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COGAP: A Nuclear Power Plant Containment Hydrogen Control System Evaluation Code

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U.S. Nuclear Regulatory
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COGAP: A NUCLEAR POWER PLANT CONTAINMENT HYDROGEN CONTROL SYSTEM EVALUATION CODE

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ABSTRACT

The accounting of containment gas concentration following a loss-of-coolant accident is important in the safety evaluation of hydrogen combustible-gas control systems for nuclear power plants. The COGAP code provides such accounting including the effects of (1) the reaction of zirconium and water; (2) radiolysis of core and sump water; (3) corrosion of zinc, aluminum and copper; (4) recirculation between compartments; (5) hydrogen recombiners; (6) purging; (7) nitrogen addition; and (8) atmospheric steam. Controls are available to determine when options are initiated; for example, the hydrogen recombiner can be started when the hydrogen concentration reaches a user-specified value.

I. INTRODUCTION

Following a loss-of-coolant accident (LOCA), hydrogen gas may accumulate within the containment of a nuclear power plant. The hydrogen could result from (1) metal-water reaction involving the zirconium fuel cladding and the reactor coolant; (2) radiolytic decomposition of water, which will produce oxygen also; and (3) corrosion of construction materials. A potentially hazardous situation could result if there is sufficient oxygen to promote hydrogen burning or detonation. Therefore, calculations must be performed to determine the gas concentrations in the containment and the effect of combustible-gas control systems, that might be used to keep the gas concentrations at acceptable levels, such as recombiners.[1,2] The COGAP

(Combustible Gas Analysis Program) code was written to perform such calculations.

COGAP was written by D. Shum of the Nuclear Regulatory Commission (NRC) where it was referred to as COGAP-II (Ref. 3). COGAP-II was written as a replacement for the orginal COGAP (Ref. 4) used by the NRC for many years to evaluate containment combustible-gas control systems for nuclear power plants. COGAP-II was sent to Los Alamos for review, modification, and public release through the National Energy Software Center in Argonne, Illinois. For convenience, the original name COGAP was retained.

II. DISCUSSION

In this section the various features of COGAP are discussed. Additional insight into the code may be obtained from the Description of Input in Appendix A and the Sample Problems in Appendix B. The discussion that follows will be presented in terms of sources of hydrogen (and sometimes oxygen) and means of controlling the gas concentrations.

A. Hydrogen Sources

1. Oxidation of Core Zirconium. Hydrogen can be generated during a LOCA by the reaction of hot zirconium cladding with the surrounding steam. The equation used for this reaction in COGAP is

$$Zr + 2H_2O = ZrO_2 + 2H_2 + \text{Energy} \quad . \qquad (1)$$

The amount of hydrogen generated is controlled by user specification of the total core zirconium and the per cent of the total that is oxidized. The hydrogen generated is added to compartment number one only as a linear function of time over a user-specified interval after the end of blowdown.

2. Radiolysis of Core and Sump Water. Following a LOCA, hydrogen and oxygen can be produced in the core and sump by radiolysis of water according to the equation

$$H_2O + \text{energy} = H_2 + 0.5 \times O_2 \quad . \qquad (2)$$

The core cooling water radiolysis primarily results from gamma radiation energy produced by the decay of fission fragments in the fuel. The sump water radiolysis results from the energy produced by the decay of fission fragments and heavy elements dissolved in the sump water. The rate of hydrogen and oxygen production due to radiolysis therefore is dependent on the (1) energy production rate as a function of time, (2) fraction of the energy that is absorbed by the water, and (3) the hydrogen yield per unit of energy absorbed (the oxygen yield will be 0.5 of the hydrogen yield). The general format for the calculation of hydrogen production due to radiolysis is described below. The energy production rates, which are based primarily on Ref. 5, are described in greater detail in Appendix C. Reference 6 provides guidance regarding the values of the user-specified parameters that affect the radiolytic hydrogen production. Note that the hydrogen and oxygen due to radiolysis of the core water are deposited initially into compartment one. The hydrogen and oxygen due to radiolysis of the sump water are distributed according to the user-input compartment FRC parameter.

In equation form, the total hydrogen production can be expressed by (see Ref. 2, Sect. 6.2.5, Appendix A)

$$S_H = \frac{P}{B\ N} \frac{G_c E_c + G_s E_s}{100} , \tag{3}$$

where

S_H = hydrogen production rate, H_2 lb_m-mole/s;

P = reactor operating thermal power level, MW_t, a user-specified value;

B = conversion factor, 454 g-mole/lb_m-mole;

N = Avagadro's number, 6.023×10^{23} H_2 molecules/g-mole;

G_c = radiolytic hydrogen yield $[G(H)_c]$ in the core water relative to the energy absorbed, H_2 molecules/100eV, a user-specified value;

E_c = fission product gamma decay energy absorbed by the core water, eV/(s-MW_t), see Eq. (4) below;

G_s = radiolytic hydrogen yield $[G(H)_s]$ in the sump water solution relative to the energy absorbed, H_2 molecules/100eV, a user input value; and

E_s = dissolved radioisotope decay energy absorbed by the sump water, $eV/(s\text{-}MW_t)$, see Eq. (5) below.

The expression G(H) is introduced because of its use in Ref. 6 and Appendix A, COGAP Input Description. The E_c term in Eq. (3) is defined by

$$E_c = (f_\gamma)_c \, H_\gamma \quad , \tag{4}$$

where

$(f_\gamma)_c$ = fraction of total gamma decay energy absorbed by the core water, a user input value, and

H_γ = total fission product gamma decay energy production rate, $eV/(s\text{-}MW_t)$, see Appendix C.

The E_s term in Eq. (3) above is defined by

$$E_s = (f_{\gamma+\beta})_s \, H_{\gamma+\beta} + (f_I)_s \, H_I \quad , \tag{5}$$

where

$(f_{\gamma+\beta})_s$ = fraction of total dissolved-solid decay energy absorbed in the sump water outside the core;

$H_{\gamma+\beta}$ = total dissolved-solid decay energy production rate, $eV/(s\text{-}MW_t)$, see Appendix C;

f_I = fraction of radioiodine decay energy absorbed in the sump water outside the core; and

H_I = radioiodine decay energy production rate, $eV/(s\text{-}MW_t)$, see Appendix C.

3. Reaction of Containment Surfaces. Another possible source of hydrogen could be from metal surfaces exposed to environments containing high-temperature steam, corrosive sprays, fission products, and radioactivity. Such exposure might result in surface corrosion reactions that produce hydrogen. Surfaces composed of aluminum, zinc (including galvanized and

zinc-base painted surfaces), and copper are candidates. Corrosion tests have been performed to determine the behavior of the various metals used in the containment when exposed to emergency core cooling solutions at reference design-base-accident conditions.

The chemical equations used in COGAP to determine the hydrogen generated due to corrosion are

$$\begin{aligned} 2Al + 3H_2O &= 3H_2 + Al_2O_3 \quad , \\ Zn + H_2O &= H_2 + ZnO \quad , \text{ and} \\ Cu + H_2O &= H_2 + CuO \quad . \end{aligned} \tag{6}$$

Thus, 1.5, 1.0, and 1.0 moles of hydrogen are generated for each mole reacted of aluminum, zinc, and copper, respectively. The hydrogen production rates are completely controlled by user input of corrosion surface area, surface thickness, and rate of corrosion.

4. Hydrogen (and Oxygen) Dissolved in Primary Coolant. The moles of hydrogen and oxygen dissolved in the primary coolant during normal operation can be specified by input. These are released in the first time step of the COGAP calculation. Distribution of these gases is controlled by the compartment FRC parameter, which is specified for each compartment by the user. Each compartment's fractional distribution is based on the compartment FRC fraction of the sum of the FRC for all compartments, which is described in the Appendix A input description.

