tilde{\theta}$ values based on the new velocities.

At this point, we test to see if $\tilde{D}$ convergence has been satisfied throughout the mesh. The first time through, though, a $\tilde{D}$ has yet to be calculated, but we purposely preset the test to the "fail" condition to force iteration, for which PH2DTIL is called:

PH2DTIL obtains the fields of $\tilde{D}$ and $\tilde{D}'$ [Eqs. (24) and (25)], which in turn enter the new β [Eq. (28)], and then the new pressures [Eqs. (29) and (30)]. Finally, a test is made on $\tilde{D}$ convergence and a count is kept of the number of cells that fail to converge. This is the number to be tested for $\tilde{D}$ convergence.

The sequence goes back to the call to PH2UV above, then PH2TH, the convergence test, and PH2DTIL. The loop is maintained until either convergence has been obtained for all cells, or the maximum allowed number of iteration loops have been made. In either case, iteration is terminated and the remainder of the cycle is calculated.

PMIN normalizes the final pressure field by determining the minimum pressure in the system and then subtracting this value from all the pressures. The resultant field represents the final pressures for the cycle.

NEWTEMP calculates the new water temperatures, ${}^{n+1}T_1$, and then replaces the ${}^{n}T_1$ field with the new values. In addition, new values of the conduction depth, γ, are calculated.

MOVTHETA is called one last time to replace ${}^{n}\theta_1$ and ${}^{n}\theta_2$ fields with the ${}^{n+1}\theta_1$ and ${}^{n+1}\theta_2$ that resulted from the iteration.

As indicated in Fig. 4, the flow returns to the point where SIGLAM is called, to complete the cycle.

B. The Indexing Notation

Figure 3 shows that some variables are defined at cell centers and some at cell edges, as is typical of a number of Eulerian computing methods. In FORTRAN, p_i^j can be represented simply by P(I,J), but $u_{i+\frac{1}{2}}^j$ cannot be represented by a half-integer index; therefore, our convention is that U(I,J) denotes this particular velocity. Thus the indexes I and J denote a quantity located at the center of cell (i,j), at the right edge (i+½,j), or at the top edge (i,j+½), depending on where the quantity is defined to be by the difference equations. In K-TIF, (I,J) is replaced simply by (IJ), because only single subscripts are used for computer efficiency. In the K-TIF subscript notation, the letter P stands for + , and M stands for - . Thus, we write

IJ = (i,j) ,

IMJ = (i-1,j) ,

IJM = (i,j-1) ,

IPJP = (i+1,j+1) ,

etc. Such a notation makes the programmed difference equations in the code easy to read.

Because the number of cell edges in either direction is one greater than the number of cells, the grid in computer storage must be at least $(\bar{I}+1)$ by $(\bar{J}+1)$ in

size. Because our indexing refers to cell centers and right and top edges, one extra column of storage on the left and one extra row along the bottom are provided. K-TIF also includes an extra row of cells across the top and an extra column up the right, which gives an $(\bar{I}+2)$ by $(\bar{J}+2)$ mesh. As described in Sec. I.E, these exterior zones are known as outside or fictitious cells, and surrounding the mesh with them helps in treating the boundary conditions.

An example of the basic K-TIF mesh is shown in Fig. 5, which shows that double DO loops in FORTRAN would have the limits J=2 to JP1 and I=2 to IP1 to sweep all cell centers. Similarly, DO loops with limits J=2 to JP1 and I=2 to IBAR will access all interior u velocity components, and those with limits of J=2 to JBAR and I=2 to IP1 will access all interior v velocity components. Boundary velocities and exterior values of the cell-centered variables receive special treatment and normally are not included within the limits of the DO loops.

C. The Input Data

BCD data cards punched according to specific formats provide the parameters required to set up a K-TIF calculation. Operating under LTSS, true cards are no longer used, and are replaced by a disk file of card images with one line per card image. The number of lines varies depending upon the number of entries in the tables of experimental values of (t, psia, J^*_{gc}) and the number of A and B ports and hot-leg obstacles. The input file has the following appearance.

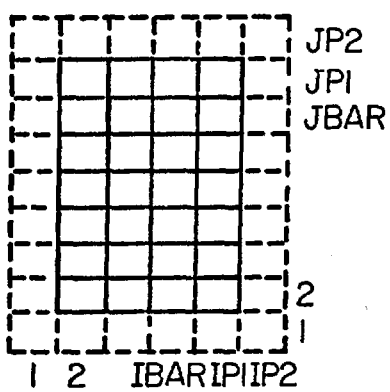

Fig. 5. The FORTRAN column and row notation used in K-TIF. Fictitious cells are denoted by dashed lines.

Line No. 1: IBAR, JBAR, JTOPLP, NTAB, DX, DY, CD, MU(1), MU(2), SIGIJ (Format 4I4, 6F8.3), where

IBAR = $\bar{I}$, the number of real (interior) cells in the azimuthal (x) direction.

JBAR = $\bar{J}$, the number of real (interior) cells in the axial (y) direction.

JTOPLP = the height of the lower plenum, an integer number of cells, chosen to match the experimental lower plenum volume as nearly as possible within the constraints of mesh width, cell size, and gap width.

NTAB = the number of entries per table for TABT, TABP, and TABJG below, from experimental data.

DX = δx, the cell size in the azimuthal direction.

DY = δy, the cell size in the axial direction.

CD = C_D, the drag coefficient.

$$\left.\begin{array}{l} MU(1) = \mu_1 \\ \\ MU(2) = \mu_2 \end{array}\right\} \text{ the optional viscosity coefficients.}$$

SIGIJ = σ, the turbulent diffusion coefficient.

<u>Line No. 2</u>: NAME (Format 8A10), where columns 2-80 are used for problem identification on prints and all film frames.

<u>Line No. 3</u>: WE, BIGJL, TWINF, TECCF, JFSTAR, S, HFCRIT (Format 7F8.3), where

WE = We, the constant Weber number used in the r_1 and r_2 calculation. If We < 1.0, the value is interpreted as a constant r_p instead.

BIGJL = J_L, the phase transition coefficient.

TWINF = Temperature of wall interior, $T_{w,in}$, in °F.

TECCF = T_{ECC} (°F), to match a particular experiment.

JFSTAR = $J^*_{f,in}$, a dimensionless measure of the ECC flux, to match a particular experiment.

S = s, the width of the downcomer gap, to match a particular experiment.

HFCRIT = CHF, the critical heat flux, in cal/(in^2 sec). For forced convective boiling, a CHF may not apply; in this case we supply some large number, e.g., 10^{10}.

Line No. 4 (or 4 and 5): (TABT(N), N=1, NTAB) (Format 10F8.3), where TABT is the table of time values at which pressure and steam flux measurements were made in a particular experiment. The dimension allows a maximum of 20 entries. Used with TABP and TABJG, below.

Line 5 (or 6 and 7): (TABP(N), N=1, NTAB) (Format 10F8.3), where TABP is the table of pressure values in units of psia corresponding to the times in TABT. A linear interpolation is performed every cycle to obtain the current pressure.

Line 6 (or 8 and 9): (TABJG(N), N=1, NTAB) (Format 10F8.3), where TABJG is the table of J^*_{gc} values corresponding to the times in TABT. A linear interpolation is performed every cycle to obtain the current J^*_{gc}.

Line 7 (or 10): T, DT, DTMAX, TLIMD, TWFIN, LPR, MPR, MOD59 (Format 5F8.3, 3I4), where:

T = t_o, the problem starting time in seconds, usually zero.

DT = δt_o, the initial δt. After the first 10 cycles, δt is chosen automatically from prevailing conditions.

DTMAX = δt_{max}, the maximum δt allowed in the calculation.

TLIMD = 1.0 to force a restart dump and a RETURN just before the CP time limit is reached; > 1.0 to force a restart dump and a RETURN immediately after cycle 0 output;

= 0.0 to run to the CP time limit with no dump.

TWFIN = problem finish time. When this time (t ≥ TWFIN) is reached, control returns to the main program KTIF. (Upon RETURN to KTIF for either the TLIMD or TWFIN condition, KTIF searches the input

queue for further problems.)

LPR = "Long Print" control, where

0 = movie option, 1 = cell-data listing on film only, 2 = cell-data listing on both film and printer, 3 = cell-data listing on printer only. These options are described in the next section.

MPR = "Monitor Print" control, where

0 bypasses, and 1 performs, a one-line summary monitor print to the printer file every other cycle.

MOD59 = the number of cycles between summary monitor prints on the remote (time-sharing) terminal. Usually ~200.

<u>Line 8 (or 11)</u>: (DTO(N), N=1, 10) is used in conjunction with:

<u>Line 9 (or 12)</u>: (DTOC(N), N=1, 10) (both are Format 10F8.3), where DTO_n specifies the problem time output interval between calls to PLTPRTS. $DTOC_n$ specifies the time at which to change to DTO_{n+1}. As an example, assume that output is wanted every 0.25 sec of problem time for the first second, then every 2 sec up to 8 sec of problem time, then every 0.125 sec up to t = 10 sec, then more infrequently again, with output only every 10 sec until t = 50 sec. One would use:

DTO(1-4) = 0.25, 2.0, 0.125, 10.0,

DTOC(1-4) = 1.0, 8.0, 10.0, 50.0.

To keep the output time interval fixed throughout a run, specify DTO(1) = (interval) and DTOC(1) > TWFIN. As an output time is approached, the automatic δt will choose a special δt for one cycle so that the output occurs at the precise time specified.

<u>Line 10 (or 13)</u>: NOAB (Format I4), where

NOAB is the combined number of obstacles, A ports, and B ports. For each, then, a card is read that contains

Next (NOAB) lines: OABFL(N), NL, NR, NB, NT (Format F8.3, 4I4), where

OABFL(N) is an identification flag, where 1.0 = hotleg (obstacle), 2.0 = A (ECC inlet) port, or 3.0 = B (broken cold leg) port.

NL, NR, NB, and NT are four dimensions (see Fig. 6), specified in integers, that locate the obstacle, A or B port in the mesh. Thus, NL and NB specify how many cells in from the left boundary and up from the bottom boundary to locate the lower left corner of the region, and NR and NT similarly locate the upper right corner.

Each of these lines is processed individually, and the dimension statement allows any combination of obstacle, A and B ports, up to 16. In the typical example of a downcomer, we use NOAB = 8 for a situation involving four hot-leg obstacles, three A (inlet) ports, and one B (broken cold leg) port.

This completes the discussion of the input data cards. We see that an input deck consists of at least (10 + NOAB) lines. The final line normally placed at the end of the input file is in reality the first line for the next problem. The first quantity on Card No. 1 is IBAR, which determines the action to be taken by KTIF. If IBAR > 0, it is valid for use as $\overline{I}$, and SETUP is called. The value IBAR = 0 indicates a restart and IBAR < 0 indicates that the end of data has been reached. Thus, a negative IBAR card is the appropriate way to terminate the input file, and hence, the job.

D. Output - Plots, Prints, and Motion Pictures

The K-TIF output is in two forms, visual information on microfiche, 35-mm microfilm, or 16-mm motion-picture film and printed information on microfiche, microfilm, or fanfold paper. Both

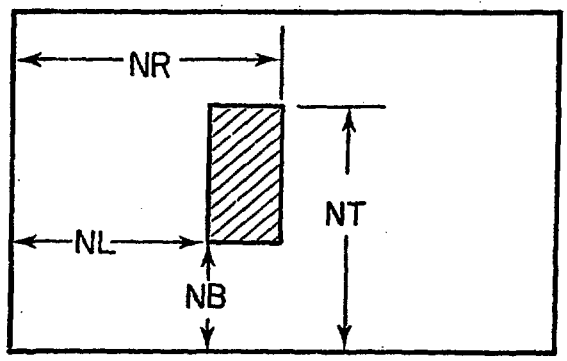

Fig. 6. Four dimensions locate an obstacle, A or B port in K-TIF.

forms are provided automatically in cycles 0 and 1, and thereafter at intervals specified by DTO and DTOC in the input data. The microfiche (or microfilm) plots are generally the most useful output and are made on the III FR-80 or the S-C 4020 computer output microfilm devices. Eleven plots are provided, four vector plots and seven contour plots. The first pair of vector plots are simply velocity vectors for each field. They are useful because they show at a glance both the direction of flow and the relative magnitude of the velocities. They are provided separately for both the water and the steam. Vectors are plotted as if originating at each cell center (denoted by a +), and their length and direction are proportional to the velocity components. If (x_1, y_1) are the coordinates of the center of cell (i,j), the coordinates of the vector end points (x_2, y_2) are given by

$$x_2 = x_1 + \left(\frac{u^j_{i+\frac{1}{2}} + u^j_{i-\frac{1}{2}}}{2}\right) \text{DXOU} \quad ,$$

and

$$y_2 = y_1 + \left(\frac{v^{j+\frac{1}{2}}_i + v^{j-\frac{1}{2}}_i}{2}\right) \text{DXOU} \quad ,$$

where u and v refer either to (u_1 and v_1) or (u_2 and v_2) and DXOU is a scaling coefficient defined as

$$\text{DXOU} = \delta x/\text{VEL}_{max} \ .$$

This coefficient is recalculated for each individual vector plot. It scales the length of a vector drawn for the largest $|u|$ or $|v|$ velocity in the system at that instant, VEL_{max}, to be the cell dimension δx. This method ensures that the vectors are always of reasonable length, regardless of velocity magnitudes. The plot is omitted if there are no significant velocities $\left(\text{VEL}_{max} < 10^{-10}\right)$ in a particular field.

The second pair of vector plots are velocities multiplied by the local θ of the field. These are generally more meaningful plots than velocities alone, because vectors of significant lengths occur only where appreciable volumes of water or steam are moving.

Contour plots are provided for the arrays θ_1, θ_2, p, K, T_1, the conduction depth, γ, and the size scale, r. These plots have connected vector segments joining points of equal value and are linear in contour increment.

In addition to the various plots, three different types of numerical listed data are provided.

The "long print" is a complete numerical listing of the principal field variables over the entire mesh. Two lines containing i and j and 16 field quantities are given for each cell:

$$i,\ j,\ (\theta_1)_i^j,\ (u_1)_{i+\frac{1}{2}}^j,\ (v_1)_i^{j+\frac{1}{2}},\ (r_1)_i^j,\ (S_1)_i^j,\ (T_1)_i^j,\ K_i^j,\ p_i^j,$$

$$(\theta_2)_i^j,\ (u_2)_{i+\frac{1}{2}}^j,\ (v_2)_i^{j+\frac{1}{2}},\ (r_2)_i^j,\ (S_2)_i^j,\ (\gamma)_i^j,\ \tilde{D}_i^j,\ J_i^j\ .$$

The "short print" is a two-line listing containing sums over the mesh, for each field separately, of volume fraction and internal, kinetic, and total energy. This print is provided as an appendage to every long print.

The above plots and prints are provided by subroutine PLTPRTS. In addition, CONTROL provides the one-line monitor print mentioned for input quantities MPR and MOD59. This is provided (on film if LPR is greater than zero, and on the printer if MPR is greater than zero) every even-numbered cycle, and contains the following 10 quantities.

T is the current problem time in seconds.

NCYC is the current cycle number.

DT is the current δt.

NUMIT is the number of iterations required for convergence in the preceding Phase-2 pressure iteration.

SMDTAU = $\Sigma\delta x\delta y\tilde{D}$ over the mesh.

STAUB1 = $\Sigma\delta x\delta y S_{B1}$ over the B cell(s).

STAUB2 = $\Sigma\delta x\delta y S_{B2}$ over the B cell(s).

FP is the total volumetric rate change due to phase transitions.

GLP is the current number of gallons of water in the lower plenum, $= \sum_{LP} \theta_1 \, \delta x\delta y s$, converted from cubic inches to gallons.

FB2 = F_{B2}, the current volumetric flow rate of steam entering the system.

Every MOD59 (usually 200) cycles, a subset of the above quantities is provided on the remote terminal; this includes T, NCYC, NUMIT, DT, SMDTAU, FP, and GLP.

E. Restart Dumps

Dumps for restarting a calculation are written out as file 8 (TAPE8) in CONTROL under direction of TLIMD and TWFIN, which are defined in Sec. II.C. The variables dumped are the contents of the SCM commons KC1, KC2, and KCS. The restart from this data is performed by reading this data back as file 7 (TAPE7). The input file consists of one data line, with IBAR = 0, and JBAR = the dump number, used as a check.

F. LTSS Remote Terminal Operation: DROP and UNDROP

In the LTSS operating system, the executing program is rolled out from memory to disk many times before it completes execution. The copy on the disk is called the drop file. Ordinarily, the drop file name would be the same as the name of the original compiled program, and thus the drop file would occupy the same physical disk space as the original program. As a result, the original file would be overwritten continually with the current image of the executing program. There is nothing wrong with this procedure unless one wishes to preserve the original compiled program so that it can be executed repeatedly with

different input data. This preservation is done in KTIF by telling LTSS to drop the executing program to a disk file other than the original one before the first rollout of the program. We accomplish this with a call to the library routine UNQCHG, the first executable statement in KTIF, which causes a duplicate of the original file to be written. This file becomes the executing drop file and is given a unique name change from the original file, consisting of a prefix + and a random A-Z alphabetic suffix.

After the CALL UNQCHG, KTIF next ensures that an input file is available for the job by performing a CALL INSIST (see Sec. II.H). KTIF then calls one of its own subroutines, UNDROP, which contains a series of LTSS library system-interface routines (described in Sec. II.H) that create output and film files required by the run. With the return from UNDROP, the problem is set to proceed.

The restart data dump described in the previous section is primarily intended for use by the Deferred Batch System (DBS), in which a queue of long-running production jobs are run by the computer-room staff on evenings, nights, and weekends.

The K-TIF user can run the code from a remote terminal in the same fashion, but may often find it more convenient to start and stop the run by controlling the drop file as a unit. For this purpose, a short KTIF subroutine named DROP is provided, along with a variable flag (in the common block) named IDROP, which normally has a value of 0. To halt (DROP) the program, the user resets IDROP to 1 from the remote terminal. CONTROL notes this change and performs a CALL DROP, which in turn calls several system interface routines to close job files (see Sec. II.H) and comes to a PAUSE. At this point, the drop file may be saved for later continuation of the run, and film and output files may be given to the system for processing.

To subsequently "undrop" or continue the run from the PAUSE state, the user restarts the drop file, giving an extra carriage return to move from the PAUSE. Control thus returns to subroutine CONTROL, from which a call is immediately made to UNDROP to create output files for the new run. UNDROP returns to CONTROL, the IDROP flag is reset to 0 and the run proceeds.

To avoid unnecessary confusion in the introductory discussion of the K-TIF program structure in Sec. II.A, we purposely omitted subroutines UNDROP and DROP from the general flow diagram of Fig. 4.

G. Microfilm Plots - Scaling and Subroutine CALLs

The microfilm plots discussed in Sec. II.D are the most useful form of output from our fluid dynamics codes because they quickly convey information about a flow process that would be less readily grasped by examining only numerical listings.

Our original Computer Output Microfilm (COM) device is the S-C 4020, which has a matrix of 1024 by 1024 raster points on the CRT face, as shown in Fig. 7. Usefulness of the 4020 has been increased by adding a set of three color filters between the tube face and the camera, individually movable under control commands. The III FR-80 COM device has a resolvable matrix of 10K by 10K points, which allows more accurate plotting, and is also a programmable computer in its own right. For our relatively simple plots, whatever COM is assigned to our offline film output is treated as a 4020. The FR-80 becomes a 4020 simulator when used in this manner. Therefore, the following description of our plot scaling is based on the 4020 film frame of Fig. 7.

Note from Fig. 7 that the origin of the x-y coordinate system lies at the upper left corner of the frame and the values of the two integer indexes increase to the right and down. This coordinate system obviously does not match that of the fluid dynamics computing mesh shown in Figs. 1 and 5, where the origin is at

the lower left corner. A conversion from physical mesh position to a corresponding 4020 frame position is required for all plotting. In K-TIF, the left, bottom, right, and top edges of the physical mesh are specified by

$$XL = YB = 0.0,$$

$$XR = \bar{I}\delta x,$$

$$YT = \bar{J}\delta y,$$

and their counterparts in 4020 coordinates are given by the integers IXL, IYB, IXR, and IYT, calculated in accordance with the following considerations. First we reserve areas across the top and bottom of the frame for plot identification, problem time, cycle number, and so forth. These are indicated by the shaded areas in Fig. 8. (The technique for generating alphanumeric information in these regions is discussed below.) The unshaded area that remains is 1024 points wide by 900 points high, although we consider the available width to be 1022 points to ensure frame separation. Second, within this rectangular region, we maximize the size of the plot, while maintaining its true physical proportion of height to width. Thus, if the physical area encompassed by the computing mesh is higher than it is wide, $XR < YT$, the resulting plot occupies the region exemplified by the fine shading in Fig. 9. The coordinates in this case are given by

$$FIXL = 511. - 450. \left(\frac{XR}{YT - YB}\right),$$

$$FIXR = 511. + 450. \left(\frac{XR}{YT - YB}\right),$$

$$FIYB = 916.,$$

and

$$FIYT = 16.$$

Conversely, if the computing area is wider than it is high, XR > YT, the plot occupies the region exemplified by the fine shading in Fig. 10. Here the coordinates are given by

$$FIXL = 0. \quad ,$$

$$FIXR = 1022. \quad ,$$

$$FIYB = 916. \quad ,$$

and

$$FIYT = 916. - 1022. \left(\frac{YT - YB}{XR}\right) \quad .$$

In either case, the equivalent integers IXL, IXR, IYB, and IYT are then simply set directly from FIXL, FIXR, FIYB, and FIYT. The "Setup for Microfiche-Microfilm Plots" in SETUP calculates these eight quantities and then calculates the two conversion factors that will be required for translating physical mesh coordinates to 4020 frame coordinates. These are given by the ratios

$$XCONV = (FIXR - FIXL)/(XR - XL)$$

and

$$YCONV = (FIYT - FIYB)/(YT - YB) \quad .$$

A physical mesh coordinate is multiplied by the appropriate factor to convert it, and this product is then added to FIXL or FIYB and the sum is converted to an integer to locate the position on the 4020 frame of Fig. 7. A conversion subroutine is available that would handle this task for us, but it is more efficient for K-TIF to do it, thus avoiding recalculation of these two ratios whenever a point is plotted or a vector segment is drawn.

A set of software subroutines provided by C Division (Computer Sciences and Services) of the Los Alamos Scientific Laboratory handles the communication be-

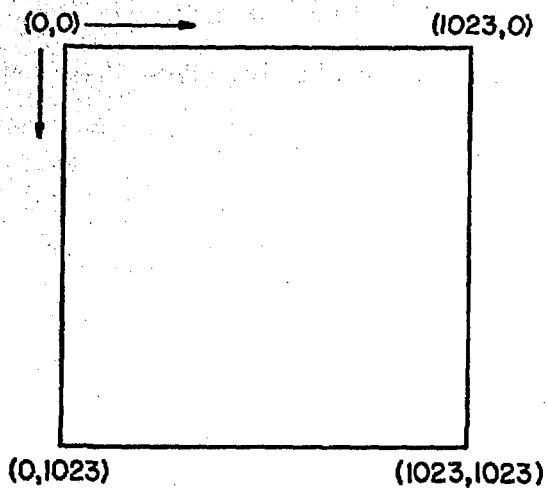

Fig. 7. The 4020 grid is a reflection of the first quadrant and contains a matrix of 1024 by 1024 raster points, with the origin located at the upper left corner. x increases to the right, and y increases downward.

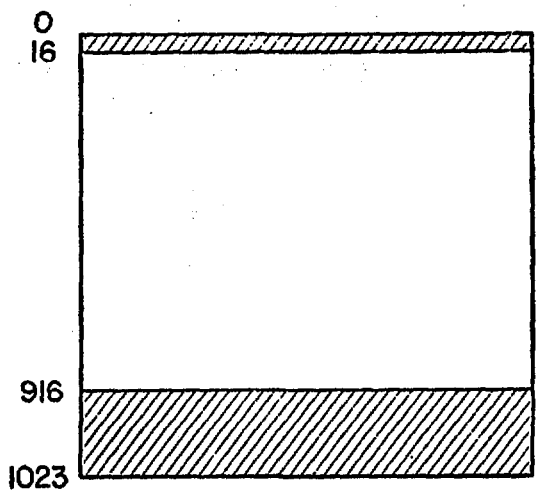

Fig. 8. The area in the center, available for plotting, encompasses 1024 by 900 raster points. The shaded areas are reserved for labeling, allowing two lines at the top and six at the bottom.

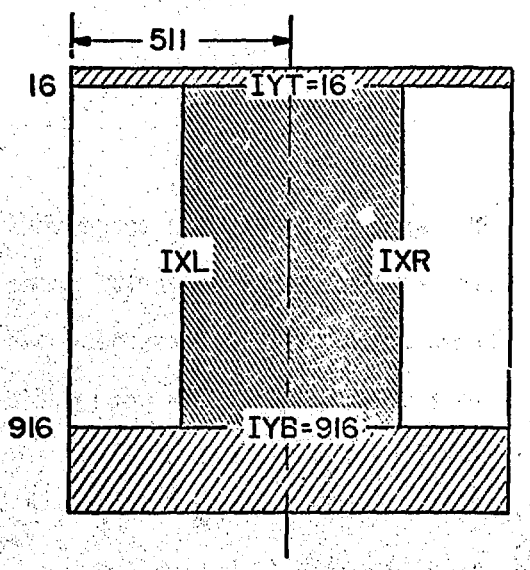

Fig. 9. The plotting area when the computing mesh is higher than it is wide, XR < YT.

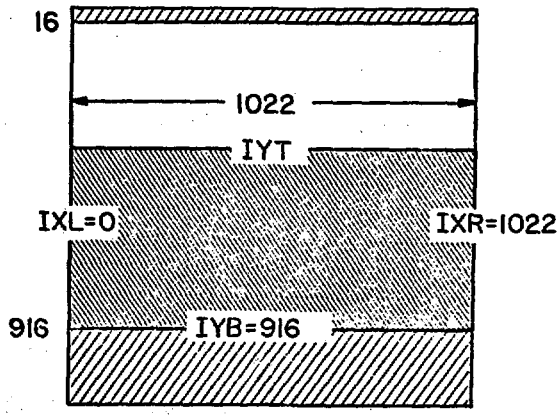

Fig. 10. The plotting area when the computing mesh is wider than it is high, XR > YT.

tween the problem program and the COM devices by producing 4020-format commands. K-TIF uses several of these subroutines, which are accessed by the following FORTRAN calling sequences.

CALL ADV (nf) advances the film by nf frames.

CALL FRAME (IXL, IXR, IYB, IYT) draws a rectangular outline of the computing mesh. Two horizontal axes are drawn through IYT and IYB from IXL to IXR, and two vertical axes are drawn through IXL and IXR from IYT to IYB.

CALL PLT (IX, IY, ch) plots the 4020 character identified by ch at 4020 frame coordinates (IX, IY).

CALL DRV (IX1, IY1, IX2, IY2) draws a straight line vector segment connecting the 4020 point (IX1, IY1) with the 4020 point (IX2, IY2).

CALL COLOR (c) controls the filter selection for color processing; c is a floating-point variable with a value in the range 0.0 to 4.0. Single-filter selections are determined as follows.

c = 0.0 no filter (white),

c = 1.5 yellow filter,

c = 2.5 cyan filter,

c = 3.5 magenta filter.

The primary colors are obtained by appropriate filter combinations.

c = 1.0 red (= yellow + magenta),

c = 2.0 green (= yellow + cyan),

c = 3.0 blue (= cyan + magenta).

Several additional subroutines are available for writing alphanumeric information on the frame. Whereas some of these write large characters composed of dot patterns or vector segments, the basic CRT tube has a set of small alpha-

numeric characters that can be generated in the "typewriter" command mode. The latter form is used in K-TIF. In typewriter mode, the 4020 frame of Fig. 7 is composed of 64 lines of 128 characters each. The lines are numbered 0-63, but only 2-61 are accessible. Each character occupies a rectangular region 8 raster points wide by 16 high. The first character of a line is treated as a carriage control, completely analogous to line printer use.

CALL LINCNT (ℓ) locates the first column of line ℓ, where ℓ ranges from 2 (topmost accessible line of the frame) through 61 (bottommost accessible line of frame). After LINCNT locates the desired starting line position, ordinary formatted WRITE statements generate the actual alphanumeric information. The FORMAT statements are identical to those appropriate for a line printer provided the 128-character-per-line restriction is observed. Line advancement is automatic, as on a line printer, until either line 61 has been written on, after which the film is advanced automatically to the top of the next frame, or another CALL LINCNT is issued to specify any desired line (2-61) of the current frame.

H. Miscellaneous System Library Subroutine CALLs

In addition to the CALLs directly related to the microfilm plots described in the previous section, K-TIF also calls various other library subroutines for interfacing with the LTSS system. Inasmuch as these routines are entirely system dependent, a brief description here should suffice.

CALL UNQCHG changes the name of a drop file to a unique name (see Sec. II.F).

CALL INSIST (ifile, irep) determines whether a required file exists. If it does not, it will give the user an opportunity to correct the oversight. Here, ifile is the name of the file, and irep is re-

turned as -1 if the file exists. (Without the CALL INSIST, the job would have been given an error termination by LTSS upon the first attempt to access the nonexistent file.)

CALL DATEH (idate) returns the date as a Hollerith constant of the form MM/DD/YY.

CALL TIMEH (itime) returns the time as a Hollerith constant of the form HH MM SS.

CALL SECOND (time) returns the current amount of time in seconds used by the job since its beginning.

CALL GETJTL (tl) returns the job time limit in seconds.

CALL CFL (ifile, length) creates a file of specified length.

CALL ASSIGN (ℓ, i, name, ldf, locbuf, lbuf) connects a logical I/O unit number (ℓ) with a tape, file, or other device, (name), identified by i. A value of i=0 specifies that name refers to a disk file of length ldf. In K-TIF subroutine UNDROP, the CALL CFL has already created the disk file and specified its length; ldf=0 is a signal to open this disk file. Finally, locbuf is the first word address of a previously dimensioned buffer to be associated with the disk file, and lbuf is the length of this buffer.

FILM80, IDENT80, and HEAD80 are required routines:

CALL FILM80 sets up system linkage to two routines for processing formatted WRITEs and job termination, and sets common storage for the film routines. FILM80 has no arguments.

CALL IDENT80 (ifsn, buf, nwbuf, nwdisk, icam, ifilm) identifies an integer file number ifsn as an FR-80 film file and supplies other necessary file variables: buf is the name of the LCM buffer for film data storage, nwbuf is the number of words in this buffer,

nwdisk is the number of words reserved in the disk buffer, icam is the camera to be used to process the film, where the available options are 16 (16 mm), 0 or 35 (35 mm), and 105 (105 mm microfiche), and ifilm is the film type, where 0 is black and white and 1RC is color.

CALL HEAD80 (ifsn, nc, char, nbox) puts out header information for the specified film file number ifsn (previously identified by IDENT80), nc is the number of characters (60 maximum), char specifies the characters, and nbox is the film user identification, of the form 10HBOXaaaaaaa.

CALL KEEPFLM (ifilm) indicates that the file ifilm is not to be given to the system. It may be called anytime before the release of film file information. Its purpose in K-TIF is to retain a copy of the file available for scanning under LTSS at a Tektronix terminal.

CALL EXIT terminates the code. The user should be aware that a drop file will remain in user file space <u>only</u> if a CALL EXIT(n) is used to terminate the code, where n is a nonzero integer. This latter form is recommended for use in debugging, but does not appear in the K-TIF version of this report because it always gives an "ABNORMAL TERMINATION" message to the operator, which may be misleading.

CALL EMPTY (ifile) ensures that all data is flushed from the buffer for the output unit specified by ifile.

CALL DEVICE (iopt, ifile) is used to open (iopt = 4HOPEN) or close (iopt = 5HCLOSE) the file of the name specified by file.

I. The Common Blocks KC1 and KC2

The following list provides the names and descriptions of all quantities in the SCM common blocks KC1 and KC2. These common blocks, along with the cell-data storage common KCS, allow communication among all the subroutines that comprise the code. By design, these commons contain all the information that must be maintained from cycle to cycle, and comprise the information saved in the restart dump.

NAME	DESCRIPTION
AA(1)	Dummy word, always the first word in common.
ACELL	Flag for A (ECC inlet) cell.
BCELL	Flag for B (broken cold leg) cell.
BIGJL	J_L, the phase transition coefficient.
BLAMZ	$\overline{\lambda}_0$, a function of δt used in the $(\theta_1 + \theta_2 \rightarrow 1)$ correction.
B2	Specific heat of steam, in cal/(lb kelvins).
CAPPAW	κ_w, thermometric conductivity of the wall (= 0.028 in^2/sec for iron).
CAPPAZ	κ_0, $= k_w/\rho_1 b_1$.
CCELL	Flag for a C (steam insertion) cell.
CD	C_D, the drag coefficient.
CD04	$C_D/4$, for use in the K equation.
CNUSX(2)	$\nu_s/\delta x^2$ for each field.
CNUSY(2)	$\nu_s/\delta y^2$ for each field.
CUIN2GL	Conversion factor from $in.^3$ to gallons.
C1	The hrs/min/sec on the wall clock when the job began. Printed with D1.
DT	δt, the time step, subject to automatic recalculation.
DTEST	The comparand for $\tilde{D}$ convergence.
DTF	δt_f, a factor to control the automatic calculation of ν_s and δt.
DTMAX	δt_{max}, the upper limit on δt.
DTO(10)	Problem time interval between full output of plots and prints, used with DTOC.
DTOC(10)	Problem time at which to change to next DTO in the set.
DTODX	$\delta t/\delta x$.

DTODY	$\delta t/\delta y$.
DTPOS	δt possible for the cycle, but actual δt may be reduced to adjust to output time.
DTSIG	δt_σ, the upper limit on δt for the σ_i^j specified.
DTUVEL	Maximum $\|u\|$ in the system, for automatic δt calculation.
DTVVEL	Maximum $\|v\|$ in the system, for automatic δt calculation.
DX	δx, the cell size in the azimuthal direction.
DXDY	$\delta x * \delta y$.
DXO2	$\delta x/2$.
DY	δy, the cell size in the axial direction.
DYO2	$\delta y/2$.
D1	The month/day/year when the job began; printed with C1.
ELSUBL	L_L, $= L/(\rho_1 b_1)$, where L is the latent heat of vaporization and b_1 is the specific heat of water.
EPP	ε_p, a small fraction of the mean dynamical pressure in the system.
EPSD	ε_D, the convergence criterion for the pressure iteration.
EPSTH	ε_θ, the convergence criterion for the $(\theta_1 + \theta_2 \rightarrow 1)$ correction.
FB2	F_{B2}, the total steam volume per unit time per gap width entering the system.
FB2BAS	Base for converting J^*_{gc} to F_{B2}.
FB2COF	$F_{B2}/(\delta x \delta y)$, used in steam distribution to C cells.
FIXL	Floating-point frame coordinate for left edge of plots.
FIXR	Floating-point frame coordinate for right edge of plots.
FIYB	Floating-point frame coordinate for bottom edge of plots.
FIYT	Floating-point frame coordinate for top edge of plots.
FP	Total volumetric change rate due to phase transitions.
G	g, gravity, in in./sec^2.

GDT	$g * \delta t$.
HCKW	k_w, the wall heat conduction coefficient, cal/(in kelvins sec).
HFCRIT	The critical heat flux (CHF), cal/(in.^{2} sec).
HFC1	Heat flux coefficient, = MHF/(s $\rho_1 b_1$).
HFMIN	The minimum heat flux (MHF), cal/(in.^{2} sec).
IBAR	$\bar{I}$, the number of interior cells in the x direction.
IDROP	Flag used for job control in time-sharing operating system.
IDTCUT	Flag indicating δt cut due to excessive flux at broken leg.
IDTO	Index for DTO and DTOC tables.
IJ	Index for cell (i,j), required for SUBROUTINE FASE.
IPERT	Index I of column containing A cell furthest from broken cold leg, for velocity perturbation.
IP1	$\bar{I}$+1, index of rightmost column of interior cells.
IP2	$\bar{I}$+2, index of column of exterior cells on the right.
IVB(16)	Integer frame coordinate for bottom edge of A and B ports and obstacles.
IVL(16)	Integer frame coordinate for left edge of A and B ports and obstacles.
IVR(16)	Integer frame coordinate for right edge of A and B ports and obstacles.
IVT(16)	Integer frame coordinate for top edge of A and B ports and obstacles.
IXL	Integer frame coordinate for left edge of plots.
IXR	Integer frame coordinate for right edge of plots.
IYB	Integer frame coordinate for bottom edge of plots.
IYT	Integer frame coordinate for top edge of plots.
JBAR	$\bar{J}$, the number of interior cells in the y direction.

