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A KINETIC MODEL OF SODIUM-WATER REACTION APPLIED TO DYNAMIC SIMULATION OF LEAK DETECTION IN THE CORE COMPONENTS TEST LOOP

by

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MASTER

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D. Saphier*

July 1976

*On leave from the Israel Atomic Energy Commission Soreq Nuclear Research Centre

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ABSTRACT

A detailed model for the CCTL steam-generator leak-detection simulation was developed to predict the hydrogen- and oxygen-detector response during a series of experiments to be performed at ANL. The detailed kinetic equations for the sodium-water interaction are given, as well as the assumptions made in assessing the various reactivity rates and hydrogen-gas migration in the sodium toward a free surface in contact with the cover gas. A dynamic model was developed describing concentration changes as a result of primary and secondary sodium reactions, sodium flow through the system piping, mixing processes in various plenum elements, cold-trap operation, cover-gas pressure changes, and water leaks. A computer program CCTL-DYSP has been written in which the dynamic model was simulated to obtain the concentration of the different reaction products as functions of time for any segment of the CCTL system. A generalized approach was used in the modeling and programming procedures, so that only the input data have to be changed in order to analyze different experiments and different system configurations. With minor changes, the computer program can be adapted to simulate leak detection in the CRBR. Some representative results are included in the report, and qualitatively they are in agreement with similar results published elsewhere. Some experimental results also became available recently, and they are in good agreement with the simulated concentrations.

I. INTRODUCTION

The hazard to LMFBR steam generators from small water leaks has long been recognized and has been the subject of several theoretical and experimental studies.[1-12] Large water leaks in a superheater or evaporator will lead to a spontaneous violent reaction and to subsequent partial or complete destruction of the steam generator. Small leaks, if permitted to continue during a period sufficiently long, will produce corrosive agents that cause destructive wastage of the steam-generator tubing and finally result in "secondary" large leaks with extensive damage. It is, therefore, of utmost importance to detect the small leaks and their location so that the plant can be shut down before significant damage occurs.

Accordingly, an experimental leak-detection program[1] is underway in the Argonne Core Components Test Loop (CCTL) to evaluate methods for small-leak detection. The purpose of this experimental program is to evaluate the most efficient means for detecting water-to-sodium leaks in the range of 10^{-7}-10^{-3} lb/sec and to gather enough experimental data on the leak-detection methods so that they can be applied to the Clinch River Breeder Reactor (CRBR). A series of experiments, as described in Ref. 1, to simulate water leaks in the CRBR heat exchangers will be performed. These experiments will be carried out under different flow rates, sodium temperatures, leak rates, and leak positions.

The purpose of the present study is to develop a mathematical model for the CCTL leak-detection experiment, and to set up a simulation program capable of solving the model equations in order that the leak-detector response can be predicted with reasonable accuracy. The modeling and the program are set up in a general way so that the CCTL experiment is a particular case. The computer program is modular and with minor changes can be applied to the simulation of other systems having water leaks into a sodium loop.

Several investigators[1,6,8,10,12] have formulated general relationships between the size of the water leak and the quantity of hydrogen to be found in sodium after steady-state conditions are established. However, these relationships are usually system-dependent. In contrast, the mathematical model for the CCTL leak-detection experiment was developed from basic principles of conservation and the kinetic equations of the chemical reactions. Where certain basic parameters, such as reaction rates and hydrogen-gas disengagement rates, were not well known, reasonable assumptions were introduced. These assumptions can later be checked and improved by appropriate experiments. With this approach, the simulation program is rendered system-independent and can easily be expanded to simulate leak detection in the CRBRP or other sodium systems.

II. THE CCTL LEAK-DETECTION EXPERIMENTAL SETUP

The Core Components Test Loop (CCTL) as well as the leak-detection experimental program are described in Ref. 1. Briefly, the CCTL is a large isothermal sodium loop, as is shown schematically in Fig. 1. The sodium is circulated through the main loop by a mechanical pump having a capacity of 800 gpm. The major component is a large sodium tank within which a simulated module of an CRBRP steam generator is placed. The water and steam pipes are simulated by solid stainless steel rods of the same diameter as the actual pipe. Water leaks are simulated by steam injections made directly into the module.

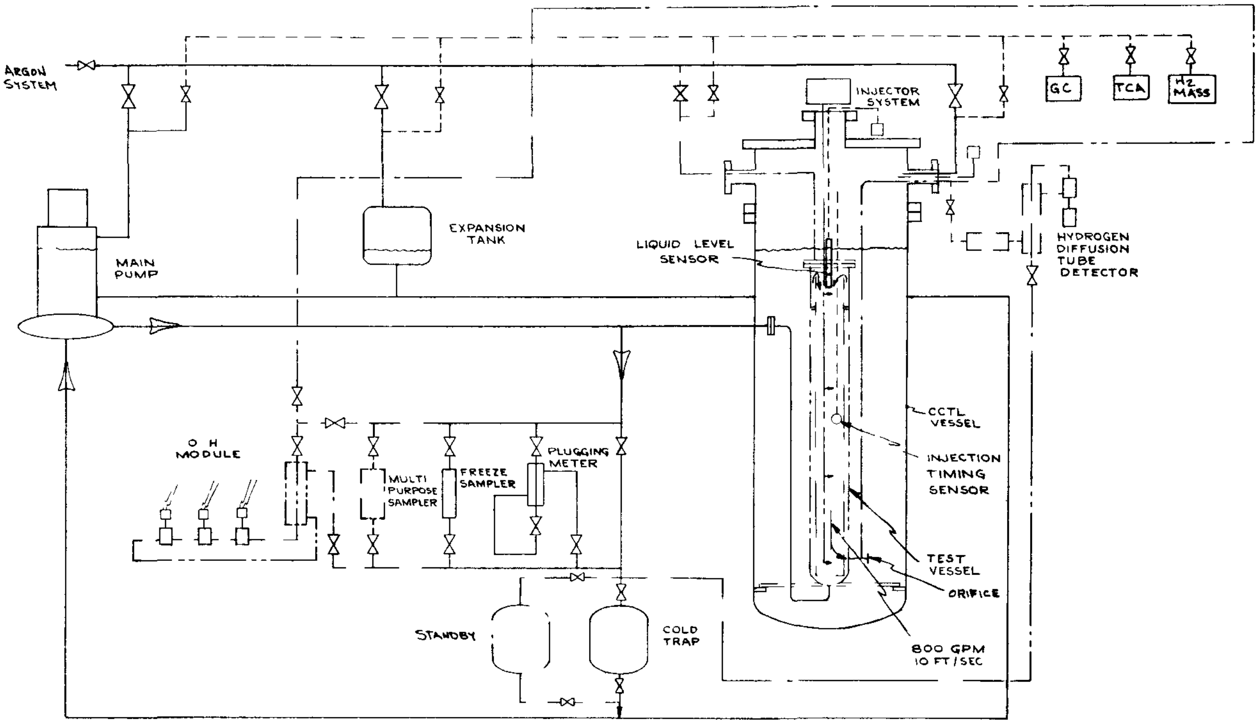

Fig. 1. Schematic Description of CCTL Loop

At several points in the system, sample lines direct a small fraction of the flow to various types of hydrogen and oxygen detectors. Among others, in-sodium hydrogen-diffusion, cover-gas hydrogen-diffusion, and electrochemical-oxygen meters are used. A bypass flow also passes to a purifying system, a cold trap, in which the impurities are removed from the sodium by precipitation. The bypass flows are governed by a series of valves and EM pumps, as shown in Fig. 1.

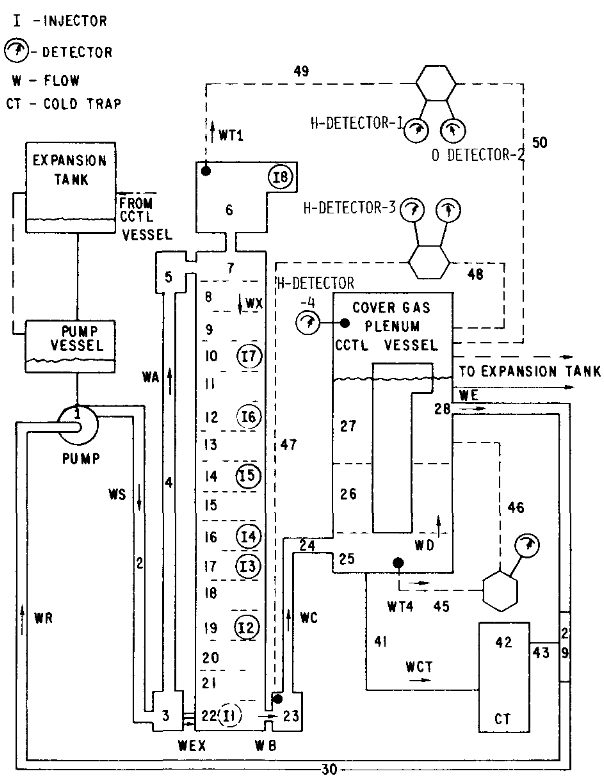

Fig. 2. CCTL Schematics for Simulation Program

A schematic diagram of the CCTL leak-detection experiment, presenting features of importance to the mathematical modeling, is shown in Fig. 2. The CCTL system is divided into segments, each being considered as a lumped-parameter node. Two basic types of segments are used: (1) a mixing plenum, in which ideal mixing is assumed; and (2) pipes in which a pure delay and secondary reactions are assumed.

The steam-generator segments, nodes 6-22, are mixing-plenum segments each having two baffle plates as a physical boundary. The flow between the segments is forced around the simulated tubes and the periphery of the baffle plate so that the total mixing is a good assumption for these segments. Steam injection points are designated as I1-I8.

Nodes 25-27 are the CCTL vessel segments and contain large volumes of sodium. Node 1 (the pump) and node 27 (the upper vessel section) are in contact with the cover gas, and hydrogen can leave sodium through these segments.

Node 42 is the cold trap where hydrogen and oxygen are removed from the system by cooling and precipitation.

In Fig. 2, detectors are connected to nodes 6, 23, and 25, and the cover-gas plenum; the other nodes depicted are pipe nodes.

The total flow through the system as it leaves the pump is designated as WS; constant flow is assumed. There is a small sodium bypass flow WEX from node 3 to node 22. Flow from node 7 to node 6 is equal to bypass flow WT1 to the detectors connected to pipe node 49. Other flows leaving the main flow are WT3 and WT4, detector flows, and WCT, the cold-trap flow. All bypass flows to the detectors return to the system through upper sodium node 27 in the CCTL vessel. In the version of the program given in Appendix C, up to 50 segments having sodium flow and sodium-water reactions can be simulated.

The CCTL DYnamic Simulation Program (CCTL-DYSP) is based on the above schematic description of the system. The computer code is described in Appendix B. In the program, a mass and concentration balance for each segment shown in Fig. 2 is performed, using the kinetic and the dynamic equations developed in Secs. III and IV.

Simulation of slow transients must include the influence of cold trapping on the hydrogen and oxygen concentration in the system. Details on cold-trap dynamics appear in Sec. V.

Finally, the detector response is simulated by accounting for the hydrogen and oxygen diffusion through the detectors, and the appropriate time delays in the instrumentation piping.

III. THE KINETICS OF SODIUM-WATER INTERACTIONS

A. The Sodium-Water Reactions

When physical contact is made between sodium and water, with an excess of water, a spontaneous violent reaction occurs, producing sodium hydroxide and hydrogen:

$$Na + H_2O \rightarrow NaOH + \tfrac{1}{2} H_2(g). \tag{1}$$

However, under small-leak conditions prevailing in steam generators, the ratio of sodium to water is of the order of 10^6 and additional reactions take place:

$$2Na + H_2O \rightarrow NaOH + NaH; \tag{2}$$

$$4Na + H_2O \rightarrow 2NaH + Na_2O; \tag{3}$$

$$2Na + H_2O \rightarrow Na_2O + H_2. \tag{4}$$

The relative fraction of water participating in each of these reactions is dependent on the quantity of water introduced by the leak, the sodium temperature, and the sodium pressure. However, no numerical values were reported in the literature as to the quantity of water going into any of the four above reactions.

Therefore, in the present study, it was assumed that the above reactions are instantaneous and the fraction of water associated with each reaction is K1, K2, K3, and K4, respectively, and that

$$K_1 + K_2 + K_3 + K_4 = 1. \tag{5}$$

Accordingly, when Q moles of water leak into sodium, four reaction products are generated with the following distribution:

$$Q(0.5\ K_1 + K_4) \text{ moles of } H_2; \tag{6}$$

$$Q(K_1 + K_2) \text{ moles of NaOH}; \tag{7}$$

$$Q(K_1 + 2K_3) \text{ moles of NaH}; \tag{8}$$

$$Q(K_3 + K_4) \text{ moles of } Na_2O. \tag{9}$$

These products are predominantly dissolved and entrained by the rapid turbulent sodium flow. However, a fraction of the hydrogen is entrained as bubbles rather than dissolved in the liquid sodium. These bubbles will either diffuse and dissolve in the fluid, or escape into the cover gas.

Some of the products formed in the primary reactions are unstable at the temperatures prevailing in a steam generator or in the CCTL. The NaH and NaOH are dissociated according to the equations

$$Na + NaOH \rightarrow Na_2O + \tfrac{1}{2} H_2 \tag{10}$$

and

$$NaH \rightleftarrows Na + \tfrac{1}{2}H_2. \qquad (11)$$

Thus, it is apparent that the ultimate products of the sodium-water reaction are predominantly hydrogen gas and sodium oxide, which can be detected by hydrogen and oxygen meters.

B. Hydrogen Equilibrium Concentration in Sodium

In systems under equilibrium conditions, some of the hydrogen dissolved in sodium escapes to the cover gas and is found to have a partial pressure P_H, independent of the cover gas pressure (usually argon). The equilibrium relation between the hydrogen in the cover gas and hydrogen in sodium (either as hydrogen or as NaH) is governed by the Sieverts' law:[8]

$$C_H = K_S P_H^{1/2}, \qquad (12)$$

where C_H is the hydrogen concentration in sodium (in mol/lb) and K_S is Sieverts' constant given by

$$K_S = 2.255 \times 10^{-6} \exp(1.9733 - 276.77/T_K), \qquad (13)$$

where K_S is in mol/lb-Torr$^{1/2}$, T_K is the temperature in degrees Kelvin, and P_H is the hydrogen partial pressure, in Torr (i.e., mm Hg).

C. Decomposition Rate of Sodium Hydroxide

In reactions 1 and 2, sodium hydroxide (NaOH) is formed. This product is unstable under normal reactor operating conditions and decomposes according to Eq. 10. In his experiments, which involved heating sodium with NaOD* at 500°C under vacuum, Fischer[4] found that the reaction is of the first order according to

$$Rt = \ln[C_0/(C_0 - C)] \qquad (14)$$

where C_0 is the initial concentration, C is the concentration at time t, and R is the rate constant.

From the linear portion of the experimental curve, Fischer[4] determined the rate constant to be

$$R = 0.0045 \text{ min}^{-1},$$

or in other terms, the half-life $\tau_{1/2}$ of NaOH is

*D denotes deuterium.

$\tau_{1/2}$ = 150 min.

Therefore, K_{NaOH} = 7.5×10^{-5} sec^{-1} was used in this study.

The hydroxide decomposition in sodium has also been treated by several authors,[4,7,10] but none gave the temperature dependence of the reaction rate. In the present study, it was therefore assumed that the reaction rate is a constant.

D. Dissociation Pressure of Sodium Hydride

The partial pressure of hydrogen over NaH has been well established for a wide range of temperatures[1,4,9] and is given by

$$P_{dis} = \exp(26.71 - 14046/T_K), \tag{15}$$

where P_{dis} is the dissociation pressure, in mm Hg, and T_K is the temperature, in degrees Kelvin. Banus et al.[11] have shown that Eq. 15 is correct, even in dilute sodium solutions; therefore the equation was used in the present study.

E. Hydrogen Absorption by Sodium

Under vacuum conditions at elevated temperatures, all the sodium hydride will be decomposed. However, hydrogen also will be absorbed by sodium if it is available in significant quantities in a cover-gas plenum over the sodium. Experiments by Longton[3] reveal that if hydrogen is admitted over sodium at a pressure greater than the dissociation pressure, sodium hydride will form until the pressure decreases to a value equal to the dissociation pressure. The rate of absorption in terms of a pressure change ΔP_H is given by a simple parabolic law

$$\Delta P_H = K(P_H - P_{dis})^2, \tag{16}$$

where P_H is the actual pressure in the cover gas, P_{dis} is the dissociation pressure, Δ indicates change in the variable, and K is the rate constant, which is temperature-dependent according to the Arrhenius equation

$$K = A \exp(-Q/RT). \tag{17}$$

From the semilogarithmic plots given by Longton,[3] A and Q/R have been determined to be

$$A = 1.42 \times 10^9 \text{ sec}^{-1} \text{ and } Q/R = 11795°K.$$

Note, however, that at the temperatures of interest in the steam generator, the dissociation pressure of NaH is high [for 940°F (504°C), P_{dis} = 5670 mm-Hg]; hence, hydrogen from the cover-gas plenum is not expected to be absorbed in sodium.

F. Decomposition Rate of Sodium Hydride

Naud[6] has reported some experiments to determine NaH dissociation rates. He reported large experimental errors. However, since these are the only rate constants available, they will be used in the present study. The values reported by Naud are

$$K(310°C) = 0.05 \text{ min}^{-1}$$

and

$$K(280°C) = 0.035 \text{ min}^{-1}.$$

On substituting these values into Eq. 17, we obtain the following expression for the rate of NaH dissociation:

$$R_2 = 0.597 \exp(-3883/T_K). \tag{18}$$

If, however, the partial pressure of hydrogen in the cover gas is equal to or greater than the NaH dissociation pressure, there will be no NaH dissociation. It is, therefore, assumed that both processes, i.e., NaH dissociation, and hydrogen absorption by the sodium and formation of sodium hydride, are governed by Eq. 16 and the combined rate constant is given by

$$K_{NaH} = R_2\left(\frac{P_{dis} - P_H}{P_{dis}}\right)^2. \tag{19}$$

G. Kinetic Equations

In Secs. A-F the various chemical reactions occurring when a small quantity of water is introduced into sodium were described. The dissociation equations of some of the products and their reaction rates were also given.

It is now possible to write the kinetic equations for a volume of sodium into which a leak of Q lb/sec of water has been injected. These equations give the change in concentration of the reaction products as a function of time:

$$\dot{C}_{Nah} = \frac{d}{dt} C_{NaH} = (K_2 + 2K_3)\frac{Q}{M} - K_{NaH}C_{NaH}, \tag{20}$$

$$\dot{C}_{NaOH} = \frac{d}{dt} C_{NaOH} = (K_1 + K_2)\frac{Q}{M} - K_{NaOH}C_{NaOH}, \tag{21}$$

$$\dot{C}_{Na_2O} = \frac{d}{dt} C_{Na_2O} = (K_3 + K_4)\frac{Q}{M} + K_{NaOH}C_{NaOH}, \tag{22}$$

and

$$\dot{C}_{H_2} = \frac{d}{dt}C_{H_2} = (0.5K_1 + K_4)\frac{Q}{M} + 0.5(K_{NaH}C_{NaH} + K_{NaOH}C_{NaOH}), \tag{23}$$

where C is the concentration (in mol/lb) of the different products, M is the sodium mass (in lb) in the calculated segment, K_{NaH} is given by Eq. 19, K_{NaOH} is a constant (in sec^{-1}), and Q is the leak rate (in mol/sec).

These equations are used in subsequent sections to develop the dynamic equations used in the simulation study.

IV. DYNAMICS OF SODIUM-WATER REACTION-PRODUCT PROPAGATION

The dynamic equations developed in this section are based mainly on mass balance applied to each segment and each product of the CCTL system. The equations are written in a general way so that the program can be adopted to other systems mainly by changing the input data. Some additional changes may be required due to differences in the physical-loop configurations.

A. Sodium Flow and Concentration Changes

The CCTL system is subdivided into several segment nodes as shown in Fig. 2. In a generalized node, the following processes occur:

1. Primary reactions resulting from water leak.
2. Secondary reactions.
3. Sodium flowing into and out of the segment.
4. Hydrogen gas entering or leaving the node.
5. Precipitation of reaction products.

The appropriate balance equations are

$$\frac{d}{dt}C_1 = \frac{1}{M}\sum_j (W_{ij}C_{1ij} - W_{xj}C_1) + \dot{C}_{NaH}, \tag{24}$$

$$\frac{d}{dt}C_2 = \frac{1}{M}\sum_j (W_{ij}C_{2ij} - W_{xj}C_2) + \dot{C}_{NaOH}, \tag{25}$$

$$\frac{d}{dt}C_3 = \frac{1}{M}\sum_j (W_{ij}C_{3ij} - W_{xj}C_3) + \dot{C}_{Na_2O}, \tag{26}$$

and

$$\frac{d}{dt}C_4 = \frac{1}{M}\sum_j (W_{ij}C_{4ij} - W_{xj}C_4) + \dot{C}_{H_2} - W_H/M, \tag{27}$$

where

j = 1, ..., j for all inlet and outlet flows,

i = inlet,

x = exit,

C_1 = concentration of NaH (in mol/lb) at any particular node,

C_2 = concentration of NaOH (in mol/lb) at any particular node,

C_3 = concentration of Na_2O (in mol/lb) at any particular node,

C_4 = concentration ot hydrogen (in mol/lb) at any particular node,

W_{ij} = node inlet flow (in lb/sec) at the jth inlet,

W_{xj} = node exit flow (in lb/sec) at the jth outlet,

M = total mass of sodium (in pounds) in the node,

W_H = net hydrogen gas (in mol/sec) leaving (or entering) the node,

and

$\dot{C}_{NaH}$, $\dot{C}_{NaOH}$, $\dot{C}_{Na_2O}$, and $\dot{C}_{H_2}$ are time derivatives given by Eqs. 20, 21, 22, and 23, respectively.

B. Hydrogen Partial Pressure in the Cover Gas

In the sodium loop of an LMFBR steam generator, as well as in the CCTL leak-detection experiment, the sodium may have a free surface with an inert cover gas in several places. Under leak conditions, hydrogen generated in the sodium will escape into the cover gas. If, for some reason, a high concentration of hydrogen or steam exists in the cover gas, it will be partially absorbed in the sodium flow.

In the CCTL experiment, the coolant contacts the cover gas in two places: the pump and the CCTL vessel. The amount of gas (in mol/sec) that can leave these nodes is W_{HP} and W_{HC} for the pump and the CCTL vessel, respectively. All cover-gas plena are connected through the expansion tank, and equal pressure is assumed to exist in each plenum.

The hydrogen partial gas pressure P_H is calculated from the ideal gas law PV = nRT:

$$W_H = W_{HP} + W_{HC}; \tag{28}$$

$$\frac{dP_H}{dt} = 554.4 W_H T_{p\ell}/V_{p\ell}, \tag{29}$$

where P_H is in mm Hg, W_H is in mol/sec; $T_{p\ell}$ is the temperature (in degrees Rankine), and $V_{p\ell}$ is the total plenum volume (in cubic feet).

C. Hydrogen-gas Migration

The quantity of hydrogen gas produced at the leak site is given by Eq. 6. This hydrogen can be in two forms; it can be either dissolved in the sodium or in the form of tiny bubbles. No information was found in the literature on whether any hydrogen bubbles are formed and what the fraction or sizes of these bubbles are. From the experiments performed so far there is, however, a strong indication that no bubbles are formed at the high temperatures prevailing in the heat exchanger, but some of the hydrogen might be produced in bubbles under low-temperature condition.

The conditions under which hydrogen bubbles are formed and their subsequent behavior in the system are the subject of ongoing theoretical and experimental investigations. In this study, it is assumed that if free hydrogen is formed during reactions at the leak site, it will be completely dissolved in the sodium. This assumption is well justified above 600°F (316°C) and will probably be increasingly erroneous as the temperature of the sodium in the CCTL experiment is lowered.

A model for the possible migration or diffusion of the dissolved hydrogen and its subsequent escape into the cover gas has been developed based on the following assumptions:

1. Dissolved hydrogen will diffuse from the sodium into the cover gas only when the partial pressure in the cover gas is less than the value governed by Sieverts' law (Eq. 12).

2. Hydrogen from the cover gas will enter the sodium only if the partial pressure of the cover gas is higher than the NaH dissociation pressure.

3. Independent hydrogen-gas migration occur only in parts of the system where very slow flow exists; otherwise the gas will be entrained in the sodium flow.

4. The gas will migrate only in the upward direction.

5. The rate at which the hydrogen migrates to the cover gas is determined by the difference between hydrogen concentration and the equilibrium value according to Seiverts' law:

$$W_H = R_1(C_H - C_{HS})M \quad \text{for} \quad C_H > C_{HS}. \tag{30}$$

6. The rate constant R_1, which governs the hydrogen disengagement rate, is assumed to be such that, if zero partial pressure of hydrogen exists in the cover gas, it will take $\tau_{1/2}$ for half the hydrogen necessary to establish equilibrium to leave the sodium node:

$$R_1 = (\ln 2)/\tau_{1/2} = 0.693/\tau_{1/2}. \quad (31)$$

D. Dynamics of a Pipe Segment

Dynamic equations for a pipe containing M pounds of sodium flowing at W lb/sec are determined by the transit time τ, which is given by

$$\tau = M/W. \quad (32)$$

The concentration of any of the reaction products at time $t - \tau$ is given by

$$C' = C(t - \tau). \quad (33)$$

Hence, C' is the concentration of a reaction product τ seconds before it reaches the pipe exit.