B. Gas Concentration Control Options

Gas concentrations and their control are based on the ideal gas equation

$$P V = N R T \quad , \tag{7}$$

where P is the absolute pressure, V is the volume, N is the total number of gas moles, R is the universal gas constant, and T is the absolute temperature.

As a result, constant volume flow rate fans (that is, constant rotations per unit time) transfer gas moles according to

$$\frac{dN}{dt} = \frac{dV}{dt} \times \frac{P}{R \times T} \quad , \tag{8}$$

where t is time and P and T are the pressure and temperature for the flow source. These equations are used to exercise the control options that are described in the following.

Note that all flow devices in COGAP are assumed to have a constant volumetric flow rate specified by the user in cubic feet per minute (cfm). The resulting molar flow rate is that based on Eq. (8) with the pressure and temperature being those for the flow source. If the flow source is a compartment, its pressure and temperature are used with (a) temperature specified by the initial-temperature and the temperature-variation-with-time inputs and (b) pressure calculated from Eq. (7). The nitrogen addition and purging flow sources are assumed to be at standard ambient conditions of 14.7 psia and 70 ^{o}F. Ambient flow sources at different conditions can be specified by modification of the cfm on the basis of Eq. (8). For example, an ambient flow source at a pressure of 2 × 14.7 psia would require a cfm specification that is twice that for the same volumetric flow rate of an ambient flow source at 14.7 psia.

1. Steam Accounting. To include the presence of steam and its effect on gas concentrations, an input flag must be set. This allows use of the initial compartment relative humidity to specify the initial amount of steam in each compartment; this in turn is based on relative humidity as the ratio of the steam partial pressure to the steam saturation pressure at the compartment initial temperature. The steam partial pressure then is used in Eq. (7) to determine the compartment steam moles. For each time thereafter, the number of steam moles in each compartment is determined from an input table of temperatures vs time. These temperatures are taken to be the steam saturation temperatures in the compartments from which corresponding steam partial pressures are obtained. The compartment steam moles then are determined from Eq. (7). Note that this procedure results in compartment steam mole content

that is independent of mole transfer functions such as recirculation and purging. However, the presence of steam on the concentrations of other gases is accounted for in the transfer calculations. The steam option is not part of the accepted method of licensing analysis and is provided only for the convenience of the user.

2. Purging. A purge for each compartment can be specified. The purge causes the addition of air at standard ambient conditions to the compartment and the removal of compartment contents at the compartment conditions that existed at the beginning of the time step. The addition and removal are calculated by Eq. (8) for the user-specified volumetric flow rate. The purge could cause the compartment gas concentrations to change because the mixtures being exchanged could have different concentrations. In addition, the total gas moles in the compartment could change because the mixtures being exchanged could have different densities.

3. Nitrogen Addition. Nitrogen addition is specified by giving a nonzero value for the volumetric flow rate of the addition. The nitrogen is assumed to be at standard ambient conditions with the moles added determined by Eq. (8). The addition is made for all times. Note that the addition of nitrogen from a source with values of pressure and temperature different from standard conditions could be accomplished by modification of the volumetric flow rate rate based on Eq. (8).

4. Recirculation. The exchange of compartment contents can be specified by identification of the (1) number of recirculation connections, (2) compartments involved in each connections, and (3) volumetric flow rates for each connection.

5. Hydrogen Recombiners. Several recombiner connections can be specified to modify the hydrogen and oxygen concentrations of the compartments at specified volumetric flow rates. The recombined flow can be designated to (1) return to the source compartment, (2) be returned to any other compartment, or (3) not be returned to any compartment. Recombiners can be specified to begin on the basis of (1) an initiation time, (2) the hydrogen concentration in a particular compartment, or (3) the average hydrogen concentration for all compartments.

REFERENCES

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2. "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Office of Nuclear Reactor Regulation, U. S. Nuclear Regulatory Commission report NUREG-75/087, LWR Edition (May 1980).

3. D. H. Shum, "Development of a Code (COGAP-II) for Evaluation of Combustible Gas Concentrations and Mixing in Various Compartments of a Containment," Memo to Z. R. Rosztoczy, Chief, Analysis Branch, Division of Systems Safety, U. S. Nuclear Regulatory Commission (September 16, 1976).

4. J. A. Kudrick, "Computer Program (COGAP) for Predicting Containment Hydrogen and Oxygen Concentrations Following Loss-of-Coolant Accidents," Memo to R. L. Tedesco, Assistant Director for Containment Safety, Atomic Energy Commission, Directorate of Licensing (December 2, 1972).

5. "Residual Decay Energy for Light Water Reactors for Long-Term Cooling," Branch Technical Position APCSB 9-2, attached to Section 9.2.5 of Ref 2.

6. "Control of Combustible Gas Concentrations Following a Loss-of-Coolant Accident," Branch Technical Position CSB 6-2, attached to Section 6.2.5 of Ref. 2.

APPENDIX A

COGAP INPUT DESCRIPTION

This appendix presents the COGAP input format, variable names, dimensional units, and variable descriptions. Note that necessary cards are identified by use of the word REQUIRED in upper case letters. Reference to a card is made by using the referenced card name with the first letter of each card description word in upper case, for example, the note for the Integer control parameters card refers to the Temperature vs Time Sets card. Volumetric flow rates are specified in cfm with the molar flow rates based on the flow source pressure and temperature by Eq. (8). The purge and nitrogen addition flow sources are assumed to be at the standard conditions of 14.7 psia and 70^{o}F. The expression NE means not equal.

TITLE CARD(18A4) - one card REQUIRED

INTEGER CONTROL PARAMETERS (7I5) - one card REQUIRED

Word/Last Column	VARIABLE Units	Description
1/5	ICON(1) none	Specifies use of purge and recombiner where 1 = No purge and no recombiner; 2 = With purge only; 3 = With recombiner only.
2/10	ICON(2) none	Specifies whether there are more cases where 0 = Last or only case; NE 0 = Another set of input follows.
3/15	ICON(3) none	Plot control, which currently is unavailable, where 0 = No plots; NE 0 = With plots.
4/20	ICON(4) none	Number of compartments (1 min, 5 max).
5/25	ICON(5) none	Number of connections between compartments for recirculation (20 max).

6/30	ICON(6) none	Specifies H_2 concentration for comparison with CON(3) (Floating Point Control Parameters card) to decide when purging or recombination should be initiated. 0 = Average of all compartments used; X = Concentration of compartment X used.
7/35	ICON(7) none	Specifies accounting of steam where 0 = No steam accounting; NE 0 = With steam.

Note - Initial steam content for individual compartments is based on the Compartment Specifications card variable RELHUM(i). At later times, compartment steam content is based on its atmosphere being saturated at the temperature specified in the Temperature vs Time Sets card below, see Sec. II.B.1.

FLOATING POINT CONTROL PARAMETERS (5F10.0) - one card REQUIRED

Word/Last Column	VARIABLE Units	Description
1/10	CON(1) days	Problem end time.
2/20	CON(2) days	Purge or recombiner initiation time.
3/30	CON(3) %	H_2 concentration at which purging or recombination begins. CON(2) must be zero to use this option.
4/40	CON(4) days	Recirculation fan(s) start time.
5/50	CON(5) s	Interval after end of blowdown over which H_2 from the Zr-H_2O reaction is linearly released into compartment one.

COMPARTMENT SPECIFICATION (8F9.0) - ICON(4) cards expected

Compartments will be numbered in the order of entering these cards. The i index is the compartment number. Note that the first compartment is special because of the hydrogen release due to the Zr-H_2O reaction and the H_2 and O_2 due to radiolysis of the core water enter only compartment one.

Word/Last Column	VARIABLE Units	Description
1/9	V(i) ft^3	Compartment volume.
2/18	PA(i) lb$_f$/in^2	Total pressure.