JFSTAR	$J^*_{f,in}$, a dimensionless measure of the ECC flux.
JGSTAR	J^*_{gc}, a dimensionless measure of the variable steam flux.
JNM	Job name identifier of code name and operating system used.
JP1	$\bar{J}+1$, index of the topmost row of interior cells.
JP2	$\bar{J}+2$, index of row of exterior cells along the top.
JTOPLP	Height of the lower plenum, an integer number of cells.
JVECLP	Integer frame coordinate for top of lower plenum.
LPR	Determines output options on film and printer.
MAXIT	Maximum number of $\tilde{D}$ and $\check{\theta}$ iterations allowed.
MOD59	Number of cycles between monitor lines printed on remote terminal.
MPR	Controls writing of monitor line to the printer file.
MU(2)	μ, optional viscosity coefficient for each field.
MUCOF	$9\mu_1\mu_2/[2(\mu_1 + \mu_2)]$, the viscous term in the K equation.
MUSTID	Number of cells failing the $\tilde{D}$ convergence test.
MUSTIT	Number of cells failing the $\check{\theta}$ correction convergence test.
MX(2)	M_x, a function of J in the $(\overline{\theta u})$ equation for each field.
MY(2)	M_y, a function of J in the $(\overline{\theta v})$ equation for each field.
NAME(8)	Problem identification from column 2-80 of input line No. 2.
NCDBUG	For debugging; cycle at which to commence full output of plots and prints every cycle.
NCS	Number of words in the cell-data storage block.
NCYC	Number of calculation cycles completed.
NCYKIL	Number of consecutive cycles allowed at MAXIT cutoff before aborting.
NCYMAX	Counts consecutive cycles in which NUMIT = MAXIT.
NDTZ	Number of cycles at δt_0, after which δt is recalculated each cycle.

NOAB	Combined number of obstacles, A ports, and B ports.
NQ	Number of quantities, or storage words, per cell.
NQI	NQ*IP2, the number of words for one full row of cells.
NSC	Number of words in this SCM common, for use by dump.
NTAB	Number of entries per table for TABJG, TABP, and TABT.
NUMIT	Number of iterations required for pressure convergence.
NUMTD	Number of the next dump.
NUS(2)	ν_s, kinematic viscosity coefficient for each field.
OABFL(16)	Table that accumulates flags identifying obstacles, A ports or B port in the input.
OCELL	Flag for obstacle (hot-leg) cell.
OM	ω, the pressure iteration relaxation coefficient.
RDT	$1/\delta t$.
RDX	$1/\delta x$.
RDXDY	$1/(\delta x*\delta y)$.
RDXSQ	$1/\delta x^2$.
RDY	$1/\delta y$.
RDYSQ	$1/\delta y^2$.
RHO(2)	ρ, microscopic material density, lbs/in.^{3}, for each field.
RHO1B1	$\rho_1 b_1$, cal/(in.^{3} kelvins).
RHO2COF	Coefficient used to recalculate ρ_2 every cycle.
RRHO(2)	$1/\rho$, for each field.
RS	$1/s$.
RTSATK	$1/T_s$ (kelvins).
R14PT7	1/14.7, for conversion of psia to T_s.
R2DX	$1/(2\delta x)$.
R2DY	$1/(2\delta y)$.

S	s, gap width of the downcomer, to match a particular experiment.
SA1EACL	The inlet volumetric flow of water (S_{A1}) in each A cell.
SIGIJ	σ, the turbulent diffusion coefficient.
SIGPR	σ'.
SMDTAU	$\sum \delta x \delta y \tilde{D}$ over the mesh, included in the monitor print.
SP2COF	Coefficient for S_{p2} calculation, = $({}^{n+1}\rho_2 - {}^{n}\rho_2)/({}^{n+1}\rho_2 \delta t)$.
T	t, the problem time in seconds.
TABJG(20)	Table of J^*_{gc} values, from experimental data.
TABP(20)	Table of pressure in units of psia values, from experimental data.
TABT(20)	Table of t values, at specified experimental measurement times.
TECCF	T_{ECC} (°F).
TECCK	T_{ECC} (kelvins).
THMIN	Minimum allowable value for any ${}^{n}\theta_1$ or ${}^{n}\theta_2$.
TLIM	Job time limit in seconds; used with TLIMD.
TLIMD	= 1.0 to force a tape dump immediately before time limit.
TOUT	The next problem output time for plots/prints.
TSATK	Saturation temperature, T_s, in kelvins.
TWFIN	Time when to finish: calculation completed when t > TWFIN.
TWINF	Temperature of wall interior, $T_{w,in}$, in °F.
TWINK	Temperature of wall interior, $T_{w,in}$, in kelvins.
VOLFAC	Cell volume factor, = $\delta x \delta y s$.
WE	We, the Weber number used in r_1 and r_2 calculation, or the constant value of r_1 and r_2 if We < 1.0.
XCONV	Plotting factor, converts x's from problem units to COM units.
XI(18)	Table of x's at the center of each column in the mesh.
XL	= 0.0, the left edge of the mesh.

XR	= $\bar{I}*\delta x$, the right edge of the mesh. XR should equal the average annulus circumference of the experimental geometry.
YB	= 0.0, the bottom edge of the mesh.
YCONV	Plotting factor, converts y's from problem units to COM units.
YJ(24)	Table of y's at the center of each row in the mesh.
YT	= $\bar{J}*\delta y$, the top edge of the mesh.
ZLP	The z used in the T_1 equation for the lower plenum region.
ZZ	Dummy word, always the final word in the common.

III. K-TIF CALCULATIONS

A. Examples

We illustrate the type of downcomer calculations that can be performed by K-TIF by means of examples for three different circumstances.

1. Standard resolution without wall superheat,
2. Coarse resolution without wall superheat,
3. Coarse resolution with wall superheat.

These examples show a few of the results obtained with our simplest models for interfacial friction and phase-transition rate. More realistic models being investigated by Daly will be described in a future publication.[8] In particular, Daly's studies include a variable-scale model for interfacial friction based on the specification of constant Weber number. For the convenience of other investigators, this option is included in the code version described in this report, but our examples are all based on a constant-scale model.

Example 1. Standard Resolution Without Wall Superheat

This calculation is based on the configuration of Fig. 1, with 16 computational cells across the mesh, so that each A and B cold-leg and hot-leg obstacle (X) is formed of one cell, with one cell in between. Initial and input conditions (in Table I) represent experiment number H1 of Ref. 1, in which both steam flow rate and pressure vary with time. Some selected flow-configuration plots are shown in Figs. 11-15. In each figure, we present four plots at a given instant of time. The top pair are vector plots of $(\theta\vec{u})_1$ and $(\theta\vec{u})_2$ and the lower pair are contours of θ_2 and T_1. The generation of these plots is described in Sec. II.D. The time history for the amount of water in the lower plenum is compared with the experimentally observed result in Fig. 16.

Example 2. Coarse Resolution Without Wall Superheat

To illustrate K-TIF's capability for performing relatively fast-running

TABLE I

EXPERIMENTAL DATA AND K-TIF INPUT FOR EXAMPLE 1

Creare Experiment H1, using 1/15-scale cylindrical vessel:

Scaled-plenum geometry:

Intact cold legs	3
Hot legs	4
Cold-leg diameter (i.d.)	1.875 in.
Hot-leg diameter (o.d.)	3.00 in.
Downcomer gap	0.5 in.
Downcomer length (below cold leg ℄)	18 in.
Vessel length	29.75 in.
Lower plenum radius	5.75 in.
Average annulus circumference	34.6 in.
Capacity of lower plenum	2 gal

ECC water supply:

Temperature	81.5°F
Flow rate per cold leg	20 gpm
Total flow rate	60 gpm
Equivalent $J^*_{f,in}$	0.116

Transient steam flow data:

Time (sec)	Pressure (psia)	J^*_{gc}
0	27.9	0.309
0.8	26.3	0.317
0.9	27.3	0.320
2.1	24.0	0.339
2.9	20.5	0.262
3.3	17.1	0.229
4.4	14.3	0.149
5.7	13.3	0.08
7.3	10.8	0.058
9.1	11.6	0.02
10	12.3	0

TABLE I (cont.)

K-TIF Standard-Resolution Calculation of Creare Experiment H1:

Geometry:

Mesh width (= average annulus circumference)	34.6 in.
No. of cells in azimuthal direction ($\bar{I}$)	16
Cell size in azimuthal direction (δx)	2.1625 in.
Downcomer length (below cold leg ℄)	18.38125 in.
Total Number of cells in axial direction	22
Number of lower plenum cells in axial direction (JTOPLP)	12
Cell size in axial direction (δy)	2.1625 in.
Capacity of lower plenum	1.94344 gal

Miscellaneous constants:

Constant-scale value for interfacial friction (r_1 and r_2)	0.06 in.
Phase-transition coefficient (J_L)	-0.16
Wall interior temperature ($T_{w,in}$, = initial T_s)	244.3°F
Initial time step (δt_o)	5×10^{-5} sec
Maximum time step (δt_{max})	5×10^{-4} sec
Drag coefficient (C_D)	1.0
Viscosity coefficients (μ_1 and μ_2)	0.0
Turbulent diffusion coefficient (σ)	0.2
Critical heat flux (CHF)	10^{10}

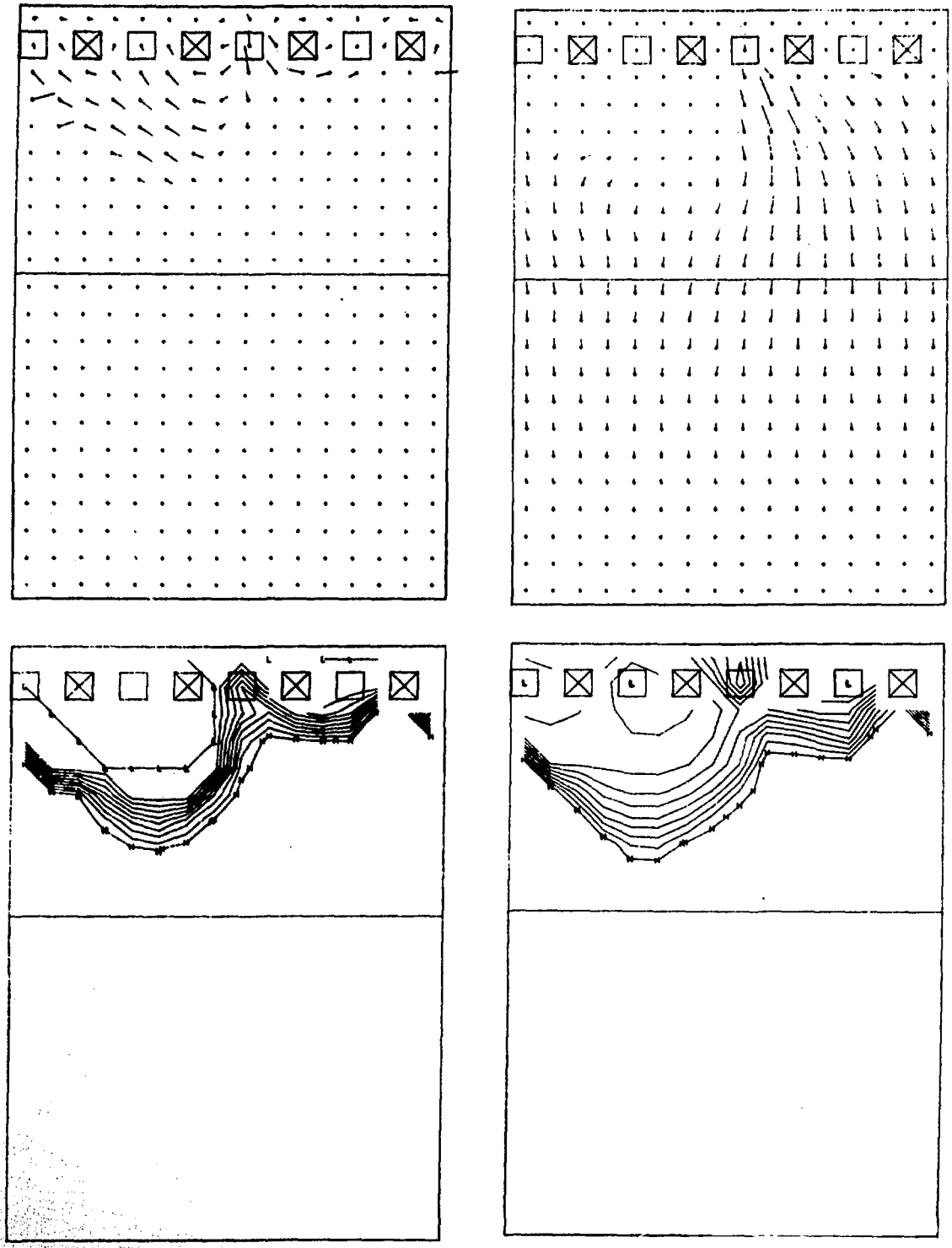

Fig. 11. K-TIF standard-resolution example at time t = 5.4 sec.

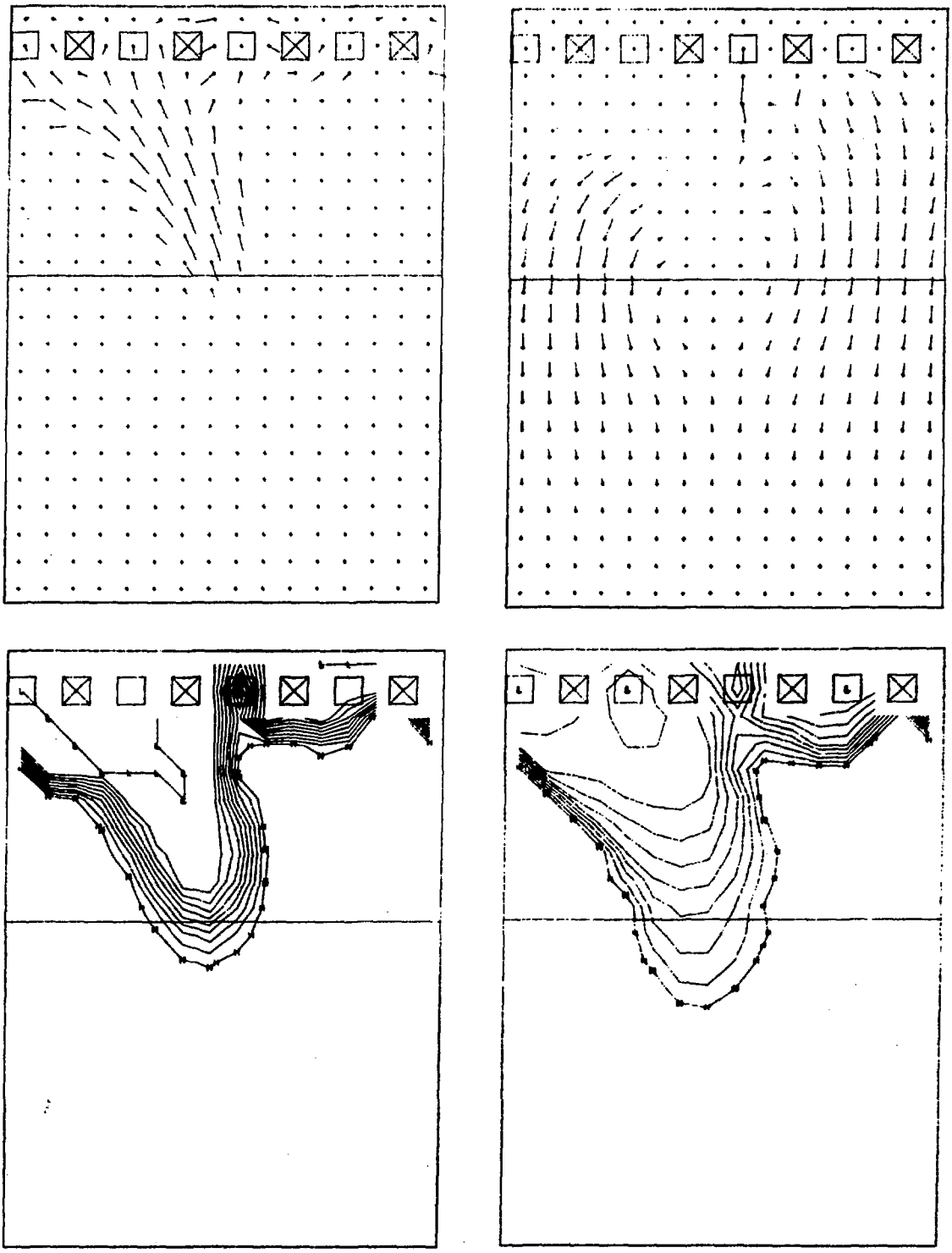

Fig. 12. K-TIF standard-resolution example at time t = 5.6 sec.

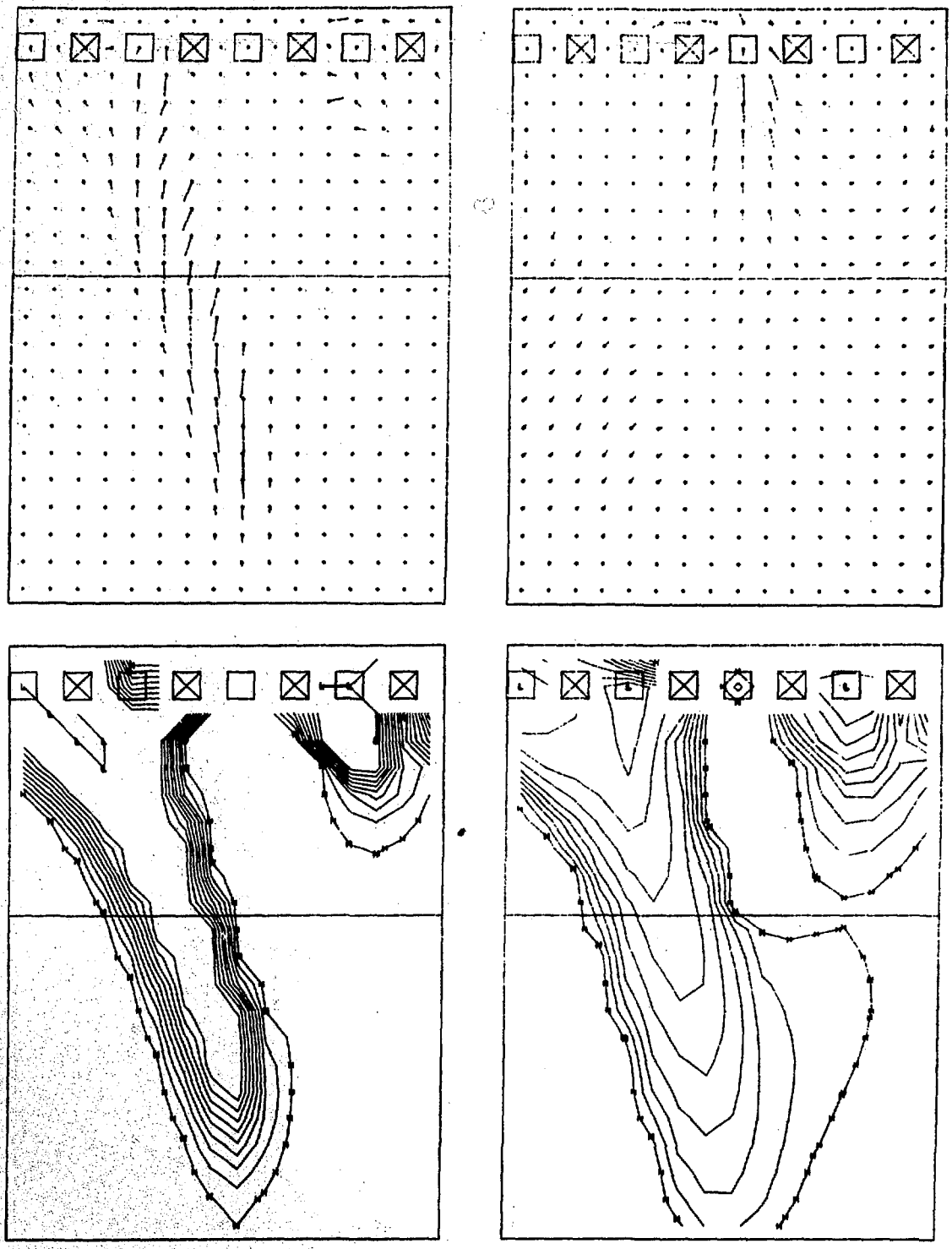

Fig. 13. K-TIF standard-resolution example at time t = 5.8 sec.

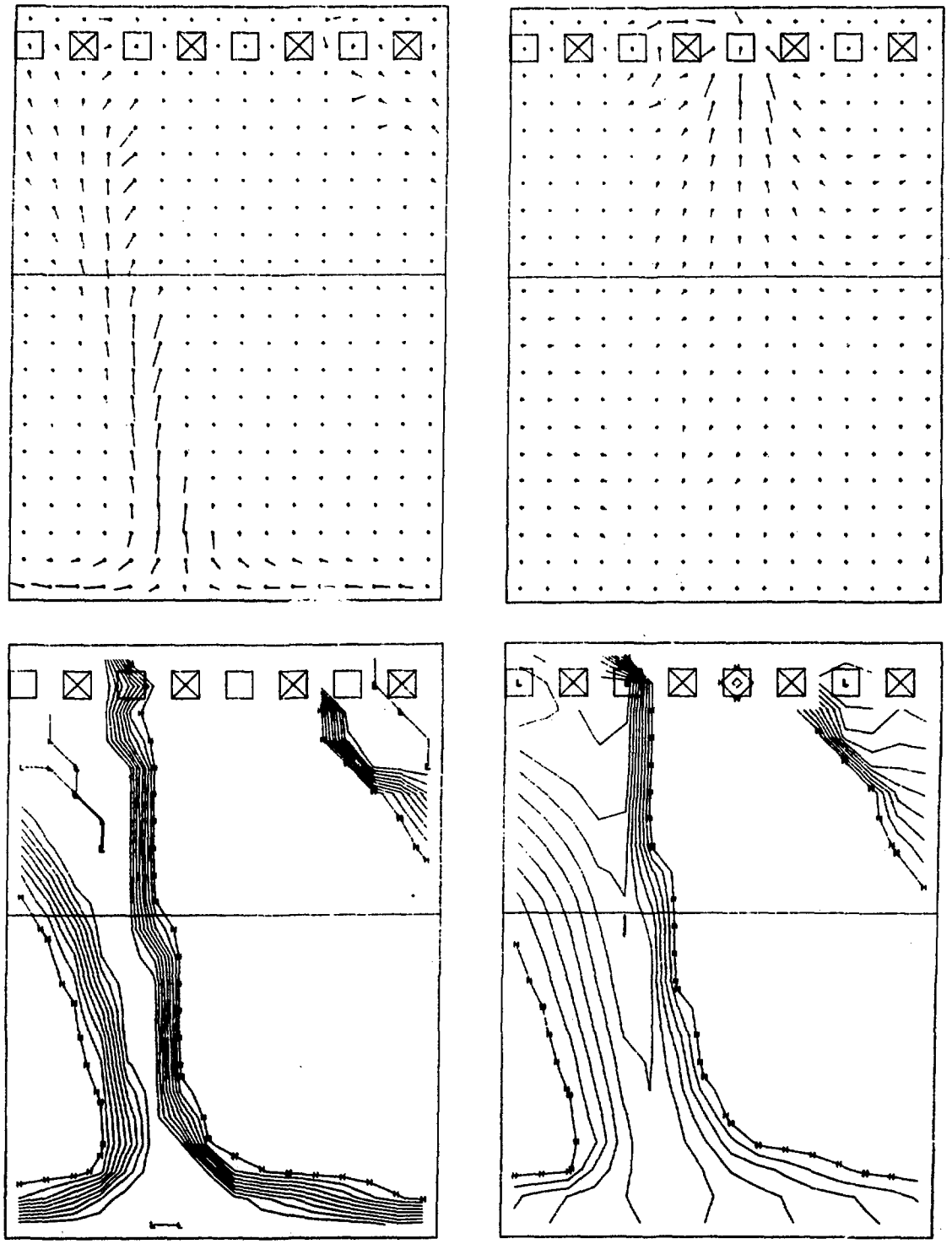

Fig. 14. K-TIF standard-resolution example at time t = 6.0 sec.

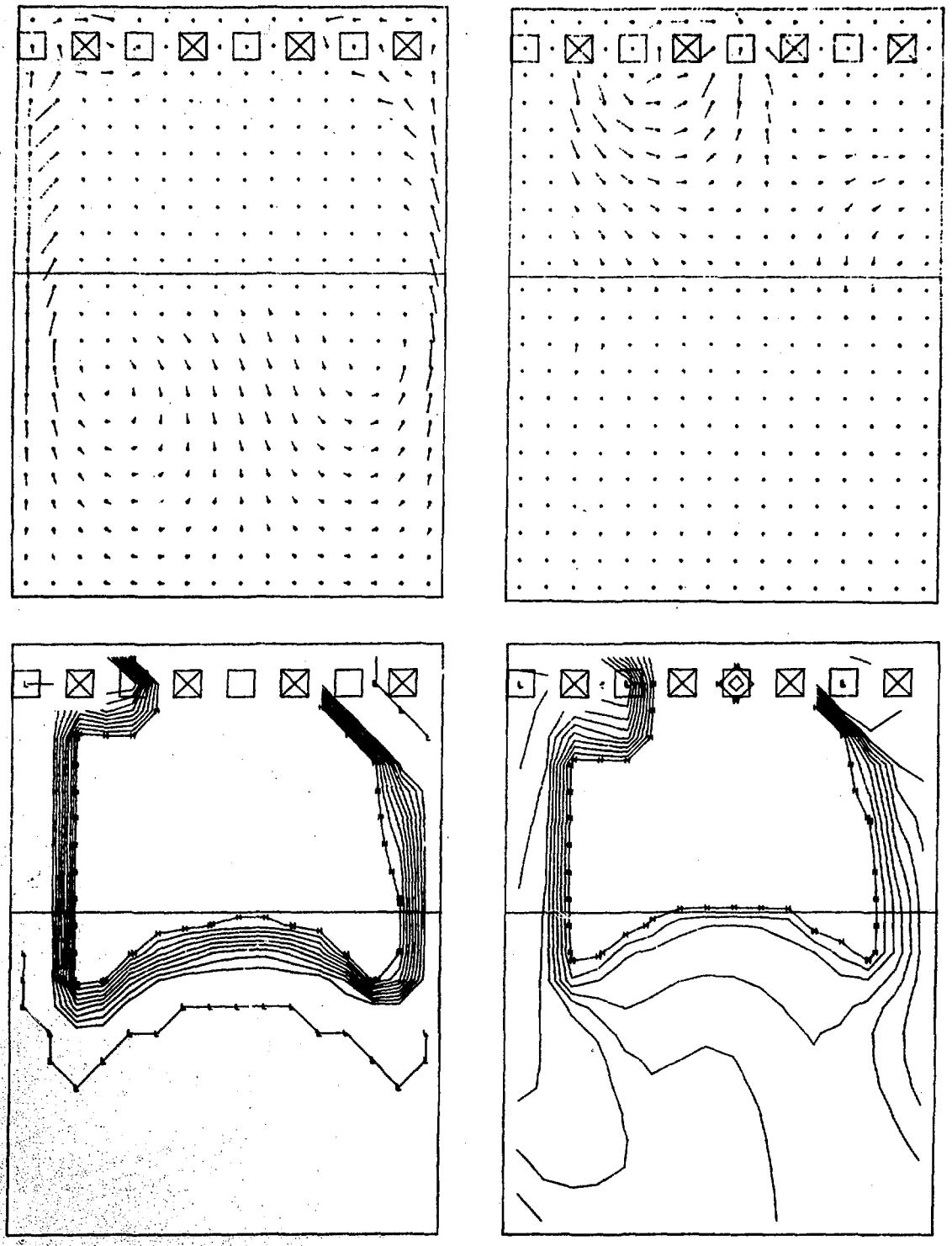

Fig. 15. K-TIF standard-resolution example at time t = 7.0 sec.

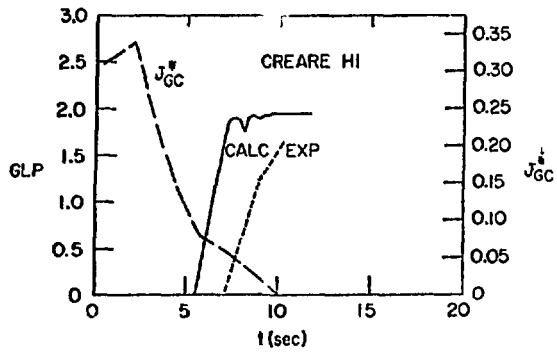

Fig. 16. Comparison of Creare experiment H1 with the K-TIF standard-resolution calculation of Figs. 11-15, showing gallons of water delivered to the lower plenum (GLP) as a function of time.

trend-scoping calculations, we repeated the H1 example with half the linear resolution described above. With this degree of resolution coarseness, including hot-leg obstacles produces a barrier to flow around the cold legs that we deemed less realistic than if the obstacles were simply eliminated. The configuration is illustrated in the selected results shown in Figs. 17-21. Comparison with the finer resolved calculation of Example 1 shows that the qualitative features are quite similar. Although the timing for the first dumping jet to the lower plenum is almost identical in the two calculations, the position of origin for the jet is strongly displaced. We suspect that the experiments would show similar variations if a particular case were repeated, each run giving essentially the same dumping history but differing from the others in the exact placement of the earliest dumping jets.

As a more incisive test of the coarsely resolved calculations, we performed a scoping series corresponding to several steam-flow ramping rates. With no changes in our modeling parameters, we also calculated downcomer flows corresponding to Creare experiment numbers H2, H3, and H5. The water delivery to the lower plenum as a function of time is shown for all four cases in Fig. 22, where there is a consistent difference of about 2 sec between the computed and observed delivery times. The water delivery curve for the finer resolved calculation of experiment number H1, shown in Fig. 16, is repeated in Fig. 22 for comparison with the more coarsely resolved results. The close agreement between the two tends to substantiate the value of the quicker running coarse-mesh studies for scoping trends.

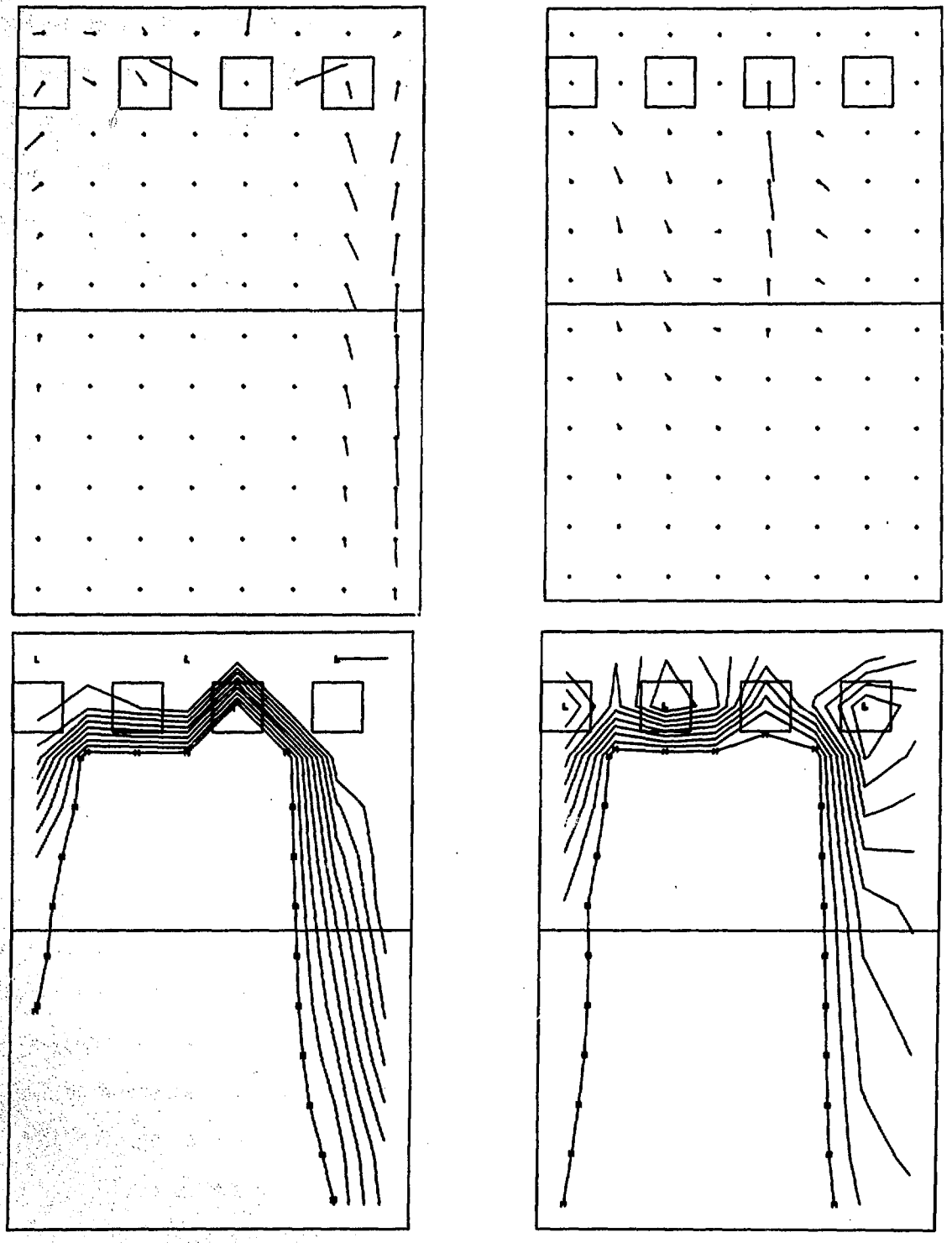

Fig. 17. K-TIF coarse-resolution example at time t = 5.4 sec.

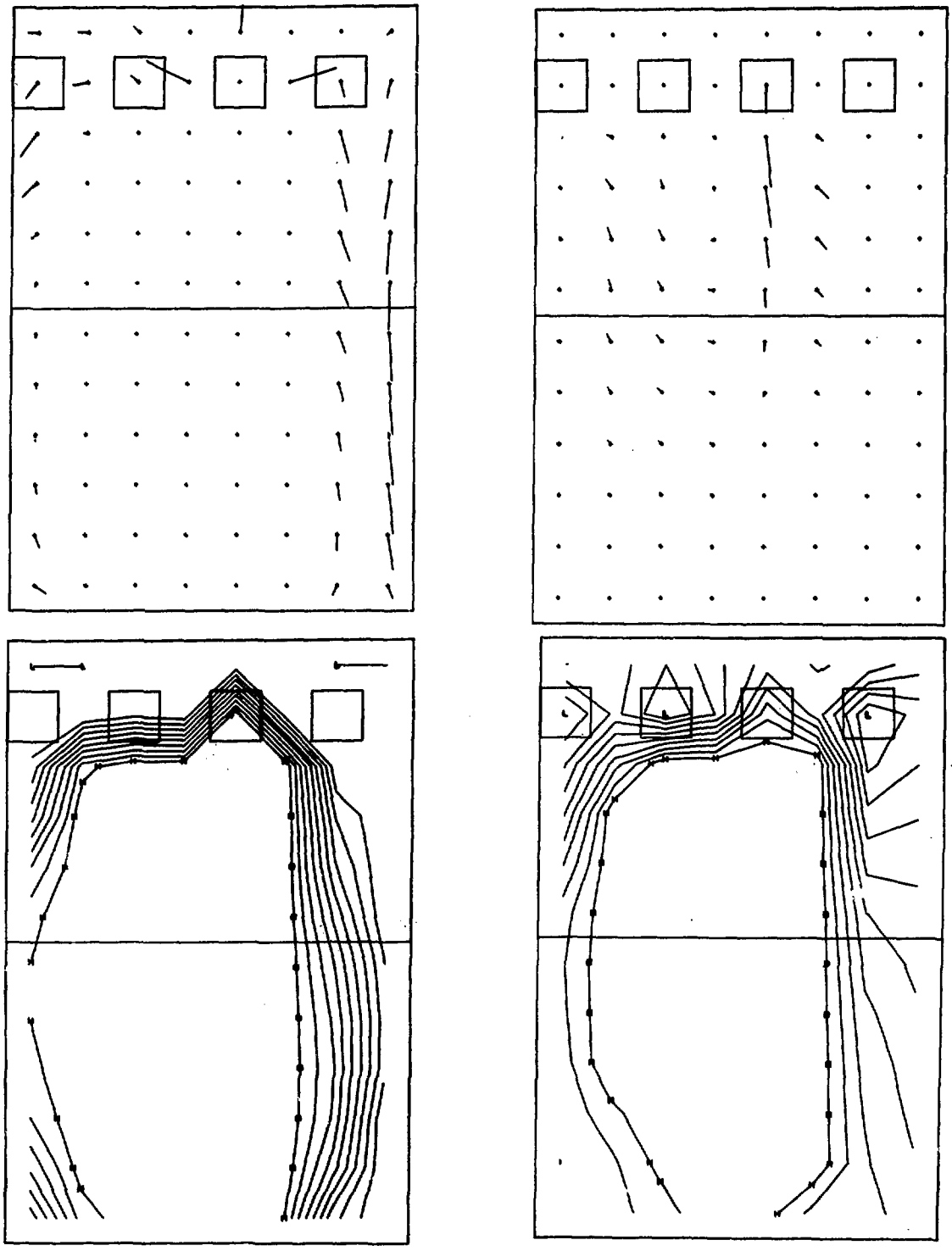

Fig. 18. K-TIF coarse-resolution example at time t = 5.6 sec.