There are no leaks in these pipe segments; therefore, only secondary reactions take place. The change in C', which was confined to the pipe segment during time τ, is obtained by the following single-step integration process:

$$\Delta C_1 = -K_{NaH}C_1'\tau, \quad (34)$$

$$\Delta C_2 = -K_{NaOH}C_2'\tau, \quad (35)$$

$$\Delta C_3 = K_{NaOH}C_2'\tau, \quad (36)$$

and

$$\Delta C_4 = 0.5(K_{NaH}C_1' + K_{NaOH}C_2')\tau. \quad (37)$$

This is a coarse integration process and can be justified only because the secondary reaction-rate constants are very small.

The concentration of any of the reaction products at the exit of the pipe at time t is given by

$$C(t) = C' + \Delta C. \quad (38)$$

V. THE COLD TRAP

Impurities are removed from the sodium by cooling it to temperatures at which the solubility of some of the reaction products is reduced considerably.

A small stream of the sodium is bypassed through a special heat exchanger called a cold trap. If the concentration of the impurities exceeds the amount that can be dissolved in sodium at the cold-trap temperature, the excess will precipitate.

A. Cold-trap Efficiency

Theoretically, the impurity concentration in sodium at the cold-trap outlet should be equal to its solubility at the cold-trap temperature. However, the operating characteristics of the cold trap change with time and flow rate, with consequent changes in its static efficiency, which is given by[12]

$$\beta = \frac{C_i - C_x}{C_i - C_{sat}}, \tag{39}$$

where C_i and C_x are the impurity concentrations at the inlet and outlet, and C_{sat} is the saturation concentration for the cold-trap temperature.

B. Cold-trap Dynamics

In a dynamic system, the widely accepted concept of the static efficiency β cannot be used. Instead, a dynamic efficiency is defined by

$$M\frac{dC}{dt} = W_{ct}(C_{in} - C) - \beta_d(C_{in} - C_{sat}), \tag{40}$$

where C is the average outlet concentration (in mol/lb), and β_d is the dynamic efficiency, given by

$$\beta_d = f(W_{ct}, T_{ct}), \tag{41}$$

where W_{ct} is flow rate through the cold trap (in lb/sec), and M is the sodium content in the cold trap (in pounds). The exact dependence of β_d on the flow rate and other factors is presently unknown.

C. Solubility of Reaction Products

Available data on the solubility of hydrogen and oxygen in sodium have been summarized by Rodgers and Dutina.[5] Their recommended values as function of temperature were used in this study.

For NaH, $C_{1sat} = \exp(13.97 - 6631.4/T_K)$. (42)

For Na_2O, $C_{3sat} = \exp(16.131 - 6493.3/T_K)$. (43)

The concentrations are given in ppm, and T_K is the cold-trap temperature in degrees Kelvin.

VI. DETECTORS

The results of the CCTL leak-detection experiments will be available through reading and interpreting outputs from the hydrogen and oxygen detectors. Outputs from the hydrogen detectors will be proportional to the NaH and hydrogen concentrations, and outputs from the oxygen detectors will be proportional to the Na_2O concentration.

To predict the detector outputs, the simulation employs three parameters that characterize the detectors: (1) the time lag τ, which is the time for the tiny stream of sodium to reach the detecting apparatus; (2) the diffusion time constant θ of the detector, i.e., the time for hydrogen or oxygen to diffuse through the membrane until equilibrium is achieved between the measured sample stream and the detector interior; and (3) the proportionality or calibration constant of the detector.

The detector transfer function is given by

$$\frac{A}{C} = \frac{K_d e^{-S\tau}}{1 + S\theta}, \tag{44}$$

where A is the detector reading, C is the actual concentration, S is the Laplace-transform operator, and K_d is the proportionality constant.

VII. A TYPICAL DATA SET TO BE USED WITH THE SIMULATION

A data set that describes the CCTL system, the conditions at which the particular experiment is performed, and some initial conditions is given in Tables I-VII. Except for the explanatory titles, the tables are reproductions of CCTL-DYSP printouts of initial data used in a CCTL leak-detection-experiment simulation.

Table I presents data describing the system segments, length, cross section, area, the total mass of sodium in each segment, and the flow through each segment. Table II shows the initial conditions in each segment. Table III gives some reaction parameters and how much of each reaction product is generated per mole of water leak. Table IV gives some system constants, and Table V gives the input flow values through various passages. Table VI shows the leak experiment for a particular run, and Table VII describes the detectors.

TABLE I Description of CCTL Experiment by Segments TYPE 0, not simulated, TYPE 1, mixing plenum, TYPE 2, a pipe segment, TYPE 3, plenum with cover gas; TYPE 4, segment with multiple entry, TYPE 5, segment with cover gas and multiple entry

******************** RUN # 24: CCTLP LEAK DETECTION

SEGM		TYPE	SEGMENT PARAMETERS LENGTH (ft)	CROSS-AREA (ft^2)	MASS (lb)	FLOW (lb/sec)
1	*	3	1.000E 00	1.069E 00	5.583E 01	9.309E 01
2	*	2	4.090E 01	9.893E-02	2.113E 02	9.309E 01
3	*	1	1.000E 00	3.395E-01	1.773E 01	9.309E 01
4	*	2	1.000E 01	9.893E-02	5.166E 01	9.297E 01
5	*	1	1.000E 00	2.127E-01	1.111E 01	9.297E 01
6	*	1	1.000E 00	1.490E 00	7.781E 01	5.618E-01
7	*	1	2.775E-01	3.240E-01	4.095E 00	9.297E 01
8	*	1	4.171E-01	3.240E-01	7.057E 00	9.239E 01
9	*	1	4.021E-01	3.240E-01	6.803E 00	9.239E 01
10	*	1	4.588E-01	3.240E-01	7.763E 00	9.239E 01
11	*	1	7.788E-01	3.240E-01	1.318E 01	9.239E 01
12	*	1	8.546E-01	3.240E-01	1.446E 01	9.239E 01
13	*	1	7.788E-01	3.240E-01	1.318E 01	9.239E 01
14	*	1	7.221E-01	3.240E-01	1.222E 01	9.239E 01
15	*	1	7.221E-01	3.240E-01	1.222E 01	9.239E 01
16	*	1	7.788E-01	3.240E-01	1.318E 01	9.239E 01
17	*	1	8.546E-01	3.240E-01	1.446E 01	9.239E 01
18	*	1	7.788E-01	3.240E-01	1.318E 01	9.239E 01
19	*	1	4.588E-01	3.240E-01	7.763E 00	9.239E 01
20	*	1	4.021E-01	3.240E-01	6.803E 00	9.239E 01
21	*	1	4.171E-01	3.240E-01	7.057E 00	9.239E 01
22	*	4	3.889E-01	3.240E-01	6.580E 00	9.251E 01
23	*	1	1.000E 00	2.127E-01	1.111E 01	9.251E 01
24	*	2	2.890E 00	9.893E-02	1.493E 01	9.192E 01
25	*	1	1.000E 00	4.030E 00	2.105E 02	9.192E 01
26	*	1	2.083E 00	6.335E 00	6.891E 02	9.146E 01
27	*	5	7.500E 00	6.445E 00	2.524E 03	9.262E 01
28	*	2	1.900E 01	1.525E-01	1.514E 02	9.262E 01
29	*	4	8.000E-01	1.525E-01	6.373E 00	9.309E 01
30	*	2	3.100E 01	1.525E-01	2.470E 02	9.309E 01
31	*	0	1.000E 00	0.0	0.0	0.0
32	*	0	1.000E 00	0.0	0.0	0.0
33	*	0	1.000E 00	0.0	0.0	0.0
34	*	0	1.000E 00	0.0	0.0	0.0
35	*	0	1.000E 00	0.0	0.0	0.0
36	*	0	1.000E 00	0.0	0.0	0.0
37	*	0	1.000E 00	0.0	0.0	0.0
38	*	0	1.000E 00	0.0	0.0	0.0
39	*	0	1.000E 00	0.0	0.0	0.0
40	*	0	1.000E 00	0.0	0.0	0.0
41	*	2	2.800E 01	2.480E-03	3.626E 00	4.654E-01
42	*	1	1.000E 00	3.276E 00	1.711E 02	4.654E-01
43	*	2	1.600E 01	2.480E-03	2.072E 00	4.654E-01
44	*	0	1.600E 01	1.796E-01	1.501E 02	0.0
45	*	0	0.0	0.0	0.0	0.0
46	*	0	0.0	0.0	0.0	0.0
47	*	2	1.858E 01	2.480E-03	2.407E 00	5.818E-01
48	*	2	3.687E 01	2.480E-03	7.182E 00	5.818E-01
49	*	2	4.267E 01	2.480E-03	5.526E 00	5.818E-01
50	*	2	4.226E 01	2.480E-03	1.100E 01	5.818E-01

TABLE II. Initial Concentration of Reaction Products in Different Segments of CCTL

SEGM		TYPE	CONCENTRATION, MOL/LB C1-NAH	C2-NAOH	C3-NA2O	C4-H2
1	*	3	1.418E-06	1.134E-08	2.561E-04	2.249E-06
2	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
3	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
4	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
5	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
6	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
7	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
8	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
9	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
10	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
11	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
12	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
13	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
14	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
15	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
16	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
17	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
18	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
19	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
20	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
21	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
22	*	4	1.418E-06	1.134E-08	2.561E-04	2.249E-06
23	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
24	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
25	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
26	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
27	*	5	1.418E-06	1.134E-08	2.561E-04	2.249E-06
28	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
29	*	4	1.418E-06	1.134E-08	2.561E-04	2.249E-06
30	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
31	*	0	0.0	0.0	0.0	0.0
32	*	0	0.0	0.0	0.0	0.0
33	*	0	0.0	0.0	0.0	0.0
34	*	0	0.0	0.0	0.0	0.0
35	*	0	0.0	0.0	0.0	0.0
36	*	0	0.0	0.0	0.0	0.0
37	*	0	0.0	0.0	0.0	0.0
38	*	0	0.0	0.0	0.0	0.0
39	*	0	0.0	0.0	0.0	0.0
40	*	0	0.0	0.0	0.0	0.0
41	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
42	*	1	1.418E-06	1.134E-08	2.561E-04	2.249E-06
43	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
44	*	0	0.0	0.0	0.0	0.0
45	*	0	0.0	0.0	0.0	0.0
46	*	0	0.0	0.0	0.0	0.0
47	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
48	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
49	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06
50	*	2	1.418E-06	1.134E-08	2.561E-04	2.249E-06

TABLE III. Leak Distribution to Various Reactions and Reaction Products

0.45	OF THE LEAK GOES TO	NA+H2O=NAOH+1/2H2(G)
0.20	OF THE LEAK GOES TO	2NA+H2O=NAOH+NAH
0.25	OF THE LEAK GOES TO	4NA+H2O=2NAH+NA2O
0.10	OF THE LEAK GOES TO	2NA+H2O=NA2O+H2
0.70	MOL OF THE LEAK IS TRANSFORMED TO	NAH
0.65	MOL OF THE LEAK IS TRANSFORMED TO	NAOH
0.35	MOL OF THE LEAK IS TRANSFORMED TO	NA2O
0.32	MOL OF THE LEAK IS TRANSFORMED TO	H2(G)

TABLE IV. Some Constant Parameters of the System

THE NAH DISSOCIATION PRESSURE IN MM-HG IS	3332.611
SODIUM TEMPERATURE IN (DEG-F)IS	900.00
SODIUM TEMPERATURE IN (DEG-K) IS	755.22
SODIUM DENSITY IN (LBS/CUF) IS	52.22
TOTAL WEIGHT OF SODIUM IN THE SYSTEM (LB)	4785.61
COVER GAS PLENUM VOLUME (CUF)	40.00
COLD TRAP DYNAMIC EFFICIENCY (1/SEC) IS	0.2449E-02
NAH SATURATION CONC. AT COLD TRAP(MOL/LB)	0.6542E-06
NA2O SATURATION CNC. AT COLD TRAP(MOL/LB)	0.4096E-05
TOTAL TRANSIT TIME IN CCTL (SEC) IS	46.87
COLD TRAP TEMPERATURE IN (DEG-K) IS	388.56
SIEVERTS CONSTANT IN (MOL/(LB*TORR**-2))	0.1125E-02
PARTIAL HYDROGEN PRESSURE IN COVER GAS (MM-HG)	0.1
PARTIAL ARGON PRESSURE IN COVER GAS (MM-HG)	800

TABLE V. Flow Distribution in CCTL (see Fig. 2 for explanation)

TOTAL SODIUM FLOW IN (LBS/SEC) IS	93.0872
WCT	0.4654
WT1	0.5818
WT2	0.0
WT3	0.5818
WT4	0.0
WEX	0.1164
WA	92.9709
WX	92.3891
WB	92.5054
WC	91.9236
WD	91.4582
WE	92.6217
WR	93.0872

TABLE VI. Water-leak Description for Experiment 1 Run 24

***************RUN # 15: CCTL LEAK DETECTION SIMULATION.(.001 LB/SEC AT INJ#4, DUR=70SEC***********

LEAKAGE DATA FOR THIS CASE ARE:

FOR NODE SEGMENT #	22	19	17	16	15	12
THE LEAKAGE IN MOL/SEC IS	0.0	0.0	0.0	0.3776E 00	0.0	0.0
THE LEAK STARTS AT TIME -	10.00	10.00	10.00	10.00	10.00	10.00
THE LEAK IS TERMINATED AT	80.00	80.00	80.00	15.00	80.00	80.00

TABLE VII. Description of Detector Connections for Experiment 1 Run 24

DETECTOR NO 1 OF TYPE 1 IS CONECTED TO NODE 49 HAS A LAG OF 10.00SEC AND A DELAY OF14.00SEC

DETECTOR NO 2 OF TYPE 2 IS CONECTED TO NODE 49 HAS A LAG OF 12.00SEC AND A DELAY OF15.00SEC

DETECTOR NO 3 OF TYPE 1 IS CONECTED TO NODE 47 HAS A LAG OF 10.00SEC AND A DELAY OF14.00SEC

DETECTOR NO 4 OF TYPE 3 IS CONECTED TO NODE 27 HAS A LAG OF 1.00SEC AND A DELAY OF10.00SEC

Type 1 = Hydrogen Detector

Type 2 = Oxygen Detector

Type 3 = Hydrogen Detector in the Cover Gas

VIII. SUMMARY OF ASSUMPTIONS

1. Reactions 1-4 are the only sodium-water reactions expected at the leak site.

2. As a result of a leak of 1 mol of water, the following reaction products will be generated instantaneously:

   0.7 mol of NaH

   0.65 mol of NaOH

   0.35 mol of Na_2O

   0.37 mol of H_2

3. The only secondary reactions taking place in the system are NaOH and NaH dissociation, as given by Eqs. 10 and 11.

4. The half-life of NaOH is 150 min.

5. The NaH dissociation pressure is given by Eq. 15:

   $$P_{dis} = \exp(26.71 - 14046/T_K).$$

6. If the system is at steady state for a long time, the hydrogen pressure in the cover gas will be in equilibrium with the hydrogen concentration in the sodium according to Sieverts' law.

7. Changes in the cover-gas hydrogen partial pressure are the result of hydrogen leaving the sodium according to the Sieverts' law and because of bubble transport from the leak site. Bubble transport occurs only at low temperatures and is assumed to be zero at the temperatures considered in this study.

8. The NaH dissociation rate is given by

   $$K_2 = 0.597 \exp(-3883/T_K)\left(\frac{P_{dis} - P_H}{P_{dis}}\right)^2.$$

9. Ideal mixing is assumed in all plenum segments.

10. Hydrogen diffusion through the system walls is neglected.

11. The hydrogen and oxygen detectors are of the diffusion type and can be characterized by the transfer function given in Eq. 44:

$$\frac{A}{C} = \frac{K_d e^{-S\tau}}{1 + S\theta}.$$

12. Solubility of NaH in sodium is given by Eq. 42,

$$C_{NaH} = \exp(13.97 - 6631.4/T_K).$$

13. Solubility of Na_2O in sodium is given by Eq. 43,

$$C_{Na_2O} = \exp(16.131 - 6493.3/T_K).$$

14. Steady-state flow conditions prevail throughout the system; therefore, there is a constant sodium level in CCTL vessel and zero flow to the expansion tank.

15. The system temperature is constant; no heat transfer is accounted for.

16. Pressure gradients throughout the flow path and their possible effects on reaction rates are neglected.

IX. SAMPLE CALCULATIONS

The following sample calculations are intended to demonstrate various output features of the program rather than to predict the results of a particular CCTL experiment.

A. Changes in Reaction-product Concentration as a Result of a Short, 0.075-lb Leak

A short leak of 0.015 lb/sec, starting at 10 sec after simulation startup and terminating at 15 sec, was generated to initiate a transient in the CCTL system. The injection point was I4 (in the middle of the steam-generator module). The conditions are basically similar to those given in Tables I-VII, except for the leak size. The simulation was run for 100 sec, a sufficient time for the major transients to be terminated.

Figure 3 shows the hydrogen concentration in sodium as a function of time (1) at the leak-injection site (node 16); (2) at the stagnant part of the steam generator (node 6) through which there is a small (5-gal/min) sampling-line flow; (3) at the end of the pipe leading to hydrogen detector No. 1; and (4) as given by the response of detector No. 1. The delays among the various nodes are clearly visible. The effect of mixing increases with distance from the injection node; therefore, the peaks observed during the transients are lower at the distant nodes.

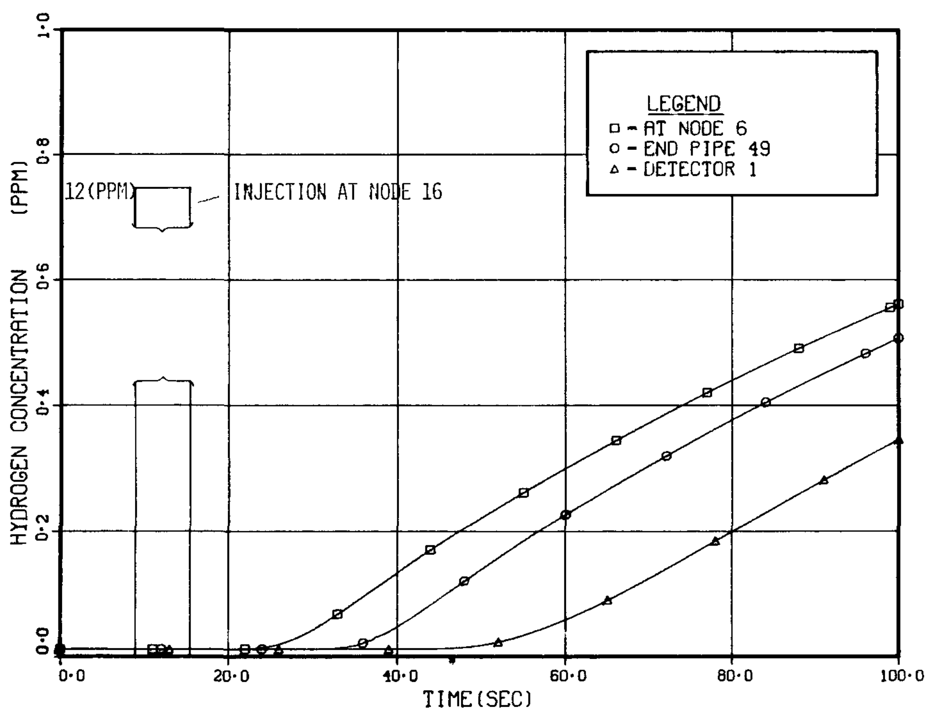

Fig. 3. Transient Hydrogen Concentrations at Node 6, End of Pipe 49, in Detector 1, Resulting from a Steam Injection of 0.015 lb/sec for 5 sec from Injector I4 at Node 16 (See Fig. 2)

Figure 4 shows the hydrogen concentration (1) at the steam-generator outlet plenum (node 23); (2) at the end of sampling line 47 leading from node 23 to the hydrogen detector No. 3; and (3) as given by the response of detector No. 3. For comparitive purposes, the hydrogen concentration at the injection node is also shown.

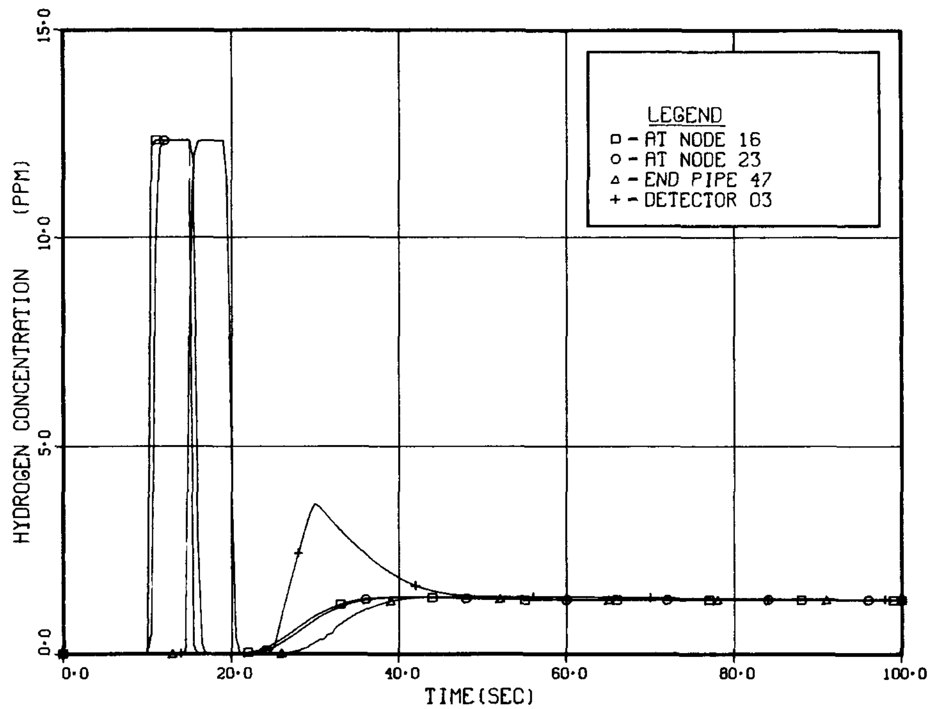

Fig. 4. Transient Hydrogen Concentrations at Nodes 16 and 23, End of Pipe 47, in Detector 3, Resulting from a Steam Injection of 0.015 lb/sec for 5 sec from Injector I4 at Node 16 (See Fig. 2)

Figure 5 shows the concentration of the four reaction products at node 27, which is in contact with the cover gas. Apart from differences in concentrations, which are the results of the assumption on how the sodium-water reaction products split, the transient forms of the four curves are identical.

Figure 6 shows the oxygen concentration at node 6, as monitored by oxygen detector No. 2.

B. Changes in Reaction-product Concentration as a Result of a 70-sec, 0.0001-lb/sec Leak

This run simulated a proposed CCTL leak-detection experiment with a sodium flow rate of 800 gal/min at 940°F (504°C). Steam at 0.001 lb/sec was introduced at Injector I4 (see Fig. 2) 10 sec after simulation startup. The leak was terminated at 80 sec, and simulation was continued up to 600 sec. The cold trap was not in operation in this experiment.