3/27	PN(i) lb_f/in^2	Nitrogen partial pressure. If the total pressure is equal to PN(i) and there is steam, the nitrogen partial pressure is reduced to accommodate the steam. A PN(i) of zero results in the nitrogen and oxygen mole fractions of air.
4/36	T(i) ^{o}F	Initial temperature. If there is steam indicated, this temperature will be the initial saturation temperature, see RELHUM(i) that follows.
5/45	RELHUM(i) none	Initial relative humidity, which is PV(i)/PSAT, where PV(i) is the steam partial pressure and PSAT is the steam saturation pressure at T(i).
6/54	HP(i) cfm	Purge volumetric flow rate of ambient air added to this compartment with an equal volumetric flow rate removed from this compartment.
7/63	FRC(i) %	Factor used to determine the distribution of the hydrogen and oxygen (a) dissolved in the reactor coolant water and (b) generated by radiolysis of sump water. The moles added to each compartment are the product of the total moles available and the FRC(i) divided by 100. Thus, the FRC(i) can be interpreted as a percentage if they sum to 100.
8/72	ADN(i) cfm	Nitrogen addition rate.

CONNECTION SPECIFICATION (2I5, F10.0) - ICON (5) cards expected
j is a connection index based on the order of inputting these cards

Word/Last Column	VARIABLE Units	Description
1/5	NJ1(j) none	Compartment at connection inlet. A zero value will result in nothing happening to compartment NJ2(j).
2/10	NJ2(j) none	Compartment at connection outlet. A zero value will result only in removal from the NJ1(j) compartment.
3/20	VR(j) cfm	Volumetric flow rate between compartments.

FIRST REACTOR COOLANT PARAMETER CARD (6F10.0) - one card REQUIRED

Word/Last Column	VARIABLE Units	Description
1/10	RC(1) MW_t	Reactor thermal power.
2/20	RC(2) h	Reactor operating time.
2/30	RC(3) lb_m	Zirconium mass.
4/40	RC(4) %	Per cent zirconium reacted with water. The resulting hydrogen is added to compartment one only.
5/50	RC(5) lb_m-mole	Oxygen dissolved in reactor coolant water.
6/60	RC(6) lb_m-mole	Hydrogen dissolved in reactor coolant water.

Note - The dissolved oxygen and hydrogen are added to each compartment over the first time step according to FRC(i) × RC(5) / 100 and FRC(i) × RC(6) / 100, respectively, with FRC(i) from the Compartment Specification card.

SECOND REACTOR COOLANT PARAMETER CARD (6F10.0) - one card REQUIRED

Word/Last Column	VARIABLE Units	Description
1/10	RC(7) molecules /100 eV	Radiolytic hydrogen yield $G(H)_c$ in core water used in Eq. (3). This hydrogen and the associated oxygen go to compartment one only.
2/20	RC(8) molecules /100 eV	Radiolytic hydrogen yield $G(H)_s$ in sump water solution used in Eq. (3).
3/30	RC(9) per cent	Per cent fission-product decay energy absorbed by the core water, resulting in radiolysis and the generation of hydrogen and oxygen, which are added to compartment one.
4/40	RC(10) per cent	Per cent of total solid fission-product decay energy absorbed by the sump water solution.

5/50	RC(11) per cent	Per cent of total iodine isotope decay energy absorbed by the sump water solution.
6/60	RC(12) s	Reactor coolant blowdown time used to determine the time after which the $Zr-H_2O$ reaction hydrogen is introduced into compartment one.

Note - RC(8), RC(10) and RC(11) affect the hydrogen and oxygen generation due to sump water radiolysis.

NUMBER OF CORROSION SURFACES (I5) - one card REQUIRED

Word/Last Column	VARIABLE Units	Description
1/5	NC none	Number of aluminum, zinc, or copper corrosion surfaces (10 max).

CORROSION SURFACE DESCRIPTION (2I5, 2F10.0) - NC cards expected
i is surface number index based on the order of entering these cards

Word/Last Column	VARIABLE Units	Description
1/5	IVO(i) none	Number of compartment in which surface is located.
2/10	MAT(i) none	Identification of surface material where 1 = aluminum, 2 = zinc, 3 = copper.
3/20	SURF(i) ft^2	Surface area.
4/30	THK(i) in.	Surface thickness.

NUMBER OF TIMES FOR CORROSION RATE SPECIFICATION (4F10.0) - one card expected if NC (Number of Corrosion Surfaces card) is not zero

Word/Last Column	VARIABLE Units	Description
1/5	NPT none	Number of cards that follow for specification of corrosion rate vs time (2 min, 10 max).

CORROSION RATES VS TIME (4F10.0) - NPT cards expected (only if NC ≠ 0)

The values of time must be increasing. i is the order of reading the cards.

Word/Last Column	VARIABLE Units	Description
1/10	TIMEV(i) days	Time.
2/20	ACOR(i) mil/yr	Aluminum corrosion rate at time TIMEV(i).
3/30	ZCOR(i) mil/yr	Zinc corrosion rate at time TIMEV(i).
4/40	CCOR(i) mil/yr	Copper corrosion rate at time TIMEV(i).

Note - More sets can be provided in a similar manner on additional cards.

NUMBER OF TIME INTERVALS AND DIAGNOSTIC CONTROL (I5, 2F10.0) - one card REQUIRED

Word/Last Column	VARIABLE Units	Description
1/5	KTIME none	Number of intervals that can have different time steps and print intervals (1 min, 20 max).
2/15	TIDIINI days	Time at which diagnostic printing begins.
3/25	TIDIFIN days	Time at which diagnostic printing ends.

TIME STEP AND PRINT CONTROL (2F10.0, 2I10) - KTIME cards expected

i is the order of reading the cards.

Word/Last Column	VARIABLE Units	Description
1/10	TIMEX(i) days	Time at begining of interval.
2/20	TIMEY(i) days	Time increment used for performing calculations within interval.

3/30	NPRINT(i) none	Number of time steps between prints.
4/40	NPLOTF(i) none	Number of time steps between points plotted; however, plotting is currently unavailable.

Notes - To get printed output at TIMEX(i+1), the NPRINT(i) and TIMEY(i) should be specified to produce output at TIMEX(i+1).

Also, the time increments [TIMEY(i)] (1) must be sufficiently small to preclude the removal of more moles from a volume than are available, (2) should be varied to establish that the results of interest are not affected by the time increment size, and (3) are required to satisfy (1) when the steam option is used has been found to be smaller than when this option is not used; e. g., the Appendix B sample problem time increments had to be reduced by a factor of 10 when the steam option was included.

NUMBER OF TEMPERATURE VS TIME SETS (I5) - one card REQUIRED

Word/Last Column	VARIABLE Units	Description
1/5	NT1 none	Number of time-temperature sets (2 min, 20 max).

Note - The temperatures that follow will be the those for all compartments after zero time. The zero time temperature is specified on the Compartment Specification card. If ICON(7) of the Integer Control Parameter is zero, these temperatures only result in a change in the compartment pressures by Eq. (7). The accounting of steam may be called for by ICON(7) of the Integer Control Parameter card as nonzero. In this case, these temperatures are the compartment steam saturation temperatures for the determination of compartment steam moles.

TIME VS TEMPERATURE SETS (6F10.0) - cards expected based on NT1 and the fact that three sets can be specified per card

Word/Last Column	VARIABLE Units	Description
1/10	TME(1) days	First set time.
2/20	TEMP(1) °F	First set temperature.

3/30	TME(2) days	Second set time.
4/40	TEMP(2) °F	Second set temperature.
5/50	TME(3) days	Third set time.
6/60	TEMP(3) °F	Third set temperature.

Note - More sets can be provided in a similar manner on additional cards.

NUMBER OF HYDROGEN RECOMBINER CONNECTIONS (I5) - one card expected only if ICON(1) on the Integer Control Parameter card is three

Word/Last Column	VARIABLE Units	Description
1/5	NT3 none	Number of hydrogen recombiner connections (20 max).

HYDROGEN RECOMBINER CONNECTIONS (2I5, F10.0) - NT3 cards expected
j is the order of reading these cards.

