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COMPUTER CODE FOR LARGE LEAK SODIUM-WATER REACTION ANALYSIS -SWACS/REG3-

(PROGRAM DESCRIPTION)

—Large Leak Sodium-Water Reaction Analysis—

(Report No.3 Revision)

September, 1979

Steam Generator Safety Section
Steam Generator Division
O-arai Engineering Center

Power Reactor and Nuclear Fuel Development Corporation

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Computer Code for Large Leak Sodium-Water Reaction Analysis (SWACS/REG 3) (Program Description)

Large Leak Sodium-Water Reaction Analysis (Report No.3, Revision)

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Keywords

Sodium-water reaction, large leak, SWACS code, steam generator, secondary cooling circuit, relief system, water leak rate, initial pressure spike, pressure propagation, hydraulic transients, quasi-steady pressure, LMFBR

Abstract

A computer code, SWACS, has been developed for analyzing a large-scale sodium-water reaction accident in a steam generator system of LMFBRs.

The SWACS integrated code system is capable of predicting the principal events relevant to the large-scale water leak accident in the steam generator of LMFBRs: leaking flow of water/steam mixture from a ruptured heat-transfer tube into sodium in any one of the steam generators; propagation of pressure wave generated by sodium-water reaction both within the faulted steam generator and into the secondary cooling system; and hydraulic transients induced in the secondary cooling circuit and reaction relief system.

The water/steam leaks postulated in the SWACS code are, in principle, equivalent to those from the breach of one double-ended (guillotine) rupture of heat-transfer tube.

This report summarizes the underlying models and numerical methods adopted in the SWACS code. It is to be noted that a companion volume (PNC SN952 79-20) may serve as an input manual for users.

SWACS contains and controls the following three prenomenological modules SWAC-11, -5K/7 and -13:

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(1) SWAC-11 is the module for analyzing the water-side transients and the leaking flow of water/steam mixture into sodium of a faulted steam generator. Fundamental equations are one-dimensional mass, momentum and energy conservation for either subcooled or saturated water, or superheated steam. The two phase flow is assumed to be homogeneous (non-slip) flow in thermal equilibrium between the two phases. Compressibility of the fluid is considered for accounting the rapid transient of the water/steam flow in the very early stage of tube rupture. Boundary conditions are imposed at the inlet and outlet headers of water loop and the openings of the ruptured heat-transfer tube. The back pressure at the openings is taken as the pressure of reaction zone which is provided by the SWAC-5K/7 module.

(2) SWAC-5K/7 analyzes the behavior of rapid pressure transient, called initial pressure spike, which may occur immediately after the water/steam leak due to sodium-water reactions. This module consists of the models for reaction zone and fluid-hammer analysis both in the faulted steam generator and in the secondary cooling circuit. The reaction zone is represented with spherical bubble expansion model in which water and sodium are assumed to react instantaneously and produce a hydrogen gas bubble. The resulting hydrogen gas bubble is assumed to expand isothermally based on the law of perfect gas.

Pressure wave propagation within the faulted steam generator is analyzed with combination of one-dimensional fluid-hammer equations in spherical and linear coordinates. The pressure propagation in the vicinity of the reaction zone is analyzed in spherical coordinates, while the remaining region in the steam generator in linear coordinates.

With regard to the propagation of the pressure wave into the secondary cooling system, the fluid-hammer equations represented in linear coordinates are applied. In this case, the models for area change, branching/connection of pipes, orifices, gas space and boundaries for pressure and flow velocity can be used for specifying the network of the secondary cooling system. In addition, users can specify two boundary pressures as a function of time for independent analysis of the pressure wave behavior in the secondary system from intial spike pressure in the faulted steam generator.

(3) SWAC-13 follows hydraulic transients, called quasi-steady pressure

transients, induced in the whole secondary cooling system and the reaction relief system provided against large-scale water leak accidents. The transients covered by this module are pressure build-up due to hydrogen generation and its reduction by the pressure relief system. Fundamental equations are mass and momentum conservation for homogeneous mixture of hydrogen gas and liquid sodium, and only the gas is assumed to be compressible. A numerical method adopted is a combined node/link technique in which mass and momentum conservation are devised for each node and link respectively.

CONTENTS

APPENDICES

Note for English Translation

Since English translation is prepared only for the SWAC-13 module, which is a part of the SWACS code, sections whose page number is replaced by a asterisk are not included in this print. For this reason, descriptions may not be consistent in some parts, altough, those are not important for SWAC-13 users.

Symbols

1. Water leak rate calculation

A_j	: Work amount of heat	kg m/kcal
a	: Speed of sound	m/sec
D_{coil}	: Helical coil diameter	m
d_i	: Internal diameter of heat transfer tube	m
E	: Total energy	kcal/kg
e	: Degree of roughness of tube wall	m
f_i	: Friction loss coefficient	–
f_s	: Pipe friction loss coefficient	–
f_T	: Two-phase friction multiplier	–
g	: Gravitational acceleration	m/sec^2
h	: Specific enthalpy	kcal/kg
h_R	: Specific enthalpy of the header	kcal/kg
I	: Specific internal energy	kcal/kg
K_R	: Header entrance pressure loss coefficient	
P	: Pressure	kg/m^{2}a
P_{ex}	: Breakage end back pressure	kg/m^{2}a
P_R	: Header pressure	kg/m^{2}a
Q	: Amount of added heat	kcal/m^3.sec
q	: Artificial-viscosity coefficient	kg/m^2
R_e	: Reynolds number	–
u	: Flow speed	m/sec
θ	: Tilt angle of heat transfer tube	rad
ξ	: Pressure loss increase factor by pipe bending ratio	–
ρ	: Specific weight	kg/m^3
τ	: Mass diffusion coefficient	–
ϕ	: Time centering weighting factor	–
ϕ	: Time centering weighting factor	–

2. Initial pressure spike calculation, Pressure propagation calculation

A	: Flow section area	m^2

C	: Speed of sound	m/sec
d	: Flow equivalence diameter	m
F	: H_2/H_2O mole conversion ratio	–
f	: Friction loss coefficient	–
g	: Gravity acceleration	m/sec^2
H	: Pressure head	m
HFS	: Free liquid level head	m
HRO	: Pressure head of the release system	m
H_T	: Pressure head of the surge tank	m
L	: Flow length	m
n	: Hydrogen gas mole number	mol
P_C	: Cover gas pressure	kg/m^2a
P_G	: Hydrogen gas bubble pressure	kg/m^2a
Q_G	: Hydrogen gas bubble volume	m^3
Q_C	: Cover gas volume	m^3
q_W	: Water leak rate	kg/sec
R_O	: General gas constant	kg. m/mol. °K
r_P	: Hydrogen gas bubble radius	m
T_G	: Hydrogen gas bubble temperature	°K
u	: Flow speed	m/sec
ZR	: Rupture disk pressure loss coefficient	–
ZT	: Surge tank opening pressure loss coefficient	–
α	: Orifice coefficient	–
ζ	: Form pressure loss coefficient	–
κ	: Cover gas specific heat ratio	–
ξ	: Incline of characteristic curve	sec/m
φ	: Flow tilt	rad

3. Quasi−steady pressure calculation

A_{ij}	: Section area of node	m^2
A_k	: Section area of link	m^2
D_C	: Heat transfer tube outer diameter	m
d	: Equivalence diameter of link	m
g	: Gravity acceleration	m/sec^2

Δh	: Head difference	m
i	: Initial node subscript	–
j	: Terminal node subscript	–
k	: Link subscript	–
L_k	: Link length	m
L_P	: Coil pitch	m
L_V	: Atomosphere release valve life length	m
M_H	: Hydrogen gas weight of node	kg
M_S	: Sodium weight of node	kg
n	: Polytrope index	–
P_{ij}	: Pressure of node	kg/m^2
Q_i	: Hydrogen gas generation rate	kg/sec
R	: Hydrogen gas constant	kg.m/kg.°K
R/r	: Ratio of bend curvature radius/inner radius	–
R_e	: Reynolds number	–
S	: Flow reduction coefficient of atomosphere release valve	–
S_k	: Slip ratio of link	–
U_H	: Hydrogen gas flow speed	m/sec
U_S	: Sodium flow speed	m/sec
U_k	: Mixture flow speed	m/sec
W_H	: Hydrogen gas weight flow rate	kg/sec
W_S	: Sodium weight flow rate	kg/sec
W_k	: Mixture weight flow rate	kg/sec
X	: Quality	–
X_{tt}	: Martinelli's coefficient	–
α	: Void fraction	–
ζ	: Local pressure loss coefficient	–
ξ_B	: Bend pressure loss coefficient	–
θ	: Bend bending angle	deg
λ	: Friction loss coefficient	–
μ	: Viscosity coefficient	kg.sec/m^2
υ	: Kinematic viscosity coefficient	m^2/sec
ρ_H	: Hydrogen gas specific weight	kg/m^3
ρ_S	: Sodium specific weight	kg/m^3
ρ_k	: Mixture specific weight	kg/m^3
ϕ	: Two-phase friction multiplier	–

1. Introduction

In the steam generator (hereafter, SG) of a sodium cooled fast reactor, a large scale water leakage accident in which in a moment there is complete breakage of both ends of one or several heat transfer tubes is called a large leak sodium water reaction and, as an important matter in the safety design of fast reactor plants, testing and research has proceeded in countries around the world.