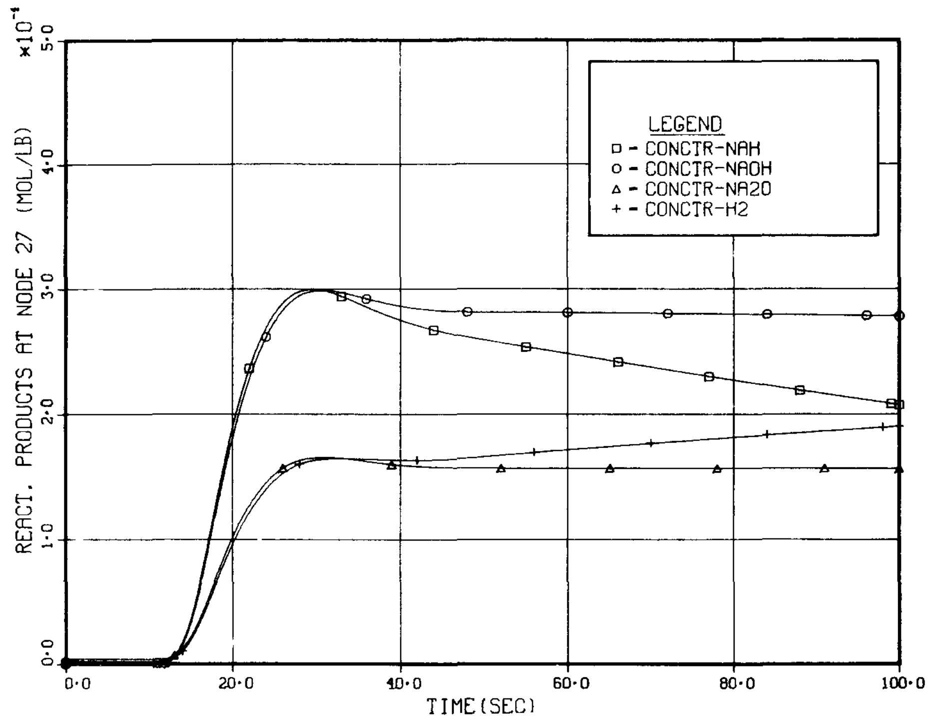

Fig. 5 Transient Concentrations of Reaction Products Resulting from Steam Injection of 0.015 lb/sec for 5 sec from Injector I4 at Node 16 (See Fig. 2)

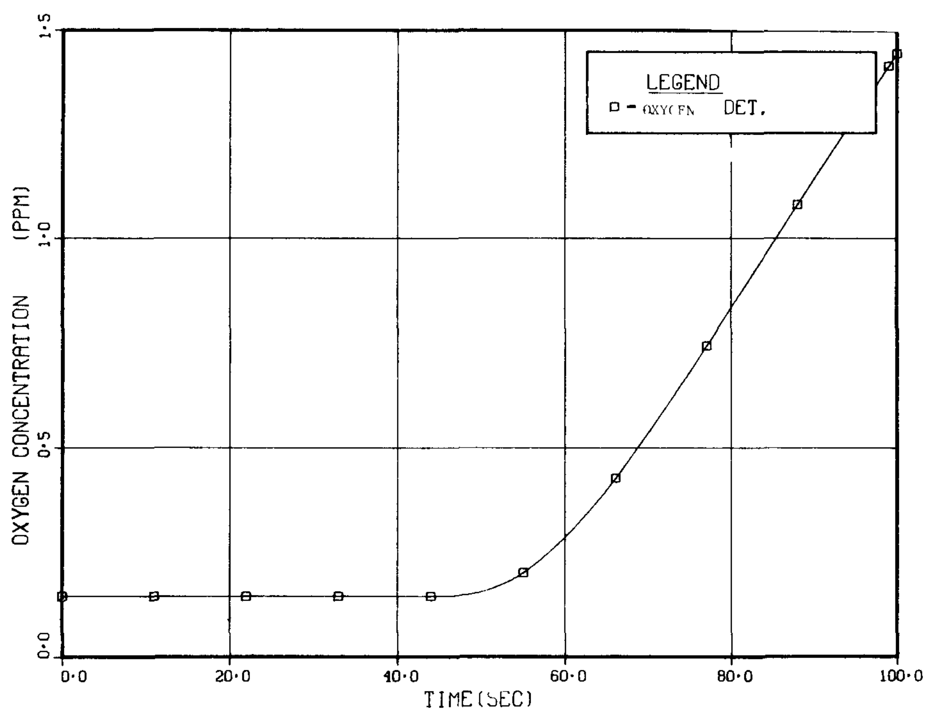

Fig. 6. Oxygen Concentration at Node 6 as Monitored by Oxygen Detector No. 2 Resulting from Steam Injection of 0.015 lb/sec for 5 sec at Injector I4 (See Fig. 2)

Figure 7 shows the hydrogen concentration at the injection point (node 16), at node 23, at the end of pipe section 47, and at hydrogen detector No. 3. The delays in concentration changes among the various nodes are clearly seen.

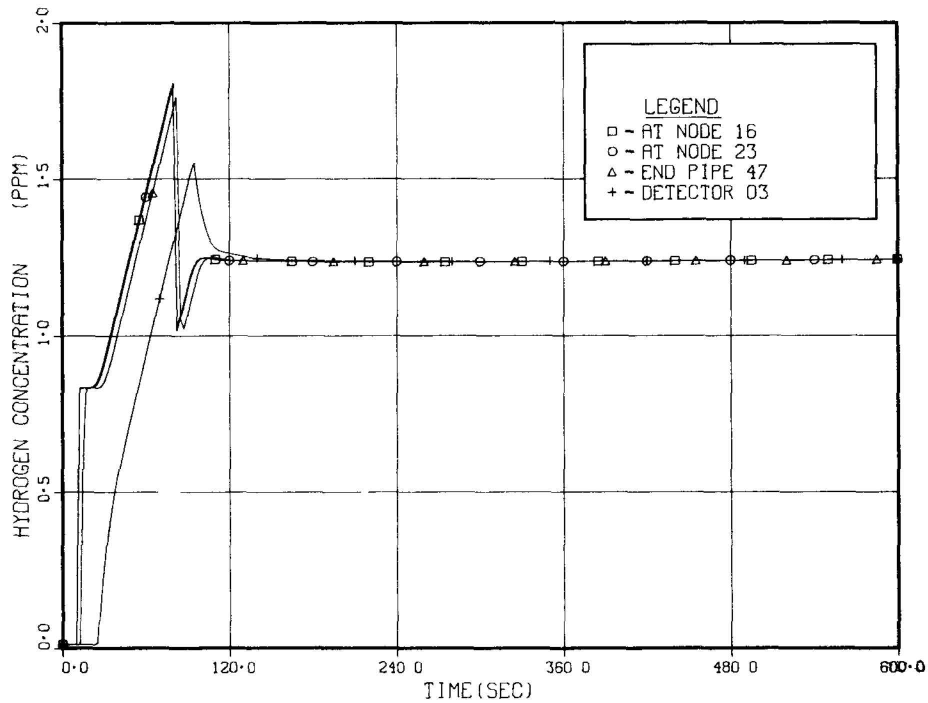

Fig. 7. Transient Hydrogen Concentrations at Nodes 16 and 23, End of Pipe 47, in Detector 3, Resulting from a Steam Injection of 0.001 lb/sec for 70 sec at Injector I4 and Node 16 (See Fig. 2), Sodium Flow Rate of 800 gal/min at 940°F (504°C), without Cold Trapping

Figure 8 shows the concentrations of the four reaction products at node 27. A relatively fast decomposition of NaH at 940°F (504°C) can be observed from the figure.

Figure 9 shows the responses of two hydrogen detectors, one monitoring node 6 and the other monitoring node 23.

Figure 10 shows the hydrogen concentration at the injection node 16, the pump node 1, and the upper CCTL vessel node 27. Except for the time scale, these results are similar to those calculated by Pellow.[12]

C. Effect of Changing Flow Rate

As mentioned earlier, the CCTL test plan[1] includes experiments to determine hydrogen-detector response to steam injections into sodium at various flow rates. Simulations of these experiments consisted of introducing steam at 0.001 lb/sec for 70 sec at node 16 into sodium at 300, 465, 630, and 800 gpm.

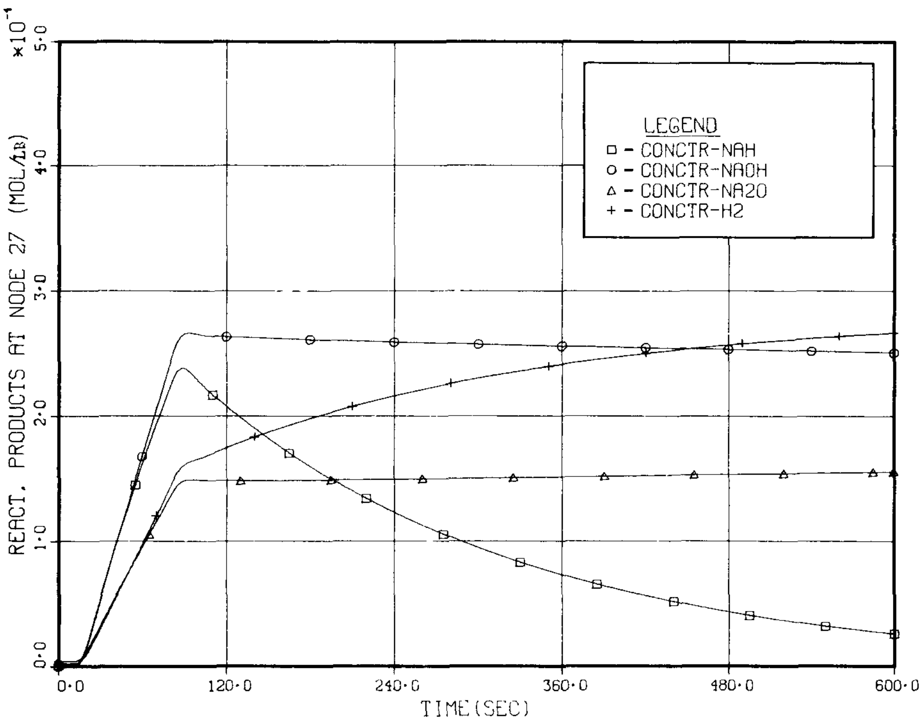

Fig. 8. Transient Concentrations of Reaction Products Resulting from a Steam Injection of 0.001 lb/sec for 70 sec at Injector I4; Sodium Flow Rate of 800 gal/min at 940°F (504°C), without Cold Trapping

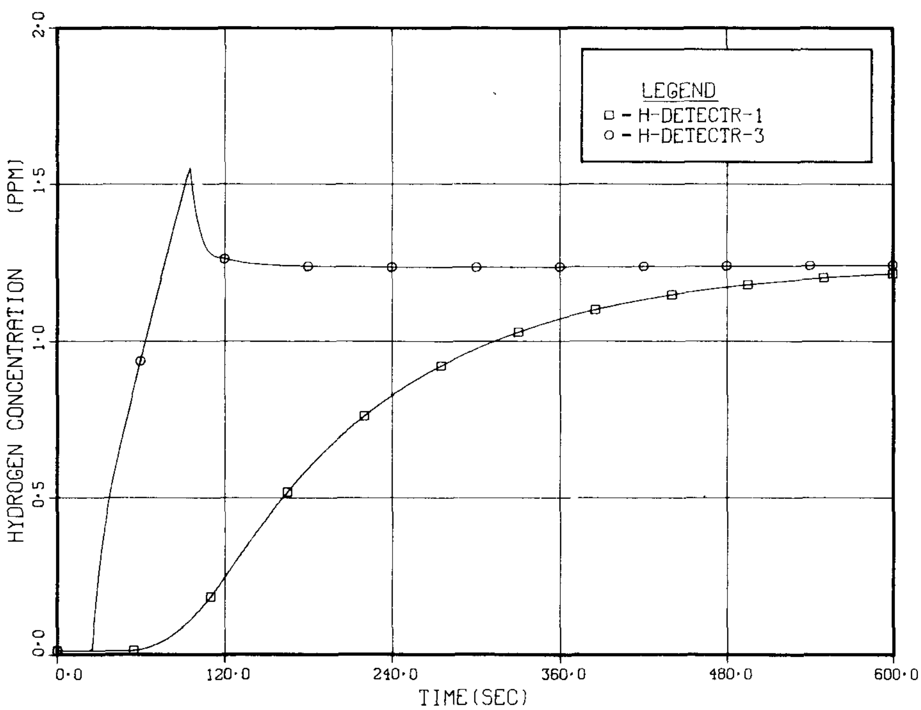

Fig. 9. Response of Hydrogen Detectors to a Steam Injection of 0.001 lb/sec for 70 sec at Injector I4 (See Fig. 2); Sodium Flow Rate of 800 gal/min at 940°F (504°C), without Cold Trapping

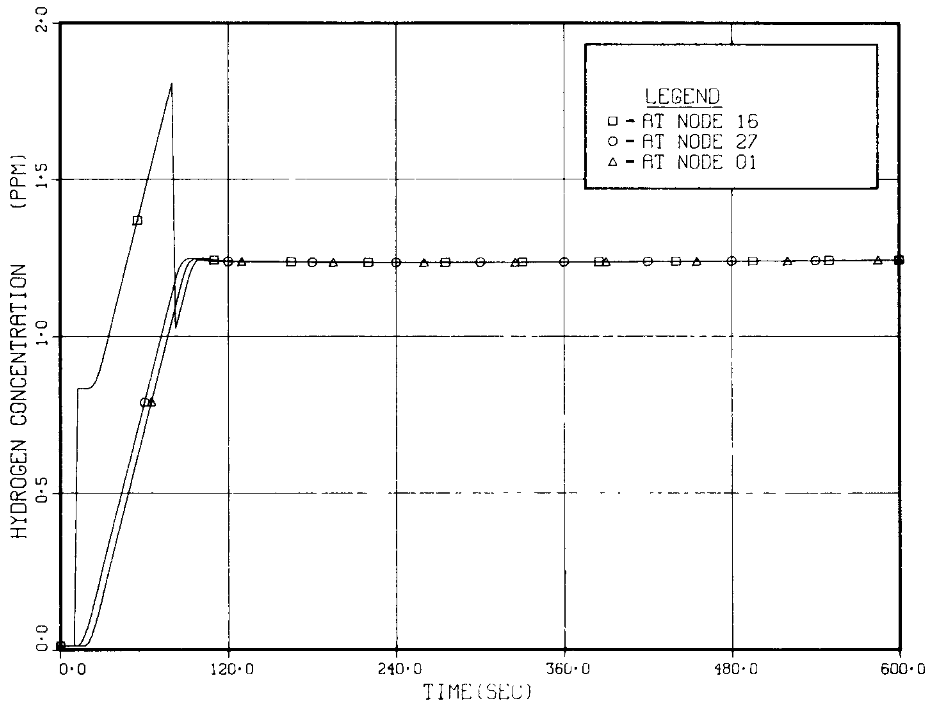

Fig. 10. Transient Hydrogen Concentrations at Nodes 1, 16, and 27 Resulting from a Steam Injection of 0.001 lb/sec for 70 sec at Injector I4 (See Fig. 2); Sodium Flow Rate of 800 gal/min at 940°F (504°C), without Cold Trapping

Figure 11 shows the response of hydrogen detector No. 1 (see end of pipe 49, Fig. 2), which monitored the upper stagnant-sodium section of the steam-generator module during sodium flow rates of 300 and 800 gpm.

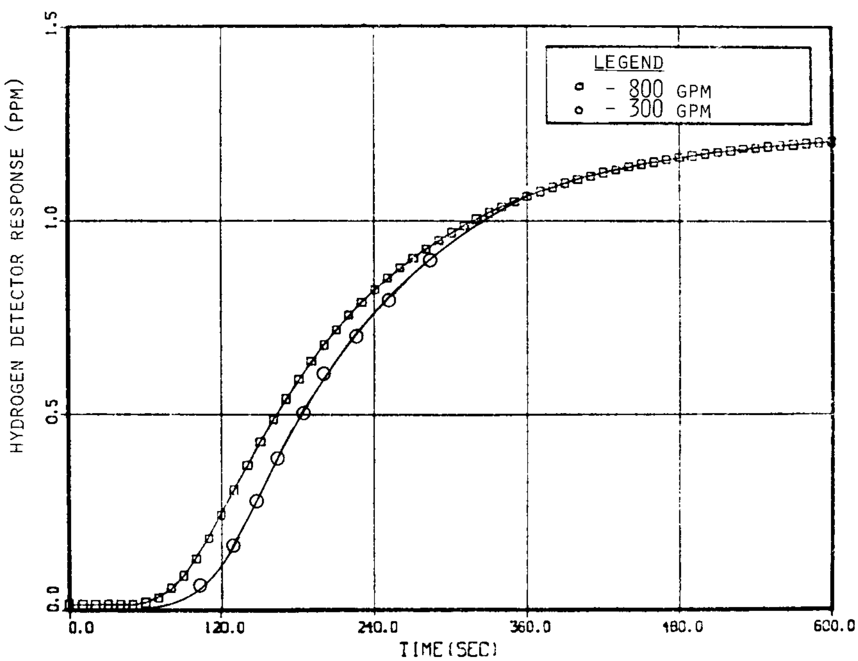

Fig. 11. Response of Hydrogen Detector No. 1 (See Fig. 2) at Different Sodium Flow Rates, to a Steam Injection of 0.001 lb/sec for 70 sec from Injector I4

Figures 12-15 show the response of hydrogen detector No. 3, which monitored the steam-generator outlet during sodium flow rates of 300, 465, 630, and 800 gpm, respectively.

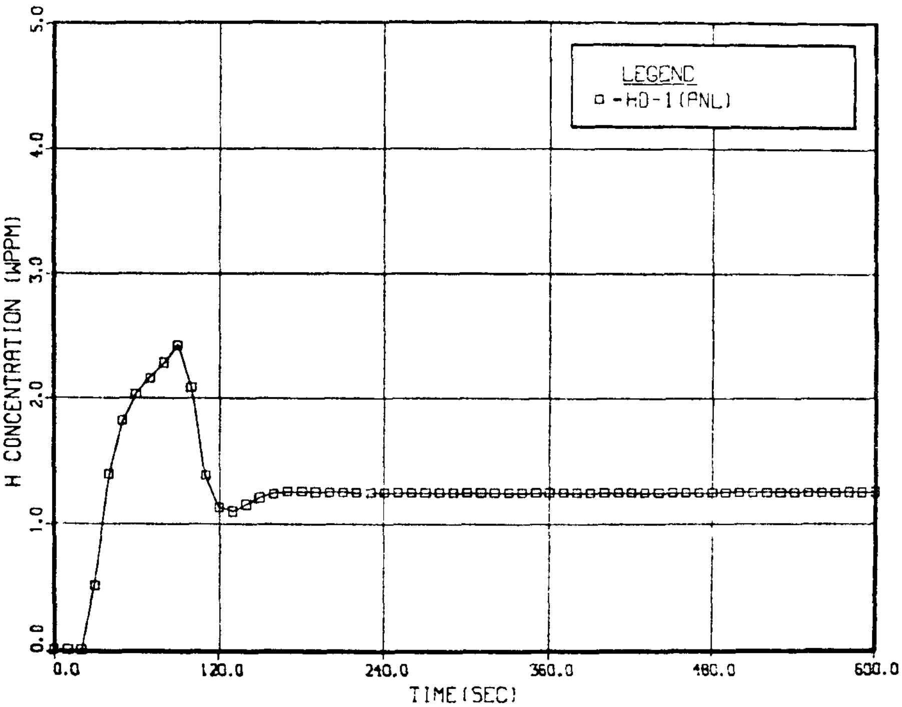

Fig. 12. Response of Hydrogen Detector No. 3 to a Steam Injection of 0.001 lb/sec for 70 sec at Injector I4, during Sodium Flow at 300 gpm

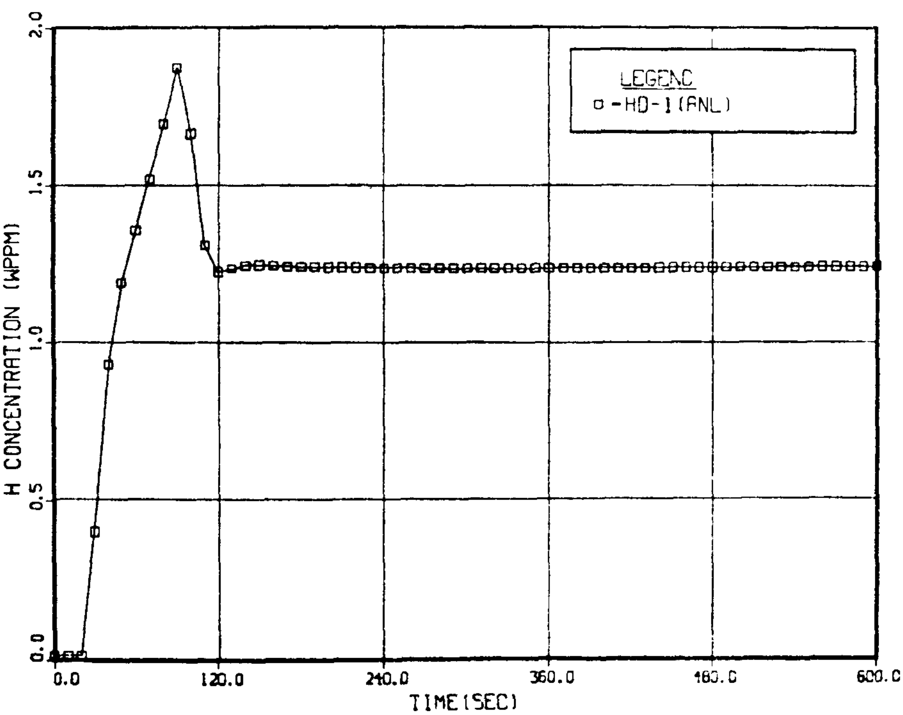

Fig. 13. Response of Hydrogen Detector No. 3 to a Steam Injection of 0.001 lb/sec for 70 sec at Injector I4, during Sodium Flow at 465 gpm

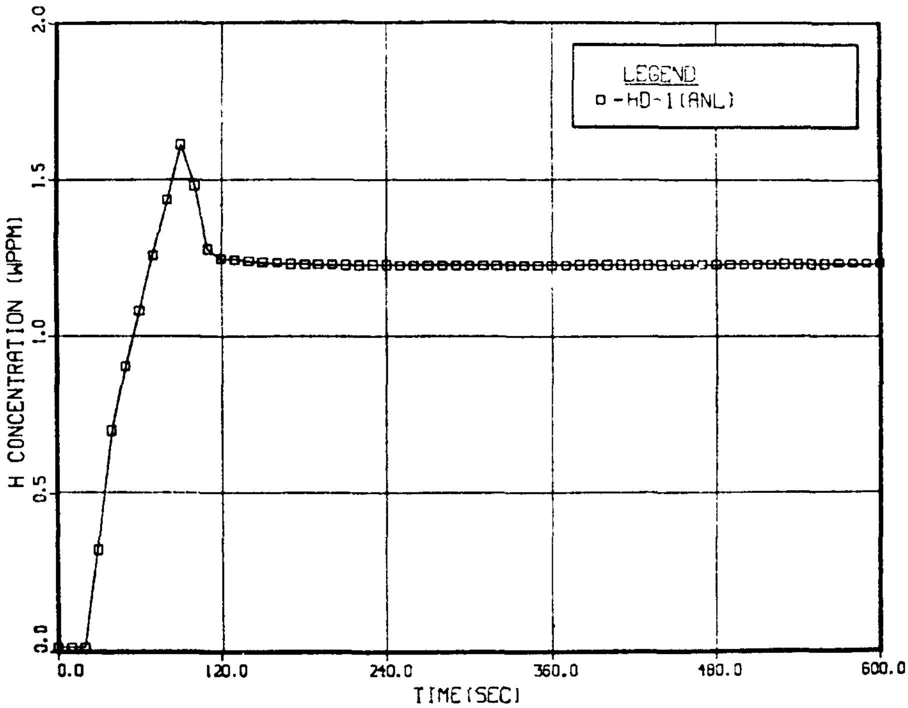

Fig. 14. Response of Hydrogen Detector No. 3 to a Steam Injection of 0.001 lb/sec for 70 sec at Injector I4, during Sodium Flow at 630 gpm

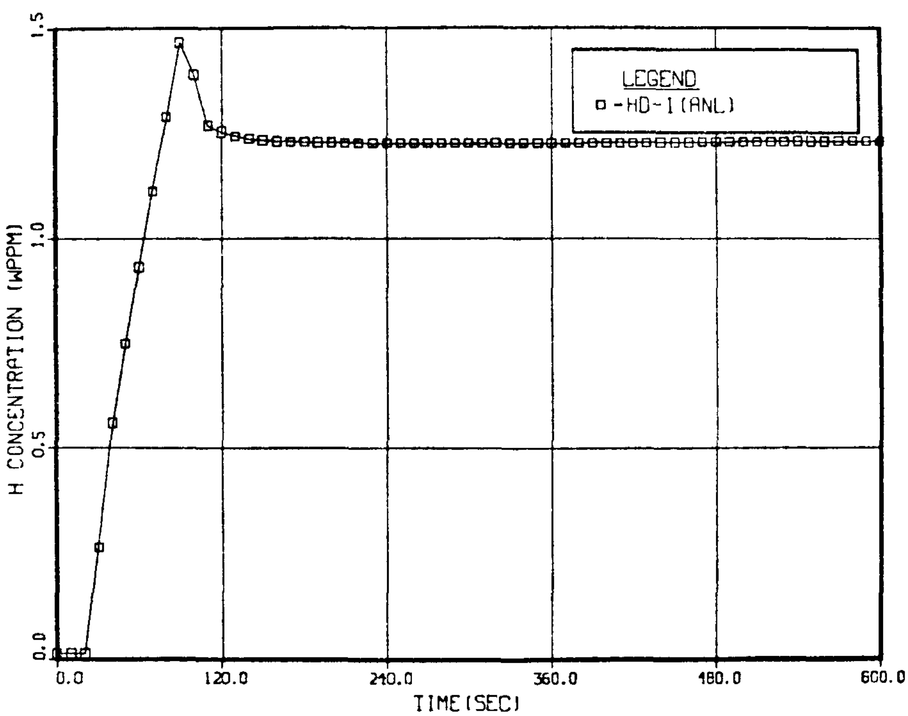

Fig. 15. Response of Hydrogen Detector No. 3 to a Steam Injection of 0.001 lb/sec for 70 sec at Injector I4, during Sodium Flow at 800 gpm

These figures reveal that the delay between leak occurrence and detection of hydrogen concentration increases as the flow rate is decreased. If the detector is close to the leak site, as with, for example, detector number 3 in this case, the maximum transient overshoot in detector response increases when flow rate is reduced.

D. Simulation of a Tightly Coupled Loop

The flexibility of the program is demonstrated by simulating a different type of loop. In this system, the huge sodium vessel containing the steam generator is excluded. Instead, three more segments are added to the steam generator unit. A short leak of 0.015 lb/sec for a 5-sec period was injected from Injector I4 at 800 gpm and was simulated at 940°F (504°C). The results are shown in Figs. 16-20.

The oscillatory nature of the concentration changes is due to the elimination of the huge mixing volumes of the CCTL vessel, which smooth out any type of transient. A short leak, such as is simulated in this experiment, will contaminate a lump of sodium. Whenever this lump passes through a segment of the loop or near a detector, an increase in contamination is observed. After several passages, the transients die out because of the mixing process. The distance between the peaks in the figures is the transit time and is observed to be 14 sec (calculated value, 13.76 sec).