Word/Last Column	VARIABLE Units	Description
1/5	NR1(j) none	Compartment that provides flow to a recombiner. NR1(j) = 0 results in no flow into compartment NR2(j) due to this connection.
2/10	NR2(j) none	Compartment that receives flow from NR1(j) after recombination. NR2(j) = 0 results in flow removal from NR1(j) only; and NR2(j) = NR1(j) results in the recombined flow being returned to NR1(j).
3/20	HR(j) cfm	Recombiner volumetric flow rate.

Note - More connections can be specified in a similar manner on additional cards.

APPENDIX B

SAMPLE PROBLEMS

Figure B-1 presents the output for two sample problems, which were constructed to demonstrate the various code options and therefore may not be representative of "real" problems. Note that the output includes a listing of the input cards, interpretive descriptions of the input, and the calculated results. The sample problems are described briefly below even though they could be constructed from the input.

Sample Problem 1

The integer-control parameters specify that there will be purging, an additional case (Sample Problem 2), no plotting, one compartment, no recirculation connections, purge initiated when the compartment one hydrogen concentration exceeds a specified value, and there is steam. The real-number control parameters specify a total problem time of 20 days, purge-initiation hydrogen concentration of 3.5%, and an interval of 120 s after the end of blowdown for the release of the Zr-H_2O reaction hydrogen. The compartment has 2×10^6 ft^3; is initially composed of air and steam at 14.7 psia, 120 °F, and a relative humidity of 0.5; has a purge capacity of 150 cfm; and will receive 100% of the (1) the H_2 due to sump-water radiolysis and (2) the O_2 and H_2 dissolved in the primary coolant, which depend on subsequent specifications. The reactor (which is always in compartment one) parameters are self explanatory. The corrosion parameters specify that the compartment has (1) an aluminum component with an area of 25 000 ft^2 and thickness of 0.2 in. and (2) a zinc component with an area of 75 000 ft^2 and a thickness of 0.003 in. The corrosion rates are specified to vary with time based on four time entries with aluminum rates that vary from 20 000 to 500 mil/yr and zinc corrosion rates from 300 to 10 mil/yr. Small time steps are specified as suggested in Appendix A. Note that after zero time, the compartment temperatures specified will be the steam-saturation temperatures.

The Sample Problem 1 calculated results show that (1) at time zero, the compartment has standard-air nitrogen and oxygen concentrations with the initial humidity, (2) the temperature and steam content increase sharply over the first time step printed because of the specified steam-saturation temperature, (3) the hydrogen increases sharply over the first time step printed because of the $Zr-H_2O$ reaction, (4) the hydrogen due to metal corrosion rates decrease with time, (5) the nitrogen and oxygen moles increase at 6 days because the hydrogen concentration reaches 3.5% causing the purge to be initiated, and (6) a maximum hydrogen concentration of ~3.8% is reached at ~12.5 days.

Sample Problem 2

The integer-control parameters specify that there will be a recombiner, no additional case, no plotting, two compartments, two recirculation connections, recombiner operation initiated when the compartment one hydrogen concentration exceeds a specified value (which has no significance for this problem because an initiation time is specified), and no steam. The real-number control parameters specify a total problem time of 20 days, recombiner initiation at 8 days, recirculation fan initiation at 0.75 days, and an interval of 120 s after the end of blowdown for the release of the $Zr-H_2O$ reaction hydrogen. The compartment volumes are 0.3×10^6 and 1.2×10^6 ft^3, initially composed of air only at 14.7 psia; the temperatures are 135 and 90 ^oF; and compartment 2 will receive 100% of (1) the H_2 due to sump-water radiolysis and (2) the O_2 and H_2 dissolved in the primary coolant, which depend on subsequent specifications. One recirculation fan will transfer 100 cfm from compartment one to compartment two and the second fan will transfer 100 cfm from compartment two to compartment one. The reactor (which is always in compartment one) parameters are self explanatory. The corrosion parameters specify that compartments one and two both have an aluminum and a zinc component. The corrosion rates are specified to vary with time based on 10 time entries with a complicated variation of corrosion rates. A recombiner to remove 100 cfm from compartment one and return the recombined flow to compartment two is specified.

For Sample Problem 2, (1) the compartment one and two concentrations start toward a common value after the recirculation starts at 0.75 days, which is about when the compartment one hydrogen concentration reaches its maximum of ~3.8% and (2) the number of hydrogen and oxygen moles begins to decrease after the recombiner is initiated at 8 days.

```
LISTING OF INPUT CARDS

CDL·5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80

CDGAP SAMPLE PROBLEM 1
    2    1    0    1    0    1    1
20.       0.        3.5       0.        120.
     2.E6 14.7    0.       120.     .5       150.     100.     0.
3651.     16000.    5000.     1.5       0.        0.
.5        .5        10.       1.        50.       20.
    2
    1    1   25000. .2
    1    2   75000. .003
    4
0.        20000.    300.      0.
.02       1000.     100.      0.
.05       1000.     50.       0.
30.       500.      10.       0.
    4
0.        .0002              500
1.        .001              1000
10.       .01                100
30.       .01                 50
    2
0.        240.      40.       240.
COGAP SAMPLE PROBLEM 2
    3    0    0    2    2    1    0
20.       8.        0.        .75       120.
     .3E6      14.7      0.     135.       0.       0.       0.       0.
    1.2E6      14.7      0.      90.       0.       0.     100.       0.
    1    2  500.
    2    1  500.
4000.     16Q00.    60000.    1.        0.        0.
.5        .5        10.       1.        50.       20.
    4
    1    1       500.       .02
    1    2     50000.      .001
    2    1       100.       .02
    2    2     70000.      .001
   10
0.        375.      2.8       0.
.02083    1280.     13.5      0.
.06944    2063.     23.1      0.
.11574    2344.     27.5      0.
.17361    2344.     27.5      0.
.34722    1875.     19.4      0.
.57870    1280.     14.4      0.
1.1574    880.      8.8       0.
2.3148    580.      4.9       0.
30.       375.      2.8       0.
    4
         0.      .001       100         0
         1.       .01       100         0
        10.       .01       500         0

COL·5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
```

```
LISTING OF INPUT CARDS

COL·5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80

        30.       .01        50         0
    2
         0.      240.       40.      240.
    1
    1    2       100.

COL·5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
```