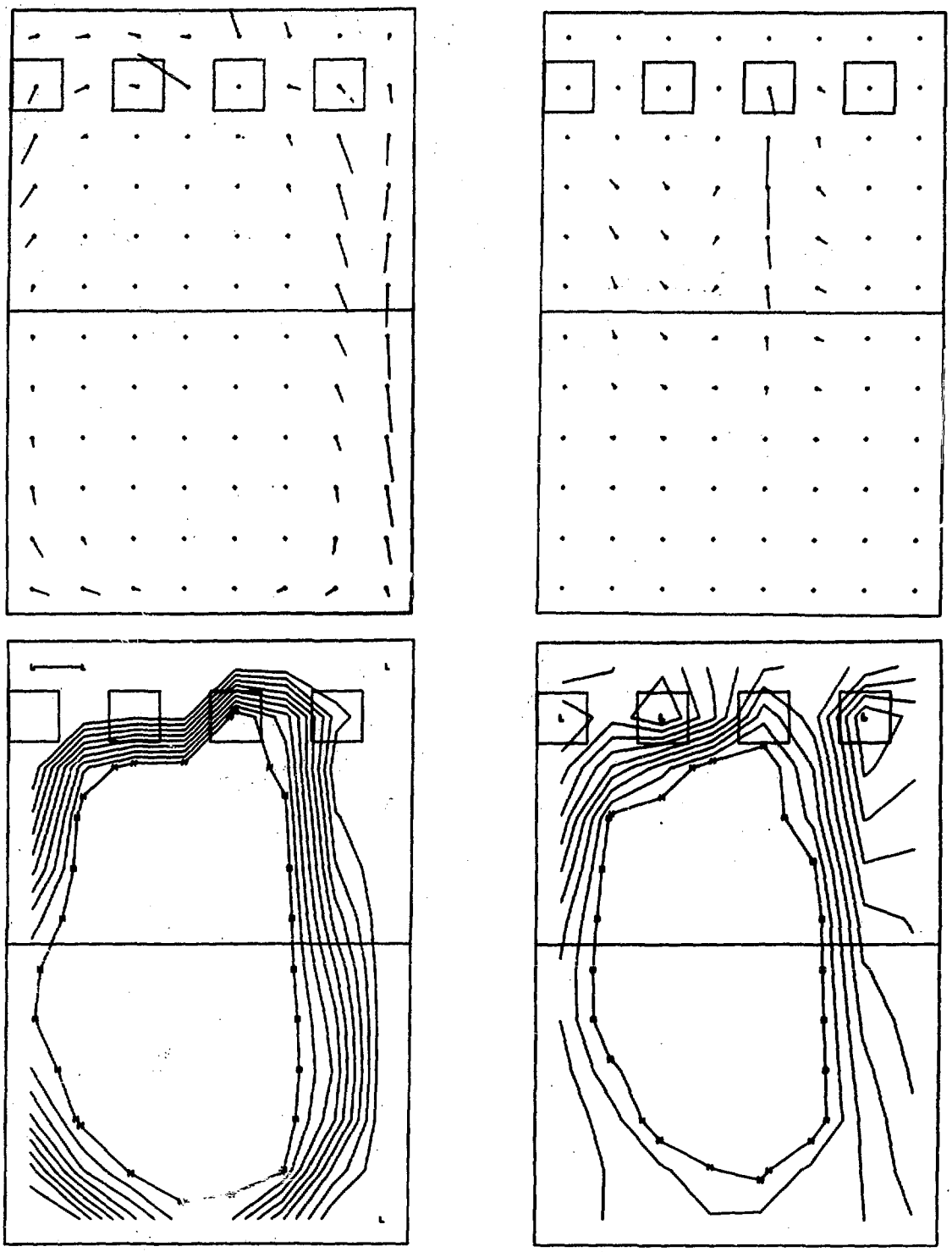

Fig. 19. K-TIF coarse-resolution example at time t = 5.8 sec.

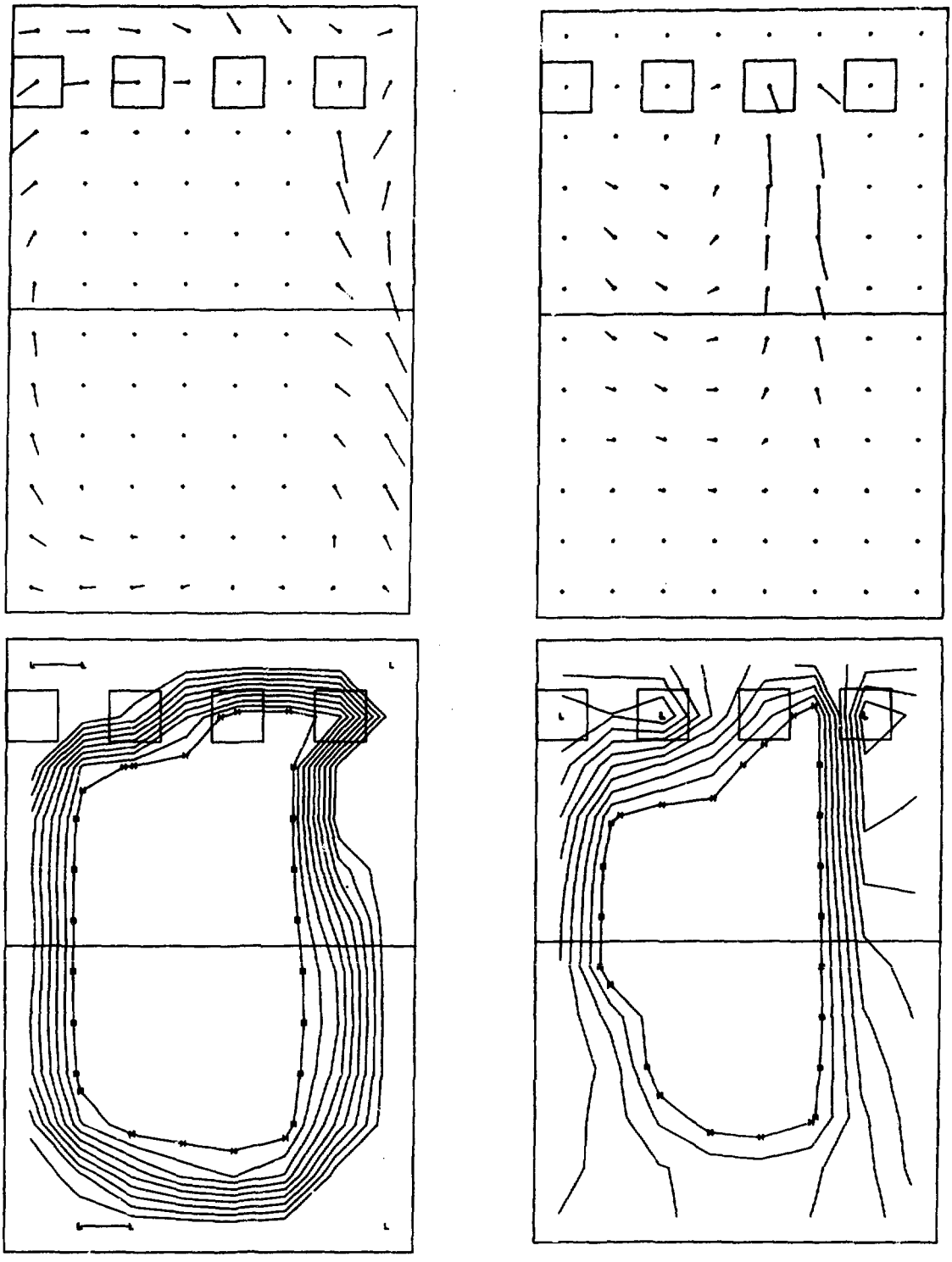

Fig. 20. K-TIF coarse-resolution example at time t = 6.0 sec.

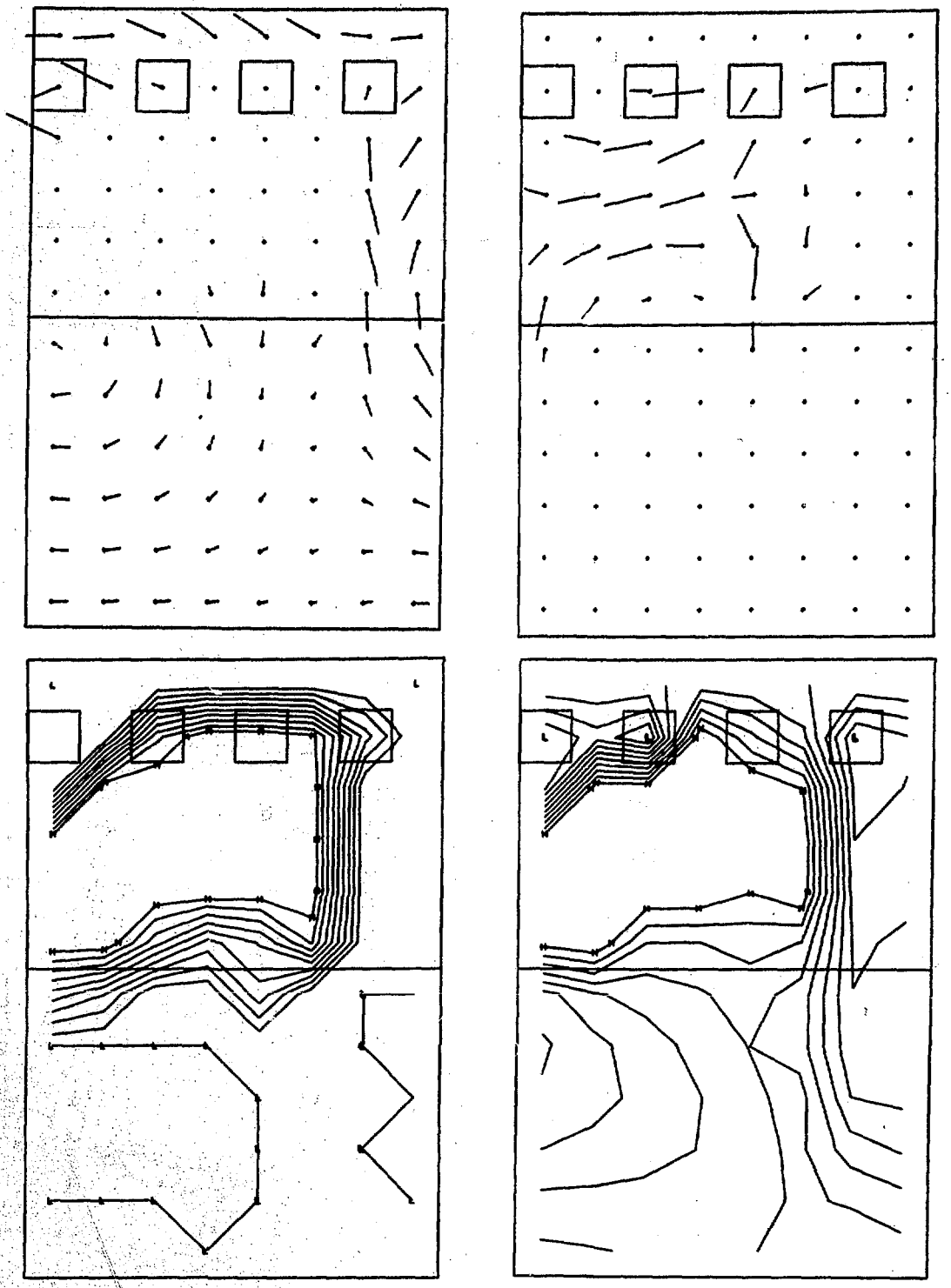

Fig. 21. K-TIF coarse-resolution example at time t = 7.0 sec.

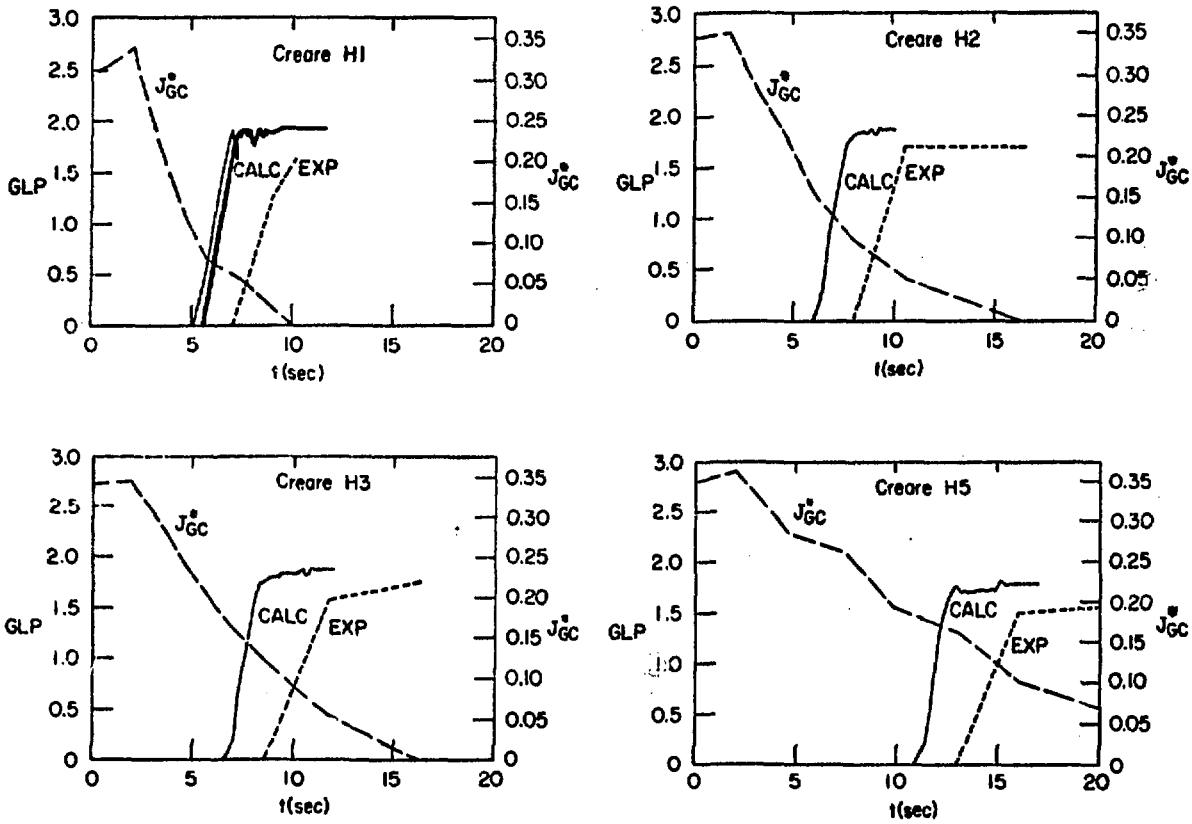

Fig. 22. Comparison of Creare results from experiments H1, H2, H3, and H5 with K-TIF coarse-resolution calculations. The curve for the standard-resolution calculation of experiment H1 (see Fig. 16) is repeated here for comparison.

Another way of comparing results is shown in Fig. 23, which summarizes the results of experiments performed with various steam-flow ramp rates[1] as compared with our four calculations. Despite the consistent discrepancy, the trends given by the calculations agree well with those of the experiments. Accordingly, we believe that these coarsely resolved studies provide a firm basis for prooftesting more elaborate models for the physical details than were used for these demonstrations of K-TIF capabilities.

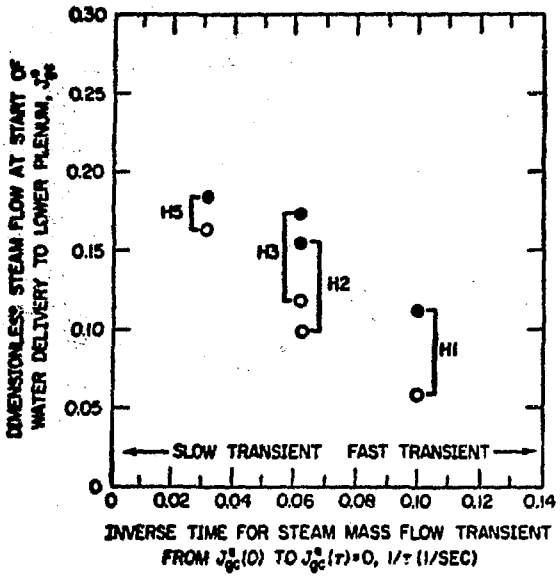

Fig. 23. Comparison of Creare experimental results (open circles) with K-TIF coarse-resolution results (black circles) for four different scaled-plenum tests without wall superheat.

Example 3. Coarse Resolution With Wall Superheat

To examine the consistency of our results in a different type of comparison, we performed calculations for Creare experiments H157 and H158, in which the walls were superheated to 350°F. No changes were made in our modeling parameters from the values used in the above examples. The time variations of water delivered to the lower plenum are shown for the two cases in Fig. 24, together with the experimental results. Comparison for H158 shows slightly more than the 2-sec difference in delivery time observed previously, but the difference appears to be much greater for H157. There is, however, a qualitative difference between the two experimental results, which is emphasized by the summary data from many similar hot-wall experiments in Fig. 25. It is apparent that the summary data lie on two different curves. Those experiments giving points on the lower curve exhibit only a single rapid rise as in experiment H157, whereas those on the upper curve have a rise-plateau-rise water-delivery trace as in experiment H158. As noted in this figure (and on the figure from which the experimental data were taken) the double-rise filling traces furnish two datum points. If our calculation for H157 is compared with the extended locus of datum points on the upper curve, then our consistent approximately 2-sec delay becomes unanimous among all these coarse-mesh scoping calculations. The calculations seem, therefore, always

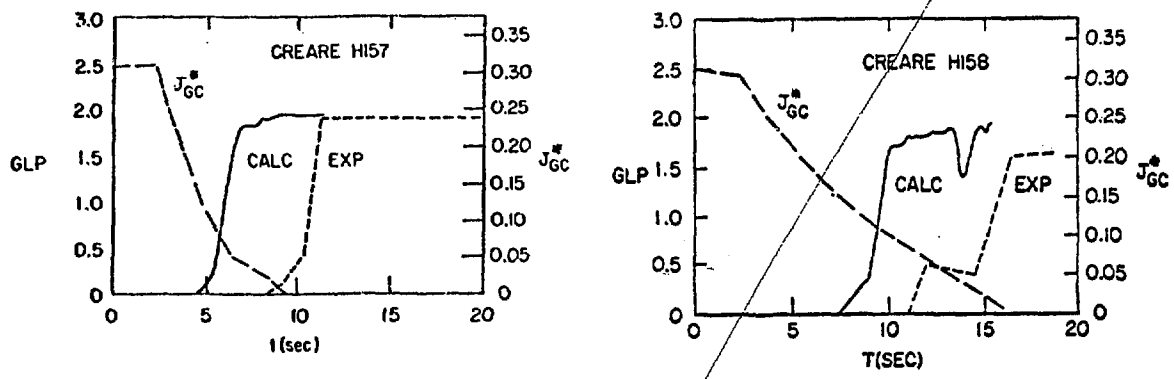

Fig. 24. Comparison of Creare experiments H157 and H158 with K-TIF coarse-mesh calculations. These examples have the walls superheated to 350°F.

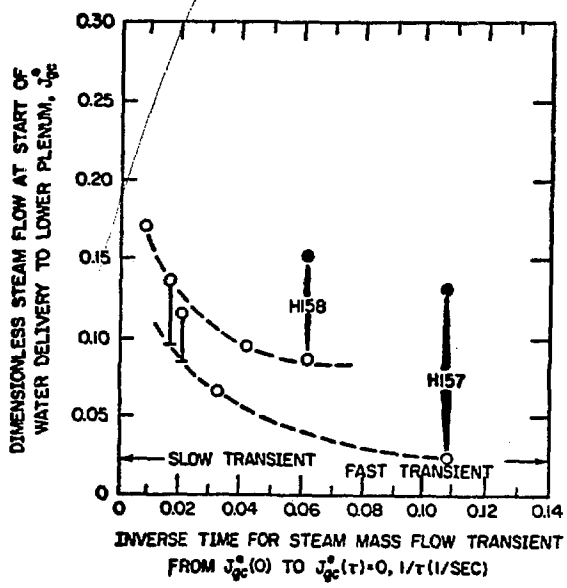

Fig. 25. The Creare results (open circles) for this series of superheated-wall tests show that the data lie on two different curves, as explained in the text. K-TIF coarse-resolution results (black circles) are shown for two of the tests.

to be sensing the sometimes-incipient precursor exhibited by the experiments and corresponding to the upper curve. Once delivery to the lower plenum commences in the calculation, it continues unabated; whereas in the experiments the onset of delivery may be followed by partial or complete reentrainment, with complete delivery occurring slightly later. For K-TIF calculations to reproduce the details of this more complicated behavior will require a more accurate representation of the lower plenum. A first step towards this improvement will come from the capability to have a variable gap size (s) in the code, so that the "gap" in the lower plenum is much larger than in the downcomer. The second step will require a fully three-dimensional resolution of the lower plenum. We believe that these improvements in K-TIF and related codes, together with the enhancement of our physical modeling of microphysical processes, can be expected to produce results whose consistent agreement with experiments will form a basis for the confident prediction of flows in configurations not yet examined in the laboratory.

B. Input Data and Results from a Sample Calculation

The first calculation in Example 2, above, corresponding to Creare experiment number H1,[1] was chosen as a comparison sample for users who wish to work with the K-TIF computer program. We present here the detailed input listing, together with a listing of cell data from the top several rows of the mesh from cycles 0, 1, 2, 10, and much later at t = 0.1 sec (cycle 386) and t = 1.0 sec (cycle 4227).

```
T3AAA KTIF UDC, CREARE H1-J, R1,2=.06, JL=-.16, NO OBSTS 092977
  IBAR=   8
  JBAR=  12
JTOPLP=   6
  NTAB=  11
    DX= 4.32500E+00
    DY= 4.32500E+00
    CD= 1.00000E+00
 MU(1)= 0.
 MU(2)= 0.
 SIGIJ= 2.00000E-01
    HE= 6.00000E-02
 BIGJL=-1.60000E-01
 THINF= 2.44300E+02
 TECCF= 8.15000E+01
JFSTAR= 1.16000E-01
     S= 5.00000E-01
HFCRIT= 1.00000E+10

          TABT                TABP                TABJO
        0.                  2.79000E+01         3.09000E-01
        8.00000E-01         2.63000E+01         3.17000E-01
        9.80000E-01         2.73000E+01         3.20000E-01
        2.10000E+00         2.40000E+01         3.38000E-01
        2.90000E+00         2.05000E+01         2.62000E-01
        3.30000E+00         1.71000E+01         2.29000E-01
        4.40000E+00         1.43000E+01         1.49000E-01
        5.70000E+00         1.33000E+01         8.00000E-02
        7.30000E+00         1.08000E+01         5.80000E-02
        8.10000E+00         1.16000E+01         2.00000E-02
        1.00000E+01         1.23000E+01         0.

     T= 0.
    DT= 1.00000E-04
 DTMAX= 5.00000E-04
 TLIMD= 1.00000E+00
 THFIN= 1.50000E+01
   LPR=   1
   MPR=   0
 MOD58= 200
 DTO(1-10)=   1.00000E-01   2.00000E-01   0.          0.          0.
              0.            0.            0.          0.          0.
DTOC(1-10)=   1.00000E+00   2.10000E+01   0.          0.          0.
              0.            0.            0.          0.          0.
TOTAL NO. OF OBSTACLES AND A AND B PORTS IS   4
A-INLET    NL=   0 NR=   1 NB=  10 NT=  11
A-INLET    NL=   2 NR=   3 NB=  10 NT=  11
B-OUTLET   NL=   4 NR=   5 NB=  10 NT=  11
A-INLET    NL=   6 NR=   7 NB=  10 NT=  11

TOTAL NO. OF A-INLETS (UNBROKEN LEGS) IS 3., WHERE THE AREA OF EACH IS 1.87056E+01
SA1 OF EACH CELL (ECC FLUX) IS -8.23988E+00   INITIAL STEAM FLUX (FB2) IS -3.75348E+04
  CALCULATED CAPACITY OF LOWER PLENUM IS  1.94344E+00 GALLONS.
T 0.       C    0 DT 1.00E-04 IT  0 DV 0.       SB1 0.       SB2 0.       FP 0.       QLP 1.94E-05 FB2-3.75E+04
```

to be sensing the sometimes-incipient precursor exhibited by the experiments and corresponding to the upper curve. Once delivery to the lower plenum commences in the calculation, it continues unabated; whereas in the experiments the onset of delivery may be followed by partial or complete reentrainment, with complete delivery occurring slightly later. For K-TIF calculations to reproduce the details of this more complicated behavior will require a more accurate representation of the lower plenum. A first step towards this improvement will come from the capability to have a variable gap size (s) in the code, so that the "gap" in the lower plenum is much larger than in the downcomer. The second step will require a fully three-dimensional resolution of the lower plenum. We believe that these improvements in K-TIF and related codes, together with the enhancement of our physical modeling of microphysical processes, can be expected to produce results whose consistent agreement with experiments will form a basis for the confident prediction of flows in configurations not yet examined in the laboratory.

B. Input Data and Results from a Sample Calculation

The first calculation in Example 2, above, corresponding to Creare experiment number H1,[1] was chosen as a comparison sample for users who wish to work with the K-TIF computer program. We present here the detailed input listing, together with a listing of cell data from the top several rows of the mesh from cycles 0, 1, 2, 10, and much later at t = 0.1 sec (cycle 386) and t = 1.0 sec (cycle 4227).

```
T3AAA KTIF UDC, CREARE H1-J, R1,2=.06, JL=-.16, NO OBSTS,092977
  IBAR=  9
  JBAR=  12
JTOPLP=  6
  NTAB=  11
    DX= 4.32500E+00
    DY= 4.32500E+00
    CD= 1.00000E+00
 MU(1)= 0.
 MU(2)= 0.
 SIGIJ= 2.00000E-01
    NE= 6.00000E-02
 BIGJL=-1.60000E-01
 TWINF= 2.44300E+02
 TECCF= 8.15000E+01
JFSTAR= 1.16000E-01
     S= 5.00000E-01
HFCRIT= 1.00000E+10

          TABT                TABP                TABJG
        0.                  2.79000E+01         3.09000E-01
        8.00000E-01         2.63000E+01         3.17000E-01
        9.00000E-01         2.73000E+01         3.20000E-01
        2.10000E+00         2.40000E+01         3.39000E-01
        2.90000E+00         2.05000E+01         2.62000E-01
        3.30000E+00         1.71000E+01         2.29000E-01
        4.40000E+00         1.43000E+01         1.49000E-01
        5.70000E+00         1.33000E+01         8.00000E-02
        7.30000E+00         1.08000E+01         5.80000E-02
        9.10000E+00         1.16000E+01         2.00000E-02
        1.00000E+01         1.23000E+01         0.

     T= 0.
    DT= 1.00000E-04
 DTMAX= 5.00000E-04
 TLIMD= 1.00000E+00
 TWFIN= 1.50000E+01
   LPR=   1
   MPR=   0
 MCD59= 200
 DTO(1-10)=   1.00000E-01   2.00000E-01   0.          0.          0.
              0.            0.            0.          0.          0.
DTOC(1-10)=   1.00000E+00   2.10000E+01   0.          0.          0.
              0.            0.            0.          0.          0.
TOTAL NO. OF OBSTACLES AND A AND B PORTS IS   4
A-INLET    NL=   0 NR=   1 NB=  10 NT=  11
A-INLET    NL=   2 NR=   3 NB=  10 NT=  11
B-OUTLET   NL=   4 NR=   5 NB=  10 NT=  11
A-INLET    NL=   6 NR=   7 NB=  10 NT=  11

TOTAL NO. OF A-INLETS (UNBROKEN LEGS) IS 3., WHERE THE AREA OF EACH IS 1.87058E+01
SAI OF EACH CELL (ECC FLUX) IS -8.23968E+00   INITIAL STEAM FLUX (FB2) IS -3.75349E+04
  CALCULATED CAPACITY OF LOWER PLENUM IS  1.94344E+00 GALLONS.
T 0.       C    0 DT 1.00E-04 IT  0 DV 0.       SB1 0.       SB2 0.       FP 0.       QLP 1.94E-05 FB2-3.75E+04
```

T= 0. CYCLE 0

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
5	8	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
6	9	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
7	9	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
8	9	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
9	9	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
10	9	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
1	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
2	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
3	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
4	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
5	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
6	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
7	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
8	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
9	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
10	10	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
1	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
2	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
3	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
4	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
5	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
6	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
7	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
8	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
9	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
10	11	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
1	12	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
2	12	1.00E-05	0.	0.	0.	0.	3.01E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.

T= 0. CYCLE 0

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
3	12	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
4	12	1.00E-05	0.	0.	0.	0.	3.01E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
5	12	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
6	12	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
7	12	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
8	12	1.00E-05	0.	0.	0.	0.	3.01E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
9	12	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
10	12	1.00E-05	0.	0.	0.	0.	3.01E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
1	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
2	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
3	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
4	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
5	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
6	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
7	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
8	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
9	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
10	13	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
1	14	1.00E-05	0.	0.	0.	0.	0.	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
	14	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
3	14	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
4	14	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
5	14	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
6	14	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
7	14	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
8	14	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
9	14	1.00E-05	0.	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.
10	14	1.00E-05	0.	0.	0.	0.	0.	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.

T= 1.00000E-04 CYCLE 1

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
5	9	1.00E-05	8.98E-02	1.58E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	9.95E+03
		1.00E+00	6.62E+01	1.20E+03	6.00E-02	-7.11E-02	4.00E-03	1.73E-02	-1.11E-12
6	9	1.00E-05	-8.98E-02	1.74E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	9.84E+03
		1.00E+00	-6.62E+01	1.31E+03	6.00E-02	-7.11E-02	4.00E-03	1.73E-02	-1.11E-12
7	9	1.00E-05	-1.83E-01	1.58E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	9.95E+03
		1.00E+00	-1.20E+02	1.20E+03	6.00E-02	-7.11E-02	4.00E-03	1.73E-02	-1.11E-12
8	9	1.00E-05	-1.34E-01	1.38E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	1.01E+04
		1.00E+00	-9.03E+01	1.08E+03	6.00E-02	-7.11E-02	4.00E-03	1.73E-02	-1.11E-12
9	9	1.00E-05	-5.04E-02	1.27E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	1.03E+04
		1.00E+00	-3.72E+01	9.67E+02	6.00E-02	-7.11E-02	4.00E-03	1.73E-02	-1.11E-12
10	9	1.00E-05	5.04E-02	1.23E+00	0.	0.	3.91E+02	0.	1.04E+04
		1.00E+00	3.72E+01	9.38E+02	0.	0.	0.	0.	-1.11E-12
1	10	1.00E-05	-9.16E-02	1.11E+00	0.	0.	3.91E+02	0.	0.
		1.00E+00	-6.76E+01	8.45E+02	0.	0.	0.	0.	-1.11E-12
2	10	1.00E-05	9.16E-02	1.05E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	8.81E+03
		1.00E+00	6.76E+01	8.01E+02	6.00E-02	-7.11E-02	4.00E-03	2.75E-02	-1.11E-12
3	10	1.00E-05	2.57E-01	1.11E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	8.70E+03
		1.00E+00	1.90E+02	8.45E+02	6.00E-02	-7.11E-02	4.00E-03	2.74E-02	-1.11E-12
4	10	1.00E-05	3.53E-01	1.30E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	8.38E+03
		1.00E+00	2.61E+02	9.87E+02	6.00E-02	-7.11E-02	4.00E-03	2.74E-02	-1.11E-12
5	10	1.00E-05	2.49E-01	1.69E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	7.94E+03
		1.00E+00	1.84E+02	1.27E+03	6.00E-02	-7.11E-02	4.00E-03	2.74E-02	-1.11E-12
6	10	1.00E-05	-2.49E-01	2.24E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	7.63E+03
		1.00E+00	-1.84E+02	1.68E+03	6.00E-02	-7.11E-02	4.00E-03	2.74E-02	-1.11E-12
7	10	1.00E-05	-3.53E-01	1.68E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	7.94E+03
		1.00E+00	-2.61E+02	1.27E+03	6.00E-02	-7.11E-02	4.00E-03	2.74E-02	-1.11E-12
8	10	1.00E-05	-2.57E-01	1.30E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	8.38E+03
		1.00E+00	-1.90E+02	9.87E+02	6.00E-02	-7.11E-02	4.00E-03	2.74E-02	-1.11E-12
9	10	1.00E-05	-9.16E-02	1.11E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	8.70E+03
		1.00E+00	-6.76E+01	8.45E+02	6.00E-02	-7.11E-02	4.00E-03	2.74E-02	-1.11E-12
10	10	1.00E-05	9.16E-02	1.05E+00	0.	0.	3.91E+02	0.	8.81E+03
		1.00E+00	6.76E+01	8.01E+02	0.	0.	0.	0.	-1.11E-12
1	11	1.00E-05	-1.48E-01	8.07E-01	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.11E+02	6.24E+02	0.	0.	0.	0.	-1.11E-12
2	11	1.00E-05	1.51E-01	5.90E-01	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	7.47E+03
		1.00E+00	1.11E+02	5.80E+02	6.00E-02	-7.11E-02	4.00E-03	3.57E-02	-1.11E-12
3	11	1.00E-05	4.48E-01	8.07E-01	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	7.28E+03
		1.00E+00	3.32E+02	6.24E+02	6.00E-02	-7.11E-02	4.00E-03	3.57E-02	-1.11E-12
4	11	1.00E-05	7.42E-01	7.97E-01	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	6.72E+03
		1.00E+00	5.48E+02	7.71E+02	6.00E-02	-7.11E-02	4.00E-03	3.57E-02	-1.11E-12
5	11	1.00E-05	8.03E-01	1.63E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	5.80E+03
		1.00E+00	5.93E+02	1.23E+03	6.00E-02	-7.11E-02	4.00E-03	3.57E-02	-1.11E-12
6	11	1.00E-05	-8.03E-01	3.03E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	4.81E+03
		1.00E+00	-5.93E+02	2.87E+03	6.00E-02	-7.11E-02	4.00E-03	3.58E-02	-1.11E-12
7	11	1.00E-05	-7.42E-01	1.63E+00	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	5.80E+03
		1.00E+00	-5.48E+02	1.23E+03	6.00E-02	-7.11E-02	4.00E-03	3.57E-02	-1.11E-12
8	11	1.00E-05	-4.48E-01	7.97E-01	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	6.72E+03
		1.00E+00	-3.32E+02	7.71E+02	6.00E-02	-7.11E-02	4.00E-03	3.57E-02	-1.11E-12
9	11	1.00E-05	-1.48E-01	8.07E-01	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	7.28E+03
		1.00E+00	-1.11E+02	6.24E+02	6.00E-02	-7.11E-02	4.00E-03	3.57E-02	-1.11E-12
10	11	1.00E-05	1.51E-01	5.90E-01	0.	0.	3.91E+02	0.	7.47E+03
		1.00E+00	1.11E+02	5.80E+02	0.	0.	0.	0.	-1.11E-12
1	12	1.00E-05	-1.08E-01	3.71E-01	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.58E+02	3.02E+02	0.	0.	0.	0.	-1.11E-12
2	12	8.34E-04	1.68E-01	2.92E-01	6.00E-02	-8.24E+00	3.01E+02	1.00E-06	6.49E+03
		9.99E-01	1.56E+02	3.05E+02	6.00E-02	-7.11E-02	4.00E-03	4.15E-02	0.