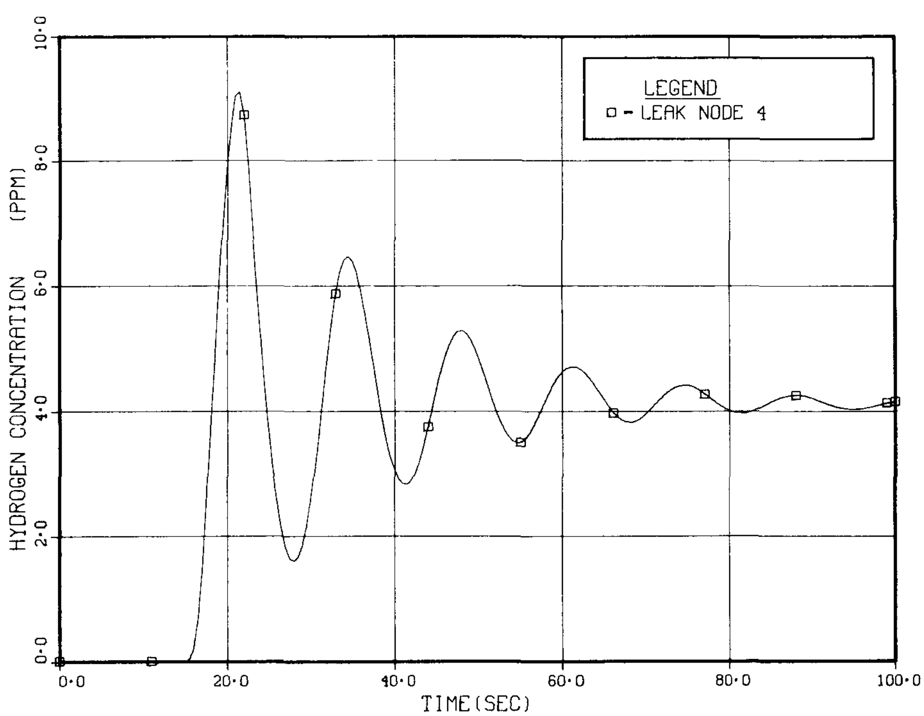

Fig. 16. Transient Hydrogen Concentration in a Tightly Coupled Loop at Pump Node 1 Resulting from a Steam Injection of 0.015 lb/sec for 5 sec into Sodium at 800 gpm and 940°F (504°C), at Injector I4

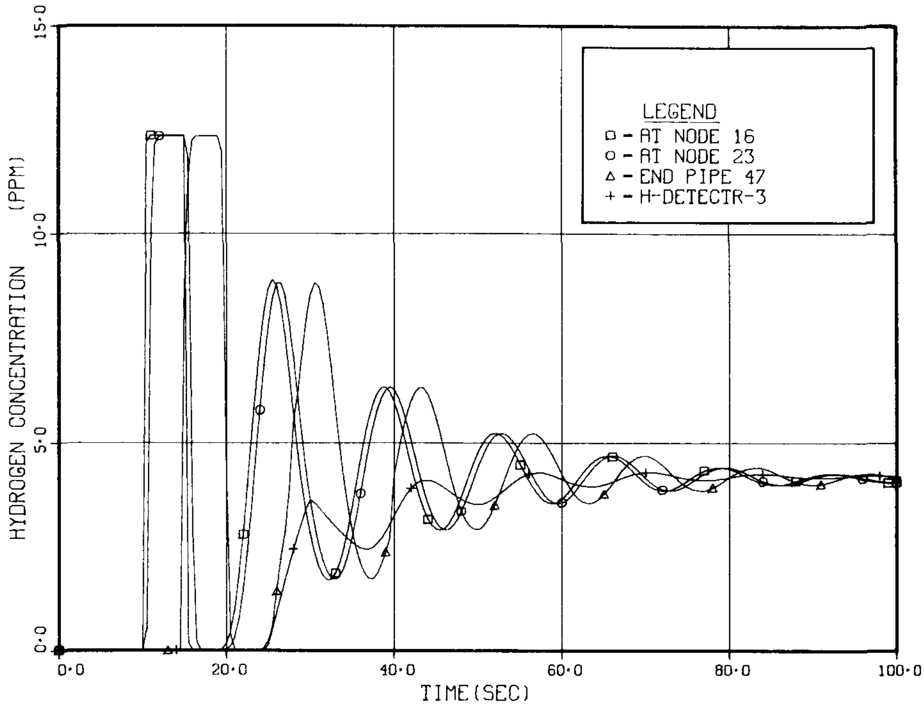

Fig. 17. Transient Hydrogen Concentrations in a Tightly Coupled Loop Resulting from a Steam Injection of 0.015 lb/sec for 5 sec at Injector I4, at 800 gpm and 940°F (504°C)

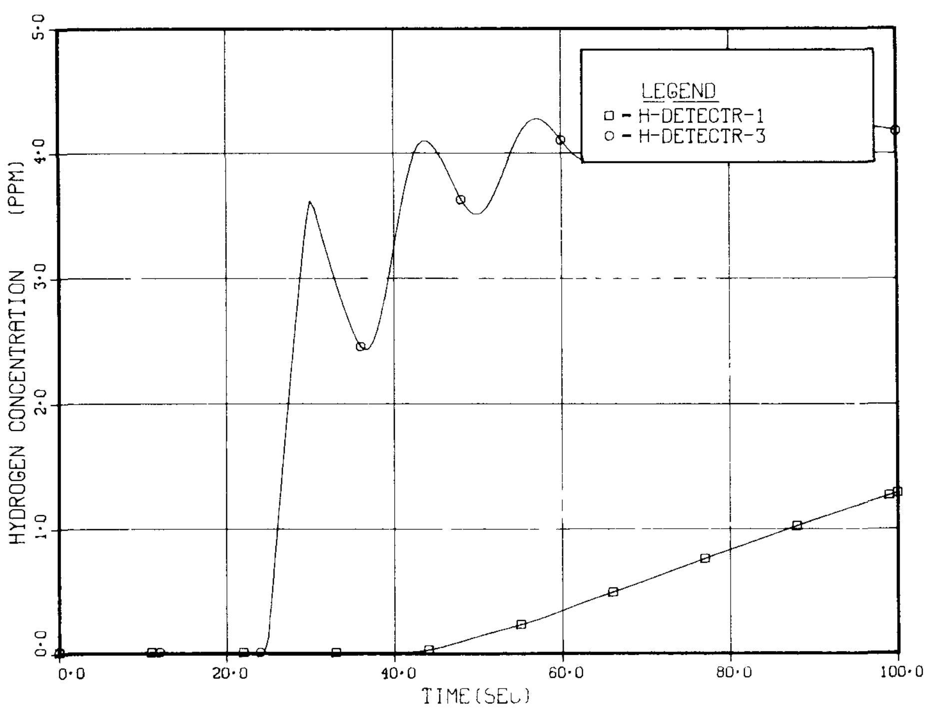

Fig. 18. Response of Hydrogen Detectors in a Tightly Coupled Loop Resulting from a Steam Injection of 0.015 lb/sec for 5 sec at Injector I4. Sodium flow is 800 gpm at 940°F (504°C).

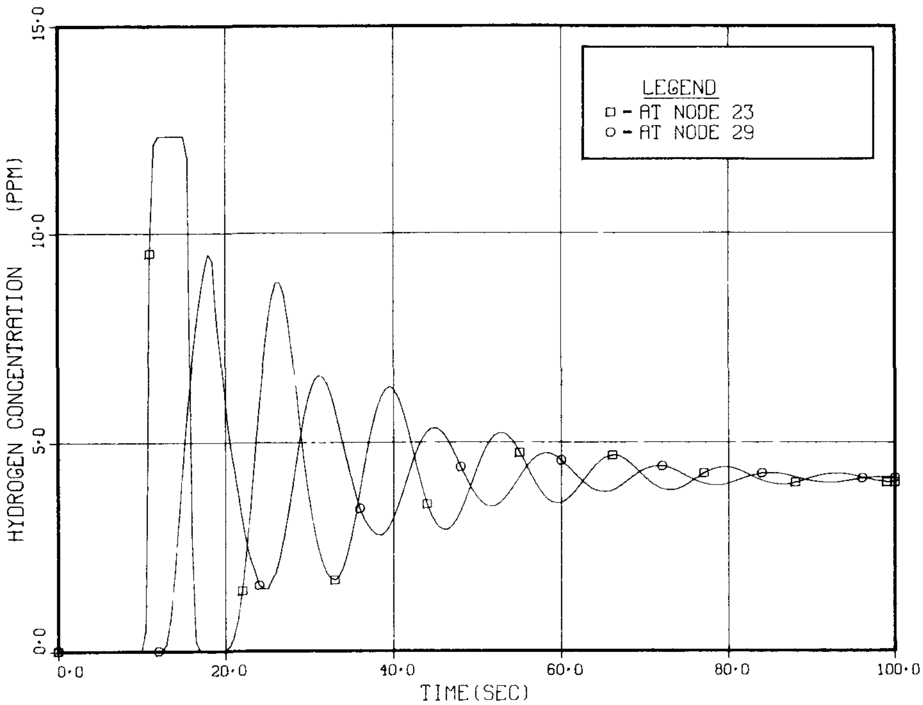

Fig. 19. Transient Hydrogen Concentrations in a Tightly Coupled Loop Resulting from a Steam Injection of 0.015 lb/sec for 5 sec at Injector I4. Sodium flow is 800 gpm at 940°F (504°C).

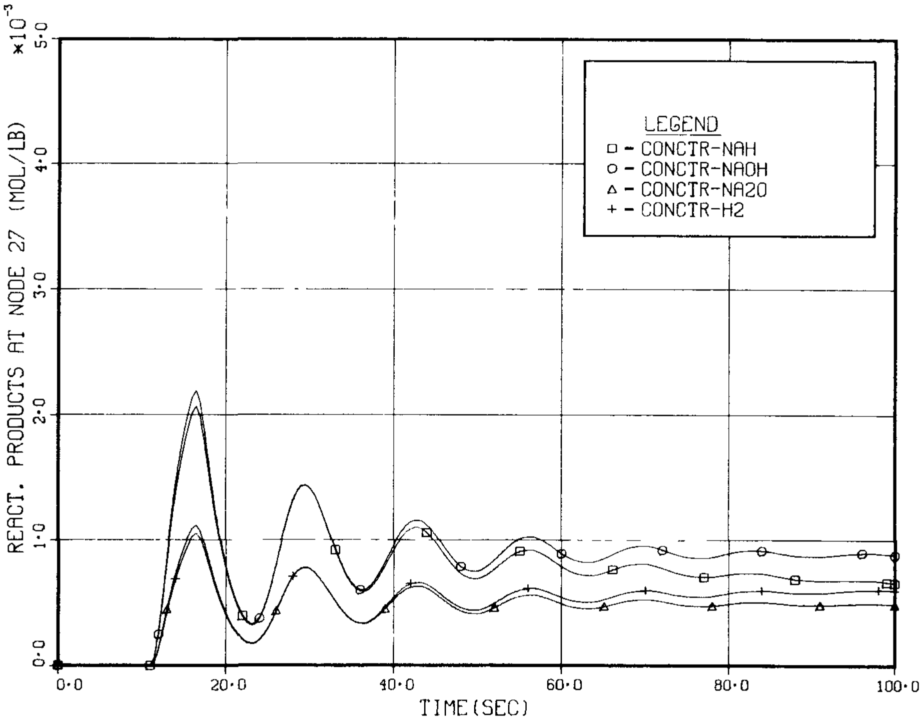

Fig. 20. Transient Concentrations of Reaction Products in a Tightly Coupled Loop Resulting from a Steam Injection of 0.015 lb/sec for 5 sec at Injector I4. Sodium flow is 800 gpm at 940°F (504°C).

Similar results were obtained by Berault et al.,[13] when a short burst of water was injected into their loop, which included mainly piping segments. The transit time was about 5 min, and 13 peaks were observed before the hydrogen diffused and mixed through system and a stable hydrogen concentration was established.

With reference to the present simulation, Fig. 16 shows the hydrogen concentration at the pump (node 1). Seven peaks occur during the first 100 sec, and the transient dies out soon thereafter.

Figure 17 compares the transient hydrogen concentrations at node 23, end of pipe 47, and the response of detector No. 3 with the transient concentration at the leaking node 16. The leak is represented by a step function 5 sec wide, after which the concentration is reduced to the background value, successive peaks appear after each transit time.

Figure 18 shows the response of hydrogen detectors No. 1 and 3. The integrating effect of the detectors compared to actual hydrogen concentration at nodes 23 and 6 is apparent.

Figure 19 shows the transient hydrogen concentration at nodes 23 and 29. Node 29 is at a "5-sec distance" from node 23. The same transient results; however, because of mixing effects, the appropriate peaks at node 29 are lower than those at segment 23.

Finally, Fig. 20 shows changes in concentration of reaction products NaH, NaOH, Na_2O, and hydrogen at node 27.

E. Effect of Cold-trap Operation

In these simulations, it was assumed that the CCTL cold trap had a static efficiency of $\beta = 0.9$, and the flow through the cold trap was 4 gal/min. Steam was introduced at Injector I4 (node 16), at a rate of 0.0001 lb/sec for 70 sec, and the simulations continued for 15 min. The results with and without cold-trap operation are shown in Figs. 21-24.

Figure 21 shows hydrogen concentrations at node 1, the pump segment. Figure 22 shows the hydrogen concentrations at node 27. Figure 23 gives the response of the hydrogen meter monitoring the steam-generator outlet. Figure 24 shows the Na_2O concentration at node 27.

These results evidence how cold-trap operation reduces impurity concentrations and is reflected in the detector readings. To obtain the new steady-state concentrations resulting from continuous cold-trap operation, the simulation would have had to be continued for about 3 hr. Due to current computer limitations, this was not considered practical. The CCTL-DYSP program has a ratio of simulation time to real time ranging from 0.2 to 0.9. For very fast rates of change in the variables and short transients, the 0.9 ratio should be taken; for slow transients and long simulation times, the 0.2 ratio can be used.

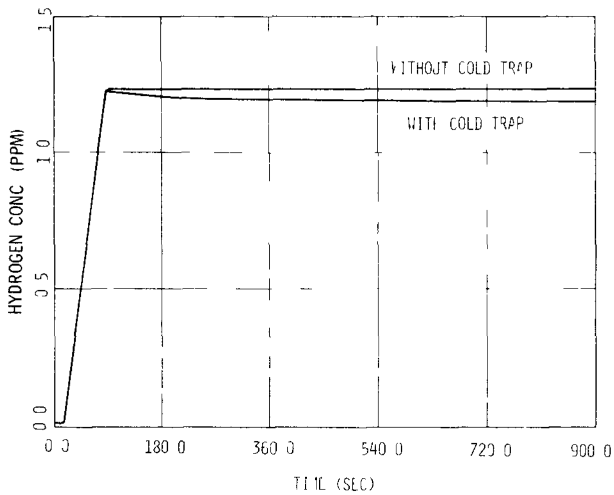

Fig 21 Effect of Cold-trap Operation on Hydrogen Concentration in the Pump Segment (Node 1)

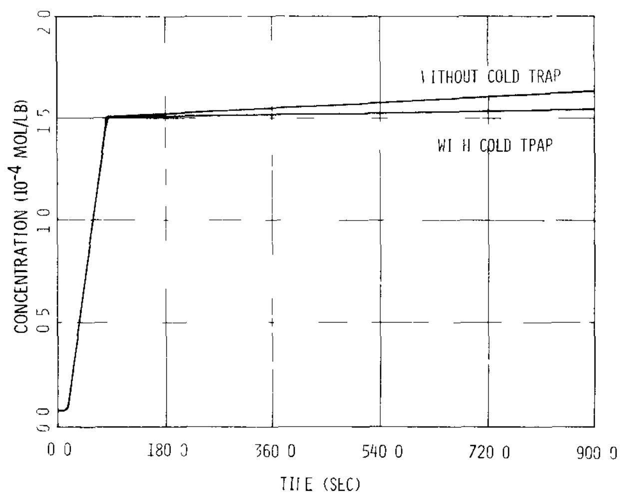

Fig. 22. Effect of Cold-trap Operation on Hydrogen Concentration in the CCTL Vessel (Node 27)

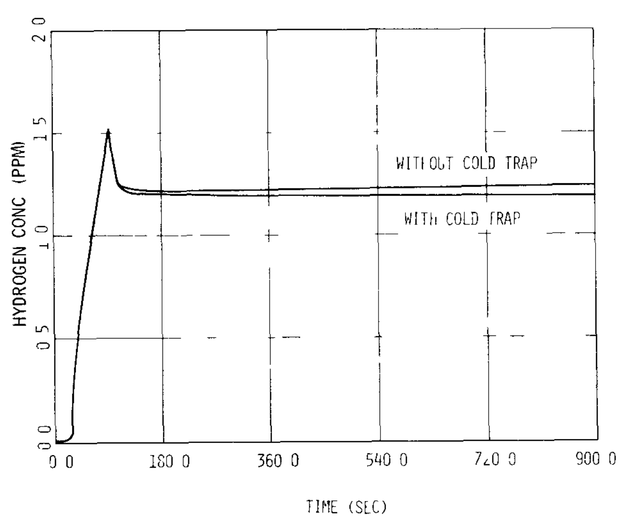

Fig. 23. Effect of Cold-trap Operation on Hydrogen Detector Monitoring the Steam-generator Outlet

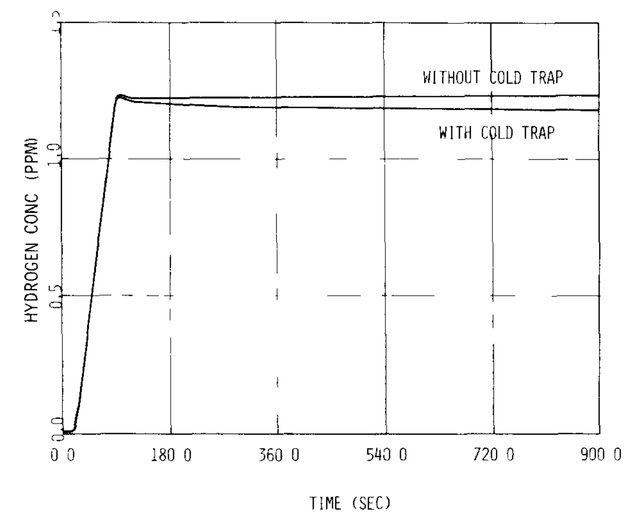

Fig. 24. Effect of Cold-trap Operation on Na_2O Concentration in the CCTL Vessel (Node 27)

F. Effect of Different Reaction Rates

As explained previously (see Sec. III.A, C, and F), little is known about the reaction rates of the various processes occurring once the impurities enter the sodium. It is evident that simulation results cited in previous paragraphs will vary according to the assumptions made concerning the various reaction parameters. For example, the rate at which hydrogen gas leaves the sodium and enters the cover gas will be considered. It is currently assumed that the half-life of hydrogen gas--to reach equilibrium with the cover gas--is 2000 min. At this rate of hydrogen disengagement, no change in the hydrogen content in the cover gas is observed. However, if this half-life is reduced to 2 min, the hydrogen concentration in the cover gas rises sharply, as shown in Fig. 25. At least some of the uncertainties in these data are expected to be resolved by the CCTL leak-detection experiments.

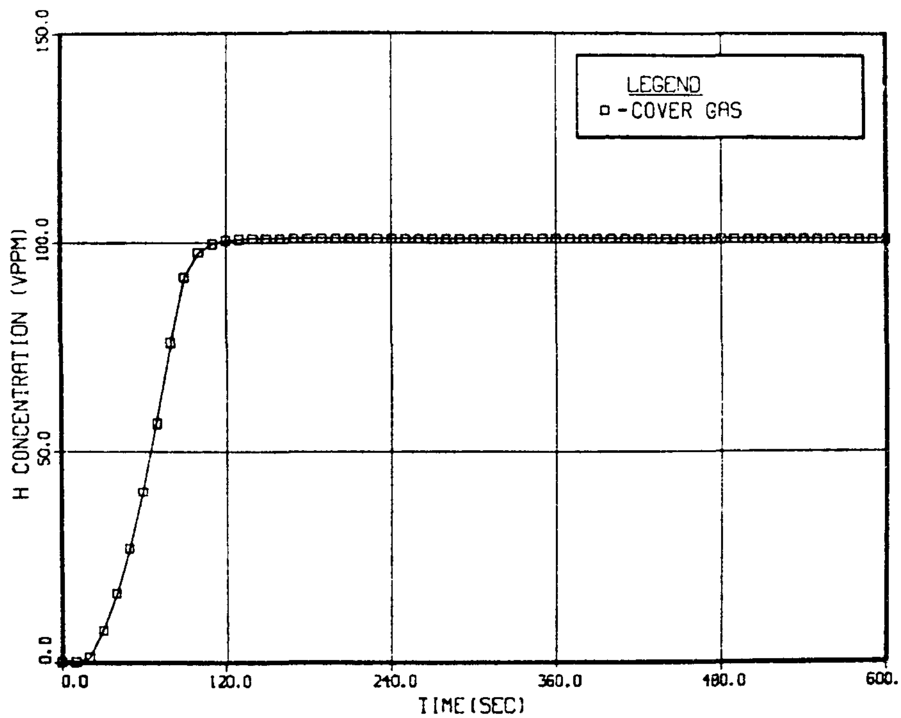

Fig. 25. Change in Cover-gas Hydrogen Concentration When Hydrogen-disengagement Half-life is Reduced by a Factor of 1000

G. Effect of Leak Location

The response of the CCTL experiment detector is expected to vary with the water-leak location. These changes are demonstrated in Figs. 26 and 27, which show the detector response to identical steam injections of 0.01 lb/sec for 5 sec. One injection is close to the steam-generator inlet, Injector I7; the other, Injector I1 is at the steam-generator outlet. Hydrogen detector No. 3 is monitoring the outlet from the steam-generator module. In Fig. 26, the second leak--close to the outlet--is detected first. Figure 27 shows the changes in hydrogen concentration at node 27 resulting from water injected at Injectors I1 and I7.