Fig. B-1
Listing of input cards for Sample Problems 1 and 2.

```
                        COGAP SAMPLE PROBLEM 1                                                    82/07/06
                        ( CASE  1)

                                                      ---- INPUT DATA ----
                                                         ( CASE  1)


                                                    CONTROL PARAMETERS

                         ICON(1)    ICON(2)    ICON(3)    ICON(4)    ICON(5)    ICON(6)    ICON(7)

                            2          1          0          1          0          1          1


                         CON (1)    CON (2)    CON (3)    CON (4)    CON (5)
                          DAYS       DAYS      PERCENT     DAYS       SEC

                          20.00      0.00       3.50       0.00      120.00

                                                PARAMETERS FOR EACH VOLUME

              VOLUME       VOLUME     TOTAL PRES    P.N2 PRES   TEMPERATURE    REL.  HUM.     PUR.RATE        FRC         N2 AD.RATE
               NO.          CUFT         PSIA         PSIA           F         =PSTM/PSAT       CFM         FRACTION         CFM

               1        2000000.00     14.700       0.0000        120.0           .50          150.00       100.00          0.00
                                                R. COOLANT PARAMETERS

      REACTOR POWER (MWT)                   =     3651.00       REACTOR OPERATING TIME (HRS)        =    16000.00
      ZIRCONIUM WEIGHT (LBS)                =     5000.00       ZIR-WATER REACTION. PER-CENT        =        1.50
      O2 DISSOLVEO IN PRI.COOL.(LB-MOLE)=            0.00       H2 DISSOLVED IN PRI.COOL.(LB-MOLE)=          0.00
      G(H) IN CORE SOLUTION(MOLE/100 EV)=             .50       GIH) IN SUMP SOLUTIONIMOLE/100 EV)=           .50
      D/D NRG ABS. BY CORE WATER            =       10.00       O/O SOLID NRG ABS. BY SUMP WATER  =          1.00
      O/O IOOINE NRG ABS. BY SUMP WATER =           50.00       BLOWDOWN DURATION (SEC)             =       20.00
```

```
ALUMINUM  ZINC ANO COPPER CORROSION PARAMETERS
NO. OF ALU.. ZINC ANO COPPER COMPONENTS =    2

VOL. NO.      MATERIAL      SURF.AREA     THICKNESS
                               FT2          INCHES

   1             1         2.5000E+04    2 0000E-01
   1             2         7.5000E+04    3.0000E-03


    CONT. MATERIAL CORROSION RATES AFTER LOCA
           NO. OF PTS. IN TABLE =     4

    TIME      AL COR RATE   Z.COR RATE   C.COR.RATE
    DAYS        MIL/YR        MIL/YR       MIL/YR

     0.00     20000.00       300.00         0.00
      .02      1000.00       100.00         0.00
      .05      1000.00        50.00         0.00
    30.00       500.00        10.00         0.00


                 TIME STEP-SIZE TABLE
                   PTS. IN TABLE=  4

       TIME        TIME INC.   PRINT    PLOT
       DAYS           DAY      FREQ.    FREQ.

       0.000        .00020      500      0
       1.000        .00100     1000      0
      10 000        .01000      100      0
      30.000        .01000       50      0


              CONTAINMENT TEMP. AFTER LOCA
NOTE-7HESE TEMPS WILL BE SAT TEMP IF THERE IS STEAM
              NO  OF PTS. IN TABLE =     2

                      TIME          TEMP.
                      DAYS          DEG-F

                      0.000         240.00
                     40.000         240.00
```

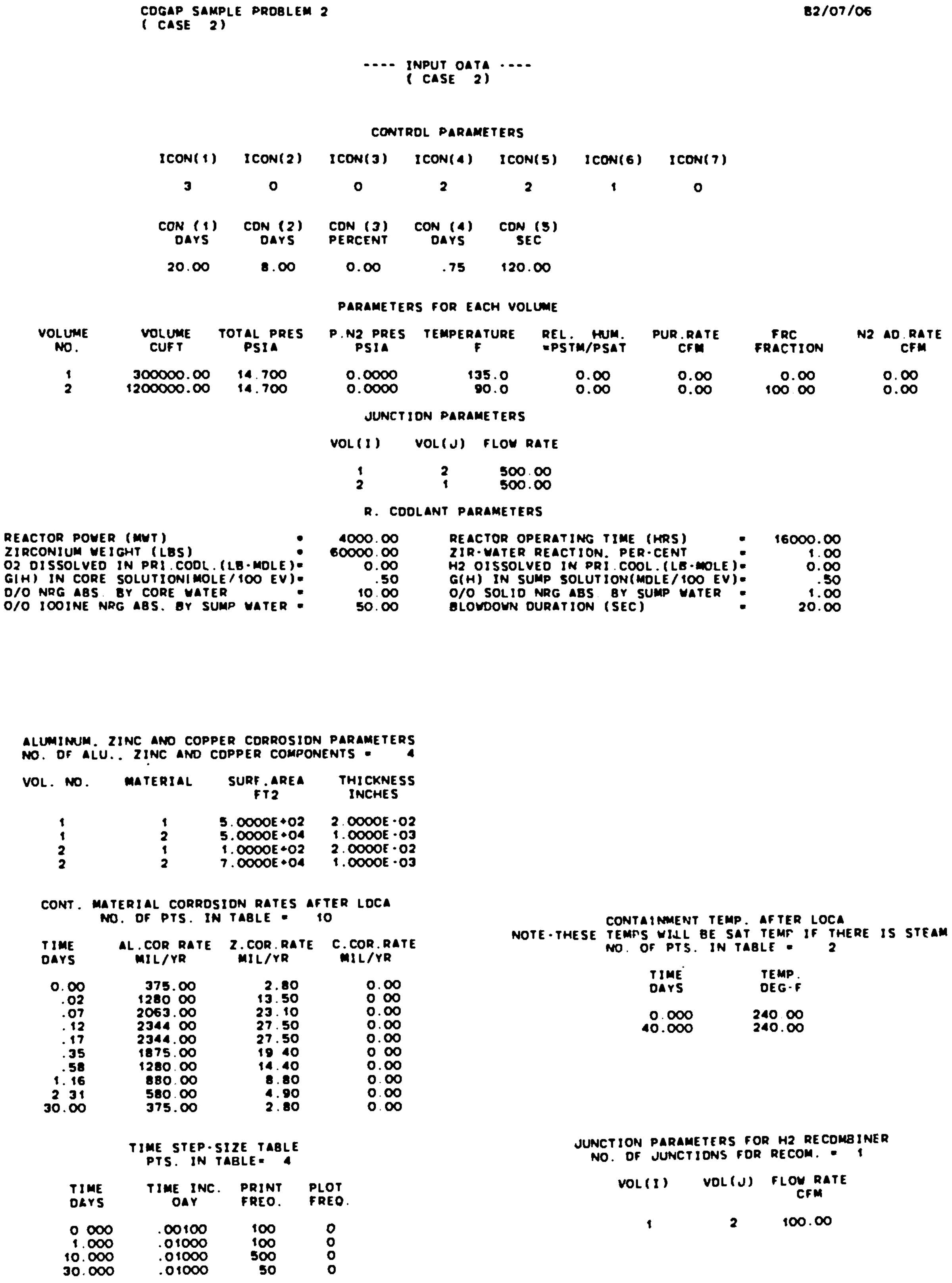
```
          LEGENO FOR INPUT VARIABLES


ICON(1)= 1  NO PURGE ANO NO H2 RECOMBINER
       = 2  WITH PURGE
       = 3  WITH H2 RECOMBINER
ICON(2)= O  LAST CASE OR ONLY ONE CASE
       = 1  MULTIPLE CASE
***PLOTTING NOT AVAILABLE(9/80/***
ICONI3)= O  NO PLOT
       = 1  PLOTTING H2 GENERATION DUE TO RADIOLYSIS
            PLOTTING H2 GENERATION DUE TO METAL CORROSION
            PLOTTING H2 GENERATION DUE TO ZR-H2O REACTION
            PLOTTING TOTAL H2 GENERATION
       = 2  PLOTTING H2 CONCENTRATION IN EA. VOL.
       = 3  PLOTTING N2 CONCENTRATION IN EA. VOL.
       = 4  PLOTTING O2 CONCENTRATION IN EA. VOL.
       = 10 ALL THE ABOVE CASES WILL BE PLOTTED
***PLOTTING NOT AVAILABLEI9/80)***
ICON(4)=    NUMBER OF VOLUMES
ICON(5)=    NUMBER OF JUNCTIONS
ICONI6)= O  THE AVERAGE VALUE OF ALL COMPARTMENT H2
            CONCENTRATION WILL BE USED
       = X  THE H2 CONC. IN X COMPT. WILL BE USED
ICON(7)= O  NO STEAM
       = 1  WITH STEAM BASED ON SATURATION TEMP
CON(1) =    PROBLEM ENO TIME.DAYS
CON(2) =    TIME AT WHICH PURGING OR H2 RECOMBINER
            STARTS, DAYS
CON(3) =    H2 CONCENTRATION AT WHICH PURGING OR H2
            RECOMBINER STARTS
CON(4) =    TIME AT WHICH THE H2 RECIRCULATION FAN
            STARTS. DAYS
CON(5) =    DURATION FOR H2 RELEASED FROM ZR-H2O
MATII) =    H2 GENERATION MATERIALS
       = 1  ALUMINUM
       = 2  ZINC
       = 3  COPPER


 NOTES - THIS LEGENO WILL BE PRINTED FOR THE FIRST CASE ONLY.
         VOL.NO. 1 HOUSES REACTOR COOL. SYS.
         INPUT O.O FOR PARTIAL N2 PRESSURE. UNLESS THE CONTAINMENT
         IS PRESSURIZED WITH N2 INITIALLY.
```