In Japan, at the O-arai Engineering Center, using large leak sodium water reaction test rig (SWAT-1) and steam generator safety test facility (SWAT-3) for the prototype fast breeder reactor "Monju" which is being developed, many tests were performed and many test results were obtained.

In order that the test results reflect the safety design of the "Monju" SG, the SWAC series calculation codes[2),3),4),5)], which principally aim at analysing the pressure behaviour at the time of the large leak sodium-water reaction, were developed. In addition, these codes were systematized and a "SWACS" calculation code was developed which analyses a series of large leak sodium water reaction phenomena.[1)] The "SWACS" code is divided into four calculation modules : pressure spike conditions immediately after the rupture of the heat transfer tubes (initial pressure spike), the propagation of the pressure spike through the secondary loop (pressure propagation), the quasi-steady pressure which develops after the decline of the initial pressure spike (quasi-steady pressure) and the water leak rate which governs all of these (water leak rate).

The SWACS code and the contents of each of the calculation modules have already been put together and reported in an outline[15)].

The already published general outline which explains the calculation code to the users, in accordance with adjustments and perfection of the general outline explaining handling of the codes and the modified portions, has been revised including those improved portions and the improved numerical calculation methods, etc.

Moreover, along with the changes and modifications, the code version name is adopted and this report describes "SWACS/REG 3" version.

In chapter two of this report, an outline of the function and formation of the "SWACS" code is explained. Chapters three to five deal with the calculation hypotheses, basic equations, fluid flow phenomena for each of the calculation modules.

The appendices contain the configuration of code, the numerical methods used in each calculation module and the registration numbers (version names) of the calculation codes.

The input/output formats for this code are explained in a separate report[14].

2. General Outline of the Code

2-1 Subjects of the analysis

The subject of analysis in this code is a type having a cover gas space in the SG similar to the SG in "Monju".

What is considered in the system are the SG in which a rupture of the heat transfer tube has occurred and the sound SG, piping, pumps, valves and intermediate heat exchanger composing the secondary cooling ciucuit.

The time period under consideration is the time from which the initial pressure spike is produced from the reaction of the water/steam leaking from the heat transfer tube, this pressure is propagated within the system, after it declines the pressure due to the buildup of hydrogen is reduced to atmospheric pressure by the pressure release system and the sodium reaction is completed.

2-2 Functions

Among the various phenomena accompanying a large leak sodium reaction, the four categories listed below are divided between each calculation module.

(1) Performing the calculation for the flow of the water system when the heat transfer tube is ruptured and water or steam leaks into the sodium and calculating the transition changes of the water leak rate. (Called the water leak rate calculation modul (SWAC-11)[2].)

(2) Calculating the sudden increase in pressure which is observed at a point about 10 m sec immediately after the sodium water reaction has occurred, the so-called initial pressure spike. (Called the initial pressure spike calculation modul (SWAC-5K/7)[3].)

(3) Calculating the process whereby the initial pressure spike passes through the piping from SG where the heat transfer tube rupture was produced and is propagated throughout the secondary cooling circuits. (Called the pressure propagation calculation module (SWAC-5K)[4].)

(4) Calculation of the quali-steady pressure process in which, after the

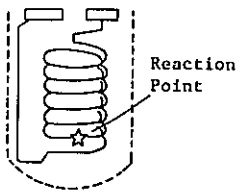
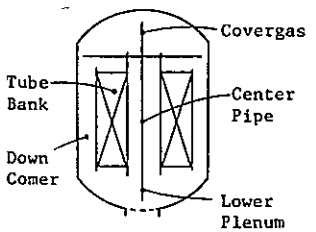
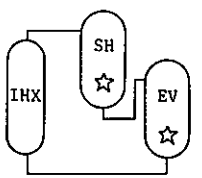
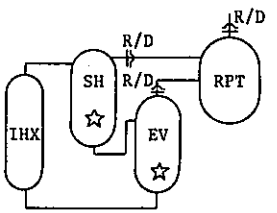
initial pressure spike declines, hydrogen gas pushes the sodium as a piston, the pressure in the SG where the heat transfer tube was ruptured increases again, and the release system operates, releasing the pressure (Called the quali-steady pressure calculation modul (SWAC-13)[5].)

2-3 Composition of the code

As has already been explained, the SWACS code[1] is composed of the water leak rate, initial pressure spike, pressure propagation and quasi-steady calculation modules. The interrelation brought about by the transfer of input/output data between each calculation module is show in Fig. 2-1. A general outline of the calculation models is shown in Table 2-1; Fig. 2-2 shows the main flow sheet which controls each of the calculation modules.

Detailed descriptions of the code are contained in the following chapters.

TABLE 2-1 Functions of SWACS Calculation Modules

Module	Calculation System*)	Calculation Model
SWAC-11 (Water Leak Rate)	Flow of water/steam in the failed heat transfer tube of the SG where the accident occured. 	Leakage water conditions Subcooled, saturated or superheated water/steam Equations One-dimensional mass, momentum, and energy conservations Numerical method Implicit finite difference method (modified ICE)
SWAC-5K/7 (Initial Pres. Spike)	Growth of a hydrogen gas bubble at the reaction zone, and the pressure propagation in the sodium. 	Fluid Compressible sodium, spherical hydrogen gas bubble Equations One-dimensional mass, momentum conservations Numerical method Method of characteristics
SWAC-5K (Pres. Propagation)	Pressure propagation in the sodium of the secondary cooling system. 	Fluid Compressible sodium Equations One-dimensional mass, momentum conservations Numerical method Method of characteristics
SWAC-13 (Quasi-Steady Pres.)	Flow of sodium and hydrogen gas mixture in the secondary cooling system and relief system. 	Fluid Non-compressible sodium, Hydrogen Equations Mass and momentum conservations for node-link network model Numerical method Implicit difference method

* The graphic depiction of the system uses the example of the prototype fast reactor "MONJU" and is for reference.