X. EXPERIMENTAL VERIFICATION

Recently some experimental results from the CCTL leak-detection experiment became available. On November 6, 1975, injection No. 22 took place in which 2.54 g/min of steam were injected at Injector I4. The leak duration was 57.5 sec, the sodium flow was 600 gpm, and the sodium temperature was 940°F (504°C). In Fig. 28 the experimental readings from the hydrogen

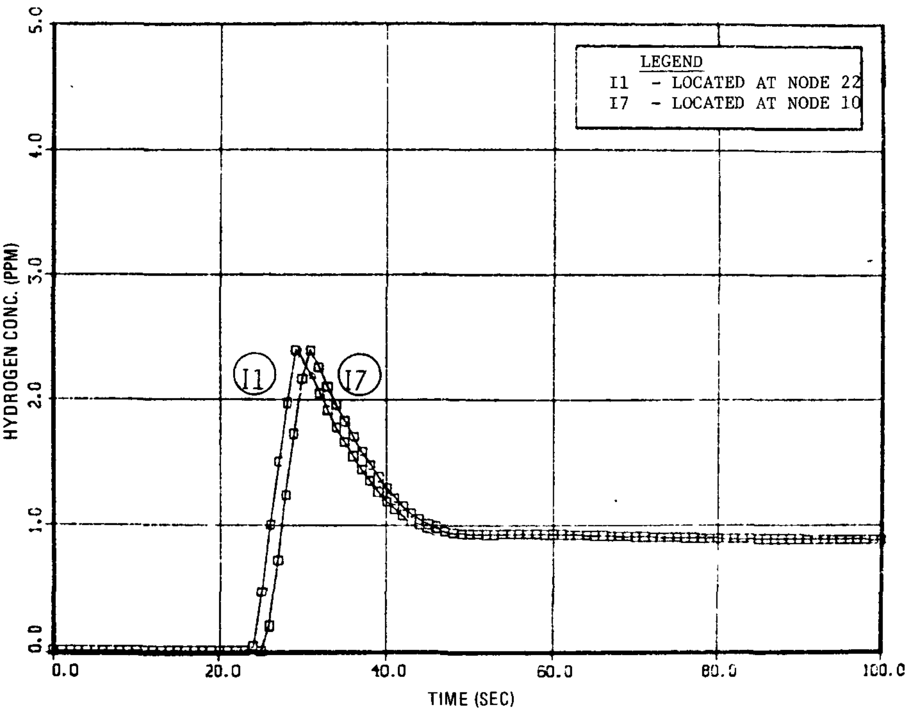

Fig. 26. Response of Hydrogen Detector No. 3 to a Steam Injection of 0.01 lb/sec for 5 sec from Two Different Injectors

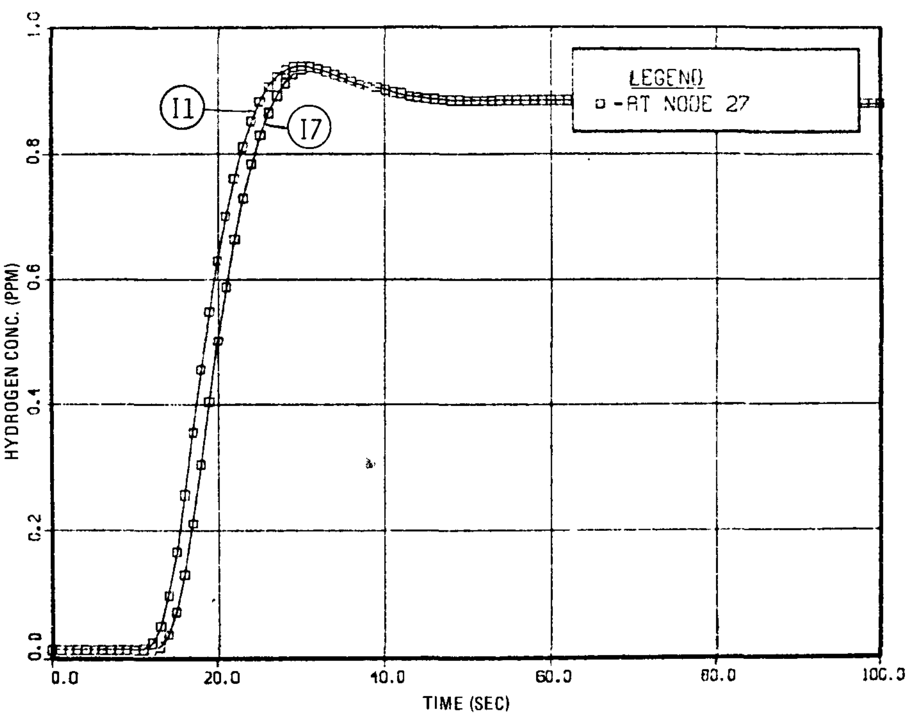

Fig. 27. Transient Hydrogen Concentrations Resulting from Steam Injection of 0.01 lb/sec for 5 sec from Two Different Injectors

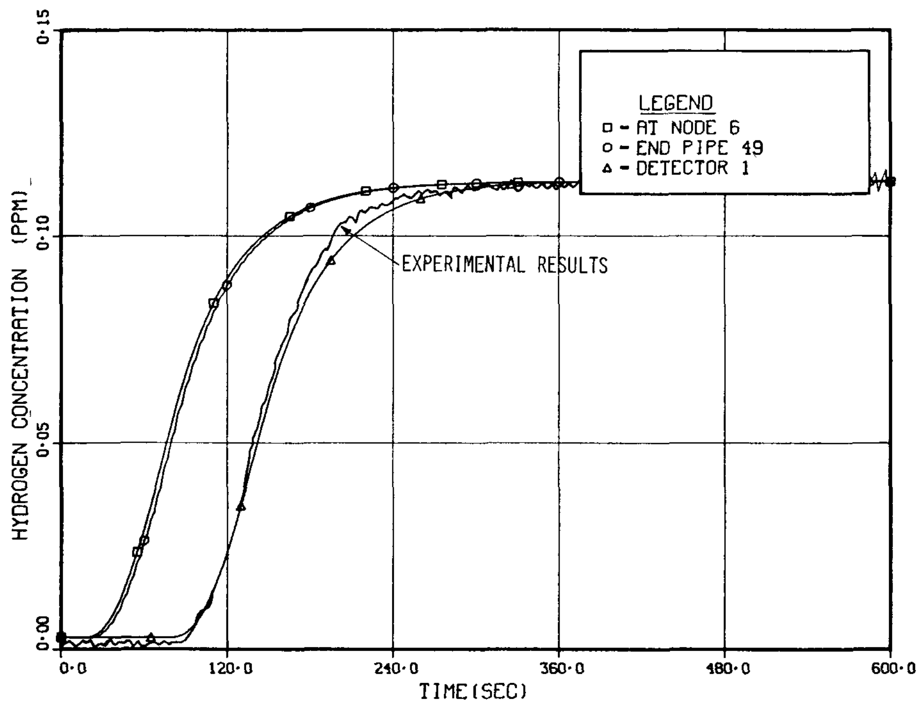

Fig. 28. Effect of Cold-trap Operation on Na_2O Concentration in CCTL Vessel (Node 27)

detector connected to segment 49 are superimposed on the detector response as predicted by the simulation program CCTL-DYSP. Except for random experimental noise, there is excellent agreement. Also shown are the predicted hydrogen concentrations at the end of pipe segment 40, and in the stagnant region of the heat exchanger (segment 6).

On November 7, 1975, injection No. 23 took place in which 0.98 g/min of steam was injected at Injector I4. The leak duration was 118.4 sec, the sodium flow was 300 gpm, and the sodium temperature was 940°F (504°C). In Fig. 29 the experimental readings from the hydrogen detector are superimposed on the detector response as predicted by the simulation. Small differences between the experimental and the predicted curves can be seen. These seem to be mainly due to the imperfect knowledge of the exact shape of the steam-injection curve, errors in the calculation of the delays in the sampling lines due to errors in the flowmeters, and random experimental noise, which is clearly visible on the experimental curve. In this experiment there was apparently a large calibration error in the interpretation of the detector readings. Therefore the experimental results were normalized to the steady-state result as obtained from the simulation.

XI. SUMMARY AND CONCLUSIONS

An analytical model has been developed to describe the kinetic and dynamic processes that occur when water leaks into a circulating sodium loop.

A computer code, CCTL-DYSP, solving the model equations was prepared. The distribution and the concentration of the sodium-water reaction products throughout the system was calculated, and it is shown that qualitatively the results are in agreement with similar calculations or experiments published elsewhere.[12,13] Subsequent calculations, simulating two CCTL experiments were in good agreement with measured hydrogen concentrations (see Sec. X). However, note that experimental and theoretical information on small leaks, sodium-water interaction, and the subsequent distribution of hydrogen in a system, is scarce and of dubious validity.

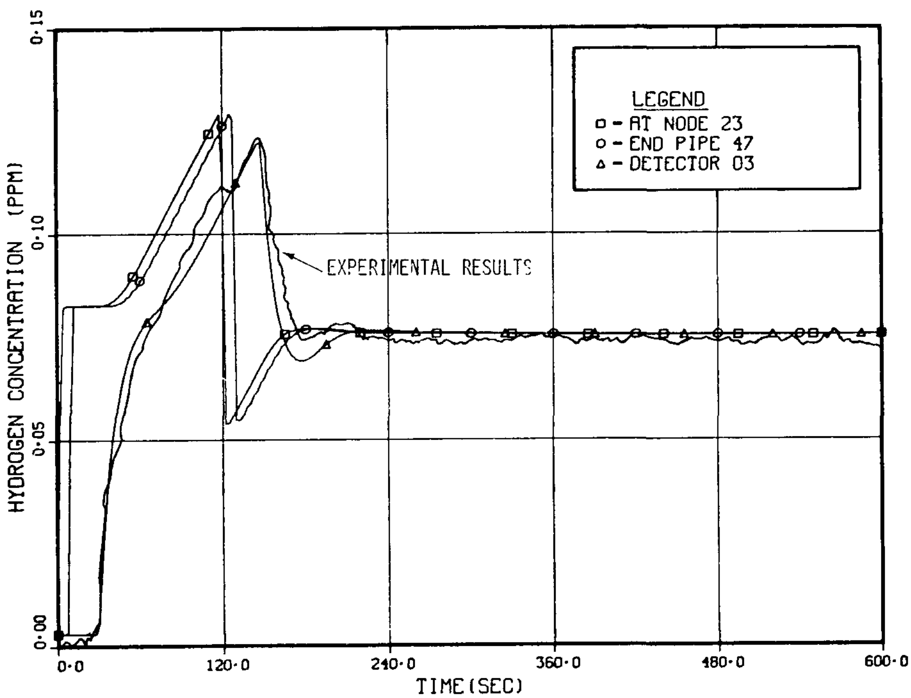

Fig. 29. Changes in Cover-gas Hydrogen Concentrations When Hydrogen-disengagement Half-life Is Reduced by a Factor of 1000

Most of the parameters governing hydrogen diffusion and transport throughout the system and its subsequent "evaporation" (or disengagement, if in bulk form) in the cover gas are not known. Some of the reaction parameters available, such as NaOH and HaH dissociation rates, are old data with large error limits obtained under laboratory conditions different from the actual operating conditions of the steam generator; and there is no quantitative information on how the reaction proceeds at the leak site. As a result, several assumptions had to be made and the results given in Sec. IX are dependent on these assumptions.

The contention is that the mathematical model is correct, since it is developed from basic principles. Values assumed for currently unknown parameters will be replaced with reliable experimental data, as they become available. In the meantime, the CCTL-DYSP will be used primarily to predict the response of the hydrogen and oxygen detectors during steam-generator leak-detection experiments in the CCTL.

Application of the CCTL-DYSP to a CRBRP steam-generator simulation will require some changes in the routines and additional input. For example, the program should account for (1) temperature variation from segment to segment (either to be calculated or supplied as input), (2) hydrogen diffusion through the steam-generator walls, and (3) other sources and sinks of hydrogen and oxygen that may be significant. These changes will not affect the program structure; rather they will add terms to the hydrogen and oxygen sources in the appropriate routine.

APPENDIX A

Mathematical Model Used in CCTL Dynamic Simulation Program (CCTL-DYSP)

The equations and notations described in this appendix are identical to those used in CCTL-DYSP; algebraic operations are written mostly in FORTRAN symbolics.

1. An Ideal Mixing Plenum

In "ideal mixing" it is assumed the inlet stream of sodium into a segment is instantly and totally mixed with the sodium in the segment. The equations describing concentration changes of the four reaction products (i.e., C1 for NaH, C2 for NaOH, C3 for Na_2O, and C4 for hydrogen) are

DC1(I) = (W(I)*(C1(II) - C1(I)) + CC1)/M(I) + S1(I), (A.1)

DC2(I) = (W(I)*(C2(II) - C2(I)) + CC2)/M(I) + S2(I), (A.2)

DC3(I) = (W(I)*(C3(II) - C3(I)) + CC3)/M(I) + S3(I), (A.3)

and

DC4(I) = (W(I)*(C4(II) - C4(I)) + CC4)/M(I) + S4(I), (A.4)

where

DC1-DC4 = time derivatives of the appropriate reaction-product concentrations,

I = index of the variables or number of node for which concentrations are calculated,

II = index number of the segment from which the main flow enters the Ith segment (usually II = I - 1),

M(I) = mass of the Ith segment,

W(I) = total flow through the Ith segment,

and CC1-CC4 account for concentration changes other than those due to the main-stream inlet and outlet for the four reaction products.

For multiple entry nodes, the following equations apply:

For node 22,

CC1 = WEX*(C1(3) - C1(21)). (A.5)

For node 27,

$$CC1 = WT1*C1(50) + WT3*C1(48) + WT4*C1(46) - WDET*C1(27), \quad (A.6)$$

where

$$WDET = WT1 + WT3 + WT4. \quad (A.7)$$

For node 29,

$$CC1 = WCT*(C1(43) - C1(28)). \quad (A.8)$$

The S terms in Eqs. A.1-A.4 are the reaction-product sources resulting from primary or secondary reactions and are given by

$$S1(I) = KK1*QS(I)/M(I) - DNAH, \quad (A.9)$$

$$S2(I) = KK2*QS(I)/M(I) - DNAOH, \quad (A.10)$$

$$S3(I) = KK3*QS(I)/M(I) + DNAOH, \quad (A.11)$$

and

$$S4(I) = KK4*QS(I)/M(I) + (DNAH + DNAOH)*0.5 - WH/M(I), \quad (A.12)$$

where

QS(I) = leak rate at the Ith node,

WH = rate of hydrogen escape from the segment into the cover-gas plenum,

$$DNAH = RR1*C1(I), \quad (A.13)$$

$$DNAOH = R3*C2(I), \quad (A.14)$$

RR1 = NaH dissociation rate,

$$RR1 = 0.597*EXP(-3833/TK)*((PDIS - PH)/PDIS)^2 \quad (A.15)$$

TK = Kelvin temperature of sodium,

$$TK = (TEMP - 32)/1.8 + 273, \quad (A.16)$$

TEMP = sodium temperature (in °F), which is an input value,

PDIS = NaH dissociation pressure,

PH = hydrogen partial pressure,

and

R3 = NaOH dissociation rate, which is an input value.

Finally, the actual values of the reaction-product concentrations are obtained by integrating the derivatives in Eqs. A.1-A.4 by an integration routine. Presently a simple Euler formula is used, but any integration procedure can be chosen.

2. Node with Cover Gas

The term WH in Eq. A.12 is given by

$$WH = R1*(C4(I) - CHNA) \text{ for } CHNA > C4(I), \quad (A.17)$$

where

R1 = hydrogen-gas disengagement constant,

CHNA = hydrogen concentration in sodium that would be achieved under equilibrium conditions according to Sieverts' constant,

$$CHNA = KS*SQRT(PH), \quad (A.18)$$

and

KS = Sieverts' constant,

$$KS = EXP(1.9733 - 276.77/TK)*453.6/2.0116*10^{-6}. \quad (A.19)$$

The partial hydrogen pressure PH in the cover gas is calculated from the ideal gas laws, and is given by

$$DPH = (WHPU + WHCT)*554*TPLEN/VPLEN, \quad (A.20)$$

where

WHPU = hydrogen gas escaping through the pump,

WHCT = hydrogen gas escaping through the CCTL vessel,

TPLEN = absolute temperature in the cover gas,

TPLEN = TEMP + 460,

and

VPLEN = total volume of gas plenum, including the CCTL vessel, the expansion tank, and the pump tank.

Finally, DPH is integrated to obtain PH.

3. Pipe Node and Generating Delay Functions

A pipe in the system generates a time lag or holds up an event occurring at the pipe inlet for a period equivalent to the passage time through the pipe.

A time lag for a specified event is generated by storing the appropriate concentrations at the pipe-inlet node along with appropriate time values. Each pipe segment is allocated 100 memory locations. Pipe-inlet values are stored initially at constant time intervals. When the simulation starts, these values are stored whenever a change larger than PDEL in the pipe-inlet variable occurs; PDEL is usually 0.5 or 1%. When the outlet variable of a pipe segment is required, the lag time τ is first calculated by

$$\tau = M(I)/W(I). \tag{A.21}$$

Then the value of the variable is calculated by linear interpolation of the two closest variables available at time $t - \tau$ in a pipe function.

The secondary reactions in the pipe are accounted for by the following equations. Assuming FX1, FX2, FX3, and FX4 are the pipe-outlet variables at time $t - \tau$, the true pipe-outlet concentrations are given by

$$C1(I) = FX1 + S1(I)*\tau, \tag{A.22}$$

$$C2(I) = FX2 + S2(I)*\tau, \tag{A.23}$$

$$C3(I) = FX3 + S3(I)*\tau, \tag{A.24}$$

$$C4(I) = FX4 + S4(I)*\tau, \tag{A.25}$$

where

$$S1(I) = -RR1*FX1, \tag{A.26}$$

$$S2(I) = -R3*FX2, \tag{A.27}$$

$$S3(I) = -S2(I), \tag{A.28}$$

and

$$S4(I) = -(S1(I) + S2(I)*0.5. \tag{A.29}$$

4. Cold Trap

The cold trap causes reaction products to precipitate at a rate

$$W42 = BETA*(C1(42) - C1SAT), \tag{A.30}$$

and

$$W420 = BETA*(C3(42) - C3SAT), \quad (A.31)$$

where

W42 = precipitation rate of NaH,

W420 = precipitation rate of Na_2O,

BETA = dynamic cold-trap efficiency,

C1SAT = saturation concentration of NaH,

$$C1SAT = 453.6*10^{-6}/23.9983*EXP(13.93 - 6631.4/TCLT), \quad (A.32)$$

C3SAT = saturation concentration of Na_2O,

$$C3SAT = 453.6*10^{-6}/61.98*EXP(16.131 - 6493.3/TCLT), \quad (A.33)$$

where

TCLT = absolute cold-trap temperature

$$TCLT = (TCLT - 32)/1.8 + 273 \quad (A.34)$$

5. Detectors

The derivative of a hydrogen-detector response is given by

$$DPP = (CD1 + CD4 - CDET(N))/TDLE(N), \quad (A.35)$$

where

TDLE(N) = diffusion delay time of Nth hydrogen detector,

CDET(N) = response of Nth detector obtained by integrating DPP or the detector internal hydrogen concentration,

$$CD1 = (FX1 + SD1*TAU)*1.0083*10^6/453.6, \quad (A.36)$$

and

$$CD4 = (FX4 + SD4*TAU)*2.0166*10^6/453.6. \quad (A.37)$$

FX1 and FX4 are hydride and hydrogen concentrations, respectively, at the outside of detector membrane, and are equal to the monitored segment concentration at time TIME - TAU, where TAU is given by

$$TAU = M(N1)/W(N1) + TLAG(N). \quad (A.38)$$

In Eq. A.38, M(N1) and W(N1) are the mass and the flow rate of the monitoring bypass pipe segment, and TLAG is the time lag of the Nth detector. The hydrogen-detector response in ppm is obtained by integrating Eq. A.35. The oxygen-detector response is calculated from

$$DPP = (CD3 - CDET(N))/TDLE(N), \tag{A.39}$$

where

$$CD3 = (FX3 + SD3*TAU)*16.0*10^6/453.6 \tag{A.40}$$

and

$$SD3 = R3*FX2. \tag{A.41}$$

The oxygen-meter response is obtained by integrating Eq. A.39. The readout of the hydrogen meter in the cover gas is proportional to the hydrogen partial pressure. The readout is converted to ppm by volume using the relation

$$CD4 = PH*10^6/(PH + PA), \tag{A.42}$$

where

PH = hydrogen partial pressure

and

PA = argon-cover-gas partial pressure.

The detector response is calculated by integrating

$$DPP = (CD4 - CDET(N))/TDLE(N), \tag{A.43}$$

where CDET(N) is the detector response, and TDLE(N) is the delay time of the Nth detector.

APPENDIX B

Description of CCTL-DYSP

A simplified schematic of the simulation program is shown in Fig. B.1. The program is written in FORTRAN in a modular form. It has five calculating subroutines, a coordinating main program, two service subroutines for printing and plotting results, and a small integrating routine.

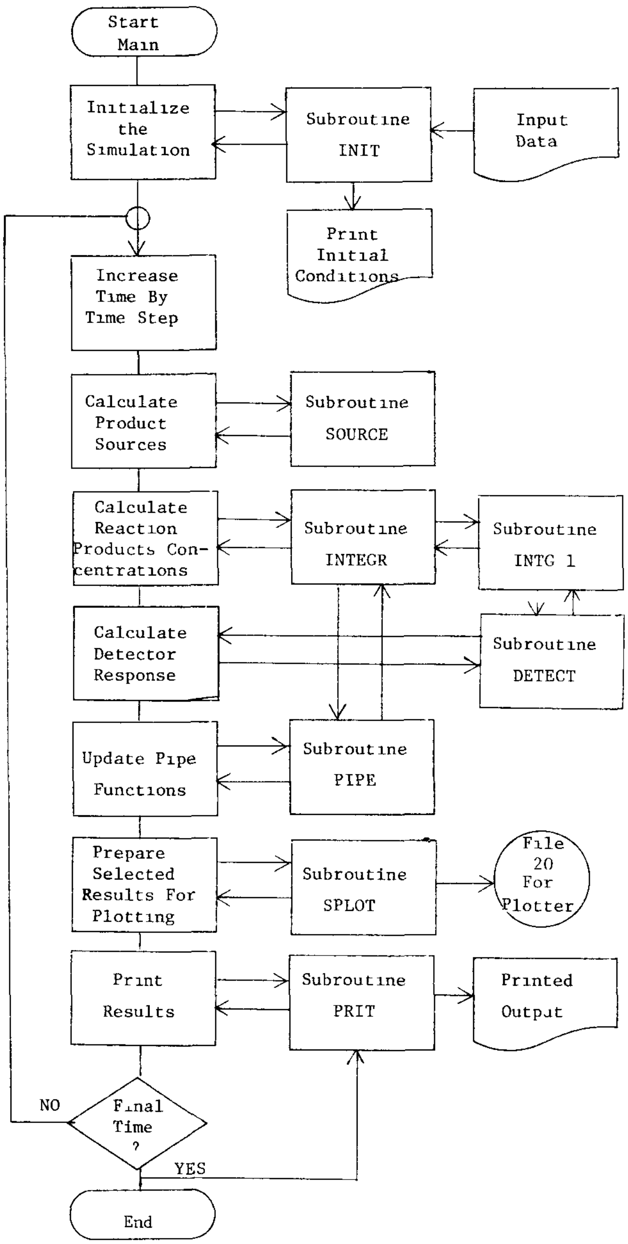

Fig. B 1. Simplified Schematic Flow-chart of CCTL-DYSP

The main coordinating program first calls the INIT routine in which data are read in, initial values are calculated and printed, and the pipe initial function is set up. The program then proceeds to the dynamic phase by increasing time by a time step, and increasing the time-step counter by 1.

The first subroutine called in the dynamic section is SOURCE. This routine calculates the source of reaction products resulting from any type of chemical reaction at each loop segment. Equations A.5-A.19 are solved.

The second routine called is INTEGR, which computes the derivatives of all reaction-product concentrations in the loop segments and pipe outlets. This routine has access to the PIPE subroutine to compute pipe-outlet concentrations, and to the INTGI routine, which performs the actual integration.

The main program then accesses the DETECT subroutine, which computes the appropriate detector responses.

After the variables for a time step have been calculated by appropriate integration of the differential equations, the program updates the inlet variables for the pipe segments by calling PIPE. The program then enters the PRIT routine, and, if requested, some data such as detector responses and concentrations at some of the nodes are printed.

Every TPR seconds--as determined by the input parameter--a complete "map" of the system is printed, which includes derivatives, sources, and actual concentration of the four reaction products at each segment and pipe outlet. The SPLOT routine is entered next, and user-selected data are stored in a specific file for later plotting.

Finally, the program checks the time; if it is less than the predetermined length of simulation, a time-step calculation is repeated. If the time is equal to the final simulation time, the program terminates by printing a final "map" of the system and print-plotting the results previously stored in a file. The listing of the program is given in Appendix C, and the input data are described in Appendix D.

APPENDIX C

Listing of CCTL-DYSP

```
CCTL.FORT
 PRESENT DATE  8/11/76         DSK203

C-----------------------------------------------------------------------C
C                                                                       C
C     CCTL-DYSP: A DYNAMIC SIMULATION PROGRAM TO CALCULATE HYDROGEN    C
C     AND OXYGEN CONCENTRATION IN WATER TO SODIUM LEAK EXPERIMENT IN   C
C     THE CORE COMPONENT TEST LOOP.                                    C
C                                                                       C
C     PROGRAM CAPACITY:                                                 C
C                       50 SEGMENTS                                     C
C                       7  DETECTORS                                    C
C                       4  REACTION PRODUCTS CONCENTRATIONS             C
C                       1  COMBINED COVER GAS PLENUM                    C
C                       1  COLD TRAP                                    C
C                                                                       C
C-----------------------------------------------------------------------C

C*******************************   VOCABULARY   ************************C
C#######################################################################C
C#.....................................................................#C
C#.                                                                   .#C
C#. A - CROSS SECTION AREA OF SEGMENT (FT**2)                         .#C
C#. ABSC - THE HEADING TO BE PRINTED ALONG THE ABSCISAE OF            .#C
C#.        GRAPHIC OUTPUT                                             .#C
C#. BETA - RATE AT WHICH NAH IS REMOVED IN THE COLD TRAP              .#C
C#. C1 - CONCENTRATION OF NAH (MOL/LB)                                .#C
C#. C1SAT - SATURATION CONCENTRATION OF NAH AT COLD TRAP TEMPERATURES.#C
C#. C2 - CONCENTRATION OF NAOH (MOL/LB)                               .#C
C#. C3 - CONCENTRATION OF NA2O (MOL/LB)                               .#C
C#. C4 - CONCENTRATION OF H2  (MOL/LB)                                .#C
C#. CDET - DETECTOR READING IN PPM                                    .#C
C#. FIGTTL - TITLE GIVE TO A FIGURE DRAWN BY THA CALCOMP PLOTTER      .#C
C#. FINTIM - SIMULATION TIME FOR THIS RUN IN (SEC)                    .#C
C#. IC - NODE NUMBERS FOR WHICH CINCENTRATIONS TO BE PLOTTED          .#C
C#. ICT - NODE NUMBERS FOR WHICH PPM CONC OF H2 IS PRINTED PER STEP   .#C
C#. IQ - NUMBER OF NODE AT WHICH LEAKAGE MIGHT OCCURE                 .#C
C#. JPL - PLOTTING COUNTER                                            .#C
C#. JPR - PRINTING COUNTER                                            .#C
C#. JT - TIME STEP COUNTER                                            .#C
C#. K1 - FRACTION OF H2O LEAK TO: NA+H2O=NAOH+1/2H2(G)                .#C
C#. K2 - FRACTION OF H2O LEAK TO: 2NA+H2O=NAOH+NAH                    .#C
C#. K3 - FRACTION OF H2O LEAK TO: 3NA +H2O=2NAH+NA2O                  .#C
C#. K4 - FRACTION OF H2O LEAK TO: 2NA+H2O=NA2O+H2                     .#C
C#. KH - IF 1 WATER LEAK, IF 2 HYDROGEN LEAK.
C#. L - LENGTH OF SEGMENT (FT)                                        .#C
C#. LG - SEGMENT IDENTIFICATION NUMBER: 0 NO SEGMENT                  .#C
C#.                                     1 PLENUM MIXED SEGMENT        .#C
C#.                                     2 PIPE SEGMENT                .#C
C#.                                     3 PLENUM MIXING WITH COVER GA.#C
C#.                                     5 PLENUM WITH COVER AND MULTE.#C
C#. M - MASS OF SODIUM IN SEGMENT                                     .#C
C#. NAME - NAME OF APPROPRIATE VECTOR TO BE PLOTTED                   .#C
C#. NGRAF - NO. OF CURVES TO BE PRINTPLOTTED OR PLOTTED PER FIG.      .#C
C#. NODE - NUMBER OF NODE TO WHICH DETECTOR IS CONNECTED              .#C
C#. NTYPE - TYPE OF DETECTOR USED MONITORING AT SEGMENT 'NODE'        .#C
```