Fig. B-2
Description of input for Sample Problem 1.

```
            COGAP SAMPLE PROBLEM 1                                                      82/07/06
            ( CASE  1)

                                          ---- OUTPUT DATA ----
                                            ( CASE  1)

VOL   TIME      ----------------- LB-MOLES -----------------       -------- PER-CENT --------     PRES.  TEMP.
NO.   DAYS        H2       N2        O2      STEAM     TOTAL      H2      N2      O2    STEAM    PSIA     F

 1    0.000      0.00   3521.95    933.39    272.19    4727.53    0.00   74.50   19.74    5.78   14.70   120.0
 1     .100     24.45   3521.95    936.75   6652.85   11135.99     .22   31.63    8.41   59.74   41.79   240.0
 1     .200     34.34   3521.95    938.80   6652.85   11147.92     .31   31.59    8.42   59.88   41.84   240.0
 1     .300     43.43   3521.95    940.45   6652.85   11158.66     .39   31.56    8.43   59.62   41.88   240.0
 1     .400     52.04   3521.95    941.86   6652.85   11168.70     .47   31.53    8.43   59.57   41.91   240.0
 1     .500     60.33   3521.95    943.12   6652.85   11178.25     .54   31.51    8.44   59.52   41.95   240.0
 1     .600     68.38   3521.95    944.27   6652.85   11187.44     .61   31.48    8.44   59.47   41.98   240.0
 1     .700     76.25   3521.95    945.32   6652.85   11196.36     .68   31.46    8.44   59.42   42.02   240.0
 1     .800     83.97   3521.95    946.31   6652.85   11205.07     .75   31.43    8.45   59.37   42.05   240.0
 1     .900     91.57   3521.95    947.25   6652.85   11213.61     .82   31.41    8.45   59.33   42.08   240.0
 1    1.000     99.05   3521.95    948.14   6652.85   11221.98     .88   31.38    8.45   59.28   42.11   240.0
 1    2.000    170.47   3521.95    955.53   6652.85   11300.79    1.51   31.17    8.46   58.87   42.41   240.0
 1    3.000    237.73   3521.95    961.36   6652.85   11373.88    2.09   30.97    8.45   58.49   42.68   240.0
 1    4.000    302.19   3521.95    966.30   6652.85   11443.29    2.64   30.78    8.44   58.14   42.94   240.0
 1    5.000    364.47   3521.95    970.67   6652.85   11509.92    3.17   30.60    8.43   57.80   43.19   240.0
 1    6.000    409.81   3542.59    978.62   6652.13   11583.15    3.54   30.58    8.45   57.43   43.47   240.0
 1    7.000    423.59   3598.60    992.86   6652.13   11667.17    3.63   30.84    8.51   57.02   43.78   240.0
 1    8.000    434.53   3648.88   1005.42   6652.13   11740.96    3.70   31.08    8.56   56.66   44.06   240.0
 1    9.000    443.03   3694.01   1016.52   6652.13   11805.69    3.75   31.29    8.61   56.35   44.30   240.0
 1   10.000    449.40   3734.51   1026.34   6652.13   11862.38    3.79   31.48    8.65   56.08   44.52   240.0
 1   11.000    453.88   3770.89   1035.03   6645.67   11905.47    3.81   31.67    8.69   55.82   44.68   240.0
 1   12.000    456.71   3803.54   1042.72   6645.67   11948.64    3.82   31.83    8.73   55.62   44.84   240.0
 1   13.000    458.08   3832.85   1049.53   6645.67   11986.13    3.82   31.98    8.76   55.44   44.98   240.0
 1   14.000    458.16   3859.16   1055.55   6645.67   12018.53    3.81   32.11    8.78   55.30   45.10   240.0
 1   15.000    457.09   3882.77   1060.87   6645.67   12046.41    3.79   32.23    8.81   55.17   45.21   240.0
 1   16.000    455.01   3903.96   1065.58   6645.67   12070.22    3.77   32.34    8.83   55.06   45.30   240.0
 1   17.000    452.03   3922.98   1069.74   6645.67   12090.42    3.74   32.45    8.85   54.97   45.37   240.0
 1   18.000    448.26   3940.06   1073.40   6645.67   12107.38    3.70   32.54    8.87   54.89   45.44   240.0
 1   19.000    443.77   3955.38   1076.63   6645.67   12121.45    3.66   32.63    8.88   54.83   45.49   240.0
 1   20.000    438.65   3969.14   1079.48   6645.67   12132.94    3.62   32.71    8.90   54.77   45.53   240.0
 1   20.010    438.60   3969.27   1079.50   6645.67   12133.04    3.61   32.71    8.90   54.77   45.53   240.0


                           H2 GENERATION DUE TO DIFFERENT SOURCES (SCF)

                    VOLUME      TIME      ZIR-H2O      RAD.       METAL       TOTAL

                       1        0.000        0.00       0.00        0.00        0.00
                       1         .100      637.86    2596.74     6215.88     9450.48
                       1         .200      637.86    4176.53     8458.88    13273.27
                       1         .300      637.86    5452.02    10697.91    16787.79
                       1         .400      637.86    6547.75    12932.95    20118.56
                       1         .500      637.86    7521.00    15164.02    23322.88
                       1         .600      637.86    8405.52    17391.11    26434.49
                       1         .700      637.86    9223.06    19614.22    29475.14
                       1         .800      637.86    9988.27    21833.35    32459.48
                       1         .900      637.86   10711.37    24048.51    35397.73
                       1        1.000      637.86   11398.31    26255.27    38291.43
                       1        2.000      637.86   17112.68    48148.17    65898.71
                       1        3.000      637.86   21620.76    69643.27    91901.89
                       1        4.000      637.86   25443.40    90740.58   116821.83
                       1        5.000      637.86   28816.95   111440.08   140894.89
                       1        6.000      637.86   31876.25   131741.79   164255.90
                       1        7.000      637.86   34703.80   151645.70   186987.36
                       1        8.000      637.86   37352.45   171151.80   209142.11
                       1        9.000      637.86   39857.42   190260.11   230755.39
                       1       10.000      637.86   42243.08   208970.63   251851.56
                       1       11.000      637.86   44526.43   227281.55   272445.83
                       1       12.000      637.86   46720.81   245194.67   292553.34
                       1       13.000      637.86   48836.04   262709.99   312183.89
                       1       14.000      637.86   50879.79   279827.52   331345.16
                       1       15.000      637.86   52858.24   296547.25   350043.34
                       1       16.000      637.86   54776.50   312869.17   368283.53
                       1       17.000      637.86   56638.87   328793.30   386070.02
                       1       18.000      637.86   58449.06   344319.63   403406.54
                       1       19.000      637.86   60210.31   359448.16   420296.33
                       1       20.000      637.86   61925.51   374178.89   436742.26
                       1       20.010      637.86   61942.43   374324.19   436904.48
```