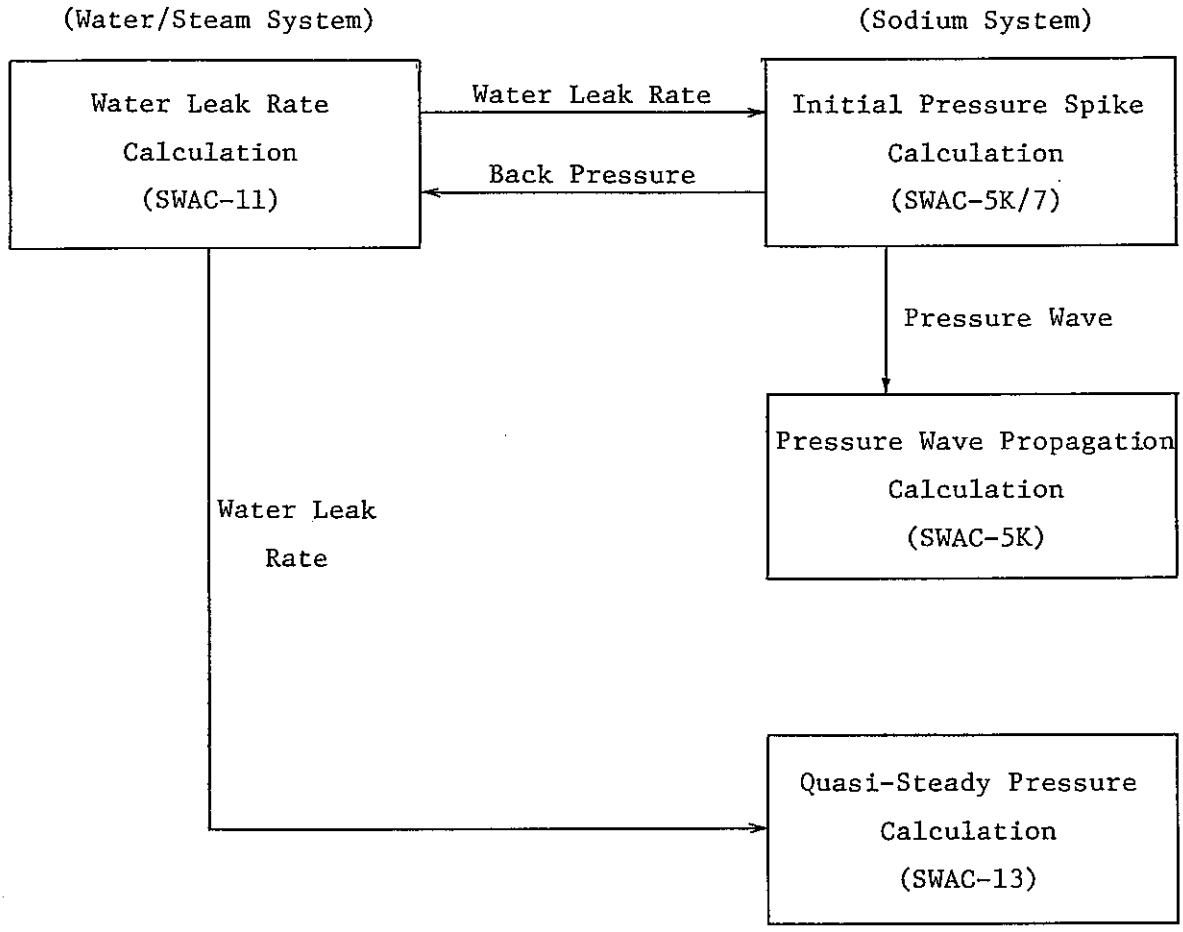


FIG. 2.1 Interrelation of SWACS Calculation Modules

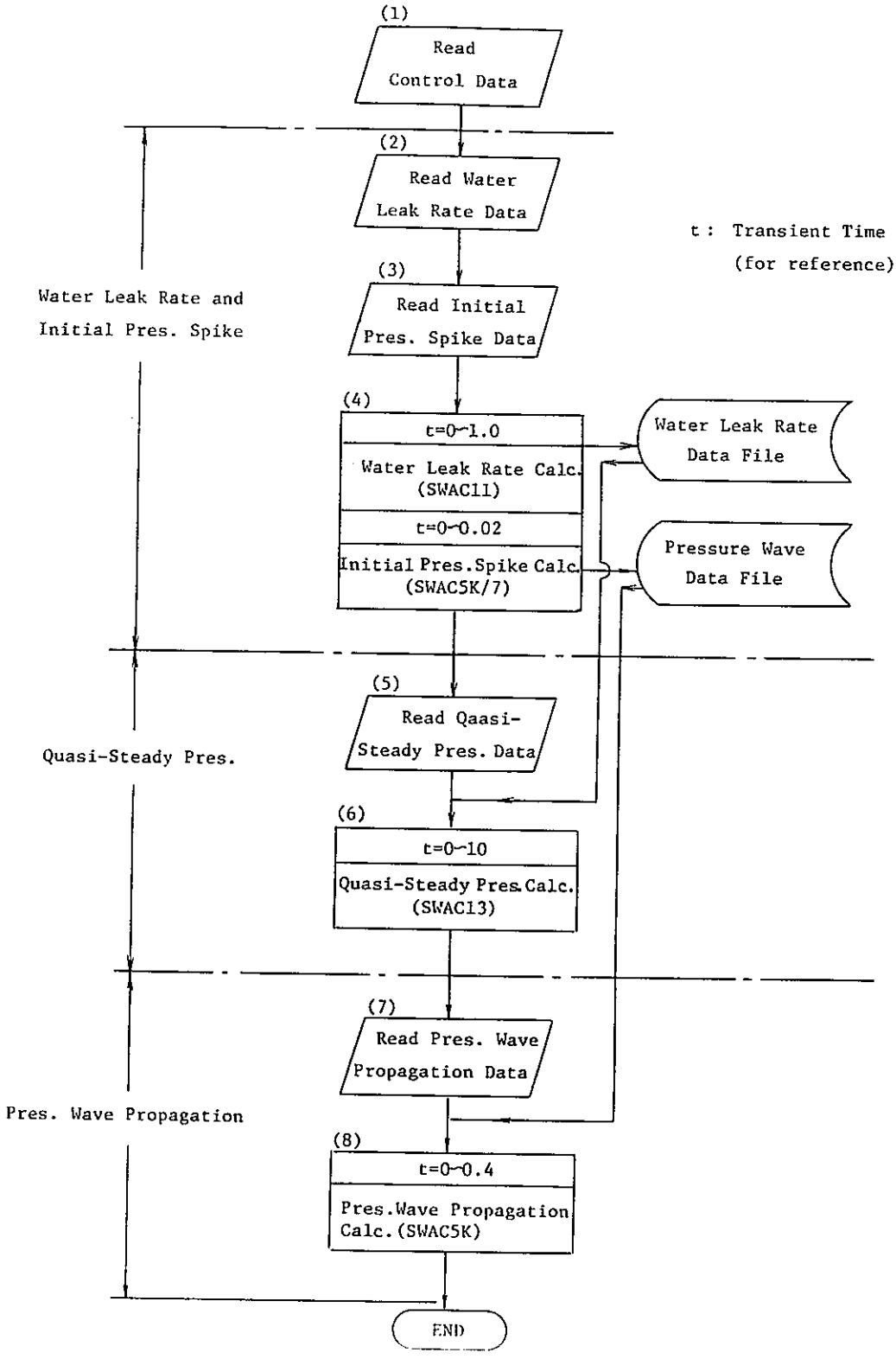


FIG. 3.1 Calculation Flow of SWACS

5. Quasi-Steady Pressure Calculation

5-1 Outline

The purpose is to calculate the phenomena of pressure of secondary cooling circuit including relief system in the quasi-steady time realm after the initial pressure spike has decreased[5]. The time sequence of the phenomena which should be analyzed by this calculation module is shown below.

(1) The internal pressure of the failed SG increases due to the sodium water reaction.

(2) As a result, part of the sodium in the SG is pushed out into the secondary cooling circuit.

(3) The pressure in the SG increases, as it reaches the established pressure for the rupture disk of the relief system the rupture disk is burst and the pressure is released to the relief system.

(4) When the gas pressure of other SG's of the secondary cooling circuit rise, as happened in the faild SG, the rupture disks of those SG's may burst.

(5) As the reaction further continues, the internal pressure of the reaction product tank of the relief system increases, the attached rupture disk bursts and the pressure is ultimately released into the atmosphere.

For calculations of the above phenomena, the SG suffering the accident, the relief system and the secondary cooling system are divided into small volumes (node), nodes are modeled into a network joined with the flow-passes (link), then, momentum conservation equations and mass conservation equations are set up and solved by the implicit method.[13]

5-2 Analysis Model

The object of analysis of the quasi-steady pressure calculation is the so-called quasi-steady pressure time realm whereby as a continuation of the initial pressure spike, the pressure in the systems quasi-steadily increases and the sodium and hydrogen gas are treated as mixed two-phase

flows as the flow.

The analysis system is divided into volumes (nodes), each node is modeled into a netweork model with flow-passes (link). For this modeled system, the conservation of mass applies to the nodes and the conservation of momentum applies to the links.

5-3 Hypotheses regarding the calculations

(1) The two-phase flow for sodium and hydrogen gas uses the one dimensional slip model and the slip ratio is determined separately.

(2) Sodium is treated as non-compressible and hydrogen gas is treated as compressible.

(3) The reaction speed of the sodium water reaction is considered to be instantaneous, there is considered to be no time lag in the reaction.

(4) The energy balance is not taken into consideration; the temperature of the hydrogen gas of each node should be given as the input data by users.

(5) The water leak rate due to the rupture of the heat transfer tube is considered to change in time and the space distribution is also taken into consideration; they should be give as the input data by users.

(6) When the rupture disk of each SG and reaction product tank reaches the set value, it is considered that they break with no lag time.

(7) The physical characteristics of the cover gas are considered to be identical with that of hydrogen gas.

5-4 Method of Calculation *

(1) Momentum conservation equation

Development in regard to the link is as follows.

$$\dot{W}_k = \frac{g}{\sum_j \frac{L_{kj}}{A_{kj}}}\left[(P_i - P_j) + \frac{W_k^2}{2\rho_k \cdot g}\left(\frac{1}{A_i^2} - \frac{1}{A_j^2}\right) + \rho_k \Delta h - P_{fk}\right] \quad \cdots\cdots (5\text{-}1)$$

* For details of the numerical calculation, refer to Appendix B-3.

Here, P_{fk} is the pressure loss term for friction, etc.

(2) Mass conservation equation

The development of the mass conservation of sodium and hydrogen gas in regard to the node is as follows.

$$\dot{M}_s = \sum_{\nu \epsilon Ti} W_s\nu - \sum_{\nu \epsilon Ii} W_s\nu \quad \cdots\cdots (5\text{-}2)$$

$$\dot{M}_H = \sum_{\nu \epsilon Ti} W_H\nu - \sum_{\nu \epsilon Ii} W_H\nu + Q_i \quad \cdots\cdots (5\text{-}3)$$

Here, the first term for the right side of both equations represents in-flow, the second term represents out-flow; Q_i is the generation of hydrogen gas.

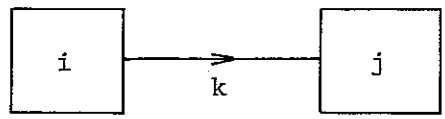


Fig. 5-1 Node·Link Model

(3) Sodium-hydrogen gas two-phase flow model

As the one-dimensional slip model, the slip ratio (S) is defined by the following equation.

$$S_k = U_{HK}/U_k \quad \cdots\cdots (5\text{-}4)$$

The relation of the flow rate of mixture with the flow rate of each of the sodium and hydrogen gas is expressed by the following eauations.

$$W_{SK} = \frac{1-\alpha_k-\alpha_k(S_k-1)\,R_{HSk}}{1-\alpha_k(1-R_{HSk})} \cdot W_k \quad \cdots\cdots$$

$$W_{Hk} = \frac{S_k\alpha_k R_{HSk}}{1-\alpha_k(1-R_{HSk})} \cdot W_k \quad \cdots\cdots (5\text{-}5)$$

Here, $R_{HSk}=\rho Hk/\rho Sk$, α_k represents the void fraction.
When the above equations are arranged, concerning the $\Delta W^{n+1}=W^{n+1}-W^n$, a reduced system of L origin (L: number of links) simultaneous equations is obtained and by solving this, the flow amount can be updated.
To obtain the pressure of each node, for the nodes including hydrogen gas or cover gas, a gas equation of state is used. In regard to sodium single phase nodes, a simultaneous equation relating to the pressure of the pressure-known nodes is set up and solved.