CCTL.FORT

```
C#. NUDET - NUMBER OF DETECTORS IN THE SYSTEM                                .#C
C#. PA - ARGON PARTIAL PRESSURE IN COVER GAS                                 .#C
C#. PDIS - NAH DISSOCIATION PRESSURE                                         .#C
C#. PDEL - MAXIMUM PERMITED CHANGE IN NODE 23 FOR PIPE UPDATA                .#C
C#. PH - HYDROGEN PARTIAL PRESSURE IN COVER GAS (MM-HG)                      .#C
C#. PRT1 - IF TRUE INITIAL PIPE FUNCTION DISTRIBUTION WILL BE                .#C
C#.        PRINTED                                                           .#C
C#. PRT2 - RESERVED                                                          .#C
C#. PRT3 - RESERVED                                                          .#C
C#. PRT4 - RESERVED                                                          .#C
C#. PRT5 - IF TRUE A CALCOMP 580 PLOT OF THE PREDETERMINED VARI-             .#C
C#.        ABLES WILL BE PREPARED                                            .#C
C#. PTDL - MAXIMUM PERMITED TIME INTERVAL FOR PIPE UPDATE                    .#C
C#. Q - H2O LEAKAGE IN THE I-TH NODE (LBS/SEC)                               .#C
C#. R1 - RATE OF H2 DISENGAGEMENT FROM LIQUID NA TO COVER GAS (SEC-1).#C
C#. R2 - RATE OF NAH DISSOCIACION NAH=NA+H (SEC-1*MM-HG-2)                   .#C
C#. R3 - RATE OF NAOH DISSOCIATION NAOH+NA=NA2O+H (SEC-1)                    .#C
C#. S1 - SOURCE OF NAH (MOL/SEC)                                             .#C
C#. S2 - SOURCE OF NAOH (MOL/SEC)                                            .#C
C#. S3 - SOURCE OF NA2O (MOL/SEC)                                            .#C
C#. S4 - SOURCE OF H2 (MOL/SEC)                                              .#C
C#. TQ - TIME AT WHICH LEAKAGE AT I-TH NODE STARTS (SEC)                     .#C
C#. TX - TIME AT WHICH LEAKAGE AT I-TH NODE TERMINATES (SEC)                 .#C
C#. TCLT - COLD TRAP TEMPERATURE (DEG F OR K)                                .#C
C#. TDLE - DIFFUSION TIME CONSTANT FOR DET. NICKEL MEMBRANE (SEC)             .#C
C#. TEMP - SODIUM TEMPERATURE (DEG F)                                         .#C
C#. TIME - CURENT SIMULATION TIME (SEC)                                       .#C
C#. TLAG - TIME LAG BETWEEN DETECTOR SAMP.LINE INLET AND DETECTOR (SE.#C
C*. TMM - TOTAL SODIUM MASS IN CCTL (LBS)                                    .#C
C*. TMT - TOTAL COOLANT TRANSIT TIME (SEC)                                   .#C
C#. TPL - PLOTING INTERVAL (SEC)                                             .#C
C#. TPR - PRINTING INTERVAL (SEC)                                            .#C
C#. WCT - FLOW THROUGH THE COLD TRAP IN (GPM)                                .#C
C*. WS - TOTAL SODIUM FLOW IN CCTL (GPM)                                     .#C
C#. WT1 - FLOW TO DETECTOR # 1 (LBS/SEC)                                     .#C
C#. WT2 - FLOW TO DETECTOR # 2 (LBS/SEC)                                     .#C
C#. WT3 - FLOW TO DETECTOR # 3 (LBS/SEC)                                     .#C
C#. WT4 - FLOW TO DETECTOR # 4 (LBS/SEC)                                     .#C
C#.......................................................................#C
C########################################################################C

      COMMON /BLK/ L,A,M,C1,C2,C3,C4,LG,WS,WCT,WT1,WT2,WT3,WT4,WEX,TEMP,
     C FINTIM,RONA,DTMIN,DTMAX,S1,S2,S3,S4,JT,KS,TPR,IQ,ICT,W,JCT,
     C WR,WA,WX,WB,WC,WD,WE,Q,TQ,TX,QS,PDIS,PH,PA,K1,K2,K3,K4,R1,R2,R3,
     C WHCT,WHPU,TPLEN,VPLEN,IC,TPL,CHNA,RR1,QX,QXT,QHT,C1SAT,BETA,
     C ALFA,TMM,NPICT,NGRAF,NVECT,NAME,IPI,NUDET,NODE,NTYPE,
     C TLAG,CDET,TDLE,C3SAT,PDEL,FIGTTL,PTDL,KH
      COMMON /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4,PRT5
      COMMON /DUB/ TIME,DELT,DC1,DC2,DC3,DC4,ABSC
      REAL*4 L(50),A(50),M(50),C1(50),C2(50),C3(50),C4(50),W(50)
      REAL*4 S1(50),S2(50),S3(50),S4(50),Q(8),TQ(8),TX(8),QS(50)
      REAL*4 K1,K2,K3,K4,KS,TITLE(18),TLAG(7),CDET(7),TDLE(7)
      REAL*8 DC1(50),DC2(50),DC3(50),DC4(50),TIME,DELT,ABSC(4,10)
```

CCTL.FORT

```
      LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
      DIMENSION LG(50),IQ(8),IC(8),ICT(8),NGRAF(10),NVECT(10,5),
     C NAME(10,15),IPI(50),NODE(7),NTYPE(7),FIGTTL(15,10)

      CALL INIT
      LV=1
      QXT=0.
      C4OLD=C4(23)
      TOLD=0.
      GOTO 20
C**** START TIME DEPENDENT CALCULATIONS
   10 TIME=TIME+DELT
      JT=JT+1
      CALL SOURCE
      CALL INTEGR
      CALL DETECT
C**** UPDATE PIPE FUNCTIONS IF CHANGE > PDEL OR ELAPSED TIME MORE THEN .
C**** 0.5 SECONDS
      TIM=TIME
      CHNG=(C4OLD-C4(23))/C4OLD
      CHTM=TIM-TOLD
      IF(ABS(CHNG).LT.PDEL.AND.CHTM.LT.PTDL) GOTO 20
      TOLD=TIM
      C4OLD=C4(23)
      DEL=DELT
      CALL PIPE(TIM,DEL,0.0,1,C1(1),C2(1),C3(1),C4(1))
      CALL PIPE(TIM,DEL,0.0,2,C1(3),C2(3),C3(3),C4(3))
      CALL PIPE(TIM,DEL,0.0,3,C1(23),C2(23),C3(23),C4(23))
      CALL PIPE(TIM,DEL,0.0,4,C1(27),C2(27),C3(27),C4(27))
      CALL PIPE(TIM,DEL,0.0,5,C1(29),C2(29),C3(29),C4(29))
      CALL PIPE(TIM,DEL,0.0,6,C1(6),C2(6),C3(6),C4(6))
      CALL PIPE(TIM,DEL,0.0,7,C1(25),C2(25),C3(25),C4(25))
      CALL PIPE(TIM,DEL,0.0,8,C1(42),C2(42),C3(42),C4(42))
      CALL PIPE(TIM,DEL,0.0,10,RR1,PH,CHNA,0.0)
C**** PERFORM TOTAL HYDROGEN BALANCE CALCULATIONS FOR THIS TIME STEP
   20 QX=0.
      QHT=0.
      DO 92 I=1,50
      IF(LG(I).EQ.0) GOTO 92
      QHT=QHT+(0.5*C1(I)+0.5*C2(I)+C4(I))*M(I)
      QX=QX+QS(I)
   92 CONTINUE
      QXT=QXT+QX*DELT
      QHT=QHT+PH*VPLEN/(TPLEN*554.0)
      ALFA=(0.5*C1(ICT(1))+C4(ICT(1)))*TMM/QHT
      CALL SPLOT(LV)
      CALL PRIT(LV)
      TIM=TIME
      LV=2
      IF(FINTIM-TIM.GT.DELT/2) GOTO 10
      CALL PRIT(3)
      CALL SPLOT(3)
      STOP
```

```
      END
C--------------------------------------------------------------------C
C                                                                    C
C          SUBROUTINE INIT                                           C
C          THIS SUBROUTINE INITIALIZES THE PROGRAM, READS INPUT DATA   C
C          AND SUPPLIES DEFAULT VALUES TO DATA NOT IN INPUT STREAM    C
C                                                                    C
C--------------------------------------------------------------------C

      SUBROUTINE INIT
      COMMON /BLK/ L,A,M,C1,C2,C3,C4,LG,WS,WCT,WT1,WT2,WT3,WT4,WEX,TEMP,
     C FINTIM,RONA,DTMIN,DTMAX,S1,S2,S3,S4,JT,KS,TPR,IQ,ICT,W,JCT,
     C WR,WA,WX,WB,WC,WD,WE,Q,TQ,TX,QS,PDIS,PH,PA,K1,K2,K3,K4,R1,R2,R3,
     C WHCT,WHPU,TPLEN,VPLEN,IC,TPL,CHNA,RR1,QX,QXT,QHT,C1SAT,BETA,
     C ALFA,TMM,NPICT,NGRAF,NVECT,NAME,IPI,NUDET,NODE,NTYPE,
     C TLAG,CDET,TDLE,C3SAT,PDEL,FIGTTL,PTDL,KH
      COMMON /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4,PRT5
      COMMON /DUB/ TIME,DELT,DC1,DC2,DC3,DC4,ABSC
      REAL*4 L(50),A(50),M(50),C1(50),C2(50),C3(50),C4(50),W(50)
      REAL*4 S1(50),S2(50),S3(50),S4(50),Q(8),TQ(8),TX(8),QS(50)
      REAL*4 K1,K2,K3,K4,KS,TITLE(18),TLAG(7),CDET(7),TDLE(7)
      REAL*8 DC1(50),DC2(50),DC3(50),DC4(50),TIME,DELT,ABSC(4,10)
      LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
      REAL*4 MOL
      DIMENSION LG(50),IQ(8),IC(8),ICT(8),NGRAF(10),NVECT(10,5),
     C NAME(10,15),IPI(50),NODE(7),NTYPE(7),FIGTTL(15,10)
      DIMENSION ADAT(20)
      DATA PI/3.1416/,CFPG/.13368981/,ADA/'9999'/
C
    1 READ 180,ADAT
      PRINT 190,ADAT
      IF(ADAT(1).NE.ADA) GOTO 1
      REWIND 5
      NAMELIST /INLST/ L,LG,A,C1,C2,C3,C4,Q,TQ,TX,IQ,IC,ICT
     C /PARM/ TEMP,WS,WCT,WT1,WT2,PH,PA,K1,K2,K3,K4,R1,R3,BETA,C1SAT,
     C  WT3,WT4,WEX,FINTIM,DELT,DTMIN,DTMAX,TPR,VPLEN,TPL,JCT,
     C PRT1,PRT2,PRT3,PRT4,PRT5,BETA,TCLT,PDEL,PTDL,KH
     C /DTCTR/ NUDET,NODE,NTYPE,TDLE,TLAG
      READ 200,TITLE
      READ (5,INLST)
      READ (5,PARM)
      READ (5,DTCTR)
      READ 210
      READ 170,NPICT
      READ 170,NGRAF
      DO 3 N=1,NPICT
      NN=NGRAF(N)
      READ 170,(NVECT(N,I),I=1,NN)
      READ 220,((NAME(N,(I-1)*3+J),J=1,3),I=1,NN)
      READ 230,(ABSC(I,N),I=1,4)
      READ 200,(FIGTTL(I,N),I=1,15)
    3 CONTINUE
```

CCTL.FORT

```
      RONA=59.566-TEMP*(7.9504E-3+TEMP*(2.872E-7-TEMP*6.035E-11))
      MOL=453.6/18.02
      QX=0.
      QXT=0.
      WS=WS*CFPG*RONA/60.
      WCT=WCT*CFPG*RONA/60.
      WT1=WT1*CFPG*RONA/60.
      WT2=WT2*CFPG*RONA/60.
      WT3=WT3*CFPG*RONA/60.
      WT4=WT4*CFPG*RONA/60.
      WEX=WEX*CFPG*RONA/60.
      WA=WS-WEX
      WX=WA-WT1-WT2
      WB=WX+WEX
      WC=WB-WT3
      WD=WC-WT4-WCT
      WE=WD+WT1+WT2+WT3+WT4
      WR=WE+WCT
      TMM=0.
      DO 5 I=1,8
    5 Q(I)=Q(I)*MOL
      C1(1)=C1(1)*453.6/23.9986
      C2(1)=C2(1)*453.6/39.9983
      C3(1)=C3(1)*453.6/61.98
      C4(1)=C4(1)*453.6/2.0166
      TCLT=(TCLT-32.0)/1.8+273.0
      C1SAT=453.6E-6/23.9983*EXP(13.97-6631.4/TCLT)
      C3SAT=453.6E-6/61.98*EXP(16.131-6493.3/TCLT)
      IF(C1(1).EQ.0.0) C1(1)=C1SAT
      IF(C3(1).EQ.0.0) C3(1)=C3SAT
      DO 10 I=1,50
      IPI(I)=0
      C1(I)=C1(1)
      C2(I)=C2(1)
      C3(I)=C3(1)
      C4(I)=C4(1)
      IF(LG(I).NE.0) GOTO 9
      C3(I)=0.
      C4(I)=0.
      C1(I)=0.
      C2(I)=0.
    9 W(I)=0.
      S1(I)=0.
      S2(I)=0.
      S3(I)=0.
      S4(I)=0.
      QS(I)=0.
      M(I)=L(I)*A(I)*RONA
      TMM=TMM+M(I)
      DC1(I)=0.
      DC2(I)=0.
      DC3(I)=0.
      DC4(I)=0.
```

CCTL.FORT

```
   10 CONTINUE
C**** INITIALIZE DETECTOR READING
      DO 11 N=1,NUDET
      NTP=NTYPE(N)
      GOTO (12,13,14), NTP
   12 CDET(N)=(0.5*C1(1)+C4(1))*2.0166E+6/453.3
      GOTO 11
   13 CDET(N)=C3(1)*16.0E+6/453.3
      GOTO 11
   14 CDET(N)=PH*1.0E+6/(PA+PH)
   11 CONTINUE
      M(46)=M(46)+M(45)
      M(48)=M(48)+M(47)
      M(50)=M(50)+M(49)
      TM=0.
      DO 15 I=1,30
   15 TM=TM+M(I)
      TM=TM-M(6)
      TMT=TM/WS
      IP=0
      CALL PIPE(TIME,DELT,0.,IP,C1(1),C2(1),C3(1),C4(1))
      TK=(TEMP-32.)/1.8+273.
      TPLEN=TEMP+460.
      KS=EXP(1.9733-276.77/TK)*453.6/2.0116*1.E-6
      PDIS=EXP(26.71-14046.0/TK)
      R2=0.597*EXP(-3833/TK)
C
C**** CALCULATE TOTAL FLOW THROUGH EACH SEGMENT
      W(1)=WR
      W(2)=WS
      W(3)=WS
      W(4)=WA
      W(5)=WA
       W(6)=WT1+WT2
       W(7)=WA
       DO 20 I=8,21
   20 W(I)=WX
       W(22)=WB
       W(23)=WB
       W(24)=WC
       W(25)=WC
       W(26)=WD
       W(27)=WE
       W(28)=WE
      W(29)=WR
      W(30)=WR
      W(41)=WCT
      W(42)=WCT
      W(43)=WCT
      W(45)=WT4
      W(46)=WT4
      W(47)=WT3
      W(48)=WT3
```

CCTL.FORT

```
      W(49)=WT1
      W(50)=WT1
C**** SET APPROPRIATE PIPE FUNCTION NUMBERS TO PIPE SEGMENTS
      IPI(2)=1
      IPI(4)=2
      IPI(24)=3
      IPI(47)=3
      IPI(48)=3
      IPI(28)=4
      IPI(30)=5
      IPI(41)=7
      IPI(45)=7
      IPI(46)=7
      IPI(49)=6
      IPI(50)=6
      IPI(43)=8
      BETA=BETA*W(42)/M(42)
      CALL SOURCE
      CALL PIPE(TIME,DELT,0.0,10,RR1,PH,CHNA,0.0)
C
C**** PRINT INITIAL DATA
      PRINT 300,TITLE
      PRINT 100
      PRINT 110, IQ,Q,TQ,TX
      YK1=K2+2.*K3
      YK2=K1+K2
      YK3=K3+K4
      YK4=0.5*K1+K4
      PRINT 150,K1,K2,K3,K4,YK1,YK2,YK3,YK4
      PRINT 120, PDIS
      PRINT 130, TEMP,TK,RONA,TMM,VPLEN,BETA,C1SAT,C3SAT,TMT,TCLT,KS
      PRINT 140, WS,WCT,WT1,WT2,WT3,WT4,WEX,WA,WX,WB,WC,WD,WE,WR
      PRINT 160,(N,NTYPE(N),NODE(N),TLAG(N),TDLE(N),N=1,NODET)
   99 RETURN
 100  FORMAT(1H ,' LEAKAGE DATA FOR THIS CASE ARE:')
  110 FORMAT(1H0,'FOR NODE SEGMENT #      ',8I12/
     C  ' THE LEAKAGE IN MOL/SEC IS',8E12.4/
     C  ' THE LEAK STARTS AT TIME -',8F12.2/
     C  ' THE LEAK IS TERMINATED AT',8F12.2/)
  120 FORMAT('0THE NAH DISSOCIATION PRESSURE IN MM-HG IS',F12.3)
  130 FORMAT(' SODIUM TEMPERATURE IN (DEG-F)IS           ',F12.2/
     C        ' SODIUM TEMPERATURE IN (DEG-K) IS          ',F12.2/
     C        ' SODIUM DENSITY IN (LBS/CUF) IS            ',F12.2/
     C        ' TOTAL WEIGHT OF SODIUM IN THE SYSTEM (LB)',F12.2/
     C        ' COVER GAS PLENUM VOLUME (CUF)             ',F12.2/
     C        ' COLD TRAP DYNAMIC EFFICIENCY (1/SEC) IS   ',E12.4/
     C        ' NAH SATURATION CONC. AT COLD TRAP(MOL/LB)',E12.4/
     C        ' NA2O SATURATION CNC. AT COLD TRAP(MOL/LB)',E12.4/
     C        ' TOTAL TRANSIT TIME IN CCTL (SEC) IS       ',F12.2/
     C        ' COLD TRAP TEMPERATURE IN (DEG-K) IS       ',F12.2/
     C        ' SIEVERTS CONSTANT IN (MOL/(LB*TORR**-2)) ',E12.4)
  140 FORMAT('0TOTAL SODIUM FLOW IN (LBS/SEC) IS          ',F12.4,
     C/30X,'WCT',9X,F12.4/30X,'WT1',9X,F12.4/30X,'WT2',9X,F12.4/
```

```
     C 30X,'WT3',9X,F12.4/30X,'WT4',9X,F12.4/30X,'WEX',9X,F12.4/
     C 30X,'WA ',9X,F12.4/30X,'WX ',9X,F12.4/30X,'WB ',9X,F12.4/
     C 30X,'WC ',9X,F12.4/30X,'WD ',9X,F12.4/30X,'WE ',9X,F12.4/
     C 30X,'WR ',9X,F12.4//)
  170 FORMAT(10(I2,1X))
  150 FORMAT(1X,F4.2,' OF THE LEAK GOES TO   NA+H2O=NAOH+1/2H2(G)'/
     C          1X,F4.2,' OF THE LEAK GOES TO  2NA+H2O=NAOH+NAH'/
     C          1X,F4.2,' OF THE LEAK GOES TO  4NA+H2O=2NAH+NA2O'/
     C          1X,F4.2,' OF THE LEAK GOES TO  2NA+H2O=NA2O+H2'/
     C          1X,F4.2,' MOL OF THE LEAK IS TRANSFORMED TO NAH'/
     C          1X,F4.2,' MOL OF THE LEAK IS TRANSFORMED TO NAOH'/
     C          1X,F4.2,' MOL OF THE LEAK IS TRANSFORMED TO NA2O'/
     C          1X,F4.2,' MOL OF THE LEAK IS TRANSFORMED TO H2(G)')
  160 FORMAT(1H0,' DETECTOR NO ',I1,' OF TYPE ',I1,' IS CONECTED',
     C ' TO NODE ',I2,' HAS A LAG OF ',F5.2,'SEC AND A DELAY OF',
     C F5.2,'SEC')
  180 FORMAT(20A4)
  190 FORMAT(10X,20A4)
  200 FORMAT(18A4)
  210 FORMAT(80X)
  220 FORMAT(5(3A4,1X))
  230 FORMAT(4A8)
  300 FORMAT('1',20('*'),18A4,20('*')//)
        END

C-------------------------------------------------------------------------C
C                                                                         C
C     SUBROUTINE SOURCE.                                                  C
C     IN THIS SUBROUTINE SOURCES AND SINKS OF THE REACTION PRODUCTS       C
C     ARE CALCULATED                                                      C
C                                                                         C
C-------------------------------------------------------------------------C

        SUBROUTINE SOURCE
       COMMON /BLK/ L,A,M,C1,C2,C3,C4,LG,WS,WCT,WT1,WT2,WT3,WT4,WEX,TEMP,
     C FINTIM,RONA,DTMIN,DTMAX,S1,S2,S3,S4,JT,KS,TPR,IQ,ICT,W,JCT,
     C WR,WA,WX,WB,WC,WD,WE,Q,TQ,TX,QS,PDIS,PH,PA,K1,K2,K3,K4,R1,R2,R3,
     C WHCT,WHPU,TPLEN,VPLEN,IC,TPL,CHNA,RR1,QX,QXT,QHT,C1SAT,BETA,
     C ALFA,TMM,NPICT,NGRAF,NVECT,NAME,IPI,NUDET,NODE,NTYPE,
     C TLAG,CDET,TDLE,C3SAT,PDEL,FIGTTL,PTDL,KH
       COMMON /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4,PRT5
       COMMON /DUB/ TIME,DELT,DC1,DC2,DC3,DC4,ABSC
       REAL*4 L(50),A(50),M(50),C1(50),C2(50),C3(50),C4(50),W(50)
       REAL*4 S1(50),S2(50),S3(50),S4(50),Q(8),TQ(8),TX(8),QS(50)
       REAL*4 K1,K2,K3,K4,KS,TITLE(18),TLAG(7),CDET(7),TDLE(7)
       DIMENSION LG(50),IQ(8),IC(8),ICT(8),NGRAF(10),NVECT(10,5),
     C NAME(10,15),IPI(50),NODE(7),NTYPE(7),FIGTTL(15,10)
       REAL*4 KK1,KK2,KK3,KK4
       REAL*8 DC1(50),DC2(50),DC3(50),DC4(50),TIME,DELT,ABSC(4,10)
       LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
C
C**** CALCULATE REACTION RATES
       GOTO (1,3),KH
```

CCTL.FORT

```
    1 KK1=K2+2*K3
      KK2=K1+K2
      KK3=K3+K4
      KK4=0.5*K1+K4
      GOTO 4
    3 KK1=2*K1
      KK2=0
      KK3=0
      KK4=1.-K1
    4 RR1=((PDIS-PH)/PDIS)*ABS((PDIS-PH)/PDIS)*R2
      CHNA=KS*SQRT(PH)
C
C**** DETERMINE LEAKAGE SOURCES
      DO 2 I=1,8
      I2=IQ(I)
      QS(I2)=0.0
      IF(TIME.GE.TQ(I).AND.TIME.LE.TX(I)) QS(I2)=Q(I)
    2 CONTINUE
C
C**** CALCULATE SOURCES IN MOL/SEC
      DO 10 I=1,50
      IF(LG(I).EQ.0.OR.LG(I).EQ.2) GOTO 10
      DNAH=RR1*C1(I)
      DNAOH=R3*C2(I)
   11 S1(I)=KK1*QS(I)/M(I)-DNAH
      S2(I)=KK2*QS(I)/M(I)-DNAOH
      S3(I)=KK3*QS(I)/M(I)+DNAOH
      S4(I)=KK4*QS(I)/M(I)+(DNAH+DNAOH)*0.5
   10 CONTINUE
C**** ACCOUNT FOR POSSIBLE BUBBLE MIGRATION IN THE CCTL VESSEL
      W25=0.
      W26=0.
      WHCT=0.
      WHPU=0.
      IF(C4(25).LE.C4(26)) GOTO 21
      W25=R1*(C4(25)-C4(26))*M(25)
   21 IF(C4(26).LE.C4(27)) GOTO 22
      W26=R1*(C4(26)-C4(27))*M(26)
   22 C27=0.5*(C4(27)+C4(26)+0.5*(C1(27)+C1(26)))
      IF(C27.LE.CHNA) GOTO 23
      WHCT=R1*(C27-CHNA)*M(27)
   23 C01=0.5*(C4(1)+C4(30)+0.5*(C1(1)+C1(30)))
      IF(C01.LE.CHNA) GOTO 24
      WHPU=R1*(C01-CHNA)*M(1)
C**** ACCOUNT FOR COLD TRAP NAH REMOOVAL
   24 W42=0.0
      W420=0.0
      IF(LG(42).EQ.0) GOTO 25
      W42=BETA*(C1(42)-C1SAT)
      W420=BETA*(C3(42)-C3SAT)
      IF(W42.LT.0.0) W42=0.0
      IF(W420.LT.0.0) W420=0.0
   25 S4(25)=S4(25)-W25/M(25)
```