Fig. B-3

Calculated results for Sample Problem 1.



```
              COGAP SAMPLE PROBLEM 2                                                    82/07/06
              ( CASE  2)


                                             ---- INPUT DATA ----
                                                 ( CASE  2)


                                             CONTROL PARAMETERS

                  ICON(1)   ICON(2)   ICON(3)   ICON(4)   ICON(5)   ICON(6)   ICON(7)

                     3         0         0         2         2         1         0


                  CON (1)   CON (2)   CON (3)   CON (4)   CON (5)
                   DAYS      DAYS     PERCENT    DAYS      SEC

                  20.00      8.00      0.00       .75     120.00

                                        PARAMETERS FOR EACH VOLUME

    VOLUME        VOLUME    TOTAL PRES   P.N2 PRES  TEMPERATURE   REL.  HUM.    PUR.RATE      FRC       N2 AD.RATE
      NO.          CUFT        PSIA        PSIA          F       =PSTM/PSAT       CFM      FRACTION        CFM

      1        300000.00    14.700      0.0000       135.0        0.00          0.00        0.00         0.00
      2       1200000.00    14.700      0.0000        90.0        0.00          0.00      100 00         0.00

                                             JUNCTION PARAMETERS

                                         VOL(I)   VOL(J)  FLOW RATE

                                            1        2     500.00
                                            2        1     500.00

                                             R. COOLANT PARAMETERS

 REACTOR POWER (MWT)                   =   4000.00    REACTOR OPERATING TIME (HRS)        =   16000.00
 ZIRCONIUM WEIGHT (LBS)                =  60000.00    ZIR-WATER REACTION. PER-CENT        =       1.00
 O2 DISSOLVED IN PRI.COOL.(LB-MOLE)=          0.00    H2 DISSOLVED IN PRI.COOL.(LB-MOLE)=         0.00
 G(H) IN CORE SOLUTION(MOLE/100 EV)=           .50    G(H) IN SUMP SOLUTION(MOLE/100 EV)=          .50
 O/O NRG ABS  BY CORE WATER            =     10.00    O/O SOLID NRG ABS  BY SUMP WATER    =       1.00
 O/O IODINE NRG ABS. BY SUMP WATER =         50.00    BLOWDOWN DURATION (SEC)             =      20.00




  ALUMINUM. ZINC AND COPPER CORROSION PARAMETERS
  NO. OF ALU.. ZINC AND COPPER COMPONENTS =   4

  VOL. NO.     MATERIAL      SURF.AREA     THICKNESS
                                FT2          INCHES

     1            1        5.0000E+02   2.0000E-02
     1            2        5.0000E+04   1.0000E-03
     2            1        1.0000E+02   2.0000E-02
     2            2        7.0000E+04   1.0000E-03

    CONT. MATERIAL CORROSION RATES AFTER LOCA                      CONTAINMENT TEMP. AFTER LOCA
          NO. OF PTS. IN TABLE =   10                 NOTE-THESE TEMPS WILL BE SAT TEMP IF THERE IS STEAM
                                                                   NO. OF PTS. IN TABLE =    2
    TIME      AL.COR RATE   Z.COR.RATE   C.COR.RATE
    DAYS        MIL/YR        MIL/YR       MIL/YR                     TIME          TEMP.
                                                                      DAYS          DEG-F
     0.00        375.00         2.80        0.00
      .02       1280 00        13.50        0 00                      0.000         240 00
      .07       2063.00        23.10        0.00                     40.000         240.00
      .12       2344 00        27.50        0.00
      .17       2344.00        27.50        0.00
      .35       1875.00        19 40        0 00
      .58       1280.00        14.40        0.00
     1.16        880.00         8.80        0.00
     2 31        580.00         4.90        0.00
    30.00        375.00         2.80        0.00

                 TIME STEP-SIZE TABLE                          JUNCTION PARAMETERS FOR H2 RECOMBINER
                  PTS. IN TABLE=  4                              NO. OF JUNCTIONS FOR RECOM. =  1

       TIME      TIME INC.   PRINT   PLOT                        VOL(I)    VOL(J)   FLOW RATE
       DAYS        DAY       FREQ.   FREQ.                                            CFM

      0 000      .00100       100      0                            1         2       100.00
      1.000      .01000       100      0
     10.000      .01000       500      0
     30.000      .01000        50      0
```