(4) Treatment of pressure loss

i) Pipe friction loss coefficient[16)]

The friction loss coefficient for laminar flow and for turbulent flow is determined as follows;

$$\left.\begin{array}{ll} \lambda = 64/\mathrm{Re} & \mathrm{Re} < 2300 \\ 1/\sqrt{\lambda} = -2\log_{10}\left[\dfrac{e/d}{3.71} + \dfrac{2.51}{\mathrm{Re}\sqrt{\lambda}}\right] & \mathrm{Re} < 2300 \end{array}\right\} \quad \cdots\cdots (5\text{-}6)$$

Here, Re is the Reynolds number, $\mathrm{Re}=\dfrac{u \cdot d}{\nu}$, u is the flow speed (m/sec), d is the hydraulic diameter (m), ν is the kinematic viscosity coefficient (m^2/sec), e is the roughness of the wall (m).

ii) Friction loss coefficient of the heat transfer tube coiled portion[19)] (for one layer of coil)

$$\lambda_C = 4 \cdot (1.72)^2 \cdot \frac{2}{3}\mathrm{Re}^{-0.15}\left[0.23 + \frac{0.11}{(L_P/D_C)^{1.08}}\right] \quad \cdots\cdots (5\text{-}7)$$

Here, $\mathrm{Re}=\dfrac{u \cdot D_C}{\nu}$, D_C is the outer diameter of the heat transfer tube (m), L_p is the coil pitch (m).

iii) Two phase flow friction multiplier[20)]

The Lockhart-Martinelli equation is principally employed.

$$\left.\begin{array}{ll} \phi_o = 1 + 2\sqrt{X\,tt} + X\,tt & \alpha k \geqq 0.2 \\ \phi_o = 1 + 2/\sqrt{X\,tt} + 1/X\,tt & \alpha k < 0.2 \\ X\,tt = \left(\dfrac{1-\alpha-\alpha\cdot(S-1)\cdot R_{HS}}{S\cdot\alpha\cdot R_{HS}}\right)^{0.9} \cdot \left(\dfrac{\rho_H}{\rho_S}\right)^{0.5} \cdot \left(\dfrac{\mu_S}{\mu_H}\right)^{0.1} & \\ \phi^2 = (\phi_o^2)^N & \end{array}\right\} \quad \cdots\cdots (5\text{-}8)$$

However, N is the revised coefficient and is given as the input data.

iv) Pressure loss coefficient of the bend portion[23)]

$$\left.\begin{array}{ll} \zeta_B = 0.00873\,\chi\,\lambda\theta(R/r) & \mathrm{Re}(r/R)^2 < 91 \\ \zeta_B = 0.00241\,\chi\,\theta\,\mathrm{Re}^{-0.17}(R/r)^{0.84} & \mathrm{Re}(r/R)^2 \geqq 91 \\ \chi = \begin{cases} 0.95 + 17.2(R/r)^{-1.96} & R/r < 19.7 \\ 1 & R/r \geqq 19.7 \end{cases} & \end{array}\right\} \quad \cdots\cdots (5\text{-}9)$$

Here, (R/r) is the ratio of the curvature radius of the bend portion to the inside radius of the tube; θ is the bend angle (deg), λ is the friction loss coefficient shown in i).

v) Other pressure loss coefficients

$$P_f = \zeta \frac{\rho u_k^2}{2g} \quad \cdots\cdots (5\text{-}10)$$

Pressure loss due to other pressure loss factors could be given as the input data, which is considered to be constant (ζ) and taken care of by equation (5-10).

(5) Critical flow speed for the relief system piping[21)]

For the relief system piping, the critical flow speed is calculated by the Fauske's equation and this is considered to be the upper limit of the flow speed in the pipe.

$$Ucri = \sqrt{g \cdot n \cdot p^2 \cdot \frac{(X/\sqrt{\rho_H} + (1-X)/\sqrt{\rho_S})^3}{X \cdot R \cdot T \sqrt{\rho_H}}} \quad \cdots\cdots (5\text{-}11)$$

Here, n is the polytrope index, ρs, ρH are the specific weight of the sodium and hydrogen gas (kg/m^3) respectively, R is the gas constant (kg·m/kg°K) of the hydrogen gas, X is the quality.

(6) Flow amount of the atmosphere release valve[22)]

The flow at the atmosphere release valve where the hydrogen gas from the reaction product tank is released into the atmosphere is calculated by the following equation.

$$W = 0.1418 \cdot S_c \cdot D \cdot Lv \cdot \Delta p \sqrt{\frac{2}{T_{H2}}} \quad \cdots\cdots (5\text{-}12)$$

Here, S_c is the contracted flow coefficient, D is the diameter of the valve (m), L_v is the lift length of the valve (m), Δp is the pressure difference (kg/m^2), T_{H2} is the temperature of gas (°K).

6. Postscript

According to the interim report of the experimental verification[6),7),8)], and the applied calculations[9),10)] of the SWACS code it can be said that the safety design calculations of the prototype FBR's SG could be performed sufficiently. At present, experimental verification is continuing, and these results will be published in a separate report.

Furthermore, as an addition to the functions of the "SWACS" code, the development of column-separation treatment routines for the initial pressure spike and pressure propagation modules and the development of downcomer leak calculation module are being continued.

Many persons have contributed either directry or indirectry to the development of SWACS; we should like to mention some of them by name: the water leak calculation module was originally developed by Naoki Yoshioka, the initial pressure spike calculation and the pressure propagation module by Kosuke Sakano, the quasi-steady pressure calculation module by Hiromi Tanabe, and the systematization as the "SWACS" code by Osamu Watanabe.

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APPENDICES

APPENDIX A Composition of the SWACS Code

A-1 Outline

As has already been mentioned in the second chapter, originally the SWACS Code consisted of four separate codes (water leak rate calculation code, initial pressure spike calculation code, pressure propagation calculation code, quasi-steady pressure calculation code) which modulized and combined.[1)]

At the time of the formation of the SWACS main program which controls each modulized calculation the following functions were incorporated.

(1) The selection of which calculation to perform is left up to the user; it is possible to perform calculations for a series of calculation modules or a specified calculation module can be run through alone.

(2) Joining of data between the calculation modules is performed by means of magnetic tape or disk files. Therefore, the user can combine calculation modules easily by preserving the file.

(3) While keeping the back pressure under consideration, the combination of data when performing related calculation of the water leak rate calculation and the initial pressure spike calculation can be passed on as common data to each time step.

(4) A restart calculation is possible for the water leak rate calculation.

(5) The calculation results for each of the calculation modules, in addition to printed output, can be formed into a file for a plotter.

Furthermore, in the formation of the SWACS code, the spherical model calculation portion of the initial pressure spike calculation code (spherical·linear sodium water reaction code: SWAC-7) was included in the boundry condition of the pressure propagation calculation (SWAC-5K); both of them can be taken as one calculation module in the composition of the SWACS program. (See Chapter 4)

A-2 Global Controls

Shown in Appendix Fig. A-1 is the procedure order of the SWACS modules, and in Appendix Fig. A-2, a flowchart of the main program.

The meanings of the abbriviations used in the charts:

JIJCT:	Do water leak rate calculation (=1)	not do(=0)
JISPB:	Do calculation of initial pressure spike (=1)	not do(=0)
JQSTD:	Do calculation of quasi-steady pressure (=1)	not do(=0)
JISPB2:	Do pressure propagation calculation (=1)	not do(=0)
TEIJ:	Completion time of water leak rate calculation	
TESP:	Completion time of initial pressure spike calculation	
TEQS:	Completion time of quasi-steady pressure calculation	
TEPR:	Completion time of pressure propagation calculation	

Functions of sub-programs which are shown in the Figures:

(1) BLOCK DATA: Zero initialize input data

(2) READIN: Read in of input data card

1) Read in of SWACS control data
2) Read in of water leak rate calculation input data
3) Read in of data for initial pressure spike and pressure propagation calculation
4) Read in of input data for calculation of quasi-steady pressure calculation

(3) OUTP: Perform control of output

1) Output of water leak calculation resluts (state in heat transfer tube)
2) Output of water leak calculation results (water leak rate)
3) Output of results of initial pressure spike, pressure propagation calculations
4) Output of calculation results of quasi-steady pressure calculation

(4) INPUT: Input data set of water leak rate calculation → READIN(2)

(5) TINPUT: Input data set of initial pressure spike, pressure propagation calculation → READIN(3)

(6) QINPUT: Input data set of quasi-steady pressure calculation → READIN(4)

(7) SWC11: Control of water leak rate calculation

(8) TFLOW: Control of initial pressure spike, pressure propagation calculation

(9) SWAC13: Control of quasi-steady pressure calculation

(10) TDETM: Calculate the parameter of the interval adjustment of time step in the case of preforming linked calculation of water leak rate calculation and initial pressure spike calculation.

A-3 Formation of each calculation module

The formation of each of the modules is shown in the following figures: water leak calculation module in A-3; initial pressure spike calculation module and pressure propagation calculation module in A-4; quasi-steady pressure calculation module in A-5.