T= 1.00000E-04 CYCLE 1

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,DAM	K,D	P,J
3	12	1.00E-05	5.18E-01	3.71E-01	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	6.23E+03
		1.00E+00	4.78E+02	3.02E+02	6.00E-02	-7.11E-02	4.00E-03	4.15E-02	-1.11E-12
4	12	8.34E-04	1.09E+00	2.04E-01	6.00E-02	-8.24E+00	3.01E+02	1.00E-06	5.43E+03
		9.99E-01	1.01E+03	2.79E+02	6.00E-02	-7.11E-02	4.00E-03	4.15E-02	0.
5	12	1.00E-05	3.02E+00	-2.98E-02	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	3.74E+03
		1.00E+00	2.23E+03	6.29E+00	6.00E-02	-7.11E-02	4.00E-03	4.14E-02	-1.11E-12
6	12	1.00E-05	-3.02E+00	-2.05E+00	6.00E-02	0.	3.91E+02	1.00E-06	0.
		1.00E+00	-2.23E+03	-1.48E+03	6.00E-02	2.04E+03	4.00E-03	4.13E-02	0.
7	12	1.00E-05	-1.09E+00	-2.98E-02	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	3.74E+03
		1.00E+00	-1.01E+03	6.29E+00	6.00E-02	-7.11E-02	4.00E-03	4.14E-02	-1.11E-12
8	12	8.34E-04	-5.18E-01	2.64E-01	6.00E-02	8.24E+00	3.01E+02	1.00E-06	5.43E+03
		9.99E-01	-4.78E+02	2.79E+02	6.00E-02	-7.11E-02	4.00E-03	4.15E-02	0.
9	12	1.00E-05	-1.69E-01	3.71E-01	6.00E-02	3.08E-11	3.91E+02	1.00E-06	6.23E+03
		1.00E+00	-1.56E+02	3.02E+02	6.00E-02	-7.11E-02	4.00E-03	4.15E-02	-1.11E-12
10	12	8.34E-04	1.69E-01	2.92E-01	0.	0.	3.01E+02	0.	6.49E+03
		9.99E-01	1.56E+02	3.05E+02	0.	0.	4.00E-03	0.	0.
1	13	1.00E-05	-2.07E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.53E+02	0	0	0.	0.	0.	-1.11E-12
2	13	1.00E-05	2.07E-01	0.	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	5.98E+03
		1.00E+00	1.53E+02	0.	6.00E-02	-7.11E-02	4.00E-03	4.46E-02	-1.11E-12
3	13	1.00E-05	6.17E-01	0	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	5.73E+03
		1.00E+00	4.55E+02	0.	6.00E-02	-7.11E-02	4.00E-03	4.46E-02	-1.11E-12
4	13	1.00E-05	9.95E-01	0.	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	4.96E+03
		1.00E+00	7.35E+02	0.	6.00E-02	-7.11E-02	4.00E-03	4.45E-02	-1.11E-12
5	13	1.00E-05	1.00E+00	0.	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	3.73E+03
		1.00E+00	7.41E+02	0.	6.00E-02	-7.11E-02	4.00E-03	4.45E-02	-1.11E-12
6	13	1.00E-05	-1.00E+00	0.	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	2.49E+03
		1.00E+00	-7.41E+02	0.	6.00E-02	-7.11E-02	4.00E-03	4.44E-02	-1.11E-12
7	13	1.00E-05	-9.95E-01	0.	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	3.73E+03
		1.00E+00	-7.35E+02	0.	6.00E-02	-7.11E-02	4.00E-03	4.45E-02	-1.11E-12
8	13	1.00E-05	-6.17E-01	0.	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	4.96E+03
		1.00E+00	-4.55E+02	0.	6.00E-02	-7.11E-02	4.00E-03	4.45E-02	-1.11E-12
9	13	1.00E-05	-2.07E-01	0.	6.00E-02	-3.08E-11	3.91E+02	1.00E-06	5.73E+03
		1.00E+00	-1.53E+02	0.	6.00E-02	-7.11E-02	4.00E-03	4.46E-02	-1.11E-1.
10	13	1.00E-05	2.07E-01	0.	0.	0.	3.91E+02	0.	5.98E+03
		1.00E+00	1.53E+02	0.	0	0.	0.	0.	-1.11E-12
1	14	1.00E-05	-2.07E-01	0.	0.	0.	-3.91E+02	0.	0
		1.00E+00	-1.53E+02	0.	0.	0.	0.	0.	0.
2	14	1.00E-05	2.07E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	1.53E+02	0.	0.	0.	0.	0.	0.
3	14	1.00E-05	6.17E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	4.55E+02	0.	0.	0.	0.	0.	0.
4	14	1.00E-05	9.95E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	7.35E+02	0.	0.	0.	0.	0.	0.
5	14	1.00E-05	1.00E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	7.41E+02	0.	0.	0.	0.	0.	0.
6	14	1.00E-05	-1.00E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-7.41E+02	0.	0.	0.	0.	0.	0.
7	14	1.00E-05	-9.95E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-7.35E+02	0.	0.	0.	0.	0.	0.
8	14	1.00E-05	-6.17E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-4.55E+02	0.	0.	0.	0.	0.	0.
9	14	1.00E-05	-2.07E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.53E+02	0.	0.	0.	0.	0.	0.
10	14	1.00E-05	0.	0.	0.	0.	-3.91E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.

T= 2.00000E-04 CYCLE 2

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
5	9	1.00E-05	2.18E-01	4.00E+00	6.00E-02	-6.07E-12	3.91E+02	6.67E-06	2.50E+02
		1.00E+00	6.68E+01	1.26E+03	6.00E-02	-7.11E-02	4.00E-03	-1.56E+00	-2.18E-13
6	9	1.00E-05	-2.18E-01	4.68E+00	6.00E-02	-6.07E-12	3.91E+02	7.04E-06	2.48E+02
		1.00E+00	-6.68E+01	1.38E+03	6.00E-02	-7.11E-02	4.00E-03	-1.56E+00	-2.18E-13
7	9	1.00E-05	-3.82E-01	4.00E+00	6.00E-02	-6.07E-12	3.91E+02	6.37E-06	2.50E+02
		1.00E+00	-1.21E+02	1.26E+03	6.00E-02	-7.11E-02	4.00E-03	-1.56E+00	-2.18E-13
8	9	1.00E-05	-3.03E-01	3.31E+00	6.00E-02	-6.07E-12	3.91E+02	6.19E-06	2.55E+02
		1.00E+00	-9.98E+01	1.12E+03	6.00E-02	-7.11E-02	4.00E-03	-1.56E+00	-2.18E-13
9	9	1.00E-05	-1.11E-01	2.69E+00	6.00E-02	-6.07E-12	3.91E+02	5.83E-06	2.56E+02
		1.00E+00	-3.75E+01	1.02E+03	6.00E-02	-7.11E-02	4.00E-03	-1.56E+00	-2.18E-13
10	9	1.00E-05	1.11E-01	2.75E+00	0.	0.	3.91E+02	0.	2.56E+02
		1.00E+00	3.75E+01	9.94E+02	0.	0.	0.	0.	-2.18E-13
1	10	1.00E-05	-1.93E-01	2.38E+00	0.	0.	3.91E+02	0.	0.
		1.00E+00	-6.79E+01	8.91E+02	0.	0.	0.	0.	-2.18E-13
2	10	1.00E-05	1.93E-01	2.18E+00	6.00E-02	-6.07E-12	3.91E+02	5.30E-06	1.65E+02
		1.00E+00	6.79E+01	8.47E+02	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
3	10	1.00E-05	5.84E-01	2.36E+00	6.00E-02	-6.07E-12	3.91E+02	5.42E-06	1.04E+02
		1.00E+00	1.91E+02	8.91E+02	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
4	10	1.00E-05	8.37E-01	3.00E+00	6.00E-02	-6.07E-12	3.91E+02	6.08E-06	1.58E+02
		1.00E+00	2.63E+02	1.03E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
5	10	1.00E-05	6.48E-01	4.40E+00	6.00E-02	-6.07E-12	3.91E+02	7.07E-06	1.47E+02
		1.00E+00	1.88E+02	1.32E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
6	10	1.00E-05	-6.48E-01	7.15E+00	6.00E-02	-6.07E-12	3.91E+02	8.25E-06	1.38E+02
		1.00E+00	-1.88E+02	1.74E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
7	10	1.00E-05	-8.37E-01	4.40E+00	6.00E-02	-6.07E-12	3.91E+02	7.07E-06	1.47E+02
		1.00E+00	-2.63E+02	1.32E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
8	10	1.00E-05	-5.84E-01	3.00E+00	6.00E-02	-6.07E-12	3.91E+02	6.08E-06	1.58E+02
		1.00E+00	-1.91E+02	1.03E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
9	10	1.00E-05	-1.93E-01	2.38E+00	6.00E-02	-6.07E-12	3.91E+02	5.42E-06	1.04E+02
		1.00E+00	-6.79E+01	8.91E+02	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
10	10	1.00E-05	1.93E-01	2.18E+00	0.	0.	3.91E+02	0.	1.65E+02
		1.00E+00	6.79E+01	8.47E+02	0.	0.	0.	0.	-2.18E-13
1	11	1.00E-05	-2.98E-01	1.58E+00	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.11E+02	6.55E+02	0.	0.	0.	0.	-2.18E-13
2	11	1.00E-05	2.93E-01	4.77E-01	6.00E-02	-6.07E-12	3.91E+02	4.34E-06	8.22E+01
		1.00E+00	1.11E+02	8.11E+02	6.00E-02	-7.11E-02	4.00E-03	-3.24E+00	-2.18E-13
3	11	1.00E-05	8.38E-01	1.58E+00	6.00E-02	-6.07E-12	3.91E+02	4.71E-06	8.03E+01
		1.00E+00	3.33E+02	6.55E+02	6.00E-02	-7.11E-02	4.00E-03	-3.25E+00	-2.18E-13
4	11	1.00E-05	1.78E+00	8.93E-01	6.00E-02	-6.07E-12	3.91E+02	5.75E-06	8.12E+01
		1.00E+00	5.52E+02	8.00E+02	6.00E-02	-7.11E-02	4.00E-03	-3.24E+00	-2.18E-13
5	11	1.00E-05	2.47E+00	4.58E+00	6.00E-02	-6.07E-12	3.91E+02	7.08E-06	5.78E+01
		1.00E+00	8.04E+02	1.28E+03	6.00E-02	-7.11E-02	4.00E-03	-3.25E+00	-2.18E-13
6	11	1.00E-05	-2.47E+00	1.04E+01	6.00E-02	-6.07E-12	3.91E+02	1.20E-05	1.38E+01
		1.00E+00	-8.04E+02	2.03E+03	6.00E-02	-7.11E-02	4.00E-03	-3.24E+00	-2.18E-13
7	11	1.00E-05	-1.78E+00	4.58E+00	6.00E-02	-6.07E-12	3.91E+02	7.08E-06	5.78E+01
		1.00E+00	-5.52E+02	1.28E+03	6.00E-02	-7.11E-02	4.00E-03	-3.25E+00	-2.18E-13
8	11	1.00E-05	-8.38E-01	8.93E-01	6.00E-02	-6.07E-12	3.91E+02	5.75E-06	8.12E+01
		1.00E+00	-3.33E+02	8.00E+02	6.00E-02	-7.11E-02	4.00E-03	-3.24E+00	-2.18E-13
9	11	1.00E-05	-2.98E-01	1.58E+00	6.00E-02	-6.07E-12	3.91E+02	4.71E-06	8.03E+01
		1.00E+00	-1.11E+02	6.55E+02	6.00E-02	-7.11E-02	4.00E-03	-3.25E+00	-2.18E-13
10	11	1.00E-05	2.93E-01	4.77E-01	0.	0.	3.91E+02	0.	8.22E+01
		1.00E+00	1.11E+02	8.11E+02	0.	0.	0.	0.	-2.18E-13
1	12	1.00E-05	-1.34E-01	6.24E-01	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.58E+02	3.17E+02	0.	0.	0.	0.	-1.20E-10
2	12	1.68E-03	1.34E-01	2.21E-01	6.00E-02	-8.24E+00	3.01E+02	1.78E-04	4.84E+01
		8.98E-01	1.58E+02	3.21E+02	6.00E-02	-7.11E-02	4.00E-03	-3.77E+00	0.

T= 2.00000E-04 CYCLE 2

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,QAM	K,D	P,J
3	12	1.00E-05	5.62E-01	6.24E-01	6.00E-02	-3.35E-09	3.91E+02	3.72E-06	4.40E+01
		1.00E+00	4.78E+02	3.17E+02	6.00E-02	-7.11E-02	4.00E-03	-3.70E+00	-1.20E-10
4	12	1.66E-03	1.21E+00	2.02E-01	6.00E-02	-8.24E+00	3.01E+02	3.68E-04	3.69E+01
		9.99E-01	1.01E+03	2.91E+02	6.00E-02	-7.11E-02	4.00E-03	-3.77E+00	0.
5	12	1.01E-05	7.25E+00	-7.64E-02	6.00E-02	-2.16E-08	3.90E+02	9.40E-06	1.44E-04
		1.00E+00	2.24E+03	7.57E+00	6.00E-02	-7.11E-02	4.00E-03	-3.78E+00	-7.79E-10
6	12	1.00E-05	-7.25E+00	-3.97E+00	6.00E-02	0.	3.91E+02	4.35E-06	2.21E+01
		1.00E+00	-2.24E+03	-1.42E+03	6.00E-02	2.04E+03	4.00E-03	-3.70E+00	0.
7	12	1.01E-05	-1.21E+00	-7.64E-02	6.00E-02	-2.16E-08	3.90E+02	9.40E-06	0.
		1.00E+00	-1.01E+03	7.57E+00	6.00E-02	-7.11E-02	4.00E-03	-3.78E+00	-7.79E-10
8	12	1.66E-03	-5.62E-01	2.02E-01	6.00E-02	-8.24E+00	3.01E+02	3.68E-04	3.69E+01
		9.99E-01	-4.78E+02	2.91E+02	6.00E-02	-7.11E-02	4.00E-03	-3.77E+00	0.
9	12	1.00E-05	-1.34E-01	6.24E-01	6.00E-02	-3.35E-09	3.91E+02	3.72E-06	4.40E+01
		1.00E+00	-1.56E+02	3.17E+02	6.00E-02	-7.11E-02	4.00E-03	-3.70E+00	-1.20E-10
10	12	1.66E-03	1.34E-01	2.21E-01	0.	0.	3.01E+02	0.	4.54E+01
		9.99E-01	1.56E+02	3.21E+02	0.	0.	4.00E-03	0.	0.
1	13	1.00E-05	-2.98E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.52E+02	0.	0.	0.	0.	0.	-2.18E-13
2	13	1.00E-05	2.98E-01	0.	6.00E-02	-5.79E-09	3.91E+02	1.74E-06	2.28E+01
		1.00E+00	1.52E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.05E+00	-2.09E-10
3	13	1.00E-05	1.03E+00	0.	6.00E-02	-6.07E-12	3.91E+02	2.64E-06	2.43E+01
		1.00E+00	4.52E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
4	13	1.00E-05	1.84E+00	0.	6.00E-02	-5.24E-09	3.91E+02	3.98E-06	2.64E+01
		1.00E+00	7.25E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.05E+00	-1.88E-10
5	13	1.00E-05	1.89E+00	0.	6.00E-02	-6.07E-12	3.91E+02	4.57E-06	3.63E+01
		1.00E+00	7.18E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
6	13	1.00E-05	-1.89E+00	0.	6.00E-02	-6.07E-12	3.91E+02	4.56E-06	7.82E+01
		1.00E+00	-7.18E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
7	13	1.00E-05	-1.84E+00	0.	6.00E-02	-6.07E-12	3.91E+02	4.57E-06	3.63E+01
		1.00E+00	-7.25E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
8	13	1.00E-05	-1.03E+00	0.	6.00E-02	-5.24E-09	3.91E+02	3.96E-06	2.64E+01
		1.00E+00	-4.52E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.05E+00	-1.88E-10
9	13	1.00E-05	-2.98E-01	0.	6.00E-02	-6.07E-12	3.91E+02	2.64E-06	2.43E+01
		1.00E+00	-1.52E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
10	13	1.00E-05	2.98E-01	0.	0.	0.	3.91E+02	0.	2.28E+01
		1.00E+00	1.52E+02	0.	0.	0.	0.	0.	-2.09E-10
1	14	1.00E-05	-2.98E-01	0.	0.	0.	-7.82E+02	0.	0.
		1.00E+00	-1.52E+02	0.	0.	0.	0.	0.	0.
2	14	1.00E-05	2.98E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	1.52E+02	0.	0.	0.	0.	0.	0.
3	14	1.00E-05	1.03E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	4.52E+02	0.	0.	0.	0.	0.	0.
4	14	1.00E-05	1.84E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	7.25E+02	0.	0.	0.	0.	0.	0.
5	14	1.00E-05	1.89E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	7.18E+02	0.	0.	0.	0.	0.	0.
6	14	1.00E-05	-1.89E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-7.18E+02	0.	0.	0.	0.	0.	0.
7	14	1.00E-05	-1.84E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-7.25E+02	0.	0.	0.	0.	0.	0.
8	14	1.00E-05	-1.03E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-4.52E+02	0.	0.	0.	0.	0.	0.
9	14	1.00E-05	-2.98E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.52E+02	0.	0.	0.	0.	0.	0.
10	14	1.00E-05	0.	0.	0.	0.	-7.82E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.

T= 2.00000E-04 CYCLE 2

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
5	9	1.00E-05	2.18E-01	4.00E+00	6.00E-02	-6.07E-12	3.91E+02	6.67E-06	2.50E+02
		1.00E+00	6.08E+01	1.28E+03	6.00E-02	-7.11E-02	4.00E-03	-1.58E+00	-2.18E-13
6	9	1.00E-05	-2.18E-01	4.68E+00	6.00E-02	-6.07E-12	3.91E+02	7.04E-06	2.48E+02
		1.00E+00	-6.68E+01	1.38E+03	6.00E-02	-7.11E-02	4.00E-03	-1.58E+00	-2.18E-13
7	9	1.00E-05	-3.02E-01	4.00E+00	6.00E-02	-6.07E-12	3.91E+02	6.67E-06	2.50E+02
		1.00E+00	-1.21E+02	1.28E+03	6.00E-02	-7.11E-02	4.00E-03	-1.56E+00	-2.18E-13
8	9	1.00E-05	-3.03E-01	3.31E+00	6.00E-02	-6.07E-12	3.91E+02	6.19E-06	2.55E+02
		1.00E+00	-9.98E+01	1.12E+03	6.00E-02	-7.11E-02	4.00E-03	-1.58E+00	-2.18E-13
9	9	1.00E-05	-1.11E-01	2.88E+00	6.00E-02	-6.07E-12	3.91E+02	5.83E-06	2.58E+02
		1.00E+00	-3.75E+01	1.02E+03	6.00E-02	-7.11E-02	4.00E-03	-1.58E+00	-2.18E-13
10	9	1.00E-05	1.11E-01	2.75E+00	0.	0.	3.91E+02	0.	2.58E+02
		1.00E+00	3.75E+01	9.94E+02	0.	0.	0.	0.	-2.18E-13
1	10	1.00E-05	-1.93E-01	2.38E+00	0.	0.	3.91E+02	0.	0.
		1.00E+00	-6.79E+01	8.91E+02	0.	0.	0.	0.	-2.18E-13
2	10	1.00E-05	1.93E-01	2.18E+00	6.00E-02	-6.07E-12	3.91E+02	5.20E-06	1.85E+02
		1.00E+00	6.79E+01	8.47E+02	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
3	10	1.00E-05	5.04E-01	2.78E+00	6.00E-02	-6.07E-12	3.91E+02	5.42E-06	1.84E+02
		1.00E+00	1.91E+02	8.91E+02	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
4	10	1.00E-05	9.37E-01	3.00E+00	6.00E-02	-6.07E-12	3.91E+02	6.08E-06	1.58E+02
		1.00E+00	2.63E+02	1.03E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
5	10	1.00E-05	8.48E-01	4.40E+00	6.00E-02	-6.07E-12	3.91E+02	7.07E-06	1.47E+02
		1.00E+00	1.68E+02	1.32E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
6	10	1.00E-05	-6.48E-01	7.15E+00	6.00E-02	-6.07E-12	3.91E+02	9.25E-06	1.38E+02
		1.00E+00	-1.88E+02	1.74E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
7	10	1.00E-05	-8.37E-01	4.40E+00	6.00E-02	-6.07E-12	3.91E+02	7.07E-06	1.47E+02
		1.00E+00	-2.63E+02	1.32E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
8	10	1.00E-05	-5.04E-01	3.00E+00	6.00E-02	-6.07E-12	3.91E+02	6.08E-06	1.58E+02
		1.00E+00	-1.91E+02	1.03E+03	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
9	10	1.00E-05	-1.93E-01	2.38E+00	6.00E-02	-6.07E-12	3.91E+02	5.42E-06	1.84E+02
		1.00E+00	-6.79E+01	8.91E+02	6.00E-02	-7.11E-02	4.00E-03	-2.48E+00	-2.18E-13
10	10	1.00E-05	1.93E-01	2.18E+00	0.	0.	3.91E+02	0.	1.85E+02
		1.00E+00	6.79E+01	8.47E+02	0.	0.	0.	0.	-2.18E-13
1	11	1.00E-05	-2.88E-01	1.58E+00	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.11E+02	6.56E+02	0.	0.	0.	0.	-2.18E-13
2	11	1.00E-05	2.93E-01	4.77E-01	6.00E-02	-6.07E-12	3.91E+02	4.34E-06	9.22E+01
		1.00E+00	1.11E+02	6.11E+02	6.00E-02	-7.11E-02	4.00E-03	-3.24E+00	-2.18E-13
3	11	1.00E-05	9.38E-01	1.58E+00	6.00E-02	-6.07E-12	3.91E+02	4.71E-06	9.03E+01
		1.00E+00	3.33E+02	6.55E+02	6.00E-02	-7.11E-02	4.00E-03	-3.25E+00	-2.18E-13
4	11	1.00E-05	1.78E+00	8.90E-01	6.00E-02	-6.07E-12	3.91E+02	5.75E-06	9.12E+01
		1.00E+00	5.52E+02	8.00E+02	6.00E-02	-7.11E-02	4.00E-03	-3.24E+00	-2.18E-13
5	11	1.00E-05	2.47E+00	4.58E+00	6.00E-02	-6.07E-12	3.91E+02	7.08E-06	9.78E+01
		1.00E+00	6.04E+02	1.28E+03	6.00E-02	-7.11E-02	4.00E-03	-3.25E+00	-2.18E-1
6	11	1.00E-05	-2.47E+00	1.04E+01	6.00E-02	-6.07E-12	3.91E+02	1.20E-05	1.38E+01
		1.00E+00	-6.04E+02	2.93E+03	6.00E-02	-7.11E-02	4.00E-03	-3.24E+00	-2.18E-13
7	11	1.00E-05	-1.78E+00	4.58E+00	6.00E-02	-6.07E-12	3.91E+02	7.08E-06	9.78E+01
		1.00E+00	-5.52E+02	1.28E+03	6.00E-02	-7.11E-02	4.00E-03	-3.25E+00	-2.18E-13
8	11	1.00E-05	-0.38E-01	8.90E-01	6.00E-02	-6.07E-12	3.91E+02	5.75E-06	9.12E+01
		1.00E+00	-3.33E+02	8.00E+02	6.00E-02	-7.11E-02	4.00E-03	-3.24E+00	-2.18E-13
9	11	1.00E-05	-2.88E-01	1.58E+00	6.00E-02	-6.07E-12	3.91E+02	4.71E-06	9.03E+01
		1.00E+00	-1.11E+02	6.55E+02	6.00E-02	-7.11E-02	4.00E-03	-3.25E+00	-2.18E-13
10	11	1.00E-05	2.93E-01	4.77E-01	0.	0.	3.91E+02	0.	9.22E+01
		1.00E+00	1.11E+02	6.11E+02	0.	0.	0.	0.	-2.18E-13
1	12	1.00E-05	-1.34E-01	6.24E-01	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.58E+02	3.17E+02	0.	0.	0.	0.	-1.20E-10
2	12	1.00E-03	1.34E-01	2.21E-01	6.00E-02	-8.24E+00	3.01E+02	1.78E-04	4.84E+01
		8.98E-01	1.58E+02	3.21E+02	6.00E-02	-7.11E-02	4.00E-03	-3.77E+00	0.

T= 2.00000E-04 CYCLE 2

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
3	12	1.00E-05	5.62E-01	6.24E-01	6.00E-02	-3.35E-09	3.91E+02	3.72E-06	4.40E+01
		1.00E+00	4.78E+02	3.17E+02	6.00E-02	-7.11E-02	4.00E-03	-3.78E+00	-1.20E-10
4	12	1.66E-03	1.21E+00	2.02E-01	6.00E-02	-8.24E+00	3.01E+02	3.68E-04	3.69E+01
		9.99E-01	1.01E+03	2.91E+02	6.00E-02	-7.11E-02	4.00E-03	-3.77E+00	0.
5	12	1.01E-05	7.25E+00	-7.64E-02	6.00E-02	-2.16E-08	3.90E+02	9.40E-06	1.44E-04
		1.00E+00	2.24E+03	7.57E+00	6.00E-02	-7.11E-02	4.00E-03	-3.78E+00	-7.79E-10
6	12	1.00E-05	-7.25E+00	-3.87E+00	6.00E-02	0.	3.91E+02	4.35E-06	2.21E+01
		1.00E+00	-2.24E+03	-1.42E+03	6.00E-02	2.04E+03	4.00E-03	-3.78E+00	0.
7	12	1.01E-05	-1.21E+00	-7.64E-02	6.00E-02	-2.16E-08	3.90E+02	9.40E-06	0.
		1.00E+00	-1.01E+03	7.57E+00	6.00E-02	-7.11E-02	4.00E-03	-3.78E+00	-7.79E-10
8	12	1.66E-03	-5.62E-01	2.02E-01	6.00E-02	-8.24E+00	3.01E+02	3.68E-04	3.69E+01
		9.99E-01	-4.78E+02	2.91E+02	6.00E-02	-7.11E-02	4.00E-03	-3.77E+00	0.
9	12	1.00E-05	-1.34E-01	6.24E-01	6.00E-02	-3.35E-09	3.91E+02	3.72E-06	4.40E+01
		1.00E+00	-1.56E+02	3.17E+02	6.00E-02	-7.11E-02	4.00E-03	-3.78E+00	-1.20E-10
10	12	1.66E-03	1.34E-01	2.21E-01	0.	0.	3.01E+02	0.	4.54E+01
		9.99E-01	1.56E+02	3.21E+02	0.	0.	4.00E-03	0.	0.
1	13	1.00E-05	-2.98E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.52E+02	0.	0.	0.	0.	0.	-2.18E-13
2	13	1.00E-05	2.98E-01	0.	6.00E-02	-5.79E-09	3.91E+02	1.74E-06	2.28E+01
		1.00E+00	1.52E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.05E+00	-2.09E-10
3	13	1.00E-05	1.03E+00	0.	6.00E-02	-6.07E-12	3.91E+02	2.64E-06	2.43E+01
		1.00E+00	4.52E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
4	13	1.00E-05	1.84E+00	0.	6.00E-02	-5.24E-09	3.91E+02	3.96E-06	2.64E+01
		1.00E+00	7.25E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.05E+00	-1.88E-10
5	13	1.00E-05	1.89E+00	0.	6.00E-02	-6.07E-12	3.91E+02	4.57E-06	3.63E+01
		1.00E+00	7.16E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
6	13	1.00E-05	-1.89E+00	0.	6.00E-02	-6.07E-12	3.91E+02	4.59E-06	7.62E+01
		1.00E+00	-7.16E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
7	13	1.00E-05	-1.84E+00	0.	6.00E-02	-6.07E-12	3.91E+02	4.57E-06	3.63E+01
		1.00E+00	-7.25E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
8	13	1.00E-05	-1.03E+00	0.	6.00E-02	-5.24E-09	3.91E+02	3.96E-06	2.64E+01
		1.00E+00	-4.52E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.05E+00	-1.88E-10
9	13	1.00E-05	-2.98E-01	0.	6.00E-02	-6.07E-12	3.91E+02	2.64E-06	2.43E+01
		1.00E+00	-1.52E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-4.06E+00	-2.18E-13
10	13	1.00E-05	2.98E-01	0.	0.	0.	3.91E+02	0.	2.28E+01
		1.00E+00	1.52E+02	0.	0.	0.	0.	0.	-2.09E-10
1	14	1.00E-05	-2.98E-01	0.	0.	0.	-7.82E+02	0.	0.
		1.00E+00	-1.52E+02	0.	0.	0.	0.	0.	0.
2	14	1.00E-05	2.98E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	1.52E+02	0.	0.	0.	0.	0.	0.
3	14	1.00E-05	1.03E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	4.52E+02	0.	0.	0.	0.	0.	0.
4	14	1.00E-05	1.84E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	7.25E+02	0.	0.	0.	0.	0.	0.
5	14	1.00E-05	1.89E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	7.16E+02	0.	0.	0.	0.	0.	0.
6	14	1.00E-05	-1.89E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-7.16E+02	0.	0.	0.	0.	0.	0.
7	14	1.00E-05	-1.84E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-7.25E+02	0.	0.	0.	0.	0.	0.
8	14	1.00E-05	-1.03E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-4.52E+02	0.	0.	0.	0.	0.	0.
9	14	1.00E-05	-2.98E-01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.52E+02	0.	0.	0.	0.	0.	0.
10	14	1.00E-05	0.	0.	0.	0.	-7.82E+02	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.

T= 1.00000E-03 CYCLE 10

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
5	9	1.00E-05	2.10E+00	3.72E+01	6.00E-02	1.91E-10	3.91E+02	1.25E-05	3.85E+01
		1.00E+00	7.17E+01	1.23E+03	6.00E-02	-7.11E-02	4.00E-03	-1.30E+00	6.88E-12
6	9	1.00E-05	-2.10E+00	4.55E+01	6.00E-02	1.91E-10	3.91E+02	1.32E-05	3.50E+01
		1.00E+00	-7.17E+01	1.36E+03	6.00E-02	-7.11E-02	4.00E-03	-2.81E-01	6.88E-12
7	9	1.00E-05	-3.57E+00	3.72E+01	6.00E-02	1.91E-10	3.91E+02	1.25E-05	3.85E+01
		1.00E+00	-1.29E+02	1.23E+03	6.00E-02	-7.11E-02	4.00E-03	-1.30E+00	6.88E-12
8	9	1.00E-05	-2.73E+00	2.91E+01	6.00E-02	1.91E-10	3.91E+02	1.15E-05	4.28E+01
		1.00E+00	-1.05E+02	1.08E+03	6.00E-02	-7.12E-02	4.00E-03	-5.21E-01	6.89E-12
9	9	1.00E-05	-9.82E-01	2.45E+01	6.00E-02	1.91E-10	3.91E+02	1.08E-05	4.66E+01
		1.00E+00	-3.91E+01	9.83E+02	6.00E-02	-7.12E-02	4.00E-03	-1.01E+00	6.88E-12
10	9	1.00E-05	9.82E-01	2.30E+01	0.	0.	3.91E+02	0.	4.74E+01
		1.00E+00	3.91E+01	9.51E+02	0.	0.	0.	0.	6.89E-12
1	10	1.00E-05	-1.62E+00	1.09E+01	0.	0.	3.91E+02	0.	0.
		1.00E+00	-7.08E+01	8.48E+02	0.	0.	0.	0.	6.89E-12
2	10	1.00E-05	1.62E+00	1.67E+01	6.00E-02	1.91E-10	3.91E+02	9.48E-06	6.44E+01
		1.00E+00	7.08E+01	8.05E+02	6.00E-02	-7.12E-02	4.00E-03	-1.47E+00	6.89E-12
3	10	1.00E-05	4.94E+00	1.09E+01	6.00E-02	1.91E-10	3.91E+02	9.92E-06	6.21E+01
		1.00E+00	1.99E+02	8.48E+02	6.00E-02	-7.12E-02	4.00E-03	-1.06E+00	6.89E-12
4	10	1.00E-05	7.08E+00	2.55E+01	6.00E-02	1.91E-10	3.91E+02	1.12E-05	5.64E+01
		1.00E+00	2.80E+02	9.90E+02	6.00E-02	-7.12E-02	4.00E-03	-1.64E+00	6.89E-12
5	10	1.00E-05	6.56E+00	4.17E+01	6.00E-02	1.91E-10	3.91E+02	1.32E-05	4.52E+01
		1.00E+00	2.03E+02	1.30E+03	6.00E-02	-7.11E-02	4.00E-03	-1.34E+00	6.88E-12
6	10	1.00E-05	-6.56E+00	7.72E+01	6.00E-02	1.91E-10	3.91E+02	1.56E-05	3.55E+01
		1.00E+00	-2.03E+02	1.75E+03	6.00E-02	-7.12E-02	4.00E-03	-9.85E-01	6.89E-12
7	10	1.00E-05	-7.08E+00	4.17E+01	6.00E-02	1.91E-10	3.91E+02	1.32E-05	4.52E+01
		1.00E+00	-2.80E+02	1.30E+03	6.00E-02	-7.11E-02	4.00E-03	-1.34E+00	6.88E-12
8	10	1.00E-05	-4.94E+00	2.55E+01	6.00E-02	1.91E-10	3.91E+02	1.12E-05	5.64E+01
		1.00E+00	-1.99E+02	9.90E+02	6.00E-02	-7.12E-02	4.00E-03	-1.64E+00	6.89E-12
9	10	1.00E-05	-1.62E+00	1.09E+01	6.00E-02	1.91E-10	3.91E+02	9.92E-06	6.21E+01
		1.00E+00	-7.08E+01	8.48E+02	6.00E-02	-7.12E-02	4.00E-03	-1.06E+00	6.89E-12
10	10	1.00E-05	1.62E+00	1.67E+01	0.	0.	3.91E+02	0.	6.44E+01
		1.00E+00	7.08E+01	8.05E+02	0.	0.	0.	0.	6.89E-12
1	11	1.00E-05	-2.21E+00	1.09E+01	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.15E+02	6.15E+02	0.	0.	0.	0.	6.89E-12
2	11	1.15E-05	2.23E+00	2.43E+00	6.00E-02	2.16E-10	3.91E+02	8.37E-06	8.19E+01
		1.00E+00	1.15E+02	5.68E+02	6.00E-02	-7.12E-02	4.00E-03	-1.46E+00	7.78E-12
3	11	1.00E-05	7.66E+00	1.09E+01	6.00E-02	1.91E-10	3.91E+02	8.41E-06	7.98E+01
		1.00E+00	3.41E+02	6.15E+02	6.00E-02	-7.12E-02	4.00E-03	-1.77E+00	6.89E-12
4	11	1.21E-05	1.66E+01	6.56E+00	6.00E-02	2.18E-10	3.91E+02	1.15E-05	7.10E+01
		1.00E+00	5.92E+02	7.34E+02	6.00E-02	-7.12E-02	4.00E-03	-1.57E+00	7.83E-12
5	11	1.00E-05	2.78E+01	3.71E+01	6.00E-02	1.92E-10	3.91E+02	1.43E-05	4.20E+01
		1.00E+00	6.77E+02	1.21E+03	6.00E-02	-7.12E-02	4.00E-03	-1.35E-01	6.90E-12
6	11	1.00E-05	-2.78E+01	1.10E+02	6.00E-02	1.91E-10	3.91E+02	2.37E-05	0.
		1.00E+00	-6.77E+02	3.11E+03	6.00E-02	-7.12E-02	4.00E-03	-3.32E+00	6.89E-12
7	11	1.00E-05	-1.66E+01	3.71E+01	6.00E-02	1.92E-10	3.91E+02	1.43E-05	4.20E+01
		1.00E+00	-5.92E+02	1.21E+03	6.00E-02	-7.12E-02	4.00E-03	-1.35E-01	6.90E-12
8	11	1.21E-05	-7.66E+00	6.56E+00	6.00E-02	2.18E-10	3.91E+02	1.15E-05	7.10E+01
		1.00E+00	-3.41E+02	7.34E+02	6.00E-02	-7.12E-02	4.00E-03	-1.57E+00	7.83E-12
9	11	1.00E-05	-2.21E+00	1.09E+01	6.00E-02	1.91E-10	3.91E+02	8.41E-06	7.98E+01
		1.00E+00	-1.15E+02	6.15E+02	6.00E-02	-7.12E-02	4.00E-03	-1.77E+00	6.89E-12
10	11	1.15E-05	2.23E+00	2.43E+00	0.	0.	3.91E+02	0.	8.19E+01
		1.00E+00	1.15E+02	5.68E+02	0.	0.	0.	0.	7.78E-12
1	12	1.04E-05	-7.07E-01	3.60E+00	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.52E+02	2.92E+02	0.	0.	0.	0.	-3.99E-09
2	12	8.25E-03	7.07E-01	1.16E+00	6.00E-02	-8.24E+00	3.01E+02	2.80E-02	9.79E+01
		9.94E-01	1.52E+02	2.97E+02	6.00E-02	-7.07E-02	4.34E-03	-1.81E+00	0.