Fig. B-4
Description of input for Sample Problem 2.

```
                    COGAP SAMPLE PROBLEM 2                                                          82/07/06
                    ( CASE  2)

                                          ---- OUTPUT DATA ----
                                            ( CASE  2)

 VOL   TIME     ---------------- LB-MOLES ----------------        -------- PER-CENT --------      PRES.  TEMP.
 NO.   DAYS        H2        N2        O2      STEAM     TOTAL      H2     N2      O2    STEAM   PSIA     F

   1   0.000      0.00    546.44    144.82     0.00     691.25     0.00  79.05   20.95    0.00  14.70  135.0
   1    .100     16.48    546.44    146.30     0.00     709.22     2.32  77.05   20.63    0.00  17.74  240.0
   1    .200     18.88    546.44    147.27     0.00     712.59     2.65  76.68   20.67    0.00  17.83  240.0
   1    .300     20.99    546.44    148.12     0.00     715.55     2.93  76.37   20.70    0.00  17.90  240.0
   1    .400     22.87    546.44    148.89     0.00     718.19     3.18  76.09   20.73    0.00  17.97  240.0
   1    .500     24.58    546.44    149.59     0.00     720.60     3.41  75.83   20.76    0.00  18.03  240.0
   1    .600     26.16    546.44    150.25     0.00     722.85     3.62  75.59   20.79    0.00  18.08  240.0
   1    .700     27.65    546.44    150.88     0.00     724.97     3.81  75.37   20.81    0.00  18.14  240.0
   1    .800     26.29    551.52    152.30     0.00     730.10     3.60  75.54   20.86    0.00  18.27  240.0
   1    .900     23.10    559.48    154.08     0.00     736.66     3.14  75.95   20.92    0.00  18.43  240.0
   1    .999     20.84    565.33    155.43     0.00     741.60     2.81  76.23   20.96    0.00  18.55  240.0
   1   1.999     16.77    581.40    160.11     0.00     758.28     2.21  76.67   21.12    0.00  18.97  240.0
   1   2.999     18.97    582.16    161.41     0.00     762.54     2.49  76.34   21.17    0.00  19.08  240.0
   1   3.999     21.22    582.20    162.39     0.00     765.81     2.77  76.02   21.21    0.00  19.16  240.0
   1   4.999     23.28    582.20    163.26     0.00     768.75     3.03  75.73   21.24    0.00  19.23  240.0
   1   5.999     25.20    582.20    164.07     0.00     771.47     3.27  75.47   21.27    0.00  19.30  240.0
   1   6.999     27.01    582.20    164.82     0.00     774.03     3.49  75.22   21.29    0.00  19.37  240.0
   1   7.999     28.74    582.20    165.53     0.00     776.47     3.70  74.98   21.32    0.00  19.43  240.0
   1   8.999     24.81    504.22    143.19     0.00     672.22     3.69  75.01   21.30    0.00  16.82  240.0
   1   9.999     24.05    501.97    142.09     0.00     668.11     3.60  75.13   21.27    0.00  16.72  240.0
   1  14.999     20.45    501.90    139.95     0.00     662.30     3.09  75.78   21.13    0.00  16.57  240.0
   1  19.999     17.48    501.90    138.17     0.00     657.55     2.66  76.33   21.01    0.00  16.45  240.0
   1  20.009     17.48    501.90    138.17     0.00     657.54     2.66  76.33   21.01    0.00  16.45  240.0
          .

   2   0.000      0.00   2364.57    626.66     0.00    2991.24     0.00  79.05   20.95    0.00  14.70   90.0
   2    .100      4.57   2364.57    628.83     0.00    2997.98      .15  78.87   20.98    0.00  18.75  240.0
   2    .200      7.45   2364.57    630.10     0.00    3002.12      .25  78.76   20.99    0.00  18.78  240.0
   2    .300      9.67   2364.57    631.06     0.00    3005.30      .32  78.68   21.00    0.00  18.80  240.0
   2    .400     11.50   2364.57    631.84     0.00    3007.92      .38  78.61   21.01    0.00  18.81  240.0
   2    .500     13.07   2364.57    632.52     0.00    3010.16      .43  78.55   21.01    0.00  18.83  240.0
   2    .800     14.44   2364.57    633.11     0.00    3012.13      .48  78.50   21.02    0.00  18.84  240.0
   2    .700     15.68   2364.57    633.64     0.00    3013.89      .52  78.46   21.02    0.00  18.85  240.0
   2    .800     19.60   2359.49    633.30     0.00    3012.39      .65  78.33   21.02    0.00  18.84  240.0
   2    .900     25.19   2351.53    632.54     0.00    3009.26      .84  78.14   21.02    0.00  18.82  240.0
   2    .999     29.71   2345.68    632.16     0.00    3007.55      .99  77.99   21.02    0.00  18.81  240.0
   2   1.999     52.40   2329.61    635.57     0.00    3017.58     1.74  77.20   21.06    0.00  18.87  240.0
   2   2.999     64.65   2328.85    640.66     0.00    3034.15     2.13  76.75   21.11    0.00  18.98  240.0
   2   3.999     74.84   2328.81    645.09     0.00    3048.74     2.45  76.39   21.16    0.00  19.07  240.0
   2   4.999     83.94   2328.81    648.99     0.00    3061.74     2.74  76.06   21.20    0.00  19.15  240.0
   2   5.999     92.26   2328.81    652.52     0.00    3073.59     3.00  75.77   21.23    0.00  19.22  240.0
   2   6.999    100.00   2328.81    655.78     0.00    3084.59     3.24  75.50   21.26    0.00  19.29  240.0
   2   7.999    107.30   2328.81    658.82     0.00    3094.93     3.47  75.25   21.29    0.00  19.36  240.0
   2   8.999    107.35   2406.79    678.47     0.00    3192.60     3.36  75.39   21.25    0.00  19.97  240.0
   2   9.999    104.64   2409.04    677.09     0.00    3190.77     3.28  75.50   21.22    0.00  19.96  240.0
   2  14.999     89.53   2409.11    667.61     0.00    3166.25     2.83  76.09   21.09    0.00  19.80  240.0
   2  19.999     76.30   2409.11    659.54     0.00    3144.96     2.43  76.60   20.97    0.00  19.67  240.0
   2  20.009     76.28   2409.11    659.53     0.00    3144.92     2.43  76.60   20.97    0.00  19.67  240.0
```

```
        H2 GENERATION DUE TO DIFFERENT SOURCES (SCF)                 H2 GENERATION DUE TO DIFFERENT SOURCES (SCF)

VOLUME     TIME     ZIR-H2O      RAD.      METAL      TOTAL      VOLUME     TIME     ZIR-H2O      RAD.      METAL      TOTAL

   1      0.000        0.00       0.00       0.00       0.00        2      0.000        0.00       0.00       0.00       0.00
   1       .100     5102.86    1147.62     121.77    6372.25        2       .100        0.00    1677.32      90.32    1767.64
   1       .200     5102.86    1897.90     297.99    7298.75        2       .200        0.00    2655.95     224.17    2880.12
   1       .300     5102.86    2554.64     456.50    8113.99        2       .300        0.00    3395.66     342.48    3738.14
   1       .400     5102.86    3145.92     591.16    8839.94        2       .400        0.00    4004.21     440.42    4444.63
   1       .500     5102.86    3690.53     708.03    9501.42        2       .500        0.00    4525.43     525.98    5051.42
   1       .600     5102.86    4201.47     808.26   10112.58        2       .600        0.00    4983.23     600.50    5583.73
   1       .700     5102.86    4687.52     899.35   10689.72        2       .700        0.00    5392.61     668.36    6060.97
   1       .800     5102.86    5154.58     984.72   11242.16        2       .800        0.00    5763.71     731.57    6495.28
   1       .900     5102.86    5606.62    1064.39   11773.86        2       .900        0.00    6103.72     790.14    6893.86
   1       .999     5102.86    6041.96    1137.62   12282.44        2       .999        0.00    6414.95     843.54    7258.48
   1      1.999     5102.86    9984.74    1691.61   16779.20        2      1.999        0.00    8725.69    1233.47    9959.16
   1      2.999     5102.86   13348.26    2082.62   20533.74        2      2.999        0.00   10297.67    1494.41   11792.08
   1      3.999     5102.86   16300.71    2458.63   23862.21        2      3.999        0.00   11531.06    1743.83   13274.89
   1      4.999     5102.86   18953.54    2829.37   26885.76        2      4.999        0.00   12572.77    1989.45   14562.22
   1      5.999     5102.86   21384.31    3194.82   29681.98        2      5.999        0.00   13492.66    2231.26   15723.92
   1      6.999     5102.86   23646.77    3554.99   32304.61        2      6.999        0.00   14327.21    2469.28   16796.49
   1      7.999     5102.86   25778.28    3909.87   34791.00        2      7.999        0.00   15096.90    2703.48   17800.38
   1      8.999     5102.86   27805.00    4259.48   37167.34        2      8.999        0.00   15814.07    2933.89   18747.95
   1      9.999     5102.86   29745.51    4603.80   39452.17        2      9.999        0.00   16486.81    3160.49   19647.30
   1     14.999     5102.86   38518.06    5439.39   49060.31        2     14.999        0.00   19344.47    4075.07   23419.54
   1     19.999     5102.86   46199.37    6005.04   57307.27        2     19.999        0.00   21597.39    4866.97   26464.36
   1     20.009     5102.86   46213.87    6006.11   57322.84        2     20.009        0.00   21601.43    4868.48   26469.91
```

Fig. B-5
Calculated results for Sample Problem 2.

APPENDIX C

DECAY ENERGY PRODUCTION FOR RADIOLYSIS

This appendix describes the decay energy production source equations that are the bases for the H_γ, $H_{\gamma+\beta}$, and H_I expressions in Eqs. (4) and (5) used for the determination of water radiolysis. The decay energy production source equations used are

1. the fission product decay energy production given by Eq. (2) of Ref. 5,
2. the heavy element decay energy production due to U^{239} given by Eq. (3) of Ref. 5,
3. the heavy element decay energy production due to Np^{239} given by Eq. (4) of Ref. 5, and
4. the decay energy production due to I^{131} through I^{135}, which provides the H_I expression.

First, the total decay energy production (H_{tot}) is calculated to be the sum of the first three items above. The sump water decay energy production term $H_{\gamma+\beta}$ then is determined by subtracting the energy production due to iodine (H_I) from the total. The core water decay energy production term H_γ is simply one-half of $H_{\gamma+\beta}$. The above operations can be expressed in equation form by

$$H_{\gamma+\beta} = H_{tot} - H_I$$

$$H_\gamma = 0.5 \times H_{\gamma+\beta} = 0.5 \times H_{tot} - 0.5 \times H_I \ .$$

The combined energy available (H_{avail}) for radiolytic hydrogen production is then

$$\begin{aligned} H_{avail} &= H_{\gamma+\beta} + H_\gamma + H_I \\ &= H_{tot} - H_I + 0.5 \times H_{tot} - 0.5 \times H_I + H_I \\ &= 1.5 \times H_{tot} - 0.5 \times H_I \ . \end{aligned}$$

This shows that the COGAP decay energy production available for radiolytic hydrogen generation is about 50% greater than the actual generation presented in Ref. 5 (the H_I is 1 to 10% of H_{tot}). However, the energy used for radiolysis is modified by the user supplied fractions that determine the energy absorbed, as shown in the input description in Appendix A.

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The accounting of containment gas concentration following a loss-of-coolant accident is important in the safety evaluation of hydrogen combustible-gas control systems for nuclear power plants. The COGAP code provides such accounting including the effects of (1) the reaction of zirconium and water; (2) radiolysis of core and sump water; (3) corrosion of zinc, aluminum and copper; (4) recirculation between compartments; (5) hydrogen recombiners; (6) purging; (7) nitrogen addition; and (8) atmospheric steam. Controls are available to determine when options are initiated; for example. the hydrogen recombiner can be started when the hydrogen concentration reaches a user-specified value.

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