A-4 Program Size

The SWACS code was made for use on a FACOM230/58 computer; the language is fortran iv; compiled by FACOM computer E-level compiler.

program size:

number of sub-programs	95 routines
number of cards	approximately 10,300
necessary core capacity	approximately 600KB

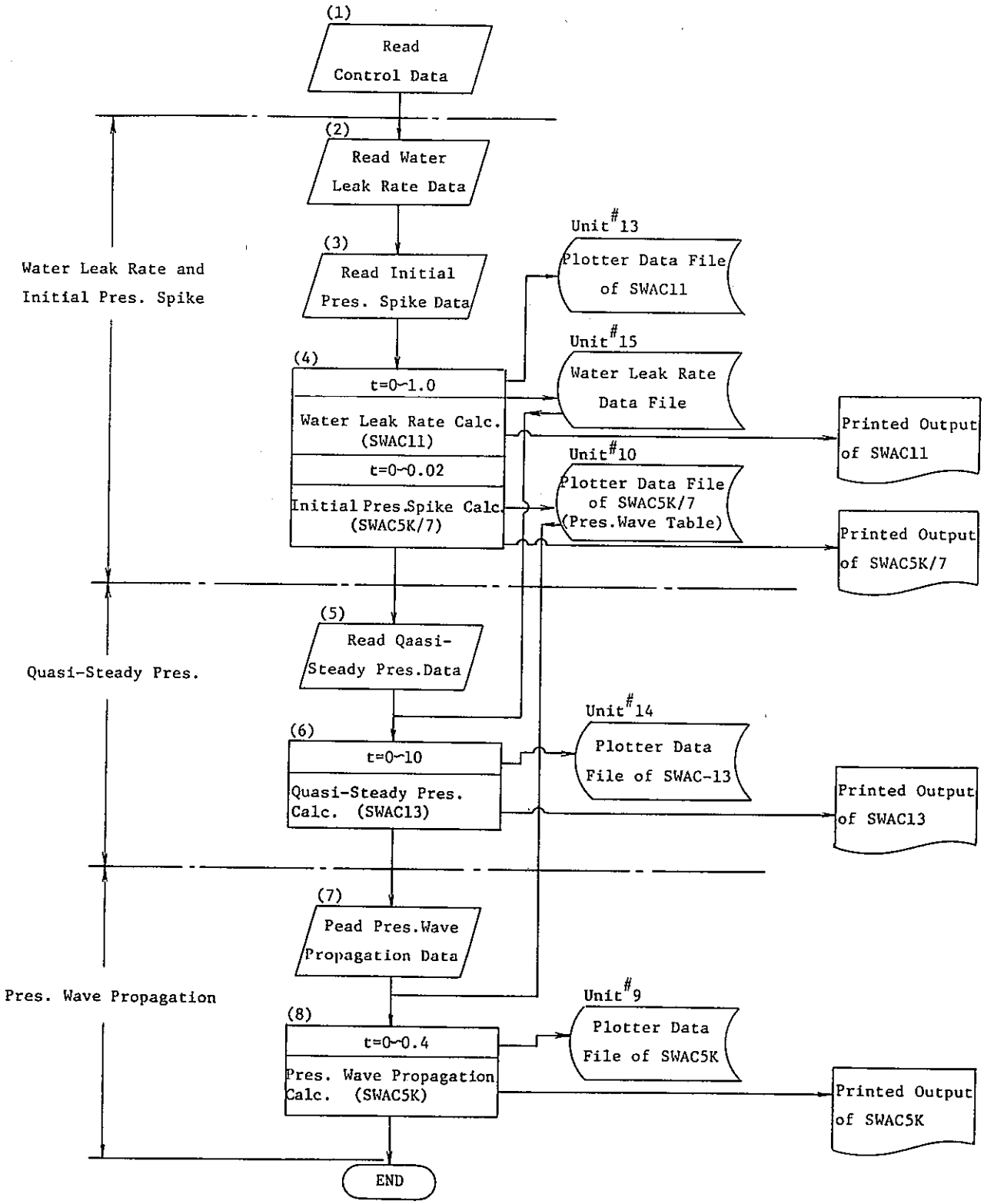

FIG. A-1 Calculation Flow of SWACS

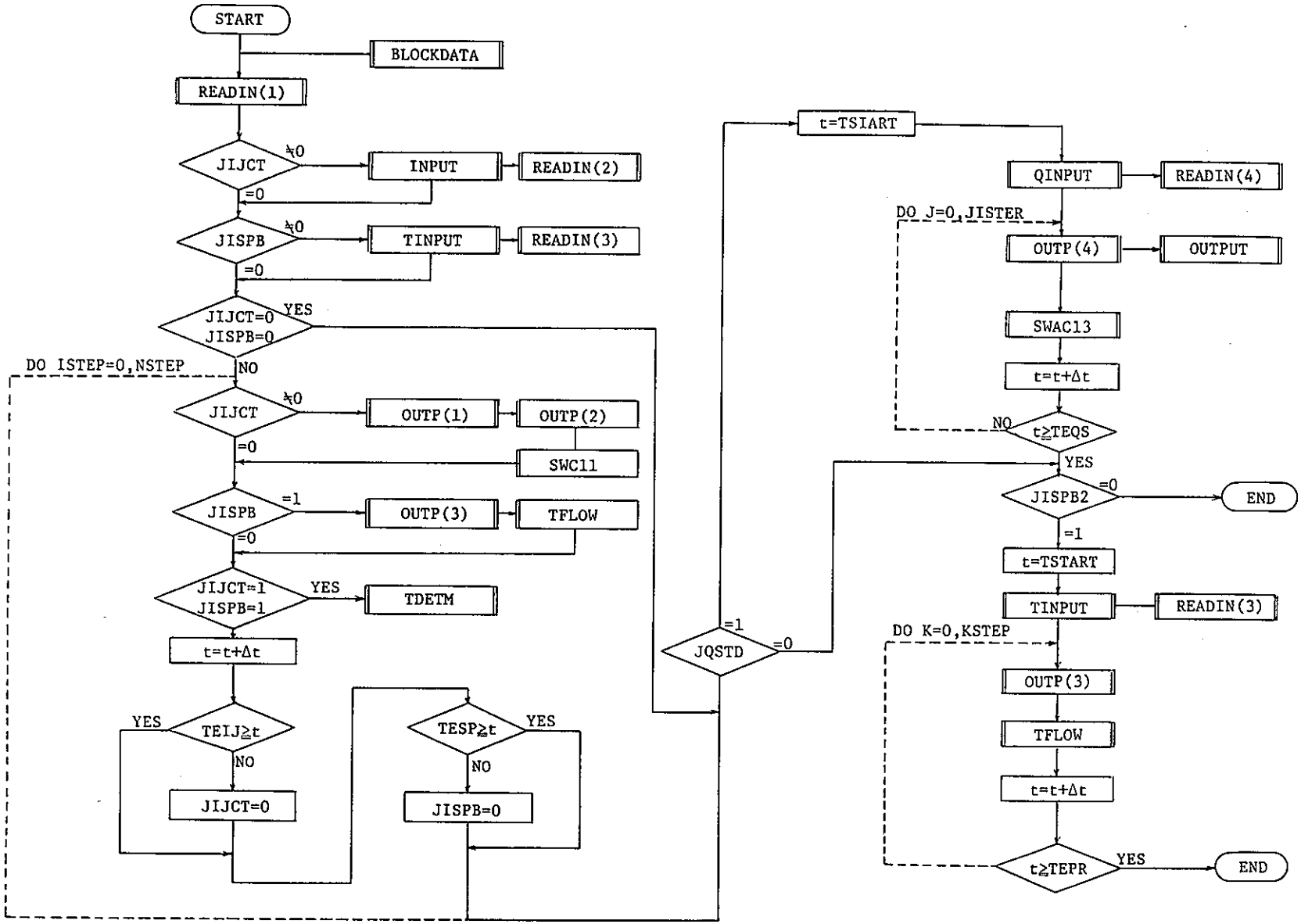

FIG. A-2 Flow Chart of SWACS Main Program Routine

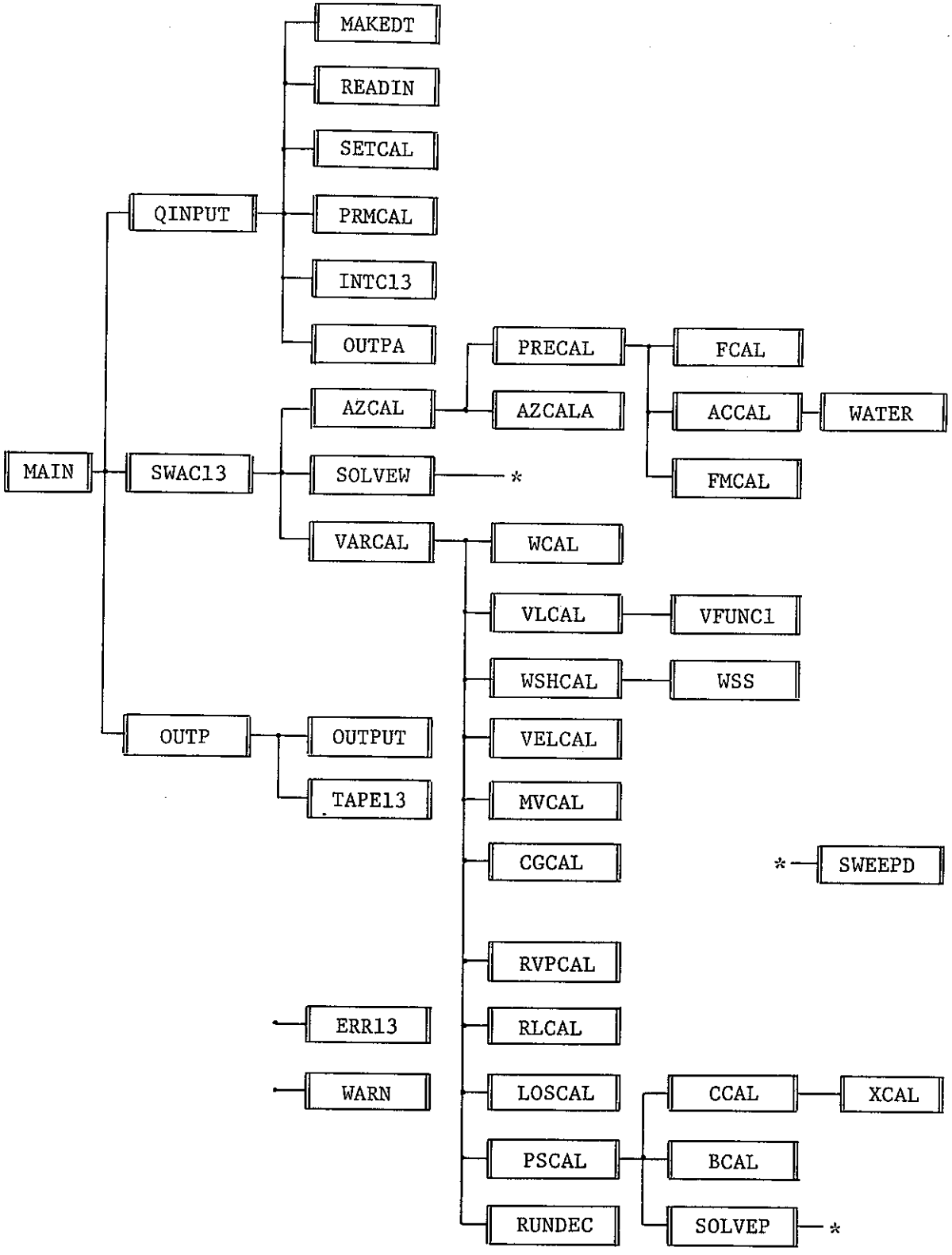

FIG. A-5 Program Tree Structure of SWAC13

TABLE A-5 Function of Sobroutines of SWAC13 Module

1.	QINPUT	;	establishment of calculation conditions
2.	SWAC13	;	calculation of basic amount at time T
3.	OUTP	;	output of results at time T
4.	MAKEDT	;	make table of water leak rate
5.	READIN	;	read input data
6.	SETCAL	;	calculation of link aggregate
7.	PRMCAL	;	calculation of various parameters
8.	INTC13	;	calculation of initial value of basic amount
9.	OUTPTA	;	output of established
10.	AZCAL	;	calculation of matrix A, vector Z
11.	SOLVEW	;	solve A·DW=Z
12.	VARCAL	;	calculate basic quantity
13.	OUTPUT	;	printout of result
14.	TAPE13	;	output of data for plotting
15.	ERR13	;	output of error message
16.	WARN	;	not used
17.	PRECAL	;	preparatory calculation for factor determination
18.	AZCAL	;	calculation of factor
19.	WCAL	;	calculation of mass flow W
20.	VLCAL	;	calculation of void fraction VOIDL
21.	WSHCAL	;	calculation of mass flow WS, WH
22.	VELCAL	;	calculation of flow speed
23.	MVCAL	;	calculation of mass MS, MN, volume VS, VN
24.	CGCAL	;	calculation of VH. VCGB of cover gas related node
25.	RVPCAL	;	calculation of density RH. R, void fraction VOID and pressure P of two-phase/hydrogen gas single phase node
26.	RLCAL	;	calculation of density RL of link
27.	LOSCAL	;	calculation of CLOSS, DELTAP
28.	PSCAL	;	calculation of pressure P of sodium single phase node
29.	RUNDEC	;	determination of non-working node
30.	FCAL	;	calculation of F. DFDW
31.	ACCAL	;	calculation of AS. AH. CS. CH.
32.	FMCAL	;	calculation of DFDMS. DFDMH.
33.	VFUNC1	;	calculation of emission void fraction
34.	WSS	;	find volume flow rate
35.	CCAL	;	calculate vector C factor

```
36.   BCAL    ;  calculate matrix B factor
37.   SOLVEP  ;  solve B•P=C
38.   WATER   ;  calculation of water leak rate
39.   SWEEPD  ;  calculation of sweep-out method
40.   XCAL    ;  calculation of X1-X4.
```

APPENDIX B OUTLINE OF NUMERICAL METHODS

The basic equations for the SWACS code are one-dimensional mass, momentum and energy conservation equations; however, other than the water leak rate calculation, the energy conservation equations are not solved.

To solve these basic equations, an appropriate calculation method for the phenomena, systems of each of the calculations must be selected. The SWACS code uses the revised ICE method[11] for the water leak rate calculation, the method of characteristics[12] for the initial pressure spike calculation and the pressure propagation calculation, the node-link method[13] for the quasi-steady pressure calculation.

Below, an explanation of the general outline of the derivation of the difference approximation and its solution and the handling of the boundry conditions are provided.