T= 1.00000E-03 CYCLE 10

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,DAM	K,D	P,J
3	12	1.04E-05	4.27E+00	3.60E+00	6.00E-02	-1.11E-07	3.91E+02	6.49E-06	9.04E+01
		1.00E+00	4.67E+02	2.92E+02	6.00E-02	-7.12E-02	4.34E-03	-1.95E+00	-3.99E-09
4	12	8.24E-03	9.25E+00	1.99E+00	6.00E-02	-8.24E+00	3.01E+02	5.63E-03	9.68E+01
		9.93E-01	1.01E+03	2.31E+02	6.00E-02	-7.07E-02	4.34E-03	-1.57E+00	0.
5	12	1.76E-05	6.12E+01	-1.03E+00	6.00E-02	-1.55E-08	3.81E+02	2.38E-05	4.55E+01
		1.00E+00	2.33E+03	-1.24E+02	6.00E-02	-7.12E-02	4.00E-03	-2.18E+00	-5.58E-10
6	12	1.03E-05	-6.12E+01	-2.42E+01	6.00E-02	0.	3.91E+02	1.03E-05	4.90E+01
		1.00E+00	-2.33E+03	-1.04E+03	6.00E-02	2.04E+03	4.34E-03	1.03E+00	0.
7	12	1.76E-05	-9.25E+00	-1.03E+00	6.00E-02	-1.55E-08	3.91E+02	2.38E-05	4.55E+01
		1.00E+00	-1.01E+03	-1.24E+02	6.00E-02	-7.12E-02	4.00E-03	-2.18E+00	-5.58E-10
8	12	8.24E-03	-4.27E+00	1.99E+00	6.00E-02	-8.24E+00	3.01E+02	5.63E-03	8.68E+01
		9.93E-01	-4.67E+02	2.31E+02	6.00E-02	-7.07E-02	4.34E-03	-1.57E+00	0.
9	12	1.04E-05	-7.07E-01	3.60E+00	6.00E-02	-1.11E-07	3.91E+02	8.49E-06	9.04E+01
		1.00E+00	-1.52E+02	2.92E+02	6.00E-02	-7.12E-02	4.34E-03	-1.95E+00	-3.99E-09
10	12	8.25E-03	7.07E-01	1.16E+00	0.	0.	3.01E+02	0.	9.79E+01
		9.94E-01	1.52E+02	2.97E+02	0.	0.	4.34E-03	0.	0.
1	13	1.00E-05	-1.32E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.44E+02	0.	0.	0.	0.	0.	6.27E-12
2	13	1.02E-05	1.32E+00	0.	6.00E-02	-1.17E-09	3.88E+02	2.49E-05	1.06E+02
		1.00E+00	1.44E+02	0.	6.00E-02	-7.13E-02	4.00E-03	-1.68E+00	-4.22E-11
3	13	1.00E-05	5.87E+00	0.	6.00E-02	1.74E-10	3.91E+02	4.12E-06	1.08E+02
		1.00E+00	4.29E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-1.95E+00	6.27E-12
4	13	1.11E-05	1.12E+01	0.	6.00E-02	-2.23E-09	3.88E+02	6.60E-06	1.09E+02
		1.00E+00	6.52E+02	0.	6.00E-02	-7.12E-02	4.00E-03	-1.28E+00	-8.04E-11
5	13	1.00E-05	1.08E+01	0.	6.00E-02	8.99E-11	3.91E+02	6.92E-08	1.19E+02
		1.00E+00	5.22E+02	0.	6.00E-02	-7.12E-02	4.00E-03	-5.95E-01	3.24E-12
6	13	1.00E-05	-1.08E+01	0.	6.00E-02	1.91E-10	3.91E+02	6.36E-06	1.70E+02
		1.00E+00	-5.22E+02	0.	6.00E-02	-7.12E-02	4.00E-03	-2.30E+00	6.88E-12
7	13	1.00E-05	-1.12E+01	0.	6.00E-02	8.99E-11	3.91E+02	6.92E-06	1.19E+02
		1.00E+00	-6.52E+02	0.	6.00E-02	-7.12E-02	4.00E-03	-5.95E-01	3.24E-12
8	13	1.11E-05	-5.87E+00	0.	6.00E-02	-2.23E-09	3.88E+02	6.60E-06	1.09E+02
		1.00E+00	-4.29E+02	0.	6.00E-02	-7.12E-02	4.00E-03	-1.28E+00	-8.04E-11
9	13	1.00E-05	-1.32E+00	0.	6.00E-02	1.74E-10	3.91E+02	4.12E-06	1.08E+02
		1.00E+00	-1.44E+02	0.	6.00E-02	-7.11E-02	4.00E-03	-1.95E+00	6.27E-12
10	13	1.02E-05	1.32E+00	0.	0.	0.	3.89E+02	0.	1.06E+02
		1.00E+00	1.44E+02	0.	0.	0.	0.	0.	-4.22E-11
1	14	1.00E-05	-1.32E+00	0.	0.	0.	-3.91E+03	0.	0.
		1.00E+00	-1.44E+02	0.	0.	0.	0.	0.	0.
2	14	1.02E-05	1.32E+00	0.	0.	0.	3.89E+02	0.	0.
		1.00E+00	1.44E+02	0.	0.	0.	0.	0.	0.
3	14	1.00E-05	5.87E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	4.29E+02	0.	0.	0.	0.	0.	0.
4	14	1.11E-05	1.12E+01	0.	0.	0.	3.88E+02	0.	0.
		1.00E+00	6.52E+02	0.	0.	0.	0.	0	0.
5	14	1.00E-05	1.08E+01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	5.22E+02	0.	0.	0.	0.	0.	0.
6	14	1.00E-05	-1.08E+01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-5.22E+02	0.	0.	0.	0.	0.	0.
7	14	1.00E-05	-1.12E+01	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-6.52E+02	0.	0.	0.	0.	0.	0.
8	14	1.11E-05	-5.87E+00	0.	0.	0.	3.88E+02	0.	0.
		1.00E+00	-4.29E+02	0.	0.	0.	0.	0.	0.
9	14	1.00E-05	-1.32E+00	0.	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.44E+02	0.	0.	0.	0.	0.	0.
10	14	1.02E-05	0.	0.	0.	0.	-3.91E+03	0.	0.
		1.00E+00	0.	0.	0.	0.	0.	0.	0.

T= 1.00000E-01 CYCLE 300

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,DAM	K,D	P,J
5	9	1.00E-05	2.99E+01	8.85E+02	6.00E-02	1.05E-08	3.91E+02	7.30E-06	2.42E+02
		1.00E+00	1.29E+02	1.33E+03	6.00E-02	-7.16E-02	4.00E-03	-4.23E-01	6.66E-10
6	9	1.00E-05	-2.99E+01	7.29E+02	6.00E-02	1.05E-08	3.91E+02	8.04E-06	2.39E+02
		1.00E+00	-1.29E+02	1.53E+03	6.00E-02	-7.16E-02	4.00E-03	5.14E-01	6.66E-10
7	9	1.00E-05	-5.28E+01	8.85E+02	6.00E-02	1.05E-08	3.91E+02	7.30E-06	2.42E+02
		1.00E+00	-2.52E+02	1.33E+03	6.00E-02	-7.16E-02	4.00E-03	-4.23E-01	6.66E-10
8	9	1.00E-05	-4.06E+01	5.73E+02	6.00E-02	1.05E-08	3.91E+02	5.93E-06	2.49E+02
		1.00E+00	-1.87E+02	1.02E+03	6.00E-02	-7.16E-02	4.00E-03	-1.20E-02	6.66E-10
9	9	1.00E-05	-1.54E+01	5.02E+02	6.00E-02	1.05E-08	3.91E+02	5.03E-06	2.53E+02
		1.00E+00	-7.56E+01	8.56E+02	6.00E-02	-7.16E-02	4.00E-03	-1.32E-01	6.66E-10
10	9	1.01E-05	1.54E+01	4.78E+02	0.	0.	3.91E+02	0.	2.55E+02
		1.00E+00	7.56E+01	7.92E+02	0.	0.	0.	0.	6.70E-10
1	10	1.37E-05	-2.60E+01	3.21E+02	0.	0.	3.91E+02	0.	0.
		1.00E+00	-1.34E+02	6.43E+02	0.	0.	0.	0.	9.13E-10
2	10	1.44E-05	2.61E+01	3.40E+02	6.00E-02	2.67E-04	3.91E+02	4.49E-06	2.60E+02
		1.00E+00	1.34E+02	5.23E+02	6.00E-02	-7.18E-02	4.00E-03	-2.71E-01	9.60E-10
3	10	1.37E-05	7.00E+01	3.21E+02	6.00E-02	2.54E-08	3.91E+02	6.14E-06	2.57E+02
		1.00E+00	3.46E+02	6.43E+02	6.00E-02	-7.17E-02	4.00E-03	-4.87E-02	9.13E-10
4	10	1.12E-05	1.12E+02	4.64E+02	6.00E-02	2.08E-08	3.91E+02	8.73E-06	2.50E+02
		1.00E+00	5.40E+02	8.23E+02	6.00E-02	-7.16E-02	4.00E-03	-5.31E-01	7.48E-10
5	10	1.04E-05	8.59E+01	6.66E+02	6.00E-02	1.92E-08	3.91E+02	9.33E-06	2.30E+02
		1.00E+00	3.38E+02	1.53E+03	6.00E-02	-7.17E-02	4.00E-03	1.31E+00	6.90E-10
6	10	1.03E-05	-8.59E+01	8.85E+02	6.00E-02	1.90E-08	3.91E+02	1.15E-05	2.22E+02
		1.00E+00	-3.38E+02	2.21E+03	6.00E-02	-7.16E-02	4.00E-03	-2.68E-01	6.84E-10
7	10	1.04E-05	-1.12E+02	6.66E+02	6.00E-02	1.92E-08	3.91E+02	9.33E-06	2.30E+02
		1.00E+00	-5.40E+02	1.53E+03	6.00E-02	-7.17E-02	4.00E-03	1.31E+00	6.90E-10
8	10	1.12E-05	-7.00E+01	4.64E+02	6.00E-02	2.08E-08	3.91E+02	8.73E-06	2.50E+02
		1.00E+00	-3.46E+02	8.23E+02	6.00E-02	-7.16E-02	4.00E-03	-5.31E-01	7.48E-10
9	10	1.37E-05	-2.60E+01	3.21E+02	6.00E-02	2.54E-08	3.91E+02	6.14E-06	2.57E+02
		1.00E+00	-1.34E+02	6.43E+02	6.00E-02	-7.17E-02	4.00E-03	-4.88E-02	9.13E-10
10	10	1.44E-05	2.61E+01	3.40E+02	0.	0.	3.91E+02	0.	2.60E+02
		1.00E+00	1.34E+02	5.23E+02	0.	0.	0.	0.	9.60E-10
1	11	3.62E-05	-4.03E+01	3.32E+01	0.	0.	3.91E+02	0.	0.
		1.00E+00	-2.04E+02	3.83E+02	0.	0.	0.	0.	2.39E-09
2	11	1.04E-05	4.05E+01	5.78E-01	6.00E-02	3.67E-08	3.91E+02	3.30E-06	2.88E+02
		1.00E+00	2.04E+02	1.14E+02	6.00E-02	-7.17E-02	4.00E-03	-1.77E-01	1.32E-09
3	11	3.62E-05	9.04E+01	3.32E+01	6.00E-02	2.65E-08	3.91E+02	1.58E-05	2.63E+02
		1.00E+00	4.65E+02	3.83E+02	6.00E-02	-7.17E-02	4.00E-03	-3.88E-01	2.40E-09
4	11	1.77E-05	2.34E+02	2.09E+01	6.00E-02	5.68E-08	3.91E+02	1.84E-05	2.55E+02
		1.00E+00	1.04E+03	2.48E+02	6.00E-02	-7.17E-02	4.00E-03	9.37E-01	2.04E-09
5	11	1.99E-05	3.21E+02	2.39E+02	6.00E-02	3.50E-08	3.91E+02	2.53E-05	1.94E+02
		1.00E+00	9.71E+02	1.61E+03	6.00E-02	-7.18E-02	4.00E-03	4.11E-01	1.79E-09
6	11	1.40E-05	-3.21E+02	1.19E+03	6.00E-02	2.59E-08	3.91E+02	2.88E-05	1.35E+02
		1.00E+00	-9.71E+02	4.15E+03	6.00E-02	-7.17E-02	4.00E-03	1.75E+00	9.31E-10
7	11	1.99E-05	-2.34E+02	2.38E+02	6.00E-02	3.50E-08	3.91E+02	2.53E-05	1.94E+02
		1.00E+00	-1.04E+03	1.61E+03	6.00E-02	-7.18E-02	4.00E-03	4.10E-01	1.28E-09
8	11	1.77E-05	-9.04E+01	2.09E+01	6.00E-02	5.68E-08	3.91E+02	1.84E-05	2.55E+02
		1.00E+00	-4.65E+02	2.48E+02	6.00E-02	-7.17E-02	4.00E-03	9.37E-01	2.04E-09
9	11	3.62E-05	-4.03E+01	3.32E+01	6.00E-02	6.65E-08	3.91E+02	1.58E-05	2.63E+02
		1.00E+00	-2.04E+02	3.83E+02	6.00E-02	-7.17E-02	4.00E-03	-3.88E-01	2.39E-09
10	11	1.04E-05	4.05E+01	5.78E-01	0.	0.	3.91E+02	0.	2.68E+02
		1.00E+00	2.04E+02	1.14E+02	0.	0.	0.	0.	1.32E-09
1	12	1.34E-02	-2.77E+00	2.54E+01	0.	0.	3.76E+02	0.	0.
		9.87E-01	-1.54E+02	2.57E+02	0.	0.	0.	0.	-7.77E-05
2	12	7.24E-01	2.77E+00	3.47E+00	6.00E-02	-8.24E+00	3.01E+02	3.11E-02	2.83E+02
		2.76E-01	1.54E+02	2.12E+02	6.00E-02	-1.98E-02	5.25E-02	-1.21E-01	0.

T= 1.00000E-01 CYCLE 306

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
3	12	1.34E-02	5.09E+01	2.54E+01	6.00E-02	-2.16E-03	3.76E+02	4.05E-03	2.62E+02
		9.87E-01	1.67E+02	2.57E+02	6.00E-02	1.95E+00	4.09E-02	2.22E-01	-7.78E-05
4	12	4.07E-01	5.26E+01	1.14E+01	6.00E-02	-9.24E+00	3.01E+02	9.18E-02	2.47E+02
		5.93E-01	6.96E+02	1.03E+01	6.00E-02	-4.25E-02	5.25E-02	3.29E-02	0.
5	12	1.52E-02	1.40E+03	3.14E+01	6.00E-02	-1.08E-02	3.28E+02	1.40E-02	9.65E+01
		9.85E-01	2.54E+03	-5.38E+02	6.00E-02	1.00E+01	5.25E-02	-1.10E-01	-3.09E-04
6	12	8.90E-03	-1.40E+03	2.21E+02	6.00E-02	0.	3.91E+02	1.30E-02	0.
		9.91E-01	-2.54E+03	5.04E+02	6.00E-02	1.98E+03	5.25E-02	-2.48E+00	0.
7	12	1.52E-02	-5.26E+01	3.14E+01	6.00E-02	-1.08E-02	3.28E+02	1.40E-02	9.65E+01
		9.85E-01	-6.96E+02	-5.38E+02	6.00E-02	1.00E+01	5.25E-02	-1.10E-01	-3.09E-04
8	12	4.07E-01	-5.09E+01	1.14E+01	6.00E-02	-9.24E+00	3.01E+02	9.18E-02	2.47E+02
		5.93E-01	-1.67E+02	1.03E+01	6.00E-02	-4.25E-02	5.25E-02	3.28E-02	0.
9	12	1.34E-02	-2.77E+00	2.54E+01	6.00E-02	-2.16E-03	3.76E+02	4.05E-03	2.62E+02
		9.87E-01	-1.54E+02	2.57E+02	6.00E-02	1.95E+00	4.09E-02	2.22E-01	-7.77E-05
10	12	7.24E-01	2.77E+00	3.47E+00	0.	0.	3.01E+02	0.	2.03E+02
		2.76E-01	1.54E+02	2.12E+02	0.	0.	5.25E-02	0.	0.
1	13	2.74E-03	-2.84E+00	0.	0.	0.	3.91E+02	0.	0.
		9.97E-01	-1.08E+01	0.	0.	0.	0.	0.	-3.08E-07
2	13	5.02E-02	2.85E+00	0.	6.00E-02	-1.02E-02	3.72E+02	4.73E-03	2.50E+02
		9.50E-01	1.09E+01	0.	6.00E-02	9.44E+00	5.07E-02	2.85E-01	-3.66E-04
3	13	2.74E-03	8.95E+01	0.	6.00E-02	-1.08E-05	3.91E+02	3.87E-04	2.56E+02
		9.97E-01	2.67E+02	0.	6.00E-02	-6.13E-02	4.47E-03	2.30E-01	-3.89E-07
4	13	2.85E-02	1.01E+02	0.	6.00E-02	-9.11E-03	3.65E+02	4.35E-03	2.46E+02
		9.71E-01	2.54E+02	0.	6.00E-02	7.51E+00	4.66E-02	2.13E-01	-2.92E-04
5	13	1.54E-02	1.29E+02	0.	6.00E-02	-1.17E-03	3.84E+02	4.65E-03	2.40E+02
		9.85E-01	-3.25E+02	0.	6.00E-02	1.02E+00	4.27E-02	-3.79E-01	-4.23E-05
6	13	1.13E-01	-1.29E+02	0.	6.00E-02	-3.15E-04	3.91E+02	1.69E-02	3.28E+02
		8.87E-01	3.25E+02	0.	6.00E-02	2.31E-01	4.00E-03	-2.25E+00	-1.13E-05
7	13	1.54E-02	-1.01E+02	0.	6.00E-02	-1.17E-03	3.84E+02	4.65E-03	2.40E+02
		9.85E-01	-2.54E+02	0.	6.00E-02	1.02E+00	4.27E-02	-3.80E-01	-4.20E-05
8	13	2.85E-02	-8.95E+01	0.	6.00E-02	-9.11E-03	3.65E+02	4.35E-03	2.46E+02
		9.71E-01	-2.67E+02	0.	6.00E-02	7.51E+00	4.66E-02	2.13E-01	-2.92E-04
9	13	2.74E-03	-2.84E+00	0.	6.00E-02	-1.08E-05	3.91E+02	3.87E-04	2.56E+02
		9.97E-01	-1.08E+01	0.	6.00E-02	-6.13E-02	4.47E-03	2.30E-01	-3.88E-07
10	13	5.02E-02	2.85E+00	0.	0.	0.	3.72E+02	0.	2.50E+02
		9.50E-01	1.09E+01	0.	0.	0.	0.	0.	-3.66E-04
1	14	2.74E-03	-2.84E+00	0.	0.	0.	-1.51E+05	0.	0.
		9.97E-01	-1.08E+01	0.	0.	0.	0.	0.	0.
2	14	5.02E-02	2.85E+00	0.	0.	0.	3.72E+02	0.	0.
		9.50E-01	1.09E+01	0.	0.	0.	0.	0.	0.
3	14	2.74E-03	8.95E+01	0.	0.	0.	3.91E+02	0.	0.
		9.97E-01	2.67E+02	0.	0.	0.	0.	0.	0.
4	14	2.85E-02	1.01E+02	0.	0.	0.	3.65E+02	0.	0.
		9.71E-01	2.54E+02	0.	0.	0.	0.	0.	0.
5	14	1.54E-02	1.29E+02	0.	0.	0.	3.84E+02	0.	0.
		9.85E-01	-3.25E+02	0.	0.	0.	0.	0.	0.
6	14	1.13E-01	-1.29E+02	0.	0.	0.	3.91E+02	0.	0.
		8.87E-01	3.25E+02	0.	0.	0.	0.	0.	0.
7	14	1.54E-02	-1.01E+02	0.	0.	0.	3.84E+02	0.	0.
		9.85E-01	-2.54E+02	0.	0.	0.	0.	0.	0.
8	14	2.85E-02	-8.95E+01	0.	0.	0.	3.65E+02	0.	0.
		9.71E-01	-2.67E+02	0.	0.	0.	0.	0.	0.
9	14	2.74E-03	-2.84E+00	0.	0.	0.	3.91E+02	0.	0.
		9.97E-01	-1.08E+01	0.	0.	0.	0.	0.	0.
10	14	5.02E-02	0.	0.	0.	0.	-1.51E+05	0.	0.
		9.50E-01	0.	0.	0.	0.	0.	0.	0.

T= 1.00000E+00 CYCLE =227

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
5	9	1.02E-05	6.11E+01	5.87E+02	6.00E-02	9.54E-08	3.91E+02	7.53E-06	1.14E+03
		1.00E+00	2.91E+02	1.22E+03	6.00E-02	-1.01E-01	4.00E-03	6.20E-03	3.43E-09
6	9	1.00E-05	-2.60E+01	7.60E+02	6.00E-02	9.98E-08	3.91E+02	9.13E-06	1.13E+03
		1.00E+00	-7.92E+01	1.75E+03	6.00E-02	1.01E-01	4.00E-03	2.45E-03	3.38E-09
7	9	1.03E-05	-7.33E+01	6.59E+02	6.00E-02	9.62E-08	3.91E+02	8.68E-06	1.13E+03
		1.00E+00	-2.79E+02	1.53E+03	6.00E-02	-1.01E-01	4.00E-03	4.98E-05	3.46E-09
8	9	1.11E-05	-7.15E+01	5.15E+02	6.00E-02	1.04E-07	3.91E+02	7.66E-06	1.14E+03
		1.00E+00	-2.72E+02	1.17E+03	6.00E-02	-1.01E-01	4.00E-03	-2.07E-03	3.74E-09
9	9	1.18E-05	-4.53E+01	4.26E+02	6.00E-02	1.09E-07	3.91E+02	6.90E-06	1.14E+03
		1.00E+00	-1.73E+02	9.44E+02	6.00E-02	-1.01E-01	4.00E-03	2.12E-02	3.91E-09
10	9	1.19E-05	-6.74E+00	3.77E+02	0.	0.	3.91E+02	0.	1.15E+03
		1.00E+00	-5.08E+00	7.90E+02	0.	0.	0.	0.	4.01E-09
1	10	2.53E-05	-9.06E+01	1.69E+02	0.	0.	3.91E+02	0.	0
		1.00E+00	-2.97E+02	7.76E+02	0.	0.	0	0.	7.89E-09
2	10	2.51E-05	-2.77E+01	1.10E+02	6.00E-02	2.37E-07	3.91E+02	1.09E-05	1.15E+03
		1.00E+00	-1.84E+01	5.12E+02	6.00E-02	-1.01E-01	4.00E-03	1.65E-02	8.52E-09
3	10	1.42E-05	7.81E+01	2.34E+02	6.00E-02	1.34E-07	3.91E+02	5.04E-06	1.16E+03
		1.00E+00	2.84E+02	4.68E+02	6.00E-02	-1.01E-01	4.00E-03	-1.32E-02	4.81E-09
4	10	1.55E-05	1.55E+02	2.50E+02	6.00E-02	1.46E-07	3.91E+02	8.20E-06	1.15E+03
		1.00E+00	5.87E+02	5.94E+02	6.00E-02	-1.01E-01	4.00E-03	5.02E-03	5.26E-09
5	10	1.56E-05	1.57E+02	3.85E+02	6.00E-02	1.47E-07	3.91E+02	1.31E-05	1.13E+03
		1.00E+00	7.32E+02	1.07E+03	6.00E-02	-1.01E-01	4.00E-03	4.95E-03	5.28E-09
6	10	1.25E-05	-1.13E+02	9.60E+02	6.00E-02	1.17E-07	3.91E+02	1.77E-05	1.09E+03
		1.00E+00	-3.22E+02	2.80E+03	6.00E-02	-1.01E-01	4.00E-03	-7.86E-03	4.23E-09
7	10	1.70E-05	-1.82E+02	5.14E+02	6.00E-02	1.60E-07	3.91E+02	1.90E-05	1.11E+03
		1.00E+00	-6.04E+02	1.81E+03	6.00E-02	-1.01E-01	4.00E-03	6.06E-03	5.76E-09
8	10	2.11E-05	-1.46E+02	2.55E+02	6.00E-02	1.98E-07	3.91E+02	1.69E-05	1.14E+03
		1.00E+00	-4.65E+02	1.03E+03	6.00E-02	-1.01E-01	4.00E-03	-8.55E-03	7.14E-09
9	10	2.33E-05	-9.06E+01	1.69E+02	6.00E-02	2.19E-07	3.91E+02	1.46E-05	1.15E+03
		1.00E+00	-2.97E+02	7.76E+02	6.00E-02	-1.01E-01	4.00E-03	9.62E-04	7.89E-09
10	10	2.51E-05	-2.77E+01	1.10E+02	0.	0.	3.91E+02	0.	1.15E+03
		1.00E+00	-1.84E+01	5.12E+02	0.	0.	0.	0.	8.52E-09
1	11	3.89E-04	-1.20E+02	3.98E+01	0.	0.	3.91E+02	0.	0.
		1.00E+00	-4.33E+02	6.07E+02	0.	0.	0.	0.	1.13E-07
2	11	4.18E-04	-6.77E+01	1.77E+01	6.00E-02	3.41E-06	3.91E+02	1.13E-04	1.16E+03
		1.00E+00	-3.34E+01	1.13E+02	6.00E-02	-1.04E-01	4.00E-03	-9.04E-03	1.23E-07
3	11	2.60E-05	1.49E+02	2.52E+01	6.00E-02	1.83E-07	3.91E+02	5.63E-06	1.16E+03
		1.00E+00	3.41E+02	9.33E+01	6.00E-02	-1.01E-01	4.00E-03	1.71E-02	6.59E-09
4	11	8.38E-05	3.04E+02	3.33E+01	6.00E-02	5.09E-07	3.91E+02	3.47E-05	1.16E+03
		1.00E+00	8.88E+02	4.70E+01	6.00E-02	-1.01E-01	4.00E-03	-6.18E-03	1.03E-08
5	11	2.15E-04	3.28E+02	1.13E+02	6.00E-02	1.23E-06	3.91E+02	2.25E-04	1.13E+03
		1.00E+00	1.85E+03	1.15E+02	6.00E-02	-1.02E-01	4.00E-03	-3.81E-03	4.42E-08
6	11	8.27E-05	-3.59E+02	1.91E+03	6.00E-02	5.93E-07	3.91E+02	2.28E-04	8.74E+02
		1.00E+00	-1.25E+03	5.90E+03	6.00E-02	-1.01E-01	4.00E-03	4.63E-03	2.10E-08
7	11	2.04E-04	-3.20E+02	2.60E+02	6.00E-02	1.64E-06	3.91E+02	3.12E-04	1.06E+03
		1.00E+00	-1.15E+03	1.71E+03	6.00E-02	-1.02E-01	4.00E-03	-7.02E-03	5.90E-08
8	11	3.25E-04	-1.95E+02	4.55E+01	6.00E-02	2.60E-06	3.91E+02	2.65E-04	1.14E+03
		1.00E+00	-6.02E+02	4.76E+02	6.00E-02	-1.03E-01	4.00E-03	7.68E-03	9.37E-08
9	11	3.98E-04	-1.20E+02	3.98E+01	6.00E-02	3.14E-06	3.91E+02	2.53E-04	1.15E+03
		1.00E+00	-4.33E+02	6.07E+02	6.00E-02	-1.04E-01	4.00E-03	-4.17E-03	1.13E-07
10	11	4.18E-04	-6.77E+01	1.77E+01	0.	0.	3.91E+02	0.	1.16E+03
		1.00E+00	-3.34E+01	1.13E+02	0.	0.	0.	0.	1.23E-07
1	12	4.08E-01	-3.15E+01	1.27E+01	0.	0.	3.32E+02	0.	0.
		5.92E-01	-3.41E+02	1.28E+01	0.	0.	0.	0.	-5.79E-03
2	12	7.29E-01	-1.29E+01	2.14E+01	6.00E-02	-8.24E+00	3.01E+02	2.49E-02	1.18E+03
		2.71E-01	4.52E+01	2.15E+01	6.00E-02	-2.74E-02	1.67E-01	7.89E-03	0.

T= 1.00000E+00 CYCLE 4227

I	J	TH1,TH2	U1,U2	V1,V2	R1,R2	S1,S2	T1,GAM	K,D	P,J
3	12	2.62E-02	6.53E+01	3.40E+01	6.00E-02	-1.48E-03	3.09E+02	1.08E-03	1.17E+03
		9.74E-01	6.52E+01	3.45E+01	6.00E-02	1.30E+00	1.66E-01	-1.39E-02	-5.24E-05
4	12	2.94E-01	1.27E+02	2.05E+01	6.00E-02	-8.24E+00	3.01E+02	1.36E-03	1.18E+03
		7.06E-01	1.28E+02	2.08E+01	6.00E-02	-7.13E-02	1.67E-01	1.12E-02	0.
5	12	9.36E-01	6.02E+01	-1.81E+01	6.00E-02	-4.83E-02	3.19E+02	1.97E+02	0.
		6.41E-02	6.02E+01	-1.81E+01	6.00E-02	4.63E+01	1.67E-01	3.72E-03	-1.74E-03
6	12	1.60E-02	-5.96E+02	-3.64E+00	6.00E-02	2.09E+01	3.90E+02	3.23E-02	1.60E+02
		9.84E-01	-2.10E+03	9.73E+01	6.00E-02	1.78E+03	1.67E-01	-6.10E-02	0.
7	12	1.10E-01	-1.29E+02	-1.09E+01	6.00E-02	-8.11E-02	3.17E+02	1.22E-01	6.59E+02
		8.90E-01	-8.50E+02	-1.13E+01	6.00E-02	7.76E+01	1.67E-01	-1.57E-02	-2.92E-03
8	12	4.17E-01	-4.90E+01	6.39E+00	6.00E-02	-8.24E+00	3.01E+02	9.49E-02	1.08E+03
		5.83E-01	-4.01E+01	6.41E+00	6.00E-02	-5.88E-02	1.67E-01	1.35E-03	0.
9	12	4.08E-01	-3.15E+01	1.27E+01	6.00E-02	-1.61E-01	3.32E+02	7.29E-02	1.02E+03
		5.92E-01	-3.41E+02	1.28E+01	6.00E-02	1.54E+02	9.92E-02	-4.72E-03	-5.79E-03
10	12	7.29E-01	-1.29E+01	2.14E+01	0.	0.	3.01E+02	0.	1.18E+03
		2.71E-01	4.52E+01	2.15E+01	0.	0.	1.67E-01	0.	0.
1	13	9.97E-01	-7.07E+00	0.	0.	0.	3.42E+02	0.	0.
		3.35E-03	-7.07E+00	0.	0.	0.	0.	0.	-6.54E-05
2	13	9.98E-01	8.60E+00	0.	6.00E-02	-1.40E-03	3.22E+02	1.97E+02	9.65E+02
		1.80E-03	8.60E+00	0.	6.00E-02	1.34E+00	1.67E-01	1.82E-04	-5.04E-05
3	13	9.82E-01	9.75E+00	0.	6.00E-02	-8.04E-03	3.50E+02	1.97E+02	8.08E+02
		1.78E-02	9.75E+00	0.	6.00E-02	7.71E+00	1.56E-01	3.42E-04	-2.90E-04
4	13	9.94E-01	1.58E+01	0.	6.00E-02	-3.54E-03	3.38E+02	1.97E+02	9.07E+02
		5.96E-03	1.58E+01	0.	6.00E-02	3.39E+00	1.65E-01	4.61E-04	-1.28E-04
5	13	1.00E+00	-2.76E+00	0.	6.00E-02	-1.24E-04	3.52E+02	1.97E+02	1.20E+03
		2.86E-04	-2.82E+00	0.	6.00E-02	1.19E-01	1.64E-01	-3.53E-04	-4.45E-06
6	13	8.48E-01	-3.90E+00	0.	6.00E-02	-2.27E-02	3.75E+02	6.09E-03	1.51E+03
		1.52E-01	-3.86E+00	0.	6.00E-02	2.17E+01	1.57E-01	-1.13E-03	-8.16E-04
7	13	1.00E+00	-1.49E+01	0.	6.00E-02	-1.84E-05	3.61E+02	1.97E+02	1.20E+03
		5.55E-05	-1.49E+01	0.	6.00E-02	1.76E-02	1.64E-01	-4.54E-05	-6.62E-07
8	13	9.98E-01	-1.23E+01	0.	6.00E-02	-9.10E-04	3.44E+02	1.97E+02	1.09E+03
		1.73E-03	-1.23E+01	0.	6.00E-02	8.72E-01	1.65E-01	5.42E-05	-3.28E-05
9	13	9.97E-01	-7.07E+00	0.	6.00E-02	-1.82E-03	3.42E+02	1.97E+02	9.99E+02
		3.35E-03	-7.07E+00	0.	6.00E-02	1.74E+00	9.46E-02	-3.67E-05	-6.54E-05
10	13	9.98E-01	8.60E+00	0.	0.	0.	3.22E+02	0.	9.65E+02
		1.80E-03	8.60E+00	0.	0.	0.	0.	0.	-5.04E-05
1	14	9.97E-01	-7.07E+00	0.	0.	0.	-1.65E+06	0.	0.
		3.35E-03	-7.07E+00	0.	0.	0.	0.	0.	0.
2	14	9.98E-01	8.60E+00	0.	0.	0.	3.22E+02	0.	0
		1.80E-03	8.60E+00	0.	0.	0	0.	0.	0.
3	14	9.82E-01	9.75E+00	0.	0.	0.	3.50E+02	0.	0.
		1.78E-02	9.75E+00	0.	0.	0	0.	0.	0.
4	14	9.94E-01	1.58E+01	0.	0.	0.	3.38E+02	0.	0.
		5.98E-03	1.58E+01	0.	0.	0.	0.	0.	0.
5	14	1.00E+00	-2.76E+00	0.	0	0.	3.52E+02	0.	0.
		2.86E-04	-2.82E+00	0.	0.	0.	0.	0.	0.
6	14	8.48E-01	-3.90E+00	0.	0.	0.	3.75E+02	0.	0.
		1.52E-01	-3.86E+00	0.	0.	0.	0.	0.	0.
7	14	1.00E+00	-1.49E+01	0.	0.	0.	3.61E+02	0.	0.
		5.55E-05	-1.49E+01	0.	0.	0.	0.	0.	0.
8	14	9.98E-01	-1.23E+01	0.	0.	0.	3.44E+02	0.	0
		1.73E-03	-1.23E+01	0.	0.	0.	0.	0.	0.
9	14	9.97E-01	-7.07E+00	0.	0.	0.	3.42E+02	0.	0
		3.35E-03	-7.07E+00	0	0	0.	0.	0.	0
10	14	9.98E-01	0.	0.	0.	0.	1.65E+06	0.	0.
		1.80E-03	0	0.	0	0	0.	0.	0.