CCTL.FORT

```
      S4(26)=S4(26)+(W25-W26)/M(26)
      S4(27)=S4(27)+(W26-WHCT)/M(27)
      S4(1)=S4(1)-WHPU/M(1)
      S1(42)=S1(42)-W42
      S3(42)=S3(42)-W42O
      RETURN
      END

C---------------------------------------------------------------------C
C                                                                     C
C     SUBROUTINE INTEGR.                                              C
C     IN THIS ROUTINE CONCENTRATION OF THE VARIOUS REACTION PRODUCTS  C
C     FOR EACH SEGMENT ARE CALCULATED.                                C
C                                                                     C
C---------------------------------------------------------------------C

      SUBROUTINE INTEGR
      COMMON /BLK/ L,A,M,C1,C2,C3,C4,LG,WS,WCT,WT1,WT2,WT3,WT4,WEX,TEMP,
     C FINTIM,RONA,DTMIN,DTMAX,S1,S2,S3,S4,JT,KS,TPR,IQ,ICT,W,JCT,
     C WR,WA,WX,WB,WC,WD,WE,Q,TQ,TX,QS,PDIS,PH,PA,K1,K2,K3,K4,R1,R2,R3,
     C WHCT,WHPU,TPLEN,VPLEN,IC,TPL,CHNA,RR1,QX,QXT,QHT,C1SAT,BETA,
     C ALFA,TMM,NPICT,NGRAF,NVECT,NAME,IPI,NUDET,NODE,NTYPE,
     C TLAG,CDET,TDLE,C3SAT,PDEL,FIGTTL,PTDL,KH
      COMMON /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4,PRT5
      COMMON /DUB/ TIME,DELT,DC1,DC2,DC3,DC4,ABSC
      REAL*4 L(50),A(50),M(50),C1(50),C2(50),C3(50),C4(50),W(50)
      REAL*4 S1(50),S2(50),S3(50),S4(50),Q(8),TQ(8),TX(8),QS(50)
      REAL*4 K1,K2,K3,K4,KS,TITLE(18),TLAG(7),CDET(7),TDLE(7)
      REAL*8 DC1(50),DC2(50),DC3(50),DC4(50),TIME,DELT,ABSC(4,10)
      LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
      DIMENSION LG(50),IQ(8),IC(8),ICT(8),NGRAF(10),NVECT(10,5),
     C NAME(10,15),IPI(50),NODE(7),NTYPE(7),FIGTTL(15,10)
C
C**** CALCULATE DERIVATIVES FOR VARIABLES TO BE INTEGRATED AND S*TAU
C**** VALUES FOR PIPE SEGMENTS
      DO 10 I=1,50
      IF(LG(I).EQ.0) GOTO 10
       CC1=0.
       CC2=0.
       CC3=0.
       CC4=0.
      LLG=LG(I)
C**** CALCULATE DERIVATIVES FOR MIXING PLENUM NODES
    5 II=I-1
      IF(I.EQ.1)II=30
      IF(I.EQ.6)II=7
      IF(I.EQ.7)II=5
      GOTO (4,10,4,8,8),LLG
    4 DC1(I)=(W(I)*(C1(II)-C1(I))+CC1)/M(I)+S1(I)
      DC2(I)=(W(I)*(C2(II)-C2(I))+CC2)/M(I)+S2(I)
      DC3(I)=(W(I)*(C3(II)-C3(I))+CC3)/M(I)+S3(I)
      DC4(I)=(W(I)*(C4(II)-C4(I))+CC4)/M(I)+S4(I)
      GOTO 10
```

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```
C**** MULTIPLE ENTRY NODES
    8 IF(I.NE.22) GOTO 7
      CC1=WEX*(C1(3)-C1(21))
      CC2=WEX*(C2(3)-C2(21))
      CC3=WEX*(C3(3)-C3(21))
      CC4=WEX*(C4(3)-C4(21))
      GOTO 4
    7 IF(I.NE.27) GOTO 2
      WDET=WT1+WT2+WT3+WT4
      CC1=WT1*C1(50)+WT2*C1(48)+WT3*C1(48)+WT4*C1(46)-WDET*C1(27)
      CC2=W11*C2(50)+WT2*C2(48)+WT3*C2(48)+WT4*C2(46)-WDET*C2(27)
      CC3=WT1*C3(50)+WT2*C3(48)+WT3*C3(48)+WT4*C3(46)-WDET*C3(27)
      CC4=WT1*C4(50)+WT2*C4(48)+WT3*C4(48)+WT4*C4(46)-WDET*C4(27)
      GOTO 4
    2 IF(I.NE.29) GOTO 1
      CC1=WCT*(C1(43)-C1(28))
      CC2=WCT*(C2(43)-C2(28))
      CC3=WCT*(C3(43)-C3(28))
      CC4=WCT*(C4(43)-C4(28))
      GOTO 4
C**** WRONG SEGMENT IDENTIFICATION NUMBER IF PROGRAM ENTERS THIS SECTION
    1 PRINT 100,I
   10 CONTINUE
      DPH=(WHPU+WHCT)*554.0*TPLEN/VPLEN
C**** CALCULATE CONCENTRATION IN SEGMENTS BY INTEGRATION
      IP=0
      DO 20 I=1,50
      LLG=LG(I)
      IF(LLG.EQ.0) GOTO 20
      IF(LLG.EQ.2) GOTO 21
      CALL INTG1(I,C1(I),DC1(I),DELT)
      CALL INTG1(I,C2(I),DC2(I),DELT)
      CALL INTG1(I,C3(I),DC3(I),DELT)
      CALL INTG1(I,C4(I),DC4(I),DELT)
      GOTO 20
   21 TAU=M(I)/W(I)
      TIM=TIME
      DEL=DELT
      IF(TAU.GT.TIME) TAU=TIME
      IP=IPI(I)
      CALL PIPE(TIM,DEL,TAU,IP,FX1,FX2,FX3,FX4)
      CALL PIPE(TIM,DEL,TAU,10,X1,X2,X3,X4)
      S1(I)=-(X1+RR1)/2.*FX1
      S2(I)=-R3*FX2
      S3(I)=-S2(I)
      S4(I)=-(S1(I)+S2(I))*0.5
      C1(I)=FX1+S1(I)*TAU
      C2(I)=FX2+S2(I)*TAU
      C3(I)=FX3+S3(I)*TAU
      C4(I)=FX4+S4(I)*TAU
      IF(C1(I).LE.0.0) C1(I)=0.0
      IF(C2(I).LE.0.0) C2(I)=0.0
      IF(C3(I).LE.0.0) C3(I)=0.0
```

```
      IF(C4(I).LE.0.0) C4(I)=0.0
   20 CONTINUE
      CALL INTG1(1,PH,DPH,DELT)
      RETURN
  100 FORMAT(1H1,///1H ,20('*'),' ERROR IN SEGMENT IDENTIFICATION NUMBER
     C, CHECK LG(',I2,') ',20('*'))
      END

C-------------------------------------------------------------------C
C                                                                   C
C     SUBROUTINE INTG.                                              C
C     IN THIS SUBROUTINE THE DERIVATIVES OF THE SYSTEM              C
C     VARIABLES WILL BE INTEGRATED USING EULER INTEGRATION METHOD   C
C     PARAMETERS:                                                   C
C          I - INDEX (FOR FUTURE USE)                               C
C          Y - VARIABLE VALUE TO BE INTEGRATED                      C
C          DY - DERIVATIVE OF VARIABLE                              C
C          DT - DELT - TIME INCREMENT                               C
C                                                                   C
C-------------------------------------------------------------------C

      SUBROUTINE INTG1(I,Y,DY,DT)
C
      Y=Y+DY*DT
      RETURN
      END

C-------------------------------------------------------------------C
C                                                                   C
C     SUBROUTINE PRIT.                                              C
C     IN THIS SUBROUTINE THE RESULTS ARE BEING PRINTED              C
C     PERAMETER IPZ =                                               C
C                        1 PRINT INITIAL CONDITIONS                 C
C                        2 PRINT A LINE OF SELECTED RESULTS EVERY   C
C                          JTP TIME STEPS                           C
C                        3 PRINT FINAL MAP                          C
C                                                                   C
C-------------------------------------------------------------------C

      SUBROUTINE PRIT(IPZ)
C**** THIS ROUTINE WILL PRINT CONCENTRATION AT ALL SEGMENTS AT TIME T.
      COMMON /BLK/ L,A,M,C1,C2,C3,C4,LG,WS,WCT,WT1,WT2,WT3,WT4,WEX,TEMP,
     C FINTIM,RONA,DTMIN,DTMAX,S1,S2,S3,S4,JT,KS,TPR,IQ,ICT,W,JCT,
     C WR,WA,WX,WB,WC,WD,WE,Q,TQ,TX,QS,PDIS,PH,PA,K1,K2,K3,K4,R1,R2,R3,
     C WHCT,WHPU,TPLEN,VPLEN,IC,TPL,CHNA,RR1,QX,QXT,QHT,C1SAT,BETA,
     C ALFA,TMM,NPICT,NGRAF,NVECT,NAME,IPI,NUDET,NODE,NTYPE,
     C TLAG,CDET,TDLE,C3SAT,PDEL,FIGTTL,PTDL,KH
      COMMON /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4,PRT5
      COMMON /DUB/ TIME,DELT,DC1,DC2,DC3,DC4,ABSC
      REAL*4 L(50),A(50),M(50),C1(50),C2(50),C3(50),C4(50),W(50)
      REAL*4 S1(50),S2(50),S3(50),S4(50),Q(8),TQ(8),TX(8),QS(50)
      REAL*4 K1,K2,K3,K4,KS,TITLE(18),TLAG(7),CDET(7),TDLE(7)
      REAL*8 DC1(50),DC2(50),DC3(50),DC4(50),TIME,DELT,ABSC(4,10)
```

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```
      LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
      DIMENSION LG(50),IQ(8),IC(8),ICT(8),NGRAF(10),NVECT(10,5),
     C NAME(10,15),IPI(50),NODE(7),NTYPE(7),FIGTTL(15,10)
      DIMENSION CHX(10)
      DATA JPR,JTP,JTI/1,0,0/
      TIM=TIME
      GOTO (10,20,30), IPZ
   10 PRINT 300,TITLE
      PRINT 130
      PRINT 140, (I,LG(I),L(I),A(I),M(I),W(I),QS(I),I=1,50)
      PRINT 300,TITLE
      PRINT 100
   22 PRINT 110 ,TIME,JT,FINTIM,DELT,DTMIN,DTMAX,TPR,TPL
      GOTO 21
   30 PRINT 300,TITLE
      PRINT 120
      GOTO 22
   20 IF(ABS(TIM-JPR*TPR).GT.DELT*0.3) GOTO 90
      JPR=JPR+1
      PRINT 170,TIME,JT
   21 PRINT 180,PH,CHNA,WHPU,WHCT,RR1
      PRINT 190
      PRINT 200,(I,LG(I),DC1(I),DC2(I),DC3(I),DC4(I),S1(I),S2(I),S3(I),S
     C4(I),C1(I),  C2(I),C3(I),C4(I),I=1,50)
   25 PRINT 300,TITLE
      IF(IPZ.EQ.3) GOTO 99
      PRINT 230, (ICT(I),I=1,8)
      JTP=0
      JTI=0
   90 JTI=JTI+1
      IF(JTI.LT.JCT) GOTO 99
      JTI=0
      JTP=JTP+1
      DO 91 I=1,8
   91 CHX(I)=(0.5*C1(ICT(I))+C4(ICT(I)))*2.0166/(453.6*1E-6)
      PRINT 220,JT,TIME,PH,QX,QXT,QHT,ALFA,(CDET(I),I=1,4),(CHX(I),I=2,8
     C )
      IF(JTP.GT.50) GOTO 25
   99 RETURN
  100 FORMAT(' *** INITIAL CONDITIONS ***'//)
  110 FORMAT(' TIME      =',F10.2,'  JT      =',I10,'  FINTIM =',F10.2,
     C  '  DELT   =',F10.4,'  DTMIN  =',F10.5,'  DTMAX  =',F10.4/
     C  ' TPR       =',F10.2,'  TPL     =',F10.2)
  120 FORMAT(' *** SIMULATION TERMINATED ***'/)
  130 FORMAT('   SEGM  TYPE',7X,'SEGMENT PARAMETERS'/
     C 10X,' LENGHT      CROSS-AREA    MASS         FLOW     LEAK(MOL/SEC'/)
  140 FORMAT(I3,2H *,I3,2X,1P5E11.3)
  190 FORMAT(1H0,' SEGM  TYPE',7X,'SEGMENT DERIVATIVES MOL-SEC-LBS',18X,
     C'SOURCE IN (MOL/SEC)',19X,'CONCENTRATION IN (MOL/LIB)'/
     C  10X,'  DC1         DC2        DC3        DC4        S1-NAH    S2-NAOH
     C     S3-NA2O      S4-H2    C1-NAH     C2-NAOH  C3-NA2O   C4-H2'/)
  200 FORMAT(I3,2H *,I3,2X,1P12E10.3)
  170 FORMAT(1H1,' SOURCES AND CONCENTRATIONS FOR TIME=',F7.2,' SEC',
```

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```
     C ' AT ',I5,'-TH TIME STEP')
 180 FORMAT(' HYDROGEN PARTIAL PRESSURE IN COVER'
     C ,' GAS PH=',F10.3,' MM-HG',10X,'SIEVERTS EQUILIBRIUM H2 IN NA CHN
     CA=',E12.4,' (MOL/LB)'/' H2 LEAKING FROM THE PUMP TO '
     C ,'COVER WHPU= ',E12.4,' MOLS',11X,'H2 TO GAS PLENUM IN',
     C ' CCTL VESEL WHCT=',E11.4,' MOL'/' HYDRID DISSOCIATION RATE RR1='
     C ,11X,E12.4,' SEC-1')
 210 FORMAT (10E12.4)
 220 FORMAT(1X,I5,F6.1,F7.4,15F7.3)
 230 FORMAT(' STEP  TIME PH-(MM) H2O-LK TOT LK TOT H2  ALFA  DTCTR1 DTC
     CTR2 DTCTR3 DTCTR4 TOTAL HYDROGEN CONCENTRATION IN (PPM) AT NODE #
     C :',/42X,I2,33X,6(I2,5X),I2)
 300 FORMAT(1H1,20('*'),2X,18A4,2X,20('*'))
      END

C-----------------------------------------------------------------------C
C                                                                       C
C     SUBROUTINE SPLOT.                                                 C
C     IN THIS ROUTINE DATA WILL BE STORED IN FILE 20 EVERY TPL          C
C     PARAMETER IIP =                                                   C
C                         1 , INITIAL ENTRY                             C
C                         2 , TIME STEP ENTRY, VALUES STORED            C
C                         3 , FINAL ENTRY, VALUES RETREIVED AND         C
C                                PRINT-PLOTTED                          C
C                                                                       C
C-----------------------------------------------------------------------C

      SUBROUTINE SPLOT(IIP)
C**** THIS SUBROUTINE WILL STORE DATA OF SPECIFIED CONCENTRATION POINTS
C**** AT PREDETERMAINED SEGMENTS TO BE PLOTTED LATER ON THE TEXTRONIC
C**** TERMINAL. DATA ARE WRITEN INTO CCTX.DATA=FT20.F001
      COMMON /BLK/ L,A,M,C1,C2,C3,C4,LG,WS,WCT,WT1,WT2,WT3,WT4,WEX,TEMP,
     C FINTIM,RONA,DTMIN,DTMAX,S1,S2,S3,S4,JT,KS,TPR,IQ,ICT,W,JCT,
     C WR,WA,WX,WB,WC,WD,WE,Q,TQ,TX,QS,PDIS,PH,PA,K1,K2,K3,K4,R1,R2,R3,
     C WHCT,WHPU,TPLEN,VPLEN,IC,TPL,CHNA,RR1,QX,QXT,QHT,C1SAT,BETA,
     C ALFA,TMM,NPICT,NGRAF,NVECT,NAME,IPI,NUDET,NODE,NTYPE,
     C TLAG,CDET,TDLE,C3SAT,PDEL,FIGTTL,PTDL,KH
      COMMON /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4,PRT5
      COMMON /DUB/ TIME,DELT,DC1,DC2,DC3,DC4,ABSC
      REAL*4 L(50),A(50),M(50),C1(50),C2(50),C3(50),C4(50),W(50)
      REAL*4 S1(50),S2(50),S3(50),S4(50),Q(8),TQ(8),TX(8),QS(50)
      REAL*4 K1,K2,K3,K4,KS,TITLE(18),TLAG(7),CDET(7),TDLE(7)
      REAL*8 DC1(50),DC2(50),DC3(50),DC4(50),TIME,DELT,ABSC(4,10)
      LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
      DIMENSION LG(50),IQ(8),IC(8),ICT(8),NGRAF(10),NVECT(10,5),
     C NAME(10,15),IPI(50),NODE(7),NTYPE(7),FIGTTL(15,10)
      DIMENSION CCC(10),VMX(55),VECT(55),LINE(121),IL(5),ILX(5),
     C  DYD(6),IP(5),YZ(4),YW(4),VEPL(250,5),VTIM(250)
      LOGICAL L1
      DATA JPL/0/,VMX/55*0./,YZ/0.15,0.2,0.5,1.0/,YW/3.,4.,5.,5./
      DATA IPO/' '/,ICR/'I'/,IP/'.','*','+',',','#'/,IDLR/'$'/
      TIM=TIME
      GOTO (10,20,30), IIP
```

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```
   10 REWIND 20
   20 IF(ABS(TIM-JPL*TPL).GT.DELT*0.3) GOTO 99
      JPL=JPL+1
   21 DO 5 I=1,8
    5 CCC(I)=(0.5*C1(IC(I))+C4(IC(I)))*2.0166E+6/453.6
      WHPT=WHPU+WHCT
      EXSC=CHNA/(0.5*C1(27)+C4(27))
      VECT(1)=TIM
      VECT(2)=ALFA
      VECT(3)=QX
      VECT(4)=QXT
      VECT(5)=WHPT
      VECT(6)=EXSC
      VECT(7)=PH
      VECT(8)=QHT
      DO 11 I=1,NUDET
   11 VECT(8+I)=CDET(I)
      I=0
      DO 12 I1=16,51,5
      I=I+1
      VECT(I1)=C1(IC(I))
      VECT(I1+1)=C2(IC(I))
      VECT(I1+2)=C3(IC(I))
      VECT(I1+3)=C4(IC(I))
      VECT(I1+4)=CCC(I)
   12 CONTINUE
      WRITE (20) VECT
      DO 14 I=1,55
   14 IF(VECT(I).GT.VMX(I)) VMX(I)=VECT(I)
      GOTO 99
   30 PRINT 100,JPL
      DO 26 N=1,NUDET
      NN=8+N
   26 PRINT 170,NN,N,NTYPE(N),NODE(N)
      I=0
      DO 25 JPJ=16,51,5
      JPM=JPJ+4
      I=I+1
      PRINT 110,(J1,IC(1),J1=JPJ,JPM)
   25 CONTINUE
      PRINT 120, (I,VMX(I),I=1,55)
C
C**** THIS SECTION PREPARES PRINTPLOT
      DO 70 NP=1,NPICT
      NG=NGRAF(NP)
C**** FIND MAXIMUM VALUE IN PRESENT PICTURE
      YS=0.
      DO 60 N=1,NG
      ILX(I)=0
      N1=NVECT(NP,N)
      IF(VMX(N1).GT.YS) YS=VMX(N1)
   60 CONTINUE
C**** SELECT SCALE FOR GRAPHIC PICTURE
```

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```
      DO 61 I=1,11
      YM=10.**(I-6)
      DO 63 II=1,4
      YSC=YZ(II)*YM
      DYS=YSC/YW(II)
      IF(YS.LT.YSC)GOTO 62
   63 CONTINUE
   61 CONTINUE
   62 IDY=DYS/YSC*120.+0.001
      PRINT 130,TITLE
      PRINT 180,(FIGTTL(I,NP),I=1,15)
      PRINT 140,NP,NG
      DO 64 N=1,NG
      N1=NVECT(NP,N)
      PRINT 150,N,N1,IP(N),VMX(N1),(NAME(NP,3*(N-1)+J),J=1,3)
   64 CONTINUE
      PRINT 220,(ABSC(I,NP),I=1,4)
C**** PRINT SCALES
      IS=0
      DO 65 I=1,121,IDY
      DYD(IS+1)=DYS*IS
      IS=IS+1
   65 CONTINUE
      LAB=IDY/10.-1
      GOTO (66,67,68), LAB
   66 PRINT 166,(DYD(I),I=1,IS)
      GOTO 69
   67 PRINT 167,(DYD(I),I=1,IS)
      GOTO 69
   68 PRINT 168,(DYD(I),I=1,IS)
   69 REWIND 20
C**** SET PROPER SIGNAL CHARACTERS INTO LINE
      PRINT 210
      DO 50 J=1,JPL
      READ (20) VECT
      VTIM(J)=VECT(1)
      DO 52 N=1,NG
      N1=NVECT(NP,N)
      VEPL(J,N)=VECT(N1)
      IL(N)=VECT(N1)/YSC*120
      IF(IL(N).LE.0) IL(N)=1
   52 CONTINUE
      DO 54 I=2,120
   54 LINE(I)=IPO
      DO 56 I=1,121,IDY
   56 LINE(I)=ICR
      IF(VECT(3).EQ.0.0) GOTO 53
      DO 73 I=2,8
   73 LINE(I)=IDLR
   53 DO 51 N=1,NG
      IF(NG.NE.1) GOTO 59
      IF(IL(N).EQ.ILX(N)) GOTO 59
      IF(IL(N).LT.ILX(N)) GOTO 57
```

```
      I1=ILX(N)+1
      I2=IL(N)
      GOTO 58
   57 I1=IL(N)
      I2=ILX(N)-1
   58 DO 55 I=I1,I2
   55 LINE(I)=IP(N)
   59 LINE(IL(N))=IP(N)
      ILX(N)=IL(N)
   51 CONTINUE
      PRINT 200,VECT(1),LINE
   50 CONTINUE
      PRINT 211
      IF(PRT5) CALL PLOTER(JPL,NP,NG,VEPL,VTIM,YS,TIM,YSC,DYS,FIGTTL,
     C  ABSC,NAME,NPICT)
   70 CONTINUE
   99 RETURN
  100 FORMAT (1H0,3(/),1H ,20('*'),I6,' RECORDS ARE WRITEN FOR PLOTTING
     C  ',20('*')//10X,'#01  TIME (SEC).'/10X,'#02  ALFA'/10X,
     C '#03  LEAK H2O (MOL/SEC).'/10X,'#04  TOTAL H2O LEAK (MOL)'/
     C 10X,'#05  H2 FLOW TO PLENUM (MOL/SEC)'/10X,
     C '#06  EXCESS H2 IN COVER GAS OVER NODE 27'/10X,
     C '#07  H2 PARTIAL PRESSURE IN COVER GAS (MM-HG)'/10X,
     C '#08  TOTAL HYDROGEN IN CCTL SYSTEM (MOL)'/)
  110 FORMAT(' CONC (MOL/LB)  #',I2,'  C1(',I2,')-NAH   #',I2,
     C  '  C2(',I2,')-NAOH   #',I2,'  C3(',I2,')-NA2O   #',I2,'  C4('
     C  ,I2,')-H2       #',I2,'  DETECTABLE H IN NODE ',I2,' (PPM)')
  120 FORMAT('0THE APPROPRIATE MAXIMUM VALUES OF THE VARIABLES ARE'/
     C 11(11X,5(4X,'#',I2,1PE12.3)/))
  130 FORMAT(1H1,20('*'),18A4,20('*'))
  140 FORMAT(' PICTURE #',I2,' HAS ',I2,' GRAPHS')
  150 FORMAT(' GRAPH #',I2,' IS VECT(',I2,'), SYMBOL IS ',A1,'  MAX=',
     C E11.4,3X,3A4)
  166 FORMAT(1X,F10.1,5(14X,1PE10.3))
  167 FORMAT(1X,F10.1,4(20X,1PE10.3))
  168 FORMAT(1X,F10.1,3(30X,1PE10.3))
  170 FORMAT(10X,'#',I2,'  RESPONSE OF DETECTOR ',I2,' IN (PPM). TYPE'
     C ,'IS ',I1,' CONNECTED TO NODE ',I2)
  180 FORMAT(40X,15A4)
  200 FORMAT(1X,F7.2,3X,121A1)
  210 FORMAT(4X,'TIME',3X,121('_'))
  211 FORMAT(11X,121('-'))
  220 FORMAT(1H0,40X,4A8)
      END
C---------------------------------------------------------------------C
C     SUBROUTINE PIPE.                                                C
C     IN THIS ROUTINE PIPE FUNCTION ARE STORED. PIPE LAG FUNCTIONS    C
C     ARE THEN CALCULATED BY LINEAR INTERPOLATION BETWEE THE TWO      C
C     VALUES CLOSEST TO TIME TAU.                                     C
C     THE PARAMETERS ARE :                                            C
C          TIME - CURRENT SIMULATION TIME                             C
```

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```
C           DELT - TIME STEP INCREMENT                                    C
C           TAU - TIME LAG FOR WHICH PIPE FUNCTION IS REQUIRED            C
C           IP   PIPE FUNCTION NUMBER (1-9)                               C
C           FX1,FX2,FX3,FX4 - CACULATED PIPE FUNCTIONS FOR TIME-TAU       C
C                     OR UPDATE VALUES IF TAU=0.0                         C
C                                                                         C
C-------------------------------------------------------------------------C

      SUBROUTINE PIPE(TIME,DELT,TAU,IP,FX1,FX2,FX3,FX4)
      COMMON /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4
      LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
       DIMENSION F(10,4,100),CONCN(4),T(100),TITLE(18)
       LOGICAL L1,L2
       DATA L1,L2/2*.FALSE./,CONCN/'NAH ','NAOH','NA2O','H2  '/
      IF(L1) GOTO 2
      L1=.TRUE.
      DO 4 I=1,100
      T(I)=(I-100)*DELT*10.0
      DO 3 IP=1,9
      F(IP,1,I)=FX1
      F(IP,2,I)=FX2
      F(IP,3,I)=FX3
      F(IP,4,I)=FX4
    3 CONTINUE
    4 CONTINUE
      GOTO 99
    2 IF(L2) GOTO 5
      L2=.TRUE.
      DO 1 I=1,100
      F(10,1,I)=FX1
      F(10,2,I)=FX2
      F(10,3,I)=FX3
      F(10,4;I)=FX4
    1 CONTINUE
      GOTO 91
C**** UPDATE THE PIPE FUNCTIONS FOR PRESENT TIME
    5 IF(TAU.NE.0.0) GOTO 10
      IF(TIME.EQ.T(100)) GOTO 22
      DO 8 I=1,99
    8 T(I)=T(I+1)
      T(100)=TIME
   22 DO 20 K=1,4
      DO 20 I=1,99
   20 F(IP,K,I)=F(IP,K,I+1)
      F(IP,1,100)=FX1
      F(IP,2,100)=FX2
      F(IP,3,100)=FX3
      F(IP,4,100)=FX4
      GOTO 99
C**** SEARCH FOR PIPE OUTPUT CONCENTRATION AT PRESENT TIME (TIME-TAU)
   10 J=0
      DEL=TIME-T(100)
      IF(TAU.GT.DEL) GOTO 15
```