B-3 Quasi-Steady Pressure Calculation

B-3.1 General Outline

The quasi-steady pressure calculation uses the node-link method (volume-junction method) which is widely employed as a solution to transient phenomena of fluids.[13] Since the node-link method utilize a network model which is composed of the volumes (node) and flow passes (link) of the system which is the object of calculation, the basic equation itself of the calculation is a one-dimensional equation, however, it has characteristics which can take into consideration the effects of pseudo-multi dimensional systems. Furthermore, by way of plant simulation, the operation of plant equipment (valve, rupture disk, etc.) can be easily included in the program.

In the calculation of quasi-steady pressure, user should divide the steam generator and the secondary cooling loop, relief system into the abovementioned node-link network.

The numerical solution procedure of the difference equations of the node-link network is described below.

B-3.2 Basic equations and difference approximation equations

The basic equation are the sodium, hydrogen gas mass conservation equation, the non-compressible momentum conservation equation and the equation of state of hydrogen gas (isothermal equation of ideal gas); they are expressed in the following equations (B·3-1)-(B·3-3).

$$\frac{\partial \rho}{\partial t} = -\frac{\partial}{\partial s}(\rho u) \quad \cdots\cdots (B\cdot 3\text{-}1)$$

$$\frac{1}{g}\frac{\partial u}{\partial t}+\frac{1}{g}u\frac{\partial u}{\partial s}+\frac{\partial h}{\partial s}+\frac{1}{\rho}\frac{\partial p}{\partial s}+\frac{\partial \tau}{\partial s} = 0 \quad \cdots\cdots (B\cdot 3\text{-}2)$$

$$P\cdot V_{H2} = M_{H2}\cdot R\cdot T_{H2} \quad \cdots\cdots (B\cdot 3\text{-}3)$$

The mass conservation equation is expressed as follows considering inflow and outflow for sodium and hydrogen gas. (Refer to Fig. 5-1).

$$\dot{M}_{Si} = \sum_{\nu \epsilon Ti} W_{S\nu} - \sum_{\nu \epsilon Ii} W_{S\nu} \quad \cdots\cdots (B\cdot 3\text{-}4)$$

$$\dot{M}_{Hi} = \sum_{\nu \epsilon Ti} W_{H\nu} - \sum_{\nu \epsilon Ii} W_{H\nu} + Q_i \quad \cdots\cdots (B\cdot 3\text{-}5)$$

Furthermore, by integration of the momentum conservation equation along the link (flow path) the following equation is obtained.

$$\dot{W}_k = \frac{1}{\sum_j \left(\frac{L_{kj}}{A_{kj}}\right)} \left[(P_i - P_j)g + \frac{W_k^2}{2\rho_k}\left(\frac{1}{A_i^2}-\frac{1}{A_j^2}\right) + \rho_k g \Delta h - g P_{fk}\right] \quad \cdots\cdots (B\cdot 3\text{-}6)$$

By joining and solving the three equations (B·3-4), (B·3-5), (B·3-6) in regard to all of the nodes, links, the flow amount could be updated and in addition, by means of the equation of state, the pressure can be calculated. (B·3-4)-(B·3-6) are placed as follows.

$$\frac{dW_k}{dt} = F_k(P,W) \quad \cdots\cdots (B\cdot 3\text{-}7)$$

$$\frac{dM_{Si}}{dt} = G_i(W) \quad \cdots\cdots (B\cdot 3\text{-}8)$$

$$\frac{dM_{Hi}}{dt} = H_i(W) \quad \cdots\cdots (B\cdot 3\text{-}9)$$

The network for equations (B·3-7)-(B·3-9) can be exptessed as the following difference approximation equation.[12)]

$$[I - h\cdot dF^n]\Delta y^{n+1} = hF^n \quad \cdots\cdots (B\cdot 3\text{-}10)$$