It should be realized that exact agreement with our calculated values may be impossible to attain because of different word lengths on other computers. Also there are differences in various FORTRAN compilers, primarily due to the sequence of machine operations in the code generated, but also due to whether the compiler rounds or truncates results of arithmetic operations. In this sample, the LRLTRAN "CHAT" compiler was used in a version that rounds results. The effect of changing to a different FORTRAN compiler can produce numbers differing in the last bit after the first cycle of calculation. In any typical finite-difference method, as found in most hydrodynamic codes, and especially embodying an iterative solution the effect of this difference will gradually spread throughout all the numbers, even to the point of changing the detailed history of number of iterations in each cycle.

Thus, the user who wishes to compare his K-TIF results with ours is advised to expect an acceptable level of quantitative agreement. He should compare his time history graphs of gallons of water delivered to the lower plenum, and the appearance of the vector and contour plots after hundreds or thousands of cycles of calculation.

The sums of θ_1 and θ_2 over the mesh are also of interest. Table II shows how these sums change over the entire calculation made for Example 2 (the sample problem). Over this time, the balance shifts from almost pure steam to almost pure water. Note that the total sum ($\Sigma\ \theta_1 + \Sigma\ \theta_2$) remains constant, as it should within the degree of accuracy allowed by a corrective procedure designed to eliminate negative volume fractions, in which any that occurs is replaced by 10^{-5}, and the other in that cell is replaced by $1 - 10^{-5}$. This constant total sum is an indication of good overall volume conservation.

TABLE II

TIME HISTORY OF θ SUMS FROM THE CALCULATION OF EXAMPLE 2

Time(sec)	Cycle	$\Sigma\ \theta_1$	$\Sigma\ \theta_2$	$\Sigma\ \theta_1 + \Sigma\ \theta_2$
0	0	$8.97870000 \times 10^{-3}$	8.97861021×10^{2}	$8.978699997 \times 10^{2}$
0.0001	1	$3.20979786 \times 10^{-2}$	8.97836896×10^{2}	$8.978689940 \times 10^{2}$
0.0002	2	$5.52192919 \times 10^{-2}$	8.97871040×10^{2}	$8.979262573 \times 10^{2}$
0.0010	10	$2.40174212 \times 10^{-1}$	8.98117790×10^{2}	$8.983579642 \times 10^{2}$
0.1000	386	1.74072243×10^{1}	8.80470405×10^{2}	$8.978776293 \times 10^{2}$
1.0000	4227	1.00595648×10^{2}	7.97280799×10^{2}	$8.978764470 \times 10^{2}$
5.0000	20763	1.74355472×10^{2}	7.23674184×10^{2}	$8.980296560 \times 10^{2}$
8.8000	29522	8.38840204×10^{2}	5.89799074×10^{1}	$8.978201114 \times 10^{2}$

IV. REFERENCES

1. C. J. Crowley, J. A. Block, and C. N. Cary, "Downcomer Effects in a 1/15-Scale PWR Geometry - Experimental Data Report," Creare, Inc. Hanover, NH, NUREG-0281 (1977).

2. F. H. Harlow and A. A. Amsden, "Numerical Calculation of Multiphase Fluid Flow," J. Comput. Phys. 17, 19-52 (1975).

3. A. A. Amsden and F. H. Harlow, "KACHINA: An Eulerian Computer Program for Multifield Fluid Flows," Los Alamos Scientific Laboratory report LA-5680 (1974).

4. J. R. Travis, F. H. Harlow, and A. A. Amsden, "Numerical Calculation of Two-Phase Flows," Los Alamos Scientific Laboratory report LA-5942-MS (1975); also published in Nucl. Sci. Eng. 61, 1-10 (1976).

5. F. H. Harlow and A. A. Amsden, "Flow of Interpenetrating Material Phases," J. Comput. Phys. 18, 440-464 (1975).

6. A. A. Amsden, T. D. Butler, and F. H. Harlow, "Numerical Study of Downcomer Flow Dynamics, July-December 1976," Los Alamos Scientific Laboratory report LA-NUREG-6797-SR (1977).

7. W. C. Rivard and M. D. Torrey, "Numerical Calculation of Flashing from Long Pipes Using a Two-Field Model," Los Alamos Scientific Laboratory report LA-6104-MS (1975); reissued under LA-NUREG-6330-MS, U. S. Nuclear Regulatory Commission (1976).

8. B. J. Daly, "Nuclear Reactor Safety, Quarterly Progress Report, April 1 - June 30, 1977," LA-NUREG-6934-PR (1977); also, report to be published.

9. J. G. Collier, Convective Boiling and Condensation, McGraw-Hill Publishing Company, London (1972).

10. F. H. Harlow and A. A. Amsden, "Fluid Dynamics - A LASL Monograph," Los Alamos Scientific Laboratory report LA-4700 (1971), p.30.

11. C. W. Hirt, "Heuristic Stability Theory for Finite Difference Equations," J. Comput. Phys. 2, 339 (1968).

12. F. H. Harlow and J. E. Welch, "Numerical Calculation of Time-Dependent Viscous Incompressible Flow," Phys. Fluids. 8, 2182 (1965).

13. F. H. Harlow and A. A. Amsden, "A Numerical Fluid Dynamics Calculation Method for All Flow Speeds," J. Comput. Phys. 8, 197-213 (1971).

14. W. C. Rivard, O. A. Farmer, T. D. Butler, and P. J. O'Rourke, "A Method for Increased Accuracy in Eulerian Fluid Dynamics Calculations," Los Alamos Scientific Laboratory report LA-5426-MS (1973).

APPENDIX

FORTRAN LISTING OF THE K-TIF PROGRAM

(October 20, 1977 Status)

The following listing represents the K-TIF version for the examples described in Sec. III. It is in OLDPL program library form. The programs comprising the library are the set of 16 compiled binary routines or "decks" of Fig. 4. Selective compilation is used to minimize compile time. The CDC UPDATE SOURCE form is recognizable, in which *COMDECK, *DECK, and *CALL statements are used. In addition, a number of special delimiting and identifying lines are automatically inserted when converting from SOURCE to OLDPL. For example, see lines 2-5, 44-45, and 52-57. An advantage of the OLDPL form is that either a text editor or an alterfile can be used to make code changing quite simple and direct. The modified OLDPL is then converted to a CDC UPDATE COMPILE file, with the *COMPILE line identifying the deck(s) to be sent to the COMPILE file. The unchanged decks are loaded directly from the binary library at load time.

Notes:

1. The tests on $(\theta_1 + \theta_2 \rightarrow 1)$ convergence are lacking an outside absolute sign. Affected are lines 676 and 1579, and should be changed to read

```
THTEST=ABS(THTIL1(IJ))+ABS(THTIL2(IJ))-1.
IF(ABS(THTEST).GT.EPSTH) MUSTH=MUSTH+1  .
```

2. Lines 1531 through 1538 can be deleted because their results are never referred to in this code version.

```
 1 *COMPILE,ALL
 2
 3 ---------
 4 COMEQV     DIMEN
 5 COMEQV      0
 6        COMMON /KC1/ AA(1),ACELL,BCELL,BIGJL,BLAMI,B2,CAPPAN,CAPPAI,CCELL,
 7       1             CD,CD04,CNUSX(2),CNUSY(2),CUIN2GL,C1,DT,DTEST,
 8       2             DTF,DTMAX,DTO(10),DTOC(10),DTODX,DTODY,DTPOB,
 9       3             DTSIG,DTUVEL,DTVVEL,DX,DXDY,DXO2,DY,DYO2,
10       4             D1,ELSUBL,EPP,EPSD,EPSTH,FB2,FB2BAR,
11       5             FB2COF,FIXL,FIXR,FIYB,FIYT,FP,G,GDT,HCKW,HFCRIT,
12       6             HFC1,HFMIN,IBAR,IDROP,
13       7             IOTCUT,IOTO,IJ,IPERT,IP1,IP2,IVB(16),
14       8             IVL(16),IVR(16),IVT(16),IXL,IXR,IYB,IYT,
15       9             JBAR,JFSTAR,JGSTAR,JMM,JP1,JP2,JTOPLP,
16       1             JVECLP,LPR,MAXIT,MODS9,MPR,MU(2),
17       2             MUCOF,MUSTID,MUSTIT,MX(2),MY(2),NAME(8),NCDBUG,
18       3             NCS,NCYC,NCYKIL,NCYMAX,NDTZ,NGAB,NG,NGI
19        COMMON /KC2/ NSC,NTAB,NUMIT,NUMTD,NUS(2),OABFL(16),OCELL,OM,RDT,
20       1             RDX,RDXDT,RDXSQ,RDY,RDYSQ,RHO(2),RHO1B1,RHO2COF,
21       2             RRHO(2),RS,RTSATK,R14PT7,
22       3             R2DX,R2DY,S,SA1EACL,SIGIJ,SIGPR,SMDTAU,SP2COF,T,
23       4             TABJG(20),TABP(20),TABT(20),TECCF,TECCK,THMIN,TLIM,
24       5             TLIMD,TOUT,TSATK,TWFIN,TWINF,TWINK,VOLFAC,WE,
25       6             XCONV,XI(16),XL,XR,YB,YCONV,VJ(24),YT,ZLP,ZZ
26 C**********STANDARD RESOLUTION MESH HAS IBAR=16 AND JBAR=22,
27 C**********THUS IP2=JP2=NG REQUIRES 13392 WORDS IN AACS,**********
28 C**********HALF RESOLUTION SCOPING MESH HAS IBAR=8 AND JBAR=12,
29 C**********THUS IP2=JP2=NG REQUIRES 4340 WORDS IN AACS.**********
30        COMMON /KCS/ AACS(4340)
31        EQUIVALENCE (AACS(1),FLAG),(AACS(2),TH1),(AACS(3),TH2),
32       1            (AACS(4),P),(AACS(5),KIJ),(AACS(6),T1),(AACS(7),GAM),
33       2            (AACS(8),R1),(AACS(9),R2),(AACS(10),BIGJ),
34       3            (AACS(11),DTIL),(AACS(12),S1),(AACS(13),S2),
35       4            (AACS(14),U1,UTIL1),(AACS(15),U2,UTIL2),
36       5            (AACS(16),V1,VTIL1),(AACS(17),V2,VTIL2),
37       6            (AACS(18),THU1),(AACS(19),THU2),(AACS(20),THV1),
38                    (AACS(21),THV2),(AACS(22),KIPH,TP1),
39       8            (AACS(23),KJPH),(AACS(24),THTIL1),
40       9            (AACS(25),THTIL2),(AACS(26),THTT1),
41       1            (AACS(27),THTT2,CQ),(AACS(28),UTILP1),
42       2            (AACS(29),UTILP2),(AACS(30),VTILP1),(AACS(31),VTILP2)
43        REAL JFSTAR,JGSTAR,KIJ,KIPH,KJPH,MU,MUCOF,MX,MY,NUS
44
45 DIMEN      0
46        DIMENSION FLAG(1),TH1(1),TH2(1),P(1),KIJ(1),T1(1),GAM(1),R1(1),
47       1          R2(1),BIGJ(1),DTIL(1),S1(1),S2(1),U1(1),UTIL1(1),U2(1),
48       2          UTIL2(1),V1(1),VTIL1(1),V2(1),VTIL2(1),THU1(1),THU2(1),
49       3          THV1(1),THV2(1),KIPH(1),TP1(1),KJPH(1),THTIL1(1),
50       4          THTIL2(1),THTT1(1),THTT2(1),CQ(1),UTILP1(1),UTILP2(1),
51       5          VTILP1(1),VTILP2(1)
52
53 ---------
54  16
55 KTIF      SETUP     CONTROL   SIGLAM    TANVEL    PLTPRTS   PH1LAGR   PH2UV     PH2TH     END
56 PH2DTIL   PMIN      PAVGEPP   NEWTEMP   MOVTHETA  FASE
57 KTIF       1
58 COMEQV
59        PROGRAM KTIF(ITAPE,OTAPE1,TAPE5=ITAPE,TAPE6=OTAPE1)
60        DATA IREP5 /0/
61 C**********102077 VERSION OF K-TIF**********
62 *CALL,COMEQV
63        CALL UNQCHG
64        CALL INSIST(SMITAPE,IREP5)
65        IF(IREP5.NE.-1)) CALL EXIT
66        CALL UNDROP
67        JMM=10HKTIF-LTSS
68        CALL DATEM(D1)
69        CALL TIMEM(C1)
70 10     READ(5,100) IBAR,JBAR,JTOPLP,NTAB,DX,DY,CO,MU,SIGIJ
71        IF(IBAR) 40,30,20
72 20     CALL SETUP
73 30     CALL CONTROL
74        GO TO 10
75 40     CALL EXIT
76 C
77 100    FORMAT(4I4,6F8.3)
78        END
```

```
      SUBROUTINE UNDROP
      LCM (BINJLN),(OBUFFC),(FLMBUFC)
      COMMON /BINJLN/ IBSIZE,IBUFF(5000)
      COMMON /OBUFFC/ OBUFF(2100)
      COMMON /FLMBUFC/ FLMBUF(5000)
      DATA IDUM /0/
      DIMENSION IHEAD(6)
      IBSIZE=5000
      CALL CFL (6HOTAPE1,500000)
      CALL ASSIGN (6,0,6HOTAPE1,0,OBUFF,2100)
      CALL FILMBO
      CALL IDENTBO (12,FLMBUF,5000,1000000,105,IDUM)
      IHEAD(1)=10HK-TIF
      IHEAD(2)=10H
      IHEAD(3)=10H
      IHEAD(4)=10H
      IHEAD(5)=10H
      IHEAD(6)=10H
      CALL HEADBO (12,60,IHEAD,9HBOX T3AAA)
      CALL KEEPFLM (12)
      RETURN
      END
```

```
      SUBROUTINE DROP
      LCM (FLMBUFC)
      COMMON /FLMBUFC/ FLMBUF(5000)
      DATA IDUM /0/
      CALL EMPTY (6)
      CALL DEVICE (5HCLOSE,6HOTAPE1)
      CALL FILMBO
      CALL IDENTBO (12,FLMBUF,5000,1000000,105,IDUM)
      CALL KEEPFLM(12)
      PAUSE 111
      RETURN
      END
```

```
SETUP      2
COMEQV     DIMEN
      SUBROUTINE SETUP
*CALL,COMEQV
*CALL,DIMEN
      DIMENSION KFLAG(2,3),ITA(12)
      DATA KFLAG/13H(9H OBSTACLE),13H(9H A-INLET ),13H(9H B-OUTLET)/
      DATA NL,NR,NB,NT /0,0,0,0/
C**********READ MORE INPUT DATA*****
      READ(5,800) NAME
      READ(5,810) WE,BIGJL,TWINF,TECCF,JFSTAR,S,HFCRIT
      READ(5,820) (TABT(N),N=1,NTAB)
      READ(5,820) (TABP(N),N=1,NTAB)
      READ(5,820) (TABJG(N),N=1,NTAB)
      READ(5,830) T,DT,DTMAX,TLIMD,TWFIN,LPR,MPR,MOD59
      READ(5,820) DTO
      READ(5,820) DTOC
      KT=6
      ASSIGN 110 TO KRET
100   WRITE(KT,800) NAME
      WRITE(KT,840) IBAR,JBAR,JTOPLP,NTAB,DX,DY,CD,MU,SIGIJ
      WRITE(KT,850) WE,BIGJL,TWINF,TECCF,JFSTAR,S,HFCRIT
      WRITE(KT,860)
      DO 109 N=1,NTAB
      WRITE(KT,870) TABT(N),TABP(N),TABJG(N)
109   CONTINUE
      WRITE(KT,880) T,DT,DTMAX,TLIMD,TWFIN,LPR,MPR,MOD59
      WRITE(KT,890) DTO
      WRITE(KT,900) DTOC
      GO TO KRET
110   IF(LPR.EQ.0) GO TO 120
      KT=12
      ASSIGN 120 TO KRET
      GO TO 100
C**********CALCULATE / DEFINE CONTROLLING CONSTANTS*****
120   IP1=IBAR+1
      IP2=IBAR+2
      JP1=JBAR+1
      JP2=JBAR+2
      NQI=IP2*NQ
      XR=FLOAT(IBAR)*DX
      YT=FLOAT(JBAR)*DY
      NSC=LOCF(ZZ)-LOCF(AA)+1
      NCS=LOCF(AACS(JP2*NQI))-LOCF(AACS)+1
      IDTO=1
      TOUT=T+DTO(1)
      DTPOS=DT
      NDTZ=10
      NCYC=NUMTD=NUMIT=NCYMAX=0
      DTF=0.25
      OM=-0.85
      EPSD=4.E-3
      EPSTH=0.02
      THMIN=1.E-5
      CD04=.25*CD
      RDX=1./DX
      RDXSQ=RDX*RDX
      RDY=1./DY
      RDYSQ=RDY*RDY
      DX02=.5*DX
      DY02=.5*DY
      R2DX=.5*RDX
      R2DY=.5*RDY
      DXDY=DX*DY
      VOLFAC=DXDY*S
      RDXDY=RDX*RDY
      MAXIT=500
      NCYKIL=NCDBUG=999999
      TECCK=(5./9.)*(TECCF-32.)+273.15
C**********P(BARS) = P(PSIA)/14.7**********
      R14PT7=1./14.7
      TSATK=117.8*(TABP(1)*R14PT7)**0.223+255.2
      RTSATK=1./TSATK
      TWINK=(5./9.)*(TWINF-32.)+273.15
      G=-32.*12.
C**********DENSITIES RHO(1) AND RHO(2) ARE IN LBS./CU.IN.*****
      RHO(1)=0.036
C**********STEAM DENSITY IS A VARIABLE FUNCTION OF PSIA(T)*****
C**********USING HIRT'S STEAM DENSITY FORMULA
C**********P=(GAMMA-1)*RHO*(ECV+CG*(T-TO)),
C**********WHERE  P IN BARS, (GAMMA-1)=0.07, RHO IN GM./CU.CM.,
C**********        ECV=2.506E+4, CG=6.67, T=TSATK, TO=373.15.
      RHO2COF=0.036*R14PT7/0.07
      RHO(2)=TABP(1)*RHO2COF/(25060.+6.67*(TSATK-373.15))
      RRHO(1)=1./RHO(1)
      RRHO(2)=1./RHO(2)
```

```
C**********ELSUBL=L/RHO1B1, WHERE L=LATENT HEAT OF VAPORIZATION,
C***********=540 CAL/GM; RHO1B1=(0.036 LBS/CU.IN.*1 CAL/(GM*KELVINS)).
C**********THEREFORE ELSUBL IS IN CU.IN. KELVINS/LB.
      ELSUBL=540./0.036
C**********SPECIFIC HEAT OF STEAM TAKEN TO BE 0.49 CAL/(GM*KELVINS),
C**********CONVERTED TO CAL/(LB*KELVINS).....
      B2=0.49*28.350*16.
C********** MINIMUM HEAT FLUX=10 CAL/(CMSQ*SEC)=64.516 CAL/(INSQ*SEC)
      HFMIN=64.516
C**********NOTE -- FOR POOL BOILING (COLLIER), AN APPROPRIATE
C**********CRITICAL HEAT FLUX=25 CAL/(CMSQ*SEC)=161.29 CAL/(INSQ*SEC)
C**********BUT FOR FORCED CONVECTIVE BOILING IN DOWNCOMER, THERE
C**********MIGHT NOT BE A FIXED UPPER LIMIT ON HFCRIT.
C**********RHO1B1=(1 GM/CU.CM)*(1 CAL/(GM*KELVINS)=
C**********16.3871 CAL/(CU.IN.KELVINS)
      RHO1B1=16.3871
C**********KW=0.167 CAL/(CM*KELVINS*SEC)=0.42418 CAL/(IN*KELVINS*SEC)
      HCKW=0.42418
C**********CAPPA WALL (STEEL) = 0.028 INSQ/SEC*****
      CAPPAW=0.028
      CAPPAZ=HCKW/RHO1B1
      HFC1=HFMIN/(S*RHO1B1)
      RS=1./S
C**********CONVERSION FACTOR FROM CUBIC INCHES TO GALLONS*****
      CUIN2GL=7.4805195/(12.**3)
      MUCOF=MU(1)+MU(2)
      IF(MUCOF.NE.0.) MUCOF=4.5*MU(1)*MU(2)/MUCOF
      OCELL=1.
      ACELL=2.
      BCELL=3.
      CCELL=4.0
C**********SIGIJ*DT/DX**2 .LT. 0.25 FOR STABILITY*****
      DTSIG=0.9/(2.*(SIGIJ+1.E-6)*(RDXSQ+RDYSQ))
      GDT=G*DT
      RDT=1./DT
      DTODX=DT*RDX
      DTODY=DT*RDY
C**********SET BLAMZ AT 9/10THS OF STABILITY LIMIT*****
      BLAMZ=0.9/(2.*DT*(RDXSQ+RDYSQ))
      SIGPR=SIGIJ
      DO 129 I=2,IP2
129   XI(I)=DX*(FLOAT(I)-1.5)
      DO 139 J=2,JP2
139   YJ(J)=DY*(FLOAT(J)-1.5)
C**********SETUP FOR MICROFICHE-MICROFILM PLOTS*****
      FP=XL=YB=YY=0.
      FIYB=916.
      XD=XR/(YT-YB)
      IF(XD.LE.1.13556) YY=1.
      FIXL=AMAX1(0.,(511.-450.*XD)*YY)
      FIXR=(511.+450.*XD)*YY+1022.*(1.-YY)
      FIYT=16.*YY+(916.-1022./XD)*(1.-YY)
      XCONV=(FIXR-FIXL)/(XR-XL)
      YCONV=(FIYT-FIYB)/(YT-YB)
      IXL=FIXL
      IXR=FIXR
      IYB=FIYB
      IYT=FIYT
      YLP=FLOAT(JTOPLP)*DY
C**********Z OF LOWER PLENUM = EXP. AREA / KTIF AREA********
      TWOPI=2.*3.141592654
      RTRUE=XR/TWOPI + .5*S
      ATRUE=TWOPI*RTRUE**2
      AKTIF=XR*YLP
      ZLP=ATRUE/AKTIF
      JVECLP=FIYB+(YLP-YB)*YCONV
      JTOPLP=JTOPLP+1
C**********SETUP CELL QUANTITIES, THETA AND T
C**********SPECIFIED, ALL OTHERS SET TO ZERO.*****
C**********FLAG ENTIRE LOWER PLENUM AS C CELLS*****
      DO 179 J=1,JP2
      DO 179 I=1,IP2
      IJ=NQ*(IP2*(J-1)+I-1)+1
      DO 179 N=1,NQ
179   FLAG(IJ+N-1)=0.
      DO 219 J=2,JP1
      DO 219 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      TH1(IJ)=0.
      TH2(IJ)=1.
      T1(IJ)=TWINK
      IF(J.LE.JTOPLP) FLAG(IJ)=CCELL
219   CONTINUE
C**********SETUP OBSTACLES (HOT LEGS), A-CELLS (ECC INLETS)
C**********AND B-CELL (BROKEN INLET), FROM INPUT DATA*****
300   READ(5,910) NOAB
      WRITE(6,920) NOAB
```

```
      IF(LPR.GT.0) WRITE(12,920) NOAB
      PORTS=0.
      NDX=IPERT=0
      DO 359 N=1,NOAB
      READ(5,930) OABFL(N),NL,NR,NB,NT
      L=INT(OABFL(N))
      WRITE(6,KFLAG(1,L))
      IF(LPR.GT.0) WRITE(12,KFLAG(1,L))
      WRITE(6,940) NL,NR,NB,NT
      IF(LPR.GT.0) WRITE(12,940) NL,NR,NB,NT
      IF(OABFL(N).EQ.BCELL) ITB=NR+1
      IF(OABFL(N).NE.ACELL) GO TO 320
      PORTS=PORTS+1.
C**********ITA TABLE COLLECTS I-INDEX OF ALL A-CELLS*****
      NDX=NDX+1
      ITA(NDX)=NR+1
      NLR=NR-NL
      NBT=NT-NB
320   JB=NB+2
      IR=NR+1
      JT=NT+1
      IL=NL+2
      DO 349 J=JB,JT
      DO 349 I=IL,IR
      IJ=NQ*(IP2*(J-1)+I-1)+1
      FLAG(IJ)=OABFL(N)
      IF(FLAG(IJ).EQ.OCELL) T1(IJ)=0.
      IF(FLAG(IJ).EQ.ACELL) T1(IJ)=TECCK
349   CONTINUE
C**********VECTOR COORDINATES, FOR USE IN PLOTS*****
      IVB(N)=FIYB+(FLOAT(NB)*DY-YB)*YCONV
      IVR(N)=FIXL+(FLOAT(NR)*DX-XL)*XCONV
      IVT(N)=FIYB+(FLOAT(NT)*DY-YB)*YCONV
      IVL(N)=FIXL+(FLOAT(NL)*DX-XL)*XCONV
359   CONTINUE
C**********SET IPERT=I OF THE A-CELL LYING FURTHEST FROM THE B-CELL,
C**********WILL PERTURB CELL BELOW FOR 0.3 SEC IN SUBR. PH2UV, Q.V.*****
      MAXDIF=0
      DO 369 N=1,NDX
      NDIF=IABS(ITB-ITA(N))
      MAXDIF=MAX0(MAXDIF,NDIF)
      IF(MAXDIF.EQ.NDIF) IPERT=ITA(N)
369   CONTINUE
C**********SET FLAGS IN COLS. 1 AND IP2 FOR PERIODIC WALLS*****
      DO 379 J=2,JP1
      IL=NQ*(IP2*(J-1)+2-1)+1
      IR=NQ*(IP2*(J-1)+IP1-1)+1
      FLAG(IL-NQ)=FLAG(IR)
      FLAG(IR+NQ)=FLAG(IL)
379   CONTINUE
C**********SET TEMPERATURES INTO BOUNDARY CELLS*****
      DO 389 J=2,JP1
      IL=NQ*(IP2*(J-1)+2-1)+1
      IR=NQ*(IP2*(J-1)+IP1-1)+1
      DO 389 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(I.EQ.2) T1(IJ-NQ)=T1(IR)
      IF(I.EQ.IP1) T1(IJ+NQ)=T1(IL)
      IF(J.EQ.2) T1(IJ-NQI)=T1(IJ)
      IF(J.EQ.JP1) T1(IJ+NQI)=T1(IJ)
389   CONTINUE
C**********WITH ECC INLETS DEFINED, DETERMINE ECC FLUX*****
      RDEN=1./(ABS(G)*XR*(RHO(1)-RHO(2)))
C**********TAUA ASSUMES ALL INLETS HAVE EQUAL AREA**********
      TAUA=DXDY*FLOAT(NLR*NBT)
      SA1EACL=-JFSTAR*XR/(PORTS*TAUA*SQRT(RHO(1)*RDEN))
      FB2BAS=XR/SQRT(RHO(2)*RDEN)
      JGSTAR=TABJG(1)
      FB2=-JGSTAR*FB2BAS
      FB2COF=FB2*RDXDY
      HLP=FLOAT(JTOPLP-1)*DY
      CAPLP=(XR*HLP*S)*CUIN2GL
      WRITE(6,950) PORTS,TAUA,SA1EACL,FB2,CAPLP
      IF(LPR.GT.0) WRITE(12,950) PORTS,TAUA,SA1EACL,FB2,CAPLP
      RETURN
C
800   FORMAT(8A10)
810   FORMAT(7F8.3)
820   FORMAT(10F8.3)
830   FORMAT(5F8.3,3I4)
840   FORMAT(8H   IBAR=,I4/8H   JBAR=,I4/8H JTOPLP=,I4/8H   NTAB=,I4/
     1 5X,3HDX=,1PE12.5/5X,3HDY=,E12.5/5X,3HCD=,E12.5/8H  MU(1)=,E12.5/
     2 8H  MU(2)=,E12.5/8H  SIGIJ=,E12.5)
850   FORMAT(5X,3HNE=,1PE12.5/8H  SIGJL=,E12.5/
     1 8H  TWINF=,E12.5/8H  TECCF=,E12.5/8H JFSTAR=,E12.5/6X,2HS=,E12.5/
     2 8H HFCRIT=,E12.5)
860   FORMAT(/12X,4HTABT,16X,4HTABP,16X,5HTABJG)
```

```
870   FORMAT(1X,3(8X,1PE12.5))
880   FORMAT(/6X,2HT=,1PE12.5/5X,5HDT=,E12.5/8H  DTMAX=,E12.5/8H  TLIMD=
     1 ,E12.5/8H  TWFIN=,E12.5/4X,4HLPR=,I4/4X,4HMPR=,I4/8H  MODSS=,I4)
890   FORMAT(12H  DTO(1-10)=,5(1PE14.5)/12X,5(1PE14.5))
900   FORMAT(12H DTOC(1-10)=,5(1PE14.5)/12X,5(1PE14.5))
910   FORMAT(I4)
920   FORMAT(44H TOTAL NO. OF OBSTACLES AND A AND B PORTS IS,I4)
930   FORMAT(F8.3,4I4)
940   FORMAT(1H+,10X,4H NL=,I4,4H NR=,I4,4H NB=,I4,4H NT=,I4)
950   FORMAT(/42H TOTAL NO. OF A-INLETS (UNBROKEN LEGS) IS ,F2.0,
     1 27H, WHERE THE AREA OF EACH IS,1PE12.5/
     2 31H SA1 OF EACH CELL (ECC FLUX) IS,E13.5,
     3 30H   INITIAL STEAM FLUX (FB2) IS,E13.5/
     4 41H   CALCULATED CAPACITY OF LOWER PLENUM IS,E13.5,9H GALLONS.)
      END
```

```
CONTROL   2
COMEQV    DIMEN
      SUBROUTINE CONTROL
*CALL,COMEQV
*CALL,DIMEN
      DIMENSION VELMX(2)
      DATA TBASE,TL,TIME2 /0.,0.,0./
      CALL SECOND(TBASE)
C**********GET JOB TIME LIMIT*****
      CALL GETJTL(TL)
      WRITE(6,4130)
C**********IBAR=0 SIGNIFIES RESTART*****
      IF(IBAR.EQ.0) GO TO 170
C**********SUBTRACT 2 MINUTES TO ALLOW DUMP TIME AT END*****
      TLIM=TL-120.+(1.-TLIMD)*1.E+10
C**********NEW CYCLE BEGINS HERE.....*****
C**********MODIFY THETA BY SIGMA AND LAMBDA EFFECTS*****
10    CALL SIGLAM
C**********SET TANGENTIAL VELOCITIES ON TOP, LEFT, RIGHT*****
      CALL TANVEL
C**********ONE-LINE SUMMARY PRINT EVERY CYCLE*****
      STAUB1=STAUB2=GLP=0.
      DO 99 J=2,JP1
      DO 99 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(J.LE.JTOPLP) GLP=GLP+TH1(IJ)
      IF(FLAG(IJ).NE.BCELL) GO TO 99
      STAUB1=STAUB1+S1(IJ)
      STAUB2=STAUB2+S2(IJ)
99    CONTINUE
      STAUB1=STAUB1*DXDY
      STAUB2=STAUB2*DXDY
      GLP=GLP*VOLFAC*CUIN2GL
      IF((LPR.GT.0).AND.(MOD(NCYC,2).EQ.0)) WRITE(12,4000)
     1 T,NCYC,DT,NUMIT,SMDTAU,STAUB1,STAUB2,FP,GLP,FB2
      IF((MPR.GT.0).AND.(MOD(NCYC,2).EQ.0)) WRITE(6,4000)
     1 T,NCYC,DT,NUMIT,SMDTAU,STAUB1,STAUB2,FP,GLP,FB2
      IF(MOD(NCYC,MOD59).EQ.0) WRITE(59,4010) T,NCYC,NUMIT,DT,SMDTAU,
     1 FP,GLP
      IF(NCYC.LE.30) GO TO 130
C**********OPTIONALLY, CAN KILL PROBLEM IF (NCYKIL) CYCLES*****
C**********GO THE ITERATION LIMIT (MAXIT)*****
      IF(NUMIT-MAXIT.LT.0) GO TO 120
      NCYMAX=NCYMAX+1
      IF(NCYMAX-NCYKIL.LT.0) GO TO 130
      WRITE(6,4020)
      WRITE(59,4020)
      WRITE(12,4020)
110   TOUT=TWFIN=0.
120   NCYMAX=0
C**********SEE IF IT IS TIME FOR PLOTS AND PRINTS*****
130   IF(T+1.E-10.GE.TOUT) GO TO 140
      IF(NCYC.LE.1) GO TO 150
      IF(NCYC.GE.NCDBUG) GO TO 150
      GO TO 160
C**********ANTICIPATE NEXT DESIRED OUTPUT TIME*****
140   TOUT=TOUT+DTO(IDTO)
      IF(T+1.E-10.LT.DTOC(IDTO)) GO TO 150
C**********ADVANCE TO NEXT SET OF OUTPUT CONTROL DATA*****
      TOUT=DTOC(IDTO)+DTO(IDTO+1)
      IDTO=IDTO+1
150   CALL PLTPRTS
C**********CHECK FOR TIME LIMIT OR PROBLEM FINISH TIME*****
C**********AND DUMP IF SPECIFIED*****
160   IF(IDROP.EQ.1) CALL DROP
      IF(IDROP.EQ.0) GO TO 162
      CALL UNDROP
      IDROP=0
162   CALL SECOND(TIME2)
      IF(TIME2-TBASE.GE.TLIM) GO TO 165
      IF(T.LT.TWFIN) GO TO 180
      IF(TLIMD.EQ.0.) RETURN
C**********DUMP PROCEDURES*****
165   WRITE(6,4030) NUMTD,T,NCYC
      WRITE(59,4030) NUMTD,T,NCYC
      IF(LPR.GT.0) WRITE(12,4030) NUMTD,T,NCYC
      CALL CFL(5HTAPE8,500000)
      CALL ASSIGN(8,0,5HTAPE8)
      WRITE(8) (AA(N),N=1,NSC)
      WRITE(8) (AACS(N),N=1,NCS)
      NUMTD=NUMTD+1
      RETURN
C**********RESTART PROCEDURES*****
170   CALL DEVICE(4HOPEN,5HTAPE7)
      CALL ASSIGN(7,0,5HTAPE7)
      JTD=JBAR
```

```
      JNSC=LOCF(ZZ)-LOCF(AA)+1
      READ(7) (AA(N),N=1,JNSC)
      READ(7) (AACS(N),N=1,NCS)
      CALL DEVICE(5HCLOSE,5HTAPE7)
      IF(JTD.NE.NUMTD) GO TO 175
      NUMTD=NUMTD+1
      TLIM=TL-120.+(1.-TLIMD)*1.E+10
      WRITE(6,4040) JTD
      WRITE(6,4050) NAME,T,NCYC
      WRITE(59,4040) JTD
      WRITE(59,4050) NAME,T,NCYC
      IF(LPR.EQ.0) GO TO 180
      WRITE(12,4040) JTD
      WRITE(12,4050) NAME,T,NCYC
      GO TO 180
175   WRITE(6,4060)
      WRITE(59,4060)
      CALL EXIT
180   MAXIT=50
      IF(NCYC.LE.10) MAXIT=100
      IF(NCYC.LE.4) MAXIT=500
      DTUVEL=DTVVEL=VELMX(1)*VELMX(2)*1.E-10
      DO 189 J=1,JP1
      DO 189 I=1,IP1
      DO 189 N=1,2
      IJA=NO*(IP2*(J-1)+I-1)+N
      DTUVEL=AMAX1(DTUVEL,ABS(U1(IJA)))
      DTVVEL=AMAX1(DTVVEL,ABS(V1(IJA)))
C**********LARGEST UDX/2 OR VDY/2 IN EACH FIELD*****
      VELMX(N)=AMAX1(VELMX(N),ABS(U1(IJA))*DXO2,ABS(V1(IJA))*DYO2)
189   CONTINUE
      DTNUM=1.05*DTPOS
C**********AUTOMATIC NU (A LA SHALAKO 122374), WHERE
C**********NU=UMAX*DX/2 * (F+.5), WHERE F.LT.0.5*****
190   DO 199 N=1,2
      NUS(N)=VELMX(N)*(DTF+0.5)
      CNUSX(N)=NUS(N)*RDXSQ*.25
199   CNUSY(N)=NUS(N)*RDYSQ*.25
C**********TIME STEP CALCULATION*****
C**********USE LARGEST POSSIBLE DT AFTER CYCLE (NDTZ)*****
      DTOLD=DT
C**********DTVEL IS BASED ON LARGEST U OR V IN EITHER FIELD*****
      DTVEL=DTF*AMIN1(DX/DTUVEL,DY/DTVVEL)
C**********DTFASE IS CONCERNED WITH PHASE TRANSITION RATE*****
      DTFASE=ABS(RHO(2)*TSATK/(BIGJL*(TSATK-TECCK)+1.E-10))
      DTPOS=AMIN1(DTVEL,DTFASE,DTSIG,DTNUM,DTMAX)
      IF(DTPOS.LT.1.E-10) GO TO 110
C**********ALLOW DT CUT WHILE (NCYC.LE.NDTZ), BUT NOT DT UP*****
      IF(NCYC.LE.NDTZ.AND.DTPOS.GT.DT) GO TO 200
      DT=DTPOS
C**********HERE, DT IS ADJUSTED TO FIT OUTPUT TIME EXACTLY*****
200   IF((T+DT.GT.TOUT).AND.(TOUT-T.GT.0.02*DTOLD)) DT=TOUT-T
      T=T+DT
      NCYC=NCYC+1
      GDT=G*DT
      RDT=1./DT
      DTODX=DT*RDX
      DTODY=DT*RDY
C**********SET BLAMZ AT 9/10THS OF STABILITY CONDITION*****
      BLAMZ=0.9/(2.*DT*(RDXSQ+RDYSQ))
C**********INTERPOLATE TABULAR DATA FOR STEAM AND PRESSURE RAMPING*****
      N=NTAB
      TIMEFAC=0.
      IF(T.GE.TABT(NTAB)) GO TO 215
      DO 209 N=1,NTAB
      IF(T.GE.TABT(N).AND.T.LT.TABT(N+1)) GO TO 210
209   CONTINUE
210   TIMEFAC=(T-TABT(N))/(TABT(N+1)-TABT(N))
215   PSIA=TABP(N)+TIMEFAC*(TABP(N+1)-TABP(N))
      TSATK=117.8*(PSIA*R14PT7)**0.223+255.2
      RTSATK=1./TSATK
      JGSTAR=TABJG(N)+TIMEFAC*(TABJG(N+1)-TABJG(N))
      FB2=-JGSTAR*FB2BAS
      FB2COF=FB2*RDXDY
      RHO2OLD=RHO(2)
      RHO(2)=PSIA*RHO2COF/(25060.+6.67*(TSATK-373.15))
      RRHO(2)=1./RHO(2)
      SP2COF=(RHO(2)-RHO2OLD)*RDT*RRHO(2)
C**********THE HEART OF THE 3-PHASE CALCULATION*****
C**********FIRST, CALL THE PHASE 1 EXPLICIT LAGRANGIAN CALCULATIONS*****
      IDTCUT=0
      CALL PH1LAGR
      IF(IDTCUT.EQ.1) GO TO 200
C**********(PAVGEPP REQUIRES DTU,V VEL FROM ABOVE)*****
      CALL PAVGEPP
C**********NEXT, BEGIN PHASE 2 BY INITIALIZING TILDE THETAS*****
      CALL PH2TH
```

```
      NUMIT=0
C**********THEN, CALCULATE U AND V TILDE VELOCITIES*****
220   CALL PH2UV
C**********.....AND NEW THETA TILDES BASED ON THESE VELOCITIES*****
      CALL PH2TH
      IF(NUMIT.EQ.0) GO TO 230
      IF(NUSTID.EQ.0 .OR. NUMIT.EQ.MAXIT) GO TO 240
C**********.....AND NEW D TILDES.  LOOP UNTIL CONVERGENCE MET*****
230   CALL PH2DTIL
      GO TO 220
C**********NORMALIZE THE RESULTING PRESSURE FIELD*****
240   CALL PMIN
C**********PHASE 3 CALCULATES THE NEW TEMPERATURE FIELD*****
      CALL NEWTEMP
C**********FINALLY, MOVE THETAS TO N-TIME STORAGE*****
      CALL MOVTHETA
      GO TO 10
      RETURN
4000  FORMAT (2H T,1PE9.2,2H C,I5,3H DT,E9.2,3H IT,I3,3H DV,E9.2,4H SB1,
     1        E9.2,4H SB2,E9.2,4H  FP,E9.2,4H GLP,E9.2,4H FB2,E9.2)
4010  FORMAT(2H T,1PE9.2,2H C,I5,3H IT,I3,3H DT,E9.2,4H  DV,E9.2,
     1        3H FP,E9.2,4H GLP,E9.2)
4020  FORMAT (51H MAXIT CUTOFF FOR 10 CONSECUTIVE CYCLES - RUN ABORT)
4030  FORMAT(11H  TAPE DUMP,I3,6H AT T=,1PE12.5,6H CYCLE,I5)
4040  FORMAT(20H  RESTARTING FROM TD,I3)
4050  FORMAT(3X,8A10,5H   T=,1PE12.5,6H CYCLE,I5)
4060  FORMAT(46H ABORT - DUMP NUMBER IS NOT THE ONE REQUESTED.)
4130  FORMAT (1H1)
      END
```

```
SIGLAM     2
COMEQV    DIMEN
      SUBROUTINE SIGLAM
C**********THIS SUBROUTINE MAKES 2 MODIFICATIONS TO VOL. FRAC. FIELDS******
C**********1ST, INCORPORATE THE**********
C**********TURBULENT DIFFUSION OF THETA1 AND THETA2*****
C**********AT PRESENT, SIGIJ IS A CONSTANT.  NOTE IT IS SET TO*****
C**********ZERO AT BOUNDARIES.*****
*CALL,COMEQV
*CALL,DIMEN
10    DO 19 J=2,JP1
      IL=NQ*(IP2*(J-1)+2-1)
      IR=NQ*(IP2*(J-1)+IP1-1)
      DO 19 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 19
      IMJ=IJ-NQ
      IPJ=IJ+NQ
      IJM=IJ-NQI
      IJP=IJ+NQI
      SIGIMH=SIGIPH=SIGJMH=SIGJPH=SIGIJ
      IF(FLAG(IMJ).EQ.OCELL) SIGIMH=0.
      IF(FLAG(IPJ).EQ.OCELL) SIGIPH=0.
      IF(J.EQ.2.OR.FLAG(IJM).EQ.OCELL) SIGJMH=0.
      IF(J.EQ.JP1.OR.FLAG(IJP).EQ.OCELL) SIGJPH=0.
      DO 18 N=1,2
      IJA=IJ+N-1
      IMJA=IJA-NQ
      IPJA=IJA+NQ
      IJMA=IJA-NQI
      IJPA=IJA+NQI
      IF(I.EQ.2) TH1(IMJA)=TH1(IR+N)
      IF(I.EQ.IP1) TH1(IPJA)=TH1(IL+N)
      THTIL1(IJA)=TH1(IJA) + DT*(RDXSQ*(SIGIPH*(TH1(IPJA)-TH1(IJA) )
     1                                 -SIGIMH*(TH1(IJA) -TH1(IMJA)))
     2                           +RDYSQ*(SIGJPH*(TH1(IJPA)-TH1(IJA) )
     3                                 -SIGJMH*(TH1(IJA) -TH1(IJMA))))
18    CONTINUE
19    CONTINUE
      HBLAMZ=.5*BLAMZ
      NUMTH=0
      CALL BND
C**********2ND, A CORRECTIVE PROCEDURE **********
C**********ITERATE TO BRING (THETA1+THETA2) CLOSER TO UNITY*****
C**********IN EVERY CELL.  IF ANY LAMBDA IS CALCULATED TO BE NEGATIVE,**
C**********TAKE IT = 0.  AT BOUNDARIES, LAMBDA = 0.*****
20    MUSTH=0
      DO 29 J=2,JP1
      DO 29 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 29
      IMJ=IJ-NQ
      IPJ=IJ+NQ
      IJM=IJ-NQI
      IJP=IJ+NQI
      THL=THTIL1(IJ)+THTIL2(IJ)-THTIL1(IMJ)-THTIL2(IMJ)
      THR=THTIL1(IPJ)+THTIL2(IPJ)-THTIL1(IJ)-THTIL2(IJ)
      THB=THTIL1(IJ)+THTIL2(IJ)-THTIL1(IJM)-THTIL2(IJM)
      THT=THTIL1(IJP)+THTIL2(IJP)-THTIL1(IJ)-THTIL2(IJ)
      DO 28 N=1,2
      IJA=IJ+N-1
      IMJA=IJA-NQ
      IPJA=IJA+NQ
      IJMA=IJA-NQI
      IJPA=IJA+NQI
      BLAML=AMAX1(HBLAMZ*(THTIL1(IJA)+THTIL1(IMJA)),0.)
      BLAMR=AMAX1(HBLAMZ*(THTIL1(IJA)+THTIL1(IPJA)),0.)
      BLAMB=AMAX1(HBLAMZ*(THTIL1(IJA)+THTIL1(IJMA)),0.)
      BLAMT=AMAX1(HBLAMZ*(THTIL1(IJA)+THTIL1(IJPA)),0.)
      IF(FLAG(IMJ).EQ.OCELL) BLAML=0.
      IF(FLAG(IPJ).EQ.OCELL) BLAMR=0.
      IF(J.EQ.2.OR.FLAG(IJM).EQ.OCELL) BLAMB=0.
      IF(J.EQ.JP1.OR.FLAG(IJP).EQ.OCELL) BLAMT=0.
      THTT1(IJA)=THTIL1(IJA) + DT*(RDXSQ*(BLAMR*THR-BLAML*THL)
     1                           +RDYSQ*(BLAMT*THT-BLAMB*THB))
28    CONTINUE
29    CONTINUE
      DO 34 J=2,JP1
      DO 34 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 34
      THTIL1(IJ)=THTT1(IJ)
      THTIL2(IJ)=THTT2(IJ)
      IF((ABS(THTIL1(IJ))+ABS(THTIL2(IJ))-1.).GT.EPSTH) MUSTH=MUSTH+1
34    CONTINUE
      CALL BND
```