CCTL.FORT

```
      J=100
      TDEL=DEL-TAU
      IF(ABS(TDEL).LT.0.001) GOTO 13
      DTD=(T(100)-T(99)+TDEL)/(T(100)-T(99))
      DP=DTD
      DM=1.-DTD
      GOTO 12
   15 TDEL=TIME-TAU
      IF(TDEL.LT.T(1)) GOTO 90
    9 J=J+1
      IF(ABS(T(J)-TDEL).LE.0.001) GOTO 13
      IF(T(J).GE.TDEL) GOTO 11
      GOTO 9
   11 DT=T(J)-T(J-1)
      DTD=T(J)-TDEL
      DP=DTD/DT
      DM=1.-DP
   12 FX1=F(IP,1,J-1)*DM+F(IP,1,J)*DP
      IF(IP.EQ.10) GOTO 99
      FX2=F(IP,2,J-1)*DM+F(IP,2,J)*DP
      FX3=F(IP,3,J-1)*DM+F(IP,3,J)*DP
      FX4=F(IP,4,J-1)*DM+F(IP,4,J)*DP
      GOTO 99
   13 FX1=F(IP,1,J)
      FX2=F(IP,2,J)
      FX3=F(IP,3,J)
      FX4=F(IP,4,J)
      GOTO 99
C**** ERROR OUTPUT
   91 IF(PRT1) GOTO 92
      GOTO 99
   90 PRINT 100,TIME,TAU,IP,T(1)
   92 PRINT 110,((CONCN(K),J,T(J),(F(IP,K,J),IP=1,10),J=1,100),K=1,4)
   99 RETURN
  100 FORMAT(1H1,1H ,125('*')/' ERROR AT TIME=',F10.4/
     C ' PIPE DELAY IS TAU=',F10.4,'PIPE IS SEGMENT NUMBER ',I3/
     C ' FIRST VALUE IN PIPE SEGMENT IS GIVEN AT TIME=',F10.4/1H ,132('*
     C'))
  110 FORMAT ('1'/' PIPE FUNCTIONS'/' MAT INDX   TIME     SECT=1',10X,'3
     C',10X,'23',10X,'27',9X,'29',9X,'6',9X,'25',9X,'NU',9X,'NU',6X,'RR1
     C,PH,CHNA'/(1X,A4,I5,0PF12.5,1P10E11.3))
  200 FORMAT (1X,3E12.4,2I6,4E12.4)
      END

C-----------------------------------------------------------------------C
C                                                                       C
C     SUBROUTINE DETECT.                                                C
C     IN THIS ROUTINE THE DIECTOR RESPONSE IS COMPUTED. THREE           C
C     TYPES ARE ACCOUNTED FOR: HYDROGEN IN NA, HYDROGEN IN COVER        C
C     GAS, AND OXYGEN. THE RESPONSE IS GIVEN IN PPM WEIGHT FOR THE      C
C     SOLUTION AND PPM-VOLUME FOR THE COVER GAS.                        C
C                                                                       C
C-----------------------------------------------------------------------C
```

CCTL.FORT

```
      SUBROUTINE DETECT
C
      COMMON /BLK/ L,A,M,C1,C2,C3,C4,LG,WS,WCT,WT1,WT2,WT3,WT4,WEX,TEMP,
     C FINTIM,RONA,DTMIN,DTMAX,S1,S2,S3,S4,JT,KS,TPR,IQ,ICT,W,JCT,
     C WR,WA,WX,WB,WC,WD,WE,Q,TQ,TX,QS,PDIS,PH,PA,K1,K2,K3,K4,R1,R2,R3,
     C WHCT,WHPU,TPLEN,VPLEN,IC,TPL,CHNA,RR1,QX,QXT,QHT,C1SAT,BETA,
     C ALFA,TMM,NPICT,NGRAF,NVECT,NAME,IPI,NUDET,NODE,NTYPE,
     C TLAG,CDET,TDLE,C3SAT,PDEL,FIGTTL,PTDL,KH
      COMMON /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4,PRT5
      COMMON /DUB/ TIME,DELT,DC1,DC2,DC3,DC4,ABSC
      REAL*4 L(50),A(50),M(50),C1(50),C2(50),C3(50),C4(50),W(50)
      REAL*4 S1(50),S2(50),S3(50),S4(50),Q(8),TQ(8),TX(8),QS(50)
      REAL*4 K1,K2,K3,K4,KS,TITLE(18),TLAG(7),CDET(7),TDLE(7)
      REAL*8 DC1(50),DC2(50),DC3(50),DC4(50),TIME,DELT,ABSC(4,10)
      LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
      DIMENSION LG(50),IQ(8),IC(8),ICT(8),NGRAF(10),NVECT(10,5),
     C NAME(10,15),IPI(50),NODE(7),NTYPE(7),FIGTTL(15,10)
      TIM=TIME
      DEL=DELT
       DO 10 N=1,NUDET
      LTP=NTYPE(N)
      IF(LTP.EQ.3) GOTO 15
      N1=NODE(N)
      IP=IPI(N1)
      TAU=M(N1)/W(N1)+TLAG(N)
      IF(TAU.GT.TIME) TAU=TIME
      CALL PIPE(TIM,DEL,TAU,IP,FX1,FX2,FX3,FX4)
      CALL PIPE(TIM,DEL,TAU,10,X1,X2,X3,X4)
      SD1=-(X1+RR1)/2.*FX1
      SD2=-R3*FX2
      SD3=-SD2
      SD4=-(SD1+SD2)*0.5
      CD1=(FX1+SD1*TAU)*1.0083E+6/453.6
      CD2=(FX2+SD2*TAU)
      CD3=(FX3+SD3*TAU)*16.0E+6/453.6
      CD4=(FX4+SD4*TAU)*2.0166E+6/453.6
      GOTO 19
   15 CD4=PH*1.0E+6/(PH+PA)
   19 GOTO (20,30,40), LTP
C**** HYDROGEN DETECTOR
   20 DPP=(CD1+CD4-CDET(N))/TDLE(N)
      CALL INTG1(N,CDET(N),DPP,DELT)
      GOTO 10
C**** OXIGEN DETECTOR
   30 DPP=(CD3-CDET(N))/TDLE(N)
      CALL INTG1(N,CDET(N),DPP,DELT)
       GOTO 10
C**** HYDROGEN GAS DETECTOR
   40 DPP=(CD4-CDET(N))/TDLE(N)
      CALL INTG1(N,CDET(N),DPP,DELT)
C**** OTHER TYPES OF DETECTORS
   10 CONTINUE
```

CCTL.FORT

```
   99 RETURN
      END
      SUBROUTINE PLOTER(J,NP,NN,X,T,YMX,TF,YSC,DYS,FIGTTL,ABSI,NAME,
     C NPICT)
C-----------------------------------------------------------------------C
C                                                                       C
C       SUBROUTINE PLOTER                                               C
C       IN THIS ROTINE A FIGURE ON THE CALCOMP PLOTTER IS PREPARED      C
C       PARAMRTERS ARE:                                                 C
C                      J - NUMBER OF POINTS IN VECTOR TO BE DRAWN       C
C                      NP - FIGURE NUMBER                               C
C                      NN - NUMBER OF CURVES IN FIGURE                  C
C                      X - VECTOR INCLUDING THE CURVES                  C
C                      T - THE TIME VECTOR                              C
C                      YMX - MAXIMUM VALUE OF VECTORS TO BE DRAVN       C
C                      TF - TOTAL/FINAL TIME OF THE PLOT                C
C                      YSC - SCALE OF THE ABSCISAE                      C
C                      HEAD - FIGURE HEADING                            C
C                      ABSC - ABSCISAE HEADING                          C
C                      NAME - NAME OF CURVES - LEGEND                   C
C                                                                       C
C-----------------------------------------------------------------------C
      DIMENSION X(250,5),T(250),HEAD(15),NAMS(3),TL(2),T1(250)
     C ,Z(250),NAME(10,15),IPAK(200),FIGTTL(15,10)
      REAL*8 ABSI(4,10),ABSC(4)
      DATA KP/0/
      TF5=TF/5.
      TL(1)=TF/25.
      TL(2)=TF5-TL(1)
      TI=0.
      TX=TF
      J1=1
      J2=J
C
C**** INSERT ALL TITLES IN PROPER VECTORS FOR PLOTTER DRAWING
      DO 1 I=1,15
    1 HEAD(I)=FIGITL(I,NP)
      DO 2 I=1,4
    2 ABSC(I)=ABSI(I,NP)
      IF(NP.GT.1) GOTO 12
      CALL STRTPL
   12 KP=KP+1
      CALL BGNPL(KP)
      DO 17 N=1,NN
      DO 16 K1=1,3
      N3=(N-1)*3+K1
   16 NAMS(K1)=NAME(NP,N3)
      CALL LINES(NAMS,IPAK,N)
 17   CONTINUE
       CALL TITLE(1H ,-1,'TIME(SEC)',9,ABSC,32,8.,6.)
      CALL HEADIN(HEAD,100,3,1)
      CALL GRAF(TI,TF5,TX,0.0,DYS,YSC)
      UY=5.3-0.5*NN
```

CCTL.FORT

```
      CALL BLNK1(5.0,7.8,UY,5.8,2)
       CALL GRID(1,1)
       CALL FRAME
      DO 40 N=1,NN
      DO 10 I=1,J
      Z(I)=X(I,N)
 10   CONTINUE
      I=0
      DO 42 J3=J1,J2
      I=I+1
      Z(I)=Z(J3)
      T1(I)=T(J3)
   42 CONTINUE
      NM=2*N+20
       CALL CURVE(T1,Z,J,NM)
 40   CONTINUE
      CALL RESET('BLNK1')
      UY2=UY+0.2
      CALL LEGEND(IPAK,NN,5.2,UY2)
       CALL ENDPL(KP)
      IF(KP.LT.NPICT) GOTO 99
       CALL DONEPL
   99 RETURN
       END
C-------------------------------------------------------------------C
C                                                                   C
C        BLOCK DATA                                                 C
C        IN THIS ROUTINE DEFAULT AND OTHER INITIAL DATA ARE PLACED  C
C                                                                   C
C ------------------------------------------------------------------C
C
       BLOCK DATA
      COMMON /BLK/ L,A,M,C1,C2,C3,C4,LG,WS,WCT,WT1,WT2,WT3,WT4,WEX,TEMP,
     C FINTIM,RONA,DTMIN,DTMAX,S1,S2,S3,S4,JT,KS,TPR,IQ,ICT,W,JCT,
     C WR,WA,WX,WB,WC,WD,WE,Q,TQ,TX,QS,PDIS,PH,PA,K1,K2,K3,K4,R1,R2,R3,
     C WHCT,WHPU,TPLEN,VPLEN,IC,TPL,CHNA,RR1,QX,QXT,QHT,C1SAT,BETA,
     C ALFA,TMM,NPICT,NGRAF,NVECT,NAME,IPI,NUDET,NODE,NTYPE,
     C TLAG,CDET,TDLE,C3SAT,PDEL,FIGTTL,PTDL,KH
      COMMUN /LOG/ TITLE,PRT1,PRT2,PRT3,PRT4,PRT5
      COMMON /DUB/ TIME,DELT,DC1,DC2,DC3,DC4,ABSC
      REAL*4 L(50),A(50),M(50),C1(50),C2(50),C3(50),C4(50),W(50)
      REAL*4 S1(50),S2(50),S3(50),S4(50),Q(8),TQ(8),TX(8),QS(50)
      REAL*4 K1,K2,K3,K4,KS,TITLE(18),TLAG(7),CDET(7),TDLE(7)
      REAL*8 DC1(50),DC2(50),DC3(50),DC4(50),TIME,DELT,ABSC(4,10)
      LOGICAL PRT1,PRT2,PRT3,PRT4,PRT5
      DIMENSION LG(50),IQ(8),IC(8),ICT(8),NGRAF(10),NVECT(10,5),
     C NAME(10,15),IPI(50),NODE(7),NTYPE(7),FIGTTL(15,10)
C**      DEFAULT VALUES
      DATA BETA/0.001/,
     C     C1SAT/1.418E-6/,
     C     CDET/7*0.0/,
     C     DTMAX/1.0/,
     C     DTMIN/0.005/,
```

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```
C      JT/0/
 DATA PDEL/0.01/,
C      PRT1,PRT2,PRT3,PRT4,PRT5/5*.FALSE./,
C      Q/8*0.0/,
C      TIME/0.0/,
C      TQ/8*10.0/,
C      TX/8*80.0/,
C      WT1,WT2,WT3,WT4/4*0.0/
 END
```

APPENDIX D

The Input Data; How to Run CCTL-DYSP

1. Title

The first line is a title of 72 characters and will be printed at the top of each output page.

2. INLIST

The data in this section are inserted in a free NAMELIST format. All the data are single variables or vectors, and should be placed between

Δ&INLISTΔ* as a first card, and

Δ&END as the last card.

All the vectors can be input as whole vectors

$x = a_1, a_2, \ldots, a_{50},$

or single members; e.g.,

$x(5) = a_5; x(7) = a_7.$

In the first case, all elements of the vectors have to be supplied. (The variables can be input in any order.)

L(50) = CCTL segment length, in feet;

LG(50) = a logic variable, which determines the type of segment

= 0 the segment is excluded from the simulation

= 1 plenum mixing segment

= 2 pipe segment

= 3 plenum mixing with cover gas

= 4 multiple-entry mixing plenum

= 5 multiple-entry mixing plenum with cover gas;

A(50) = segment cross section area, in ft^2;

C1(50) = NaH concentration, in ppm;

C2(50) = NaOH concentration, in ppm;

C3(50) = Na_2O concentration, in ppm;

C4(50) = hydrogen concentration, in ppm.

---

*Δ indicates a space.

Only the first value for each of C1(1), C2(1), and C3(1), and C4(1) has to be input to calculate the initial distribution in the system.

Q(8) = leak at the Ith injection point, in lb/sec;

QT(100) = normalized time-dependent leak function;

TQ(8) = time, in seconds, when the leak at node I starts;

TQT(100) = time table at which normalized leak-function values are given;

TX(8) = time (in seconds) when the leak at node I is terminated;

IQ(8) = CCTL node number at which leak might occur, i.e., nodes at which nozzles were installed;

IC(8) = node numbers for which detailed concentration information will be stored in CCTX.DATA file for future plotting; the nodal information stored includes C1, C2, C3, C4, and detectable hydrogen concentrations, in ppm;

ICT(8) = nodes for which hydrogen concentration will be printed every JCT time steps; for ICT(1), however, ALFA will be printed.

3. PARM

The data in this section are system parameters and are inserted in a free NAMELIST format. These are scalar variables. If they will not be included in the input stream, the default value (usually 0) will be assumed by the program. The parameters should be placed between

Δ&PARMΔ as the first card, and

Δ&END as the last card, and should be separated by commas.

TEMP = sodium temperature, in °F;

WS = total sodium flow, in gal/min;

WCT = flow through the cold trap, in gal/min;

WT1 = flow toward the detectors from node 6;

WT2 = to be determined;

WT3 = flow toward the detectors from node 23, in gal/min;

WT4 = flow toward the detectors from node 25, in gal/min;

WEX = sodium leak between nodes 3 and 22, in gal/min;

PDEL = maximum permitted change in node 23 for pipe update;

PTDL = maximum time interval at which pipe is updated;

PRT1 = (Logical) if TRUE, initial pipe-function distribution will be printed;

PRT5 = (Logical) if TRUE, time-dependent results arranged for print-plot also will be plotted on the CALCOMP plotter;

TCLT = Cold-trap temperature;

PH = Hydrogen partial pressure in cover gas, in mm Hg;

PA = Argon partial pressure in cover gas, in mm Hg;

FINTIM = simulation time, in seconds;

DELT = single integration time step, in seconds;

DTMIN = minimum permitted time step, in seconds;

DTMAX = maximum permitted time step, in seconds;

VPLEN = total gas plenum volume, in ft^3;

TPR = printing time interval for complete concentration map, in seconds;

TPL = time intervals at which an entry for plotting is calculated, in seconds;

JCT = number of time steps between two consecutive printings of detectable hydrogen concentration and meter readings (a single line is printed every JCT time steps);

K1 = fraction of water leak to $Na + H_2O \rightarrow NaOH + \frac{1}{2}H_2$, reaction;

K2 = fraction of water leak to $2Na + H_2O \rightarrow NaOH + NaH$, reaction;

K3 = fraction of water leak to $4Na + H_2O \rightarrow 2NaH + Ha_2O$, reaction;

K4 = fraction of water leak to $2Na + H_2O \rightarrow Na_2O + H_2$, reaction;

R1 = rate of hydrogen disengagement from liquid sodium to cover gas, in sec^{-1};

BETA = cold-trap static efficiency;

R3 = rate of NaOH dissociation, in sec^{-1}.

4. DTCTR

This section contains a list of parameters describing the detectors monitoring CCTL. Parameters are inserted in free NAMELIST format and should be placed between

Δ&DTCTRΔ as the first card, and

Δ&END as the last card, and should be separated by commas.

NUDET = number of detectors in present simulation (maximum is 7);

NODE(7) = the node number to which detector is attached;

NTYPE(7) = type of detector

1 = hydrogen detector in sodium

2 = oxygen detector in sodium

3 = hydrogen-gas detector in cover gas;

TDLE(7) = diffusion time constant for the nickel membrane, in seconds;

TLAG(7) = time lag between detector sample line inlet and detector, in seconds.

5. Print-Plot Data

These data will direct the printing of time-dependent plots. If TPRS is true, then graphic output on a CALCOMP plotter also will be generated. The data must be input in the formats described below.

CARD 1 = The first card can be any comment of up to 80 characters.

CARD 2 = NPICT;FORMAT(I2), number of pictures to be printed.

CARD 3 = NGRAF(10);FORMAT(10(I2, 1X)), NPICT numbers each giving the number of curves to be drawn in a picture.

CARD 4-I = NVECT(10):FORMAT(10(I2, 1X))

These numbers from 2 to 55 give the position of the variables to be drawn in the 55-place vector VECT as written in the CCTX.DATA file.

#1: time (sec)

#2: ALFA defined by (C1(I) + C2(I))/average total hydrogen concentration in the loop

#3: water leak (mol/sec)

#4: total water leak (mol)

#5: hydrogen flow to the cover gas (mol/sec)

#6: excess hydrogen in cover gas over node 27 (mm Hg)

#7: hydrogen partial pressure in cover-gas plenum (mm Hg)

#8: total hydrogen in the CCTL system (mol)

#9-15: detector readings (ppm)

#16: NaH concentration in the IC(1)th node (mol/lb)

#17: NaOH concentration in the IC(1)th node (mol/lb)

#18: Na_2O concentration in the IC(1)th node (mol/lb)

#19: hydrogen concentration in the IC(1)th node (mol/lb)

#20: detectable hydrogen concentration in the IC(1)th node (ppm)

#21-25: same as #16-20, but for IC(2)th node

#26-30: same as #16-20, but for IC(3)th node

#31-35: same as #16-20, but for IC(4)th node

#36-40: same as #16-20, but for IC(5)th node

#41-45: same as #16-20, but for IC(6)th node

#46-50: same as #16-20, but for IC(7)th node

#51-55: same as #16-20, but for IC(8)th node

CARD 5-I = NAME(10):FORMAT(5(3A4, 1X)): names to be assigned to each curve; must be terminated by $

CARD 6-I = ABSC(10):FORMAT(4A8): 32 alphameric characters to be printed along the abscissa of the picture

CARD 7-I = FIGTTL(10):FORMAT(15A4): title to be given to the Ith figure can be up to 60 characters and must be terminated by $. Card sequences 4-5-6 are repeated NPICT times.

CARD 8 (A4) = 9999: this is the last card indicating the end of the data input.

A sample input data set is shown below.

6. Sample Input Data Set

```
RUN # 24: CCTLP LEAK DETECTION SIMULATION.(.015LB/SEC AT INJ#4, DUR=5SEC)
 &INLST L=1.,    40.9,    1.,    10.,    1.,    1.,    .2775,    .4171,
      .4021,    .4588,    .7788,    .8546,    .7788,    .7221,    .7221,
      .7788,    .8546,    .7788,    .4588,    .4021,    .4171,    .3889,
      1.,       2.89,     1.0,      2.083,    7.5,      19.0,     .8,
      31.,
      10*1.0,
      28.0,     1.0,      16.0,     16.,      0.0,      0.0,      18.585,
       36.87,   42.67,    42.26,
    A=   1.069,    .09893,   .3395,    .09893,   .2127,    1.49,
      16*0.324,
      .2127,    .09893,   4.03,     6.335,    6.445,    .15255,   .15255,
      .15255,
       10*0.0
      0.00248,   3.276,   0.00248, .1796,   .0,   .0,
       4*0.00248,
    LG= 3, 2, 1, 2, 1, 16*1,4,1, 2, 2*1, 5, 2, 4, 2, 0, 9*0,
        2,  1,  2, 0,  0,  0,  2,  2,  2,  2,
```

```
    C1(1)=75.E-9,
    C2(1)=1.E-9,
    C3(1)=35.E-6,
    C4(1)=1.E-8,
       Q(4)=0.015,
       TX(4)=15.0,
       TQ(4)=10.0,
       IQ=22,  19,  17,  16,  15,  12,  10,  6,
       IC=16,  6,  49,  23,  47,  1,  27,  29,
       ICT=47,  6,  49,  23,  47,  16,  27,  1,
 &END
 &PARM TEMP=900.,WS=800., WCT=4.,WT1=5.,BETA=0.9,WT3=5.0,WEX=1.,
  FINTIM=120.,DELT=0.05,IPR=20.0,  TCLT=240.0,  PDEL=0.10,
  PH=0.1,  PA=800.0,  K1=0.45,  K2=0.2,  K3=0.25,  K4=0.1,  R1=9.625E-6,
    R3=7.5E-5,  VPLEN=40.,  TPL=0.5,  JCT=10,  PRT5=.TRUE.,
 &END
 &DTCTR NUDET=4,
        NODE(1)=49, NODE(2)=49, NODE(3)=47, NODE(4)=27,
        NTYPE(1)=1, NTYPE(2)=2, NTYPE(3)=1, NTYPE(4)=3,
        TLAG(1)=10.0, TLAG(2)=12.0, TLAG(3)=10.0,  TLAG(4)=1.0,
        TDLE(1)=14.0, TDLE(2)=15.0, TDLE(3)=14.0, TDLE(4)=10.0,
 &END
******** DATA FOR PRINT PLOT FOLLOW, LAST CARD MUST BE '9999' ********
04
04,04,05,02
20,35,40,11
AT NODE 16 $,AT NODE 23 $,AT NODE 47 $,AT NODE 27 $
HYDROGEN CONCENTRATION IN (PPM)
HYDROREN TRANSIENT CONCENTRATION RESPONSE TO .075LB LEAK$
36,37,38,39
NAH AT # 23$,NAOH AT #23$,NA20 AT #23$,H2 AT # 23 $
REACTION PRODUCTS CONC. IN (PPM)
CHANGES IN REACTION PRODUCTS IN RESPONSE TO .075 LB LEAK$
09,11,20,45,50
H-DETECTOR1$,H-DETECTOR3$,INJECTOR J4$,PUMP NODE  $,CCTL VESSEL$
HYDROGEN CONCENTRATION IN (PPM)
DETECTOR READINGS RESULTING FROM .075LB LEAK-INJECTOR J4$
10,12
H-DETECTOR2$,0-DETECTOR4$
DETC2 IN (WPPM); DETC4 IN (VPPM)
H-DETECTORS READING IN COVER GAS AND STEAM GENERATOR TOP$
9999
/*
```

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