However,

$$I \equiv \begin{bmatrix} 1 & & \bigcirc \\ & \ddots & \\ \bigcirc & & 1 \end{bmatrix} \quad \cdots\cdots (B\cdot 3\text{-}11)$$

$$h \equiv (t^{n+1} - t^n) \quad \cdots\cdots (B\cdot 3\text{-}12)$$

$$dF^n \equiv \left[\begin{array}{c|c|c} \overbrace{\begin{matrix}\partial F_1/\partial W_1 & \cdots & \partial F_1/\partial W_L \\ \vdots & & \vdots \\ \partial F_L/\partial W_1 & \cdots & \partial F_L/\partial W_L\end{matrix}}^{L} & \overbrace{\begin{matrix}\partial F_1/\partial M_{S1} & \cdots & \partial F_1/\partial M_{SN} \\ \vdots & & \vdots \\ \partial F_L/\partial M_{S1} & \cdots & \partial F_L/\partial M_{SN}\end{matrix}}^{N} & \overbrace{\begin{matrix}\partial F_1/\partial M_{H1} & \cdots & \partial F_1/\partial M_{HN} \\ \vdots & & \vdots \\ \partial F_L/\partial M_{H1} & \cdots & \partial F_L/\partial M_{HN}\end{matrix}}^{N} \\ \hline \begin{matrix}\partial G_1/\partial W_1 & \cdots & \partial G_1/\partial W_L \\ \vdots & & \vdots \\ \partial G_N/\partial W_1 & \cdots & \partial G_M/\partial W_L\end{matrix} & \begin{matrix}\partial G_1/\partial M_{S1} & \cdots & \partial G_1/\partial M_{SN} \\ \vdots & & \vdots \\ \partial G_N/\partial M_{S1} & \cdots & \partial G_N/\partial M_{SN}\end{matrix} & \begin{matrix}\partial G_1/\partial M_{H1} & \cdots & \partial G_1/\partial M_{HN} \\ \vdots & & \vdots \\ \partial G_N/\partial M_{H1} & \cdots & \partial G_N/\partial M_{HN}\end{matrix} \\ \hline \begin{matrix}\partial H_1/\partial W_1 & \cdots & \partial H_1/\partial W_L \\ \vdots & & \vdots \\ \partial H_N/\partial W_1 & \cdots & \partial H_M/\partial W_L\end{matrix} & \begin{matrix}\partial H_1/\partial M_{S1} & \cdots & \partial H_1/\partial M_{SN} \\ \vdots & & \vdots \\ \partial H_N/\partial M_{S1} & \cdots & \partial H_N/\partial M_{SN}\end{matrix} & \begin{matrix}\partial H_1/\partial M_{H1} & \cdots & \partial H_1/\partial M_{HN} \\ \vdots & & \vdots \\ \partial H_N/\partial M_{H1} & \cdots & \partial H_N/\partial M_{HN}\end{matrix} \end{array}\right] \begin{matrix} n \\ L \\ N \\ N \end{matrix}$$

..... (B・3-13)

$$\Delta y^{n+1} \equiv \begin{bmatrix} \Delta W_1^{n+1} \\ \vdots \\ \Delta W_L^{n+1} \\ \Delta M_{S1}^{n+1} \\ \vdots \\ \Delta M_{SN}^{n+1} \\ \Delta M_{H1}^{n+1} \\ \vdots \\ \Delta M_{HN}^{n+1} \end{bmatrix}$$

..... (B・3-14)

$$F^n \equiv \begin{bmatrix} F_1 \\ \vdots \\ F_L \\ G_1 \\ \vdots \\ G_N \\ H_1 \\ \vdots \\ H_N \end{bmatrix}$$

..... (B・3-15)

Here, "L" is the number of links, "N" is the number of nodes; Equation (B・3-10) is the "L+2N" simultaneous equation, but mass equations after the "L+1" th can be substituted in up to the "L" th momentum equation and adjusted. That is to say, by the momentum equation being $(\partial F_k/\partial W_1)=0$

(when $k \neq \ell$), the "k" th equation is expressed as;

$$\left[1-h\frac{\partial F_k}{\partial W_k}\right]\Delta W_k^{n+1}+\sum_m^N\left[-h\frac{\partial F_k}{\partial M_{Sm}}\right]\Delta M_{Sm}^{n+1}+\sum_m^N\left[-h\frac{\partial F_k}{\partial M_{Hm}}\right]\Delta M_{Hm}^{n+1}=hF_k$$

$$(k=1\sim L) \quad \cdots\cdots (B\cdot3\text{-}16)$$

The second term and third term of Equation (B·3-16) can be written in the following forms:

$$\sum_m^N\left[-h\frac{\partial F_k}{\partial M_{Sm}}\right]^n\Delta M_{Sm}^{n+1}$$

$$=\sum_m^N h^2\left(\frac{\partial F_k}{\partial M_{Sm}}\right)^n\left[\sum_{\nu\in Im}\alpha_{S\nu}W_\nu^n-\sum_{\nu\in Tm}\alpha_{S\nu}W_\nu^n\right]+\sum_l^L h^2\alpha_{Sl}\left(\frac{\partial F_k}{\partial M_{Sli}}-\frac{\partial F_k}{\partial M_{Slj}}\right)^n\Delta W_l^{n+1}$$

$$\cdots\cdots (B\cdot3\text{-}17)$$

$$\sum_m^N\left[-h\frac{\partial F_k}{\partial M_{Hm}}\right]^n\Delta M_{Hm}^{n+1}$$

$$=\sum_m^N h^2\left(\frac{\partial F_k}{\partial M_{Hm}}\right)^n\left[\sum_{\nu\in Im}\alpha_{H\nu}W_\nu^n-\sum_{\nu\in Tm}\alpha_{H\nu}W_\nu^n\right]+\sum_l^L h^2\alpha_{Hl}\left(\frac{\partial F_k}{\partial M_{Hli}}-\frac{\partial F_k}{\partial M_{Hlj}}\right)^n\Delta W_l^{n+1}$$

$$\cdots\cdots (B\cdot3\text{-}18)$$

However, "li" expresses the initial node of link "l", "lj" is the terminal node of link "l". Furthermore, α_S, α_H are respectively the following equations. (they are same as the coefficients of the right hand side of equation (5-5), (5-6) described in Sec. 5.4).

$$\alpha_S\equiv\left[\frac{1-\alpha-\alpha(S-1)\cdot RHS}{1-\alpha(1-RHS)}\right] \quad \cdots\cdots (B\cdot3\text{-}19)$$

$$\alpha_H\equiv\left[\frac{S\cdot\alpha\cdot RHS}{1-\alpha(1-RHS)}\right] \quad \cdots\cdots (B\cdot3\text{-}20)$$

$$RHS\equiv \rho_H/\rho_S \quad \cdots\cdots (B\cdot3\text{-}21)$$

Here, S is the slip ratio, at each link it is given in the input data as a constant. By substituting equation (B·3-17), (B 3-18) in equation (B·3-16), the equation which should be finally solved is the following.

$$\left[1-h\left(\frac{\partial F_k}{\partial W_k}\right)^n+h^2\alpha_{Sk}\left(\frac{\partial F_k}{\partial M_{Ski}}-\frac{\partial F_k}{\partial M_{Skj}}\right)^n+h^2\alpha_{Hk}\left(\frac{\partial F_k}{\partial M_{Hki}}-\frac{\partial F_k}{\partial M_{Hkj}}\right)^n\right]\cdot\Delta W_k^{n+1}$$

$$+\sum_{l\ (l\neq k)}^L h^2\left[\alpha_{Sl}\left(\frac{\partial F_k}{\partial M_{Sli}}-\frac{\partial F_k}{\partial M_{Slj}}\right)^n+\alpha_{Hl}\left(\frac{\partial F_k}{\partial M_{Hli}}-\frac{\partial F_k}{\partial M_{Hlj}}\right)^n\right]\cdot\Delta W_l^{n+1}$$

$$=hF_k^n-h^2\sum_m^N\left[\left(\frac{\partial F_k}{\partial M_{Sm}}\right)^n\left(\sum_{\nu\in Im}\alpha_{S\nu}W_\nu^n-\sum_{\nu\in Tm}\alpha_{S\nu}W_\nu^n\right)+\left(\frac{\partial F_k}{\partial M_{Hm}}\right)^n\left(\sum_{\nu\in Im}\alpha_{H\nu}W_\nu^n-\sum_{\nu\in Tm}\alpha_{H\nu}W_\nu^n\right)\right]$$

(B·3.22)

B-3.3 Solution procedure of the difference approximation equations

Equation (B•3-22) is a system of "L" equations relating to ΔW_k, and when adjusted,

$$A \cdot \Delta w_k^{n+1} = z \quad \cdots\cdots (B\cdot 3\text{-}23)$$

Here, A is the square matrix of (LxL), Z is the vector of (L). Each factor of the matrix A and the vector Z respectively can be arranged as follows. (Below, the initial node of link k is abbreviated as "i" and the terminal node is abbreviated as "j".)