See notes at beginning of Appendix

```
35    NUMTH=NUMTH+1
      IF(MUSTH.GT.0.AND.NUMTH.LT.MAXIT) GO TO 20
C**********AFTER ITERATION HAS CONVERGED, IF ANY THETA IS LESS THAN
C**********ZERO, SET IT TO ZERO AND THE OTHER THETA TO UNITY.*****
C**********(SMDTAU REQD FOR CYCLIC PRINT UPON RETURN TO CONTROL.)*****
      SMDTAU=0.
      DO 39 J=2,JP1
      DO 39 I=2,IP1
      IJ=NQ*(IP2*(J-1)+1-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 39
      SMDTAU=SMDTAU+DTIL(IJ)
      IF(THTIL1(IJ).GE.THMIN) GO TO 36
      THTIL1(IJ)=THMIN
      THTIL2(IJ)=1.-THMIN
      GO TO 39
36    IF(THTIL2(IJ).GE.THMIN) GO TO 39
      THTIL1(IJ)=1.-THMIN
      THTIL2(IJ)=THMIN
39    CONTINUE
      SMDTAU=SMDTAU*DXDY
      CALL BND
      CALL MOVTHETA
      RETURN
      END
```

```
TANVEL---  2
COMEQV     DIMEN
      SUBROUTINE TANVEL
C**********SET TANGENTIAL VELOCITIES ON BOTTOM, TOP, LEFT, AND RIGHT***
*CALL,COMEQV
*CALL,DIMEN
50    DO 59 J=1,JP1
      IL=NQ*(IP2*(J-1)+2-1)
      IR=NQ*(IP2*(J-1)+IP1-1)
      DO 59 I=1,IP1
      DO 59 N=1,2
      IJA=NQ*(IP2*(J-1)+I-1)+N
      IJPA=IJA+NQI
      IPJA=IJA+NQ
      IF(J.EQ.1) U1(IJA)=U1(IJPA)
      IF(J.EQ.JP1) U1(IJPA)=U1(IJA)
      IF(I.EQ.1) V1(IJA)=V1(IR+N)
      IF(I.EQ.IP1) V1(IPJA)=V1(IL+N)
59    CONTINUE
      RETURN
      END
```

```
PLTPRTS    2
COMEQV    DIMEN
      SUBROUTINE PLTPRTS
C**********THIS ROUTINE PRODUCES PLOTS ON FILM OR FICHE*****
C**********OR, A COLOR MOVIE INSTEAD IF (LPR=0)*****
C**********IF (LPR.GT.0) THOUGH, IT SUPPLEMENTS THE PLOTS*****
C**********WITH NUMERICAL PRINTOUTS*****
C**********AVAILABLE COLOR CHOICES ARE AS FOLLOWS*****
C**********0.0 = WHITE   (NO FILTER)
C**********1.0 = RED     (MAGENTA + YELLOW FILTERS)
C**********1.5 = YELLOW  (YELLOW FILTER)
C**********2.0 = GREEN   (YELLOW + CYAN FILTERS)
C**********2.5 = CYAN    (CYAN FILTER)
C**********3.0 = BLUE    (CYAN + MAGENTA FILTERS)
C**********3.5 = MAGENTA (MAGENTA FILTER)
*CALL,COMEQV
*CALL,DIMEN
      DIMENSION CON(11),IDCON(2,7),IDFLD(3,2),IDVV(2,2),IX1(1),IX2(1),
     1          IY1(1),IY2(1),SE(1),SINTE(1),SKE(1),SPS(8),STH(1),
     2          VELMX(2),X1(4),Y1(4)
      EQUIVALENCE (SPS,IX1,STH),(SPS(2),IX2,SINTE),(SPS(3),IY1,SKE),
     1            (SPS(4),IY2,SE)
      DATA IDVV  /13H(9H VELOCITY),13H(9H VELTHETA)/
      DATA IDFLD /21H(1H+,10X,9H FIELD 1,),21H(1H+,10X,9H FIELD 2,)/
      DATA IDCON /17H(12H VOL.FRAC. 1),17H(12H VOL.FRAC. 2),
     1            17H(12H PRESSURE   ),17H(12H DRAG (=K)  ),
     2            17H(12H TEMP. 1    ),17H(12H GAMMA      ),
     3            17H(12H R1         )/
C**********FIRST, DO THE 4 VECTOR-TYPE PLOTS*****
300   IF(LPR.EQ.0) GO TO 400
C**********OUTER LOOP - NVP=1 - VELOCITIES *****
C**********                NVP=2 - VELTHETAS*****
      DO 359 NVP=1,2
      FNVP=FLOAT(NVP-1)
      VELMX(1)=VELMX(2)=0.
      DO 319 J=2,JP1
      DO 319 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      DO 319 N=1,2
      IJA=IJ+N-1
      THFAC=FNVP*(TH1(IJA)-1.)+1.
      UTERM=ABS(THFAC*.5*(U1(IJA)+U1(IJA-NQ)))
      VTERM=ABS(THFAC*.5*(V1(IJA)+V1(IJA-NQI)))
319   VELMX(N)=AMAX1(VELMX(N),UTERM,VTERM)
C**********INNER LOOP ON N PLOTS EACH FIELD IN TURN*****
      DO 349 N=1,2
      IF(VELMX(N).LT.1.E-10) GO TO 349
      DXOU=DX02/VELMX(N)
C**********DRAW ALL FRAMING*****
      ASSIGN 330 TO KRF
      GO TO 360
330   WRITE(12,IDVV(1,NVP))
      WRITE(12,IDFLD(1,N))
      WRITE(12,4070) VELMX(N)
      DO 339 J=2,JP1
      Y1=YJ(J)
      IY1=FIYB+(Y1-YB)*YCONV
      DO 339 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 339
      IJA=IJ+N-1
      X1=XI(I)
      THFAC=FNVP*(TH1(IJA)-1.)+1.
      X2=X1+(U1(IJA-NQ)+U1(IJA))*DXOU*THFAC
      Y2=Y1+(V1(IJA-NQI)+V1(IJA))*DXOU*THFAC
      IX1=FIXL+(X1-XL)*XCONV
      IX2=FIXL+(X2-XL)*XCONV
      IY2=FIYB+(Y2-YB)*YCONV
      IF(IY2.GE.1) GO TO 335
C**********VECTOR WITH (IY2.LT.1) WOULD BE OMITTED, SO*****
C**********SET IY2 TO 1 AND INTERPOLATE FOR IX2*****
      IX2=IX1+(IX2-IX1)*(IY1-1)/(IY1-IY2)
      IY2=1
335   CALL DRV(IX1,IY1,IX2,IY2)
      CALL PLT(IX1,IY1,16)
339   CONTINUE
349   CONTINUE
359   CONTINUE
      GO TO 400
C**********START PLOT BY ADVANCING FRAME, AND DRAW BOUNDARIES*****
360   CALL ADV(1)
      IF(LPR.EQ.0) CALL COLOR(3.0)
      CALL FRAME(IXL,IXR,IYB,IYT)
C**********OUTLINE ALL OBSTACLES AND A AND B CELLS*****
      DO 369 NV=1,NOAB
      IF(OABFL(NV).NE.OCELL) GO TO 365
```

```
C**********DRAW AN X ACROSS THE HOT LEG OBSTACLE CELLS*****
      CALL DRV(IVL(NV),IVB(NV),IVR(NV),IVT(NV))
      CALL DRV(IVL(NV),IVT(NV),IVR(NV),IVB(NV))
365   CALL DRV(IVL(NV),IVB(NV),IVR(NV),IVB(NV))
      CALL DRV(IVR(NV),IVB(NV),IVR(NV),IVT(NV))
      CALL DRV(IVL(NV),IVT(NV),IVR(NV),IVT(NV))
      CALL DRV(IVL(NV),IVB(NV),IVL(NV),IVT(NV))
369   CONTINUE
C**********DRAW LINE ACROSS TOP OF LOWER PLENUM*****
      CALL DRV(IXL,JVECLP,IXR,JVECLP)
370   CALL LINCNT(59)
      IF(LPR.GT.0) WRITE(12,4080) JNM,D1,C1,NAME,T,NCYC
C**********KRF=330 IF VECTORS, 460 OR 470 IF CONTOURS*****
      GO TO KRF
C**********SECOND, DO THE CONTOUR-TYPE PLOTS*****
400   IF(IBAR.EQ.1.OR.JBAR.EQ.1) GO TO 600
      LPL=7
      IF(LPR.EQ.0) LPL=1
      DO 599 L=1,LPL
      QMN=1.E+20
      QMX=-QMN
      DO 409 J=2,JP1
      DO 409 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 409
      CQ(IJ)=FLAG(IJ+L)
C**********LIMIT R1 PLOT TO THE SMALLER VALUES OF INTEREST*****
      IF(L.EQ.7) CQ(IJ)=AMIN1(CQ(IJ),0.4*S)
      QMN=AMIN1(QMN,CQ(IJ))
      QMX=AMAX1(QMX,CQ(IJ))
409   CONTINUE
C**********LINEAR PLOTS ONLY IN THIS VERSION*****
      XX=QMX-QMN
C**********SKIP PLOT IF INSUFFICIENT FIELD VARIATION*****
      IF(XX.LT.1.E-5) GO TO 599
C**********DETERMINE THE 11 ALLOWED CONTOUR VALUES*****
C**********ADDING 1.E-10 ENSURES CON(11).GT.QMX*****
      DQ=0.1*(XX+1.E-10)
      DO 449 IC=1,11
449   CON(IC)=QMN+FLOAT(IC-1)*DQ
      IC=11
C**********GO BACK TO 360 DRAW ALL FRAMING*****
      ASSIGN 460 TO KRF
      IF(LPR.EQ.0) ASSIGN 470 TO KRF
      GO TO 360
460   WRITE(12,IDCON(1,L))
      WRITE(12,4090) QMN,QMX,CON(1),CON(IC-1),DQ
      IF(L.EQ.5) WRITE(12,4100) TSATK
      GO TO 480
470   CALL COLOR(3.5)
C**********CONSIDER CELLS GROUPED IN QUADRANTS - IJ,IPJ,IJP,IPJP*****
480   DO 589 J=2,JBAR
      Y1(1)=Y1(2)=YJ(J)
      Y1(3)=Y1(4)=YJ(J+1)
      DO 579 I=2,IBAR
      X1(1)=X1(3)=XI(I)
      X1(2)=X1(4)=XI(I+1)
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IPJ=IJ+NQ
      IJP=IJ+NQI
      IPJP=IJP+NQ
C**********DRAW ALL CONTOUR SEGMENTS PASSING THRU THE AREA BOUNDED
C**********BY THE CENTERS OF THE FOUR CELLS**********
      DO 569 IK=1,IC
      KC1=KC2=KC3=KC4=0
      IF(FLAG(IJ)  .NE.OCELL.AND.CQ(IJ)  .LE.CON(IK)) KC1=1
      IF(FLAG(IPJ) .NE.OCELL.AND.CQ(IPJ) .LE.CON(IK)) KC2=1
      IF(FLAG(IJP) .NE.OCELL.AND.CQ(IJP) .LE.CON(IK)) KC3=1
      IF(FLAG(IPJP).NE.OCELL.AND.CQ(IPJP).LE.CON(IK)) KC4=1
C**********IF PRODUCT .NE. 0, THEN ALL 4 ARE = 1.
C**********IF SUM .EQ. 0, THEN ALL 4 ARE = 0.  FOR EITHER
C**********OF THESE, THE CONTOUR DOES NOT PASS THROUGH, SO
C**********IT GOES TO 569 TO TRY NEXT CONTOUR VALUE ON IK LOOP.*****
      IF(KC1*KC2*KC3*KC4.NE.0.OR.KC1+KC2+KC3+KC4.EQ.0) GO TO 569
C**********LL COUNTS NO. OF POINTS.  PLOTS WHEN LL=2*****
      LL=0
      IF(KC1+KC3.NE.1) GO TO 510
C**********CONTOUR ACROSS LEFT.....*****
      IC1=1
      IC2=3
      IJ1=IJ
      IJ2=IJP
      ASSIGN 510 TO KR1
      GO TO 540
510   IF(KC1+KC2.NE.1) GO TO 520
C**********CONTOUR ACROSS BOTTOM.....*****
      IC1=1
```

```
      IC2=2
      IJ1=IJ
      IJ2=IPJ
      ASSIGN 520 TO KR1
      GO TO 540
520   IF(KC2+KC4.NE.1) GO TO 530
C**********CONTOUR ACROSS RIGHT.....*****
      IC1=2
      IC2=4
      IJ1=IPJ
      IJ2=IPJP
      ASSIGN 530 TO KR1
      GO TO 540
530   IF(KC3+KC4.NE.1) GO TO 569
C**********CONTOUR ACROSS TOP.....*****
      IC1=3
      IC2=4
      IJ1=IJP
      IJ2=IPJP
      ASSIGN 569 TO KR1
C**********IF EITHER CELL IS AN OBSTACLE, DO NOT DRAW CONTOUR*****
540   IF(FLAG(IJ1).EQ.OCELL.OR.FLAG(IJ2).EQ.OCELL) GO TO KR1
      LL=LL+1
      XX=(CON(IK)-CQ(IJ1))/(CQ(IJ2)-CQ(IJ1))
      IX1(LL)=FIXL+(X1(IC1)+XX*(X1(IC2)-X1(IC1))-XL)*XCONV
      IY1(LL)=FIYB+(Y1(IC1)+XX*(Y1(IC2)-Y1(IC1))-YB)*YCONV
      IF(LL.LT.2) GO TO KR1
C**********WHEN LL=2, BOTH POINTS ARE CALCULATED, SO DRAW VECTOR*****
      CALL DRV(IX1,IY1,IX2,IY2)
      IF(LPR.EQ.0) GO TO 550
      IF(IK.EQ.1) CALL PLT(IX1,IY1,35)
      IF(IK.EQ.IC-1) CALL PLT(IX1,IY1,24)
550   LL=0
C**********GOES TO 520 IF IT JUST CONNECTED LEFT AND BOTTOM
      IF(IJ2.EQ.IPJ) GO TO 520
569   CONTINUE
579   CONTINUE
589   CONTINUE
599   CONTINUE
C**********THIRD, DO THE LONG PRINT OF CELL QUANTITIES*****
      IF(LPR.EQ.0) GO TO 800
C**********INITIALIZE RETURNS FOR FILM, PRINT, OR FILM+PRINT*****
600   ASSIGN 640 TO KRF
      KRP=KRF
      ASSIGN 689 TO KRFP
      GO TO (660,620,680),LPR
620   ASSIGN 680 TO KRF
      ASSIGN 670 TO KRFP
      GO TO 660
640   KRF=KRFP
      ASSIGN 689 TO KRP
      DO 699 J=1,JP2
      DO 689 I=1,IP2
C**********TO BYPASS EXTERIOR CELLS, ADD TEST.....
C**********IF(I=1 OR I=IP2 OR J=1 OR J=JP2) GO TO 689*****
      L=NQ*(IP2*(J-1)+I-1)+1
      GO TO (650,650,670),LPR
650   WRITE(12,4110) I,J,TH1(L),U1(L),V1(L),R1(L),S1(L),T1(L),KIJ(L),P(L
     1 ),TH2(L),U2(L),V2(L),R2(L),S2(L),GAM(L),DTIL(L),BIGJ(L)
      LINESF=LINESF+2
      IF(LINESF.LT.59) GO TO KRF
C**********NEW FILM FRAME*****
660   CALL ADV(1)
      WRITE(12,4080) JNM,D1,C1,NAME,T,NCYC
      WRITE(12,4120)
      LINESF=3
      GO TO KRF
670   WRITE(6,4110) I,J,TH1(L),U1(L),V1(L),R1(L),S1(L),T1(L),KIJ(L),P(L)
     1 ,TH2(L),U2(L),V2(L),R2(L),S2(L),GAM(L),DTIL(L),BIGJ(L)
      GO TO KRP
C**********ON FANFOLD, HEADER APPEARS ONLY AT START OF PRINT*****
680   WRITE(6,4130)
      WRITE(6,4080) JNM,D1,C1,NAME,T,NCYC
      WRITE(6,4120)
      GO TO KRP
689   CONTINUE
699   CONTINUE
C**********FINALLY, DO A SHORT PRINT OF THETA AND ENERGY SUMS*****
700   DO 709 N=1,8
709   SPS(N)=0.
      DO 749 J=2,JP1
      DO 749 I=2,IP1
      DO 739 N=1,2
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 749
      IJA=IJ+N-1
      IMJA=IJA-NQ
```

```
      IJMA=IJA-NQI
      NN=4*(N-1)+1
      STH(NN)=STH(NN)+TH1(IJA)
      IF(N.EQ.1) SIE=TH1(IJ)*T1(IJ)
      IF(N.EQ.2) SIE=TH2(IJ)
      SINTE(NN)=SINTE(NN)+SIE
      STKE=TH1(IJA)*.25*(U1(IJA)**2+U1(IMJA)**2+V1(IJA)**2+V1(IJMA)**2)
      SKE(NN)=SKE(NN)+STKE
739   CONTINUE
749   CONTINUE
      STH(1)=STH(1)*VOLFAC
      STH(5)=STH(5)*VOLFAC
      SINTE(1)=SINTE(1)*RHO1B1*VOLFAC
      SINTE(5)=SINTE(5)*RHO(2)*B2*VOLFAC*TSATK
      SKE(1)=SKE(1)*VOLFAC*RHO(1)
      SKE(5)=SKE(5)*VOLFAC*RHO(2)
      SE(1)=SINTE(1)+SKE(1)
      SE(5)=SINTE(5)+SKE(5)
      IF(LPR.GT.0) WRITE(12,4140) T,NCYC,(SPS(N),N=1,8)
      IF(LPR.GE.2) WRITE( 6,4140) T,NCYC,(SPS(N),N=1,8)
800   CONTINUE
      RETURN
C
4070  FORMAT(1H+,22X,8HMAXIMUM=,1PE12.5)
4080  FORMAT(5X,A10,2(5X,A8),5X,8A10/40X,3H T=,1PE12.5,6H CYCLE,I5)
4090  FORMAT(1H+,15X,5H MIN=,1PE12.5,5H MAX=,E12.5,3H L=,E12.5,3H H=,E12
     1 .5,4H DQ=,E12.5)
4100  FORMAT(1H+,96X,6HTSATK=,1PE12.5)
4110  FORMAT(2I4,8(1PE10.2)/8X,8(E10.2))
4120  FORMAT(54H  I   J    TH1,TH2    U1,U2     V1,V2     R1,R2     S1,,
     1 31HS2     T1,GAM     K,D       P,J)
4130  FORMAT(1H1)
4140  FORMAT(/3H T=,1PE12.5,6H CYCLE,I5,8H SUMTH1=,1PE15.8,9H SUMSIE1=,
     1 E15.8,8H SUMKE1=,E15.8,7H SUME1=,E15.8/26X,8H SUMTH2=,E15.8,
     2 9H SUMSIE2=,E15.8,8H SUMKE2=,E15.8,7H SUME2=,E15.8)
      END
```

```
PRTCAGR   2
COMEQV    DIMEN
      SUBROUTINE PH1LAGR
C**********THE PHASE 1 EXPLICIT LAGRANGIAN CALCULATIONS*****
C**********S1,S2,  R1,R2,  K, D TEST, THU1,THU2,  THV1,THV2*****
*CALL,COMEQV
*CALL,DIMEN
1000  DO 1049 J=2,JP1
      DO 1049 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 1049
      S1(IJ)=S2(IJ)=0.
1049  CONTINUE
C**********PHASE TRANSITION CALC. OF BIGJ, S1,S2 FIELDS, AND FP*****
      CALL FASEJ
1050  SUMA=SUMB=SUMC=SUMSP2=0.
      DO 1059 J=2,JP1
      DO 1059 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 1059
      SP2=SP2COF*TH2(IJ)
      SUMSP2=SUMSP2+SP2
      S2(IJ)=S2(IJ)+SP2
      IF(FLAG(IJ).NE.ACELL) GO TO 1055
C**********WATER FLUX IS SPECIFIED IN A (ECC INLET) CELLS*****
      S1(IJ)=SA1EACL
      SUMA=SUMA+SA1EACL
      GO TO 1059
1055  IF(FLAG(IJ).NE.BCELL) GO TO 1057
C**********IN THE B (BROKEN COLD LEG) CELL, THE PROCEDURE IS*****
C**********TO USE A SUM OF THE FLUXES (BIGH) TO DETERMINE THE OUTFLOW***
C**********REMOVE WATER AND STEAM IN PROPORTION TO THEIR LOCAL THETAS.**
      THIJ1=TH1(IJ)
      THIJ2=TH2(IJ)
      IF(THIJ1.LT.0.01) THIJ1=0.
      IF(THIJ2.LT.0.01) THIJ2=0.
      SUMB=SUMB+DXDY*(THIJ1+THIJ2)
      GO TO 1059
1057  IF(FLAG(IJ).NE.CCELL) GO TO 1059
C**********IN LOWER PLENUM, ADD SC2 TO S2(IJ) (FROM PHASE TRANS.)***
      SUMC=SUMC+TH2(IJ)
1059  CONTINUE
      IF(SUMC.NE.0.) RSUMC=1./SUMC
1060  STAUA=DXDY*SUMA
      SP2CON=DXDY*SUMSP2
      BIGH=-(FP+FB2+STAUA+SP2CON)/SUMB
      HS1=AMAX1(0.,BIGH)
      DTS12=DT
      DO 1069 J=2,JP1
      DO 1069 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).NE.BCELL) GO TO 1067
      THIJ1=TH1(IJ)
      THIJ2=TH2(IJ)
      IF(THIJ1.LT.0.01) THIJ1=0.
      IF(THIJ2.LT.0.01) THIJ2=0.
C**********ALLOW WATER OR STEAM TO LEAVE SYSTEM, BUT IF*****
C**********BIGH.LT.0., FORCE THE INFLUX TO BE PURE STEAM.....*****
      S1(IJ)=HS1*THIJ1
      S2(IJ)=S2(IJ)+BIGH*(THIJ1+THIJ2)-S1(IJ)
      IF(S1(IJ).GT.0.) DTS12=AMIN1(DTS12,.75*TH1(IJ)/S1(IJ))
      IF(S2(IJ).GT.0.) DTS12=AMIN1(DTS12,.75*TH2(IJ)/S2(IJ))
      GO TO 1069
1067  IF(FLAG(IJ).NE.CCELL) GO TO 1069
      S2(IJ)=S2(IJ)+FB2COF*TH2(IJ)*RSUMC
1069  CONTINUE
C**********AT THIS POINT, S1(IJ)=S(ABC)1 + BIGJ(IJ)/RHO(1),
C**********          AND  S2(IJ)=S(ABC)2 - BIGJ(IJ)/RHO(2) + SP2.
      IF(DTS12.EQ.DT) GO TO 1080
      IF(DTS12.GE.0.1*DT) GO TO 1070
      WRITE(6,4020) DTS12,DT
      WRITE(12,4020) DTS12,DT
1070  T=T-DT
      NCYC=NCYC-1
      DT=DTS12
      IDTCUT=1
      RETURN
1080  CDCOF=CD04*RHO(1)*RHO(2)
      DVEL=0.
      DO 1099 J=2,JP1
      DO 1099 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 1099
      IMJ=IJ-NQ
      IJM=IJ-NQI
      DU=U1(IJ)-U2(IJ)+U1(IMJ)-U2(IMJ)
```

```
      DV=V1(IJ)-V2(IJ)+V1(IJM)-V2(IJM)
C**********WE.GT.1.0 IMPLIES THE USE OF A**********
C**********CONSTANT-WEBER-NUMBER CALCULATION OF R1 AND R2,*****
C**********DALY'S TWO-PASS METHOD.....*****
C**********BUT WE.LT.1.0 IMPLIES WE=CONSTANT R INSTEAD.*****
      IF(WE.GT.1.0) GO TO 1082
      VEC=.5*SQRT(DU**2+DV**2)
      R1(IJ)=R2(IJ)=WE
      GO TO 1087
 1082 IRLOOP=0
      U12=.5*DU
      V12=.5*DV
      VEC=U12**2+V12**2
 1085 R1(IJ)=R2(IJ)=WE*3.2E-2/(RHO(2)*VEC+1.E-6)
      VEC=SQRT(VEC)
 1087 RTERM=(1./R1(IJ) + 1./R2(IJ))**2
      OLDK=KIJ(IJ)
C**********KIJ IS THE INTERFACIAL FRICTION (MOMENTUM EXCHANGE)***
C**********FUNCTION K.....*****
      KIJ(IJ)=1.5*TH1(IJ)*TH2(IJ)*RTERM*CDCOF*VEC*R1(IJ)*R2(IJ)
     1          / (R1(IJ)*RHO(2)+R2(IJ)*RHO(1)) + 1.E-6
      IF(WE.LT.1.0) GO TO 1090
      IF(NCYC.GT.1) KIJ(IJ)=.75*OLDK+.25*KIJ(IJ)
      IF(IRLOOP.EQ.1) GO TO 1090
      IRLOOP=1
      R1PK=1./(1.+KIJ(IJ)*DT*(RRHO(1)/(TH1(IJ)+1.E-6)
     1                        +RRHO(2)/(TH2(IJ)+1.E-6)))
      U12=U12*R1PK
      V12=V12*R1PK
      VEC=0.5*(VEC**2+U12**2+V12**2)
      GO TO 1085
C**********VISCOUS TERM, INCLUDES SURFACE SHEAR ONLY.....*****
 1090 VISK=MUCOF*RTERM
      KIJ(IJ)=KIJ(IJ)+VISK
C**********COUPLE RAREFIED FIELD TO DOMINANT FIELD TO REDUCE*****
C**********ACCELERATIONS THAT LIMIT DT.....*****
      IF(TH2(IJ).LT.0.1) KIJ(IJ)=RHO(1)/DTPOS
      IF(WE.LT.1.0 .AND. NCYC.GT.1) KIJ(IJ)=.5*(OLDK+KIJ(IJ))
      DVEL=AMAX1 (DVEL,(R2DX*(ABS(U1(IJ))+ABS(U1(IMJ)))
     1                 +R2DY*(ABS(V1(IJ))+ABS(V1(IJM))))*TH1(IJ),
     2                 (R2DX*(ABS(U2(IJ))+ABS(U2(IMJ)))
     3                 +R2DY*(ABS(V2(IJ))+ABS(V2(IJM))))*TH2(IJ))
 1099 CONTINUE
      DTEST=EPSD*(DVEL+1.E-6)
 1100 DO 1149 J=2,JP1
      DO 1149 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 1149
      IPJ=IJ+NQ
      IF(FLAG(IPJ).EQ.OCELL) GO TO 1149
      MX(1)=MX(2)=0.
      CALL FASEMX
      IMJ=IJ-NQ
      IJM=IJ-NQI
      IPJM=IJM+NQ
      IJP=IJ+NQI
      IPJP=IJP+NQ
      DO 1139 N=1,2
      NM1=N-1
      IJA=IJ+NM1
      IPJA=IPJ+NM1
      IMJA=IMJ+NM1
      IJMA=IJM+NM1
      IPJMA=IPJM+NM1
      IJPA=IJP+NM1
      IPJPA=IPJP+NM1
      THBRC=THTRC=0.
      IF(J.EQ.2) GO TO 1110
      IF(FLAG(IJM).EQ.OCELL.OR.FLAG(IPJM).EQ.OCELL) GO TO 1110
C**********CORNER-CENTERED THBRC, THTRC TERMS FOR VX (032476)****
      THBRC=.5*AMIN1(TH1(IJMA)+TH1(IPJMA),TH1(IJA)+TH1(IPJA))
 1110 IF(J.EQ.JP1) GO TO 1120
      IF(FLAG(IJP).EQ.OCELL.OR.FLAG(IPJP).EQ.OCELL) GO TO 1120
      THTRC=.5*AMIN1(TH1(IJA)+TH1(IPJA),TH1(IJPA)+TH1(IPJPA))
C**********VX TERM AS IN KACHINA (082274)*****
 1120 VX1=CNUSX(N)*(TH1(IPJA)*(U1(IPJA)-U1(IJA) )
     1                -TH1(IJA) *(U1(IJA) -U1(IMJA)))
     2   +CNUSY(N)*(THTRC*(U1(IJPA)-U1(IJA))-THBRC*(U1(IJA)-U1(IJMA)))
      UC=.5*(U1(IJA)+U1(IMJA))
      UR=.5*(U1(IJA)+U1(IPJA))
C**********EXTERIOR THETAS STORED ON INFLOW BOUNDARY*****
      THUJP=.5*(TH1(IJPA)+TH1(IPJPA))*U1(IJPA)
      THUJM=.5*(TH1(IJMA)+TH1(IPJMA))*U1(IJMA)
      THUIM=.5*(TH1(IJA)+TH1(IMJA))*U1(IMJA)
      THURB=.5*(TH1(IJA)+TH1(IPJA))*U1(IJA)
      IRA=IPJA+NQ
      IF(I.EQ.IP1) IRA=NQ*(IP2*(J-1)+3-1)+N
```

```
      THUIP=.5*(TH1(IPJA)+TH1(IRA))*U1(IPJA)
      VBRC=.5*(V1(IJMA)+V1(IPJMA))
      VTRC=.5*(V1(IJA)+V1(IPJA))
      XIC=SIGN(.5,UC)
      XIR=SIGN(.5,UR)
      XIBR=SIGN(.5,VBRC)
      XITR=SIGN(.5,VTRC)
      SP2TERM=FLOAT(NM1) * SP2COF*.5*(TH2(IJ)+TH2(IPJ))*U2(IJ)
      THU1(IJA)=THURB+DT*
     1    (RDX*(UC*((.5+XIC)*THUIM+(.5-XIC)*THURB)
     2          -UR*((.5+XIR)*THURB+(.5-XIR)*THUIP))
     3                +RDY*(VBRC*((.5+XIBR)*THUJM+(.5-XIBR)*THURB)
     4                      -VTRC*((.5+XITR)*THURB+(.5-XITR)*THUJP))
     5     -SP2TERM + MX(N)*RRHO(N) + VX1)
 1139 CONTINUE
 1149 CONTINUE
C**********CALCULATE K(I+1/2,J)**********
      DO 1199 J=2,JP1
      IR=NQ*(IP2*(J-1)+IP1-1)+1
      IL=NQ*(IP2*(J-1))+1
      DO 1199 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.0CELL) GO TO 1199
      IPJ=IJ+NQ
      IMJ=IJ-NQ
      IF(I.EQ.2) GO TO 1160
      IF(FLAG(IMJ).EQ.0CELL) GO TO 1165
      GO TO 1170
 1160 KIPH(IMJ)=.5*(KIJ(IJ)+KIJ(IR))
      GO TO 1170
 1165 KIPH(IMJ)=KIJ(IJ)
 1170 IF(I.EQ.IP1) GO TO 1180
      IF(FLAG(IPJ).EQ.0CELL) GO TO 1185
      GO TO 1190
 1180 KIPH(IJ)=KIPH(IL)
      GO TO 1199
 1185 KIPH(IJ)=KIJ(IJ)
      GO TO 1199
 1190 KIPH(IJ)=.5*(KIJ(IJ)+KIJ(IPJ))
 1199 CONTINUE
 1200 DO 1249 J=2,JBAR
      DO 1249 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.0CELL) GO TO 1249
      IJP=IJ+NQI
      IF(FLAG(IJP).EQ.0CELL) GO TO 1249
      MY(1)=MY(2)=0.
      CALL FASEMY
      IMJ=IJ-NQ
      IPJ=IJ+NQ
      IJM=IJ-NQI
      IMJP=IJP-NQ
      IPJP=IJP+NQ
      DO 1239 N=1,2
      NM1=N-1
      IJA=IJ+NM1
      IJPA=IJP+NM1
      IMJA=IMJ+NM1
      IPJA=IPJ+NM1
      IJMA=IJM+NM1
      IMJPA=IMJP+NM1
      IPJPA=IPJP+NM1
      THTLC=THTRC=0.
      IF(FLAG(IMJ).EQ.0CELL.OR.FLAG(IMJP).EQ.0CELL) GO TO 1210
C**********CORNER-CENTERED THTLC, THTRC TERMS FOR VY (Q32476)****
      THTLC=.5*AMIN1(TH1(IMJA)+TH1(IMJPA),TH1(IJA)+TH1(IJPA))
 1210 IF(FLAG(IPJ).EQ.0CELL.OR.FLAG(IPJP).EQ.0CELL) GO TO 1220
      THTRC=.5*AMIN1(TH1(IJA)+TH1(IJPA),TH1(IPJA)+TH1(IPJPA))
C**********VY TERM AS IN KACHINA (082274)*****
 1220 VY1=CNUSX(N)*(THTRC*(V1(IPJA)-V1(IJA))-THTLC*(V1(IJA)-V1(IMJA)))
     1   +CNUSY(N)*(TH1(IJPA)*(V1(IJPA)-V1(IJA))
     2              -TH1(IJA) *(V1(IJA) -V1(IJMA)))
      VC=.5*(V1(IJA)+V1(IJMA))
      VT=.5*(V1(IJA)+V1(IJPA))
      THVIM=.5*(TH1(IMJA)+TH1(IMJPA))*V1(IMJA)
      THVIP=.5*(TH1(IPJA)+TH1(IPJPA))*V1(IPJA)
C**********EXTERIOR THETAS STORED ON INFLOW BOUNDARY*****
      THVJM=.5*(TH1(IJMA)+TH1(IJA))*V1(IJMA)
      THVTB=.5*(TH1(IJA)+TH1(IJPA))*V1(IJA)
      THVJP=.5*(TH1(IJPA)+TH1(IJPA+NQI))*V1(IJPA)
      UTLC=.5*(U1(IMJA)+U1(IMJPA))
      UTRC=.5*(U1(IJA)+U1(IJPA))
      XIC=SIGN(.5,VC)
      XIT=SIGN(.5,VT)
      XITL=SIGN(.5,UTLC)
      XITR=SIGN(.5,UTRC)
      SP2TERM=FLOAT(NM1) * SP2COF*.5*(TH2(IJ)+TH2(IJP))*V2(IJ)
```

```
      THV1(IJA)=THVTB+DT*
     1     (RDY*(VC*((.5+XIC)*THVJM+(.5-XIC)*THVTB)
     2          -VT*((.5+XIT)*THVTB+(.5-XIT)*THVJP))
     3  +RDX*(UTLC*((.5+XITL)*THVIM+(.5-XITL)*THVTB)
     4      -UTRC*((.5+XITR)*THVTB+(.5-XITR)*THVIP))
     5      -SP2TERM + MY(N)*RRHO(N) + VY1)
 1239 CONTINUE
 1249 CONTINUE
C*********CALCULATE K(I,J+1/2)**********
      DO 1299 J=2,JP1
      DO 1299 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 1299
      IJP=IJ+NQI
      IJM=IJ-NQI
      IF(J.EQ.2) GO TO 1260
      IF(FLAG(IJM).NE.OCELL) GO TO 1270
 1260 KJPH(IJM)=KIJ(IJ)
 1270 IF(J.EQ.JP1) GO TO 1280
      IF(FLAG(IJP).NE.OCELL) GO TO 1290
 1280 KJPH(IJ)=KIJ(IJ)
      GO TO 1299
 1290 KJPH(IJ)=.5*(KIJ(IJ)+KIJ(IJP))
 1299 CONTINUE
      RETURN
C
 4020 FORMAT(34H WARNING - DTS12.LT.0.1*DT, DTS12=,1PE9.2,4H DT=,E9.2)
      END
```

```
PH2UV      2
COMEQV    DIMEN
      SUBROUTINE PH2UV
C**********THE TILDE AND TILDE PRIME VELOCITY CALCULATION*****
*CALL,COMEQV
*CALL,DIMEN
2000  DO 2049 J=2,JP1
C**********MOD GIVES THE REMAINDER OF J/2.  THIS CONTROLS A*****
C**********CHECKERBOARD PATTERN (+1 IF J IS ODD, -1 IF J IS EVEN),*****
C**********FOR + OR - EPP, IN THE FORMATION OF TILDE PRIMES*****
      CHECKER=2*MOD(J,2)-1
      IL=NQ*(IP2*(J-1)+2-1)+1
      DO 2049 I=2,IP1
C**********INVERT FOR EACH COLUMN IN THE ROW.....*****
      CHECKER=-CHECKER
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 2049
      IPJ=IJ+NQ
      IJP=IJ+NQI
      IF(FLAG(IPJ).EQ.OCELL) GO TO 2049
      THRB1=.5*(THTIL1(IJ)+THTIL1(IPJ))
      THRB2=.5*(THTIL2(IJ)+THTIL2(IPJ))
      IF(I.EQ.IP1) P(IPJ)=P(IL)
      PDIF=DTODX*(P(IJ)-P(IPJ))
      BS=RHO(1)*THU1(IJ)+THRB1*PDIF
      CS=RHO(2)*THU2(IJ)+THRB2*PDIF
      PIJ=P(IJ)+EPP*CHECKER
      PIPJ=P(IPJ)-EPP*CHECKER
      PDIFP=DTODX*(PIJ-PIPJ)
      BSP=RHO(1)*THU1(IJ)+THRB1*PDIFP
      CSP=RHO(2)*THU2(IJ)+THRB2*PDIFP
C*********PERTURB CELL BELOW A-CELL FURTHEST FROM B-CELL, FOR 0.3 SEC.
      IF(T.GT.0.30) GO TO 2020
      IF(FLAG(IJP).EQ.ACELL .AND. IPERT.EQ.I) GO TO 2010
      IF(FLAG(IPJ+NQI).NE.ACELL) GO TO 2020
      IF(I.LT.IP1 .AND. IPERT.EQ.I+1) GO TO 2010
      IF(I.EQ.IP1 .AND. IPERT.EQ.2) GO TO 2010
      GO TO 2020
2010  GXDT=0.50*0.0625*DT*SA1EACL**2*DX
      PERT1=RHO(1)*THRB1*GXDT
      PERT2=RHO(2)*THRB2*GXDT
      BS=BS+PERT1
      CS=CS+PERT2
      BSP=BSP+PERT1
      CSP=CSP+PERT2
2020  CONTINUE
      RFS=1./(THRB1*THRB2*RHO(1)*RHO(2)+KIPH(IJ)*DT*(THRB1*RHO(1)+THRB2*
     1 RHO(2)))
      UTERM=KIPH(IJ)*DT*(BS+CS)
      UTIL1(IJ)=(THRB2*RHO(2)*BS+UTERM)*RFS
      UTIL2(IJ)=(THRB1*RHO(1)*CS+UTERM)*RFS
      UTERMP=KIPH(IJ)*DT*(BSP+CSP)
      UTILP1(IJ)=(THRB2*RHO(2)*BSP+UTERMP)*RFS
      UTILP2(IJ)=(THRB1*RHO(1)*CSP+UTERMP)*RFS
2049  CONTINUE
2050  DO 2099 J=2,JBAR
      CHECKER=2*MOD(J,2)-1
      DO 2099 I=2,IP1
      CHECKER=-CHECKER
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 2099
      IJP=IJ+NQI
      IF(FLAG(IJP).EQ.OCELL) GO TO 2099
      THTB1=.5*(THTIL1(IJ)+THTIL1(IJP))
      THTB2=.5*(THTIL2(IJ)+THTIL2(IJP))
      PDIF=DTODY*(P(IJ)-P(IJP))
      DS=RHO(1)*THV1(IJ)+THTB1*PDIF+RHO(1)*THTB1*GDT
      ES=RHO(2)*THV2(IJ)+THTB2*PDIF+RHO(2)*THTB2*GDT
      PIJ=P(IJ)+EPP*CHECKER
      PIJP=P(IJP)-EPP*CHECKER
      PDIFP=DTODY*(PIJ-PIJP)
      DSP=RHO(1)*THV1(IJ)+THTB1*PDIFP+RHO(1)*THTB1*GDT
      ESP=RHO(2)*THV2(IJ)+THTB2*PDIFP+RHO(2)*THTB2*GDT
      RGS=1./(THTB1*THTB2*RHO(1)*RHO(2)+KJPH(IJ)*DT*(THTB1*RHO(1)+THTB2*
     1 RHO(2)))
      VTERM=KJPH(IJ)*DT*(DS+ES)
      VTIL1(IJ)=(THTB2*RHO(2)*DS+VTERM)*RGS
      VTIL2(IJ)=(THTB1*RHO(1)*ES+VTERM)*RGS
      VTERMP=KJPH(IJ)*DT*(DSP+ESP)
      VTILP1(IJ)=(THTB2*RHO(2)*DSP+VTERMP)*RGS
      VTILP2(IJ)=(THTB1*RHO(1)*ESP+VTERMP)*RGS
2099  CONTINUE
      RETURN
      END
```

```
PH2TH----   2
COMEQV     DIMEN
      SUBROUTINE PH2TH
C**********THE THETA TILDE CALCULATION*****
*CALL,COMEQV
*CALL,DIMEN
2100  DO 2139 J=2,JP1
      DO 2139 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.0CELL) GO TO 2139
      IMJ=IJ-NQ
      IPJ=IJ+NQ
      IJM=IJ-NQI
      IJP=IJ+NQI
      DO 2129 N=1,2
      IJA=IJ+N-1
      IMJA=IL=IJA-NQ
      IPJA=IR=IJA+NQ
      IJMA=IB=IJA-NQI
      IJPA=IT=IJA+NQI
      IF(FLAG(IMJ).EQ.0CELL) IL=IJA
      IF(FLAG(IPJ).EQ.0CELL) IR=IJA
      IF(FLAG(IJM).EQ.0CELL) IB=IJA
      IF(FLAG(IJP).EQ.0CELL) IT=IJA
      SN=S1(IJA)
      XIL=SIGN(.5,UTIL1(IMJA))
      XIR=SIGN(.5,UTIL1(IJA))
      XIB=SIGN(.5,VTIL1(IJMA))
      XIT=SIGN(.5,VTIL1(IJA))
      THTT1(IJA)=TH1(IJA)+DT*
     1     (RDX*(UTIL1(IMJA)*((.5+XIL)*THTIL1(IL) +(.5-XIL)*THTIL1(IJA))
     2          -UTIL1(IJA) *((.5+XIR)*THTIL1(IJA)+(.5-XIR)*THTIL1(IR) ))
     3+RDY*(VTIL1(IJMA)*((.5+XIB)*THTIL1(IB) +(.5-XIB)*THTIL1(IJA))
     4     -VTIL1(IJA) *((.5+XIT)*THTIL1(IJA)+(.5-XIT)*THTIL1(IT) ))-SN)
2129  CONTINUE
2139  CONTINUE
2140  DO 2149 J=2,JP1
      DO 2149 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.0CELL) GO TO 2149
      THTIL1(IJ)=THTT1(IJ)
      THTIL2(IJ)=THTT2(IJ)
2149  CONTINUE
      CALL BND
      RETURN
      END
```

```
BND-------  2
COMEQV    DIMEN
      SUBROUTINE BND
C**********SET BOUNDARY CONDITIONS ON THETAS AND VELOCITIES*****
*CALL,COMEQV
*CALL,DIMEN
      DO 2199 J=2,JP1
      IL=NQ*(IP2*(J-1)+2-1)
      IR=NQ*(IP2*(J-1)+IP1-1)
      DO 2199 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 2199
      IMJ=IJ-NQ
      IPJ=IJ+NQ
      IJM=IJ-NQI
      IJP=IJ+NQI
      DO 2189 N=1,2
      IJA=IJ+N-1
      IMJA=IJA-NQ
      IPJA=IJA+NQ
      IJMA=IJA-NQI
      IJPA=IJA+NQI
      IF(I.GT.2) GO TO 2150
C**********THE LEFT BOUNDARY .....*****
      THTIL1(IMJA)=THTIL1(IR+N)
      UTIL1(IMJA)=UTIL1(IR+N)
      UTILP1(IMJA)=UTILP1(IR+N)
      IF(J.EQ.2) THTIL1(IMJA-NQI)=THTIL1(IMJA)
      IF(J.EQ.JP1) THTIL1(IMJA+NQI)=THTIL1(IMJA)
2150  IF(J.GT.2) GO TO 2160
C**********THE BOTTOM BOUNDARY .....*****
      THTIL1(IJM)=THTIL1(IJ)
      THTIL2(IJM)=THTIL2(IJ)
2160  IF(I.LT.IP1) GO TO 2170
C**********THE RIGHT BOUNDARY .....*****
      THTIL1(IPJA)=THTIL1(IL+N)
      UTIL1(IPJA)=UTIL1(IL+N)
      UTILP1(IPJA)=UTILP1(IL+N)
      IF(J.EQ.2) THTIL1(IPJA-NQI)=THTIL1(IPJA)
      IF(J.EQ.JP1) THTIL1(IPJA+NQI)=THTIL1(IPJA)
C**********THE TOP BOUNDARY .....*****
2170  IF(J.EQ.JP1) THTIL1(IJPA)=THTIL1'IJA)
C**********SPECIAL BOUNDARY CONDITION FOR TILDE PRIME *****
C**********VELOCITIES AT A WALL (012076)*****
      IF (J.EQ.2   .OR.FLAG(IJM).EQ.OCELL)
     1             VTILP1(IJMA)=V1(IJMA)+(VTIL1(IJA) -VTILP1(IJA) )
      IF (J.EQ.JP1.OR. FLAG(IJP).EQ.OCELL)
     1             VTILP1(IJA) =V1(IJA) +(VTIL1(IJMA)-VTILP1(IJMA))
2189  CONTINUE
2199  CONTINUE
      RETURN
      END
```

```
PH2DTIL    2
COMEQV     DIMEN
      SUBROUTINE PH2DTIL
C**********CALCULATION OF D TILDE AND D TILDE PRIME*****
C**********TO OBTAIN BETA AND THEN THE NEW PRESSURE*****
C**********FINALLY, TEST D TILDE CONVERGENCE, COUNT ITERATIONS*****
*CALL,COMEQV
*CALL,DIMEN
2210  MUSTID=MUSTIT=0
      DO 2299 J=2,JP1
C**********SEE COMMENTS ON CHECKERBOARD PATTERN IN SUBR. PH2UV*****
      CHECKER=2*MOD(J,2)-1
      DO 2299 I=2,IP1
      CHECKER=-CHECKER
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 2299
      IMJ=IL=IJ-NQ
      IPJ=IR=IJ+NQ
      IJM=IB=IJ-NQI
      IJP=IT=IJ+NQI
C**********USE THETA(IJ) FOR NEIGHBOR IF OBSTACLE*****
      IF(FLAG(IMJ).EQ.OCELL) IL=IJ
      IF(FLAG(IPJ).EQ.OCELL) IR=IJ
      IF(FLAG(IJM).EQ.OCELL) IB=IJ
      IF(FLAG(IJP).EQ.OCELL) IT=IJ
      SSUM=S1(IJ)+S2(IJ)
      XIR1=SIGN(.5,UTIL1(IJ))
      XIR2=SIGN(.5,UTIL2(IJ))
      XIL1=SIGN(.5,UTIL1(IMJ))
      XIL2=SIGN(.5,UTIL2(IMJ))
      XIT1=SIGN(.5,VTIL1(IJ))
      XIT2=SIGN(.5,VTIL2(IJ))
      XIB1=SIGN(.5,VTIL1(IJM))
      XIB2=SIGN(.5,VTIL2(IJM))
      THRB1=.5*(THTIL1(IJ)+THTIL1(IR))
      THRB2=.5*(THTIL2(IJ)+THTIL2(IR))
      THLB1=.5*(THTIL1(IJ)+THTIL1(IL))
      THLB2=.5*(THTIL2(IJ)+THTIL2(IL))
      THTB1=.5*(THTIL1(IJ)+THTIL1(IT))
      THTB2=.5*(THTIL2(IJ)+THTIL2(IT))
      THBB1=.5*(THTIL1(IJ)+THTIL1(IB))
      THBB2=.5*(THTIL2(IJ)+THTIL2(IB))
      DTIL(IJ)=SSUM+RDX*
     1          (UTIL1(IJ) *((.5+XIR1)*THTIL1(IJ)+(.5-XIR1)*THTIL1(IR))
     2          +UTIL2(IJ) *((.5+XIR2)*THTIL2(IJ)+(.5-XIR2)*THTIL2(IR))
     3          -UTIL1(IMJ)*((.5+XIL1)*THTIL1(IL)+(.5-XIL1)*THTIL1(IJ))
     4          -UTIL2(IMJ)*((.5+XIL2)*THTIL2(IL)+(.5-XIL2)*THTIL2(IJ)))
     5     +RDY*(VTIL1(IJ) *((.5+XIT1)*THTIL1(IJ)+(.5-XIT1)*THTIL1(IT))
     6          +VTIL2(IJ) *((.5+XIT2)*THTIL2(IJ)+(.5-XIT2)*THTIL2(IT))
     7          -VTIL1(IJM)*((.5+XIB1)*THTIL1(IB)+(.5-XIB1)*THTIL1(IJ))
     8          -VTIL2(IJM)*((.5+XIB2)*THTIL2(IB)+(.5-XIB2)*THTIL2(IJ)))
      XIRP1=SIGN(.5,UTILP1(IJ))
      XIRP2=SIGN(.5,UTILP2(IJ))
      XILP1=SIGN(.5,UTILP1(IMJ))
      XILP2=SIGN(.5,UTILP2(IMJ))
      XITP1=SIGN(.5,VTILP1(IJ))
      XITP2=SIGN(.5,VTILP2(IJ))
      XIBP1=SIGN(.5,VTILP1(IJM))
      XIBP2=SIGN(.5,VTILP2(IJM))
      DTILP=SSUM+RDX*(UTILP1(IJ) *((.5+XIRP1)*THTIL1(IJ)
     1                            +(.5-XIRP1)*THTIL1(IR))
     2                +UTILP2(IJ) *((.5+XIRP2)*THTIL2(IJ)
     3                            +(.5-XIRP2)*THTIL2(IR))
     4                -UTILP1(IMJ)*((.5+XILP1)*THTIL1(IL)
     5                            +(.5-XILP1)*THTIL1(IJ))
     6                -UTILP2(IMJ)*((.5+XILP2)*THTIL2(IL)
     7                            +(.5-XILP2)*THTIL2(IJ)))
     8           +RDY*(VTILP1(IJ) *((.5+XITP1)*THTIL1(IJ)
     9                            +(.5-XITP1)*THTIL1(IT))
     1                +VTILP2(IJ) *((.5+XITP2)*THTIL2(IJ)
     2                            +(.5-XITP2)*THTIL2(IT))
     3                -VTILP1(IJM)*((.5+XIBP1)*THTIL1(IB)
     4                            +(.5-XIBP1)*THTIL1(IJ))
     5                -VTILP2(IJM)*((.5+XIBP2)*THTIL2(IB)
     6                            +(.5-XIBP2)*THTIL2(IJ)))
C**********NUMERICAL CALCULATION OF BETA*****
      BETA=(2.*EPP*CHECKER)/(DTILP-DTIL(IJ))
      DP=OM*BETA*DTIL(IJ)
      P(IJ)=P(IJ)+DP
C**********MUSTID.GT.0 FORCES ITERATION.  MUSTIT LACKS THIS*****
C**********POWER. IT IS FORMED ONLY FOR MONITOR PRINT, IF DESIRED*****
      IF(ABS(DTIL(IJ)).GT.DTEST) MUSTID=MUSTID+1
      IF(ABS(THTIL1(IJ)+THTIL2(IJ)-1.).GT.EPSTH) MUSTIT=MUSTIT+1
2299  CONTINUE
      NUMIT=NUMIT+1
      RETURN
      END
```