(1) Matrix factor $a_{k\nu}$

i) when $\nu = k$

$$a_{k\nu} = 1 - h\frac{\partial F_k}{\partial W_k} + h^2\frac{\partial F_k}{\partial M_{Si}}\alpha_{Sk} - h^2\frac{\partial F_k}{\partial M_{Sj}}\alpha_{Sk} + h^2\frac{\partial F_k}{\partial M_{Hi}}\alpha_{Hk} - h^2\frac{\partial F_k}{\partial M_{Hj}}\alpha_{Hk} \quad (B\cdot 3\text{-}24)$$

ii) when $\nu \in I_i, \nu \notin T_j$

$$a_{k\nu} = h^2\left(\frac{\partial F_k}{\partial M_{Si}}\alpha_{S\nu} + \frac{\partial F_k}{\partial M_{Hi}}\alpha_{H\nu}\right) \quad \cdots\cdots (B\cdot 3\text{-}25)$$

iii) when $\nu \in T_i, \nu \notin I_j$

$$a_{k\nu} = -h^2\left(\frac{\partial F_k}{\partial M_{Si}}\alpha_{S\nu} + \frac{\partial F_k}{\partial M_{Hi}}\alpha_{H\nu}\right) \quad \cdots\cdots (B\cdot 3\text{-}26)$$

iv) when $\nu \in I_j, \nu \notin T_i$

$$a_{k\nu} = h^2\left(\frac{\partial F_k}{\partial M_{Sj}}\alpha_{S\nu} + \frac{\partial F_k}{\partial M_{Hj}}\alpha_{H\nu}\right) \quad \cdots\cdots (B\cdot 3\text{-}27)$$

v) when $\nu \in T_j, \nu \notin I_i$

$$a_{k\nu} = -h^2\left(\frac{\partial F_k}{\partial M_{Sj}}\alpha_{S\nu} + \frac{\partial F_k}{\partial M_{Hj}}\alpha_{H\nu}\right) \quad \cdots\cdots (B\cdot 3\text{-}28)$$

vi) when $\nu \in I_i, \nu \in T_j$

$$a_{k\nu} = h^2\left(\frac{\partial F_k}{\partial M_{Si}}\alpha_{S\nu} + \frac{\partial F_k}{\partial M_{Hi}}\alpha_{H\nu} - \frac{\partial F_k}{\partial M_{Sj}}\alpha_{S\nu} - \frac{\partial F_k}{\partial M_{Hj}}\alpha_{H\nu}\right) \quad \cdots\cdots (B\cdot 3\text{-}29)$$

vii) when $\nu \in T_i, \nu \in I_i$

$$a_{k\nu} = h^2\left(-\frac{\partial F_k}{\partial M_{Si}}\alpha_{S\nu} - \frac{\partial F_k}{\partial M_{Hj}}\alpha_{H\nu} + \frac{\partial F_k}{\partial M_{Sj}}\alpha_{S\nu} + \frac{\partial F_k}{\partial M_{Hj}}\alpha_{H\nu}\right) \quad \cdots\cdots (B\cdot 3\text{-}30)$$

viii) others

$$a_{k\nu} = 0 \quad \cdots\cdots (B\cdot 3\text{-}31)$$

(2) Vector factor Z_{ν}

$$Z_k = hF_k + h^2\left(\frac{\partial F_k}{\partial M_{Si}}\gamma_{Si} + \frac{\partial F_k}{\partial M_{Hi}}\gamma_{Hi} + \frac{\partial F_k}{\partial M_{Sj}}\gamma_{Sj} + \frac{\partial F_k}{\partial M_{Hj}}\gamma_{Hj}\right) \quad \cdots\cdots (B\cdot3\text{-}32)$$

$$\gamma_{Si} = \sum_{\nu\in Ti}\alpha_{S\nu}W_\nu - \sum_{\nu\in Ii}\alpha_{S\nu}W_\nu$$

$$\gamma_{Hi} = \sum_{\nu\in Ti}\alpha_{H\nu}W_\nu - \sum_{\nu\in Ii}\alpha_{H\nu}W_\nu + Q_i \quad \cdots\cdots (B\cdot3\text{-}33)$$

Equation (B·3-23) can be solved by the sweep-out method; the increased amount of the flow rate and, the various quantities of each node can be updated in the order shown below.

$$W_k^{n+1} = W_k^n + \Delta W_k^{n+1} \quad \cdots\cdots (B\cdot3\text{-}34)$$

$$M_{Si}^{n+1} = M_{Si}^n + h\left(\sum_{\nu\in Ti}\alpha_{S\nu}W_\nu^{n+1} - \sum_{\nu\in Ii}\alpha_{S\nu}W_\nu^{n+1}\right) \quad \cdots\cdots (B\cdot3\text{-}35)$$

$$M_{Hi}^{n+1} = M_{Hi}^n + h\left(\sum_{\nu\in Ti}\alpha_{H\nu}W_\nu^{n+1} - \sum_{\nu\in Ii}\alpha_{H\nu}W_\nu^{n+1} + Q_i\right) \quad \cdots\cdots (B\cdot3\text{-}36)$$

$$\rho_{Hi} = \frac{M_{Hi}}{V_i - (M_{Si}/\rho_S)} \quad \cdots\cdots (B\cdot3\text{-}37)$$

Here, V_i is the volume of the node.

Next, the pressure of each node is decided as follows.

1) Sodium-hydrogen gas two-phase node

For a node containing over a certain degree of hydrogen gas, a gas equation of state is used.

$$P_i = \rho_{Hi}RT_{Hi} \quad \cdots\cdots (B\cdot3\text{-}38)$$

Here, T_{Hi} is the temperature of the hydrogen gas given as input for each node.

2) Sodium single phase node

Because this code disregards the compressibility of sodium, the pressure for the sodium single phase node cannot be obtained by the abovementioned method. In addition, even for two-pahse nodes, when the void fraction is low, the pressure of the node, being represented by the pressure of a small hydrogen bybble, is not stable. Therefore, in such a case, the pressure is obtained by the following equation.

$$\left.\begin{aligned} \dot{M}_{si} &= 0 \\ \sum_{\nu \in Ti} W_{s\nu} &= \sum_{\nu \in Ii} W_{s\nu} \\ \sum_{\nu \in Ti} \dot{W}_{s\nu} &= \sum_{\nu \in Ii} \dot{W}_{s\nu} \end{aligned}\right\} \quad \cdots\cdots (B\cdot3\text{-}39)$$

Here, when (B·3-6) is substituted, it becomes

$$\sum_{\nu \in Ti} \frac{1}{K_\nu} (P_i - P_j + \Delta P_{f\nu}) = \sum_{\nu \in Ii} \frac{1}{K_\nu} (P_i - P_j + \Delta P_{f\nu}) \quad \cdots\cdots (B\cdot3\text{-}40)$$

Here, $\Delta P_{f\nu}$ is the sum of the 2nd, 3rd, and 4th term of right side of Equation (B·3-6). "j", "i" are respectively the terminal and initial node of link "ν". Accordingly, by obtaining the value of $\Delta P_{f\nu}$, pressure P_i of a single phase node can be obtained as a solution of a simultaneous equation.

APPENDIX C REGARDING THE REGISTRATION NUMBERS FOR THE SWACS CODE

C-1 General Outline

SWACS code has been developed as an integrated code to analyze a large-leak sodium water reaction and two years have passed since it was initially reported[1]; during that interval there have been functional revisions, modifications and improvements made in the code itself by means of applied calculations on the 'Monju' system[9),10)] as well as verification calculations on the SWAT-3 experiment.[6),7),8)]

Because of this, basic assumptions and methods of calculation have not changed, however details in the calculation modules themselves have changed and so inconveniences may arise. For example, the input format of the water leak rate calculation module (SWAC-11) has changed and therefore the old data cards cannot be used at the present time.

Due to the above conditions, in order that SWACS code users are less prone to use the old cards which would give rise to confusion, we have gone back over the reports issued up until the present and added SWACS code registration numbers.

The registration numbers are abbreviated as "REG" and the version used in the first report[1),9)] is called "REG1", the most recent version treated in this report is called "REG3", and for adjustment convenience, in between a "REG2" has been established.

The major points of modification from REG1 to REG3 in the calculation modules are indicated below.

C-2 Major Points of Modifications

C-2.1 SWACS/REG1

The first report made on the SWACS code[1),9)].

C-2.2 SWACS/REG2

The modifications and changes indicated below were made on SWACS/REG1.

1) Modifications in function

-Plotter output functions were added to the water leak rate calculation module and the quasi-steady pressure calculation module.
-In the initial pressure spike calculation the speed of sound of the spherical model portion can be independently input.
-In the initial pressure spike calculation, modifications were made in the program stop routine when the bubble radius reached the spherical model radius.
-In the pressure propagation calculation, modifications were made for the pressure wave source table input format from the data file of the relults of the initial pressure spike calculation.
-In the quasi-steady pressure calculation, the equivalence diameter of the link and the section area can be separately input.
-In the quasi-steady pressure calculation, the size of the time step (Δt) can be changed in the middle of the calculation.
-In the quasi-steady pressure calculation, the output list of the calculation results was modified and the flow velocity can be output.

2) Modifications in the calculation method

-In the quasi-steady pressure calculation, the treatment of the two-phase friction multiplier has been modified. In addition, mistakes in use of the Martinelli's coefficient and the calculation of the two-phase friction multiplier have been corrected.

C-2.3 SWACS/REG3

This is the version treated in this report. Principally, large adjustments have been made in the water leak rate calculation module. Furthermore, there are no modifications between REG2 and REG3 in the initial pressure spike and pressure propagation calculations.

1) Functional modifications

The following adjustments and modifications were made in the water leak rate calculation.

-Volume junction model calculation parts were removed.
-Input format was adjusted and modified.
-Output format (output list) was adjusted.
-The largest cell number that can be handled was increased from 100

cells to 300 cells.

-Closed-end boundary condition can be treated.

2) Modifications in the method of calculation

The following changes were made in the water leak rate calculation.

-The number of fictious cells that are set up in the rupture end boundary were reduced from 3 to 1.

-Mass flux as a variable in the numerical calculation was newly established and a readjustment was made in the difference equation.

-Because the error of the sonic velocity of the liquid single-phase region was large, modifications were made to treat it as a table.

-In the calculation of pressure loss, errors were corrected in the treatment of two-phase multiplier.

The following modifications were made in the quasi-steady pressure calculation module.

-The calculation of the friction loss coefficient of a turbulent flow region was changed from the Blasius equation, and the Nikuradse equation to the Colebrook equation.

Errors in the calculation of pressure loss in the bend were corrected.