See notes at beginning of Appendix

See notes at beginning of Appendix

```
PMIN------  2
COMEQV    DIMEN
      SUBROUTINE PMIN
C**********NORMALIZE PRESSURE BY SUBTRACTING MINIMUM PRESSURE*****
C**********FROM ALL PRESSURES, TO OBTAIN FINAL PRESSURES. (050376)*****
*CALL,COMEQV
*CALL,DIMEN
3000  PMIN=1.E+40
      DO 3009 J=2,JP1
      DO 3009 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).NE.OCELL) PMIN=AMIN1(PMIN,P(IJ))
3009  CONTINUE
      DO 3019 J=2,JP1
C**********NORMALIZE COL. IP2 ALSO (WAS RESET IN PH2UV)*****
      DO 3019 I=2,IP2
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).NE.OCELL) P(IJ)=P(IJ)-PMIN
3019  CONTINUE
      RETURN
      END
```

```
PAVGEPP--  2
COMEQV    DIMEN
      SUBROUTINE PAVGEPP
C**********CALCULATE P AVERAGE AND EPSILON PRESSURE*****
C**********FOR USE IN CHECKERBOARD PLUS-MINUS PATTERN THAT*****
C**********DISTINGUISHES THE TILDE PRIME QUANTITIES FROM THEIR*****
C**********TILDE COUNTERPARTS.  ALSO USED IN BETA EQUATION.*****
*CALL,COMEQV
*CALL,DIMEN
3020  PSUM=PDEN=0.
      DO 3049 J=2,JP1
      DO 3049 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 3049
      PSUM=PSUM+P(IJ)
      PDEN=PDEN+1.
3049  CONTINUE
      PAVG=PSUM/PDEN
      IF(NCYC.GT.1.OR.PAVG.GT.0.) GO TO 3070
      PAVG=(ABS(G)*YT+(AMAX1(DTUVEL,DTVVEL))**2)*AMIN1(RHO(1),RHO(2))
3070  EPP=.01*PAVG
      RETURN
      END
```

```
1630
1631 NEWTEMP   2
1632 COMEQV    DIMEN
1633       SUBROUTINE NEWTEMP
1634 C**********CALCULATE TEMPERATURES AT TIME (N+1)*****
1635 C**********THEN STORE THIS FIELD OVER TEMPERATURES AT TIME (N)*****
1636 *CALL,COMEQV
1637 *CALL,DIMEN
1638 3100  DO 3109 J=1,JP2
1639       DO 3109 I=1,IP2
1640       IJ=NQ*(IP2*(J-1)+I-1)+1
1641       IF(FLAG(IJ).NE.OCELL) T1(IJ)=T1(IJ)-TSATK
1642 3109  CONTINUE
1643       ZDT=1.*ZLP*DT
1644       TD=TWINK-TSATK
1645       TF=CAPPAW*DT
1646       GAMMAX=-1.E+10
1647       DO 3149 J=2,JP1
1648       IF(J.GT.JTOPLP) ZDT=2.*DT
1649       DO 3149 I=2,IP1
1650       IJ=NQ*(IP2*(J-1)+I-1)+1
1651       TP1(IJ)=0.
1652       IF(FLAG(IJ).EQ.OCELL) GO TO 3149
1653       IF(FLAG(IJ).EQ.ACELL) GO TO 3140
1654       IF(FLAG(IJ).EQ.BCELL) GO TO 3149
1655       IMJ=IL=IJ-NQ
1656       IPJ=IR=IJ+NQ
1657       IJM=IB=IJ-NQI
1658       IJP=IT=IJ+NQI
1659 C**********IF NEIGHBOR IS OBST, USE (IJ) VALUE, BUT IF*****
1660 C**********NEIGHBOR IS OUTSIDE MESH, USE STORED EXTERIOR VALUE.*****
1661       IF(FLAG(IMJ).EQ.OCELL) IL=IJ
1662       IF(FLAG(IPJ).EQ.OCELL) IR=IJ
1663       IF(FLAG(IJM).EQ.OCELL) IB=IJ
1664       IF(FLAG(IJP).EQ.OCELL) IT=IJ
1665       XIL=SIGN(.5,U1(IMJ))
1666       XIR=SIGN(.5,U1(IJ))
1667       XIB=SIGN(.5,V1(IJM))
1668       XIT=SIGN(.5,V1(IJ))
1669       CFXL=U1(IMJ)*((.5+XIL)*THTIL1(IL)*T1(IL)
1670      1            +(.5-XIL)*THTIL1(IJ)*T1(IJ))
1671       CFXR=U1(IJ) *((.5+XIR)*THTIL1(IJ)*T1(IJ)
1672      1            +(.5-XIR)*THTIL1(IR)*T1(IR))
1673       CFXB=V1(IJM)*((.5+XIB)*THTIL1(IB)*T1(IB)
1674      1            +(.5-XIB)*THTIL1(IJ)*T1(IJ))
1675       CFXT=V1(IJ) *((.5+XIT)*THTIL1(IJ)*T1(IJ)
1676      1            +(.5-XIT)*THTIL1(IT)*T1(IT))
1677       CURLYD=DT*(ROX*(CFXL-CFXR)+ROY*(CFXB-CFXT))
1678       CURLYL=ELSUBL*BIGJL*DT*THTIL1(IJ)*THTIL2(IJ)*RTSATK
1679       TA=THTIL1(IJ)+1.E-10-CURLYL
1680       TB=(TH1(IJ)+1.E-10)*T1(IJ)+CURLYD
1681       TC=ZDT*CAPPAZ*RS
1682       SQGAM=SQRT(GAM(IJ)**2+TF)
1683       IF(ABS(TD-T1(IJ)).GT.0.5) GO TO 3110
1684       GAMNEW=0.004
1685       TNEW=TB/TA
1686       GO TO 3120
1687 3110  GAMNEW=SQGAM
1688       ZTERM=TC/(GAMNEW+1.E-10)
1689       TNEW=(TB+ZTERM*TD)/(TA+ZTERM)
1690 3120  T1NEW=TNEW+TSATK
1691       IF(T1NEW.LT.TSATK) GO TO 3130
1692       WHF=HCKW/GAMNEW*(TWINK-T1NEW)
1693       IF(WHF.LE.HFCRIT) GO TO 3130
1694       TNEW=(TB+ZDT*HFC1*THTIL1(IJ))/TA
1695       GAMNEW=SQGAM
1696 3130  TP1(IJ)=TNEW
1697       GAM(IJ)=GAMNEW
1698       GAMMAX=AMAX1(GAMMAX,GAMNEW)
1699       GO TO 3149
1700 C**********NET RESULT...A CELLS...T1=TECCK,
1701 C**********              B CELL....T1=TSATK,
1702 C**********(STEAM TEMP. (T2) ALWAYS = TSATK)**********
1703 3140  TP1(IJ)=TECCK-TSATK
1704 3149  CONTINUE
1705       DO 3199 J=1,JP2
1706       DO 3199 I=1,IP2
1707       IJ=NQ*(IP2*(J-1)+I-1)+1
1708       IF(FLAG(IJ).NE.OCELL) TP1(IJ)=TP1(IJ)+TSATK
1709       IF(FLAG(IJ).EQ.ACELL) GAM(IJ)=GAMMAX
1710       IF(FLAG(IJ).EQ.BCELL) GAM(IJ)=GAMMAX
1711 3199  CONTINUE
1712 3250  DO 3299 J=2,JP1
1713       IL=NQ*(IP2*(J-1)+2-1)+1
1714       IR=NQ*(IP2*(J-1)+IP1-1)+1
1715       DO 3299 I=2,IP1
1716       IJ=NQ*(IP2*(J-1)+I-1)+1
```

```
      T1(IJ)=TP1(IJ)
      IF(I.EQ.2) T1(IJ-NQ)=TP1(IR)
      IF(I.EQ.IP1) T1(IJ+NQ)=T1(IL)
      IF(J.EQ.2) T1(IJ-NQI)=T1(IJ)
      IF(J.EQ.JP1) T1(IJ+NQI)=T1(IJ)
 3299 CONTINUE
      RETURN
      END
```

```
MOVTHETA  2
COMEQV    DIMEN
      SUBROUTINE MOVTHETA
*CALL,COMEQV
*CALL,DIMEN
10    DO 99 J=1,JP2
      DO 99 I=1,IP2
      IJ=NG*(IP2*(J-1)+I-1)+1
      TH1(IJ)=THTIL1(IJ)
      TH2(IJ)=THTIL2(IJ)
99    CONTINUE
      RETURN
      END
```

```
FASE------  2
COMEQV    DIMEN
      SUBROUTINE FASE
*CALL,COMEQV
*CALL,DIMEN
C**********BASIC PHASE TRANSITION ENTRY POINT*****
C**********HERE, CALCULATE THE FIELDS OF BIG J, S1, AND S2*****
C**********AND FP, THE FLUX DUE TO PHASE TRANSITIONS*****
      ENTRY FASEJ
      FP=0.
      DO 99 J=2,JP1
      DO 99 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 40
      BIGJ(IJ)=0.
      IF(FLAG(IJ).EQ.ACELL.OR.FLAG(IJ).EQ.BCELL) GO TO 20
      BIGJ(IJ)=BIGJL*TH1(IJ)*TH2(IJ)*(TSATK-T1(IJ))*RTSATK
20    CONTINUE
      FP=FP+DXDY*BIGJ(IJ)
40    IF(I.NE.IP1) GO TO 99
      IL=NQ*(IP2*(J-1)+2-1)+1
      BIGJ(IL-NQ)=BIGJ(IJ)
      BIGJ(IJ+NQ)=BIGJ(IL)
99    CONTINUE
C**********FP.LT.0 MEANS NET EVAPORATION IN SYSTEM,
C**********FP.GT.0 MEANS NET CONDENSATION IN SYSTEM.....*****
      FP=FP*(RRHO(1)-RRHO(2))
      DO 199 J=2,JP1
      DO 199 I=2,IP1
      IJ=NQ*(IP2*(J-1)+I-1)+1
      IF(FLAG(IJ).EQ.OCELL) GO TO 199
C**********BIGJ.LT.0 IS CONDENSATION, BIGJ.GT.0 IS EVAPORATION.
      S1(IJ)=BIGJ(IJ)*RRHO(1)
      S2(IJ)=-BIGJ(IJ)*RRHO(2)
199   CONTINUE
      RETURN
C**********THIS ENTRY CALCULATES MX FOR THU EQ. IN PHASE 1*****
      ENTRY FASEMX
      NM=0
      BJR=.5*(BIGJ(IJ)+BIGJ(IJ+NQ))
      IF(BJR.LT.0.) NM=1
      MX(2)=BJR*U1(IJ+NM)
      MX(1)=-MX(2)
      RETURN
C**********THIS ENTRY CALCULATES MY FOR THV EQ. IN PHASE 1*****
      ENTRY FASEMY
      NM=0
      BJT=.5*(BIGJ(IJ)+BIGJ(IJ+NQI))
      IF(BJT.LT.0.) NM=1
      MY(2)=BJT*V1(IJ+NM)
      MY(1)=-MY(2)
      RETURN
      END
---------
```

☆ U.S. GOVERNMENT PRINTING OFFICE 1978—777-089/1