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GASOUT--
The Code Used to Calculate Gaseous Fission Product Release for a ZPR-6 and -9 Design Basis Accident

by

C. D. Swanson and E. M. Bohn

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Applied Physics Division

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ABSTRACT

PROGRAM GASOUT calculates the amount of noble gas and radioiodine fission products expelled into the atmosphere following a ZPR-6 and -9 "Design Basis Accident." Tabulated values of fission product activities following fission are combined with a calculation of time-dependent cell pressure to determine the number of fission product atoms released. This information can then be used to determine the radiological hazard to a man standing downwind from the reactor during the accident. The code is written for the IBM 360/50/75 computer.

INTRODUCTION

In the event of a nuclear excursion with a ZPR reactor, fission products released by burning fuel may be expelled into the atmosphere. PROGRAM GASOUT calculates the amount of noble gas and radioiodine atoms released. This information is used in the ZPR-6 and -9 Plutonium Safety Analysis Report[1] to assess the radiological hazard associated with the postulated Design Basis Accident (DBA).

The mathematical model used is based on tabulated values of fission product activities at various times following fission.[2] The calculation of time-dependent cell pressure from the DBA analysis is used to determine the number of fission product atoms expelled from the reactor cell into the atmosphere.

PROGRAM GASOUT is an extension of the Design Basis Accident analysis. The essential features and assumptions of the DBA are briefly discussed here. Following the central idea of safety-analysis calculations, all additional assumptions were made to provide a reasonable but safely conservative estimate of the fission products released.

I. DESCRIPTION OF PROBLEM

A. Facilities

A complete description of the ZPR-6 and -9 facility has been given.[3] For the present problem only the reactor cell and the emergency exhaust system are considered. Each ZPR reactor is located in a concrete cell with interior dimensions of 40 by 30 ft, with a height of 30 ft. In the event of a nuclear accident involving a metal fire, the pressure buildup in the cell will be relieved by the emergency exhaust system. This consists of a 24-in.-dia exhaust pipe connected to a sand filter, a double bank of HEPA (High Efficiency Particulate Attenuator) filters, and finally a 46-m stack.

A flow diagram of the emergency exhaust system appears in Fig. 1. Throughout the discussion, the facilities will be represented by the simplified schematic shown in Fig. 2.

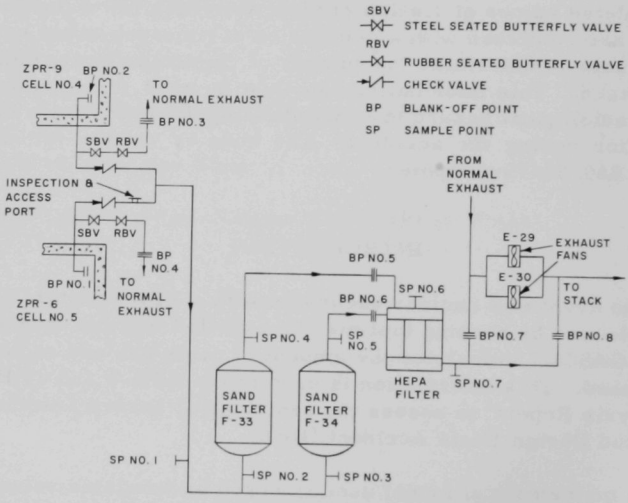

Fig. 1. Flow Diagram of Emergency Exhaust System

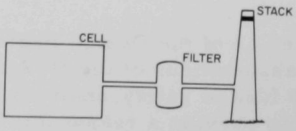

Fig. 2

Simplified Schematic of Facilities

B. Design Basis Accident

The Design Basis Accident (DBA) for plutonium use in the ZPR-6 and -9 reactors is discussed in Ch. 12 of Ref. 1. The DBA is an extremely severe nuclear accident which is postulated and analyzed to determine the containment capability of the reactor cells and associated facilities. The cause of the accident is a combination of:

(1) large fuel overloading of the reactor due to operator judgment error;

(2) inattention on the part of two reactor operators;

(3) failure of all controls.

It is assumed that criticality is achieved as the table halves are closing at intermediate speed. When combined with the above conditions, this causes a nuclear excursion. The accompanying rise in temperature eventually causes the fuel to burn and release fission products to the air in the cell. Fuel and sodium fires rapidly increase the pressure in the cell. The emergency exhaust system then relieves this pressure by exhausting air through the filters and out the stack.

The DBA was analyzed using a one-energy-group point-reactor kinetics code with a heat-transfer subroutine.[4] The pertinent results of that calculation are as follows:

(1) At time t = 0 the reactor is just critical and the closing table halves are adding reactivity (beginning of excursion).

(2) The reactor reaches prompt critical at t = 4.1 sec. The excursion is turned by the negative Doppler and expansion reactivity feedback.

(3) At t = 13 sec molten fuel flows onto the reactor bed and begins to burn. The loss of reactivity due to flowing fuel causes the reactor to go subcritical.

(4) At t = 15.2 sec the reactor is 2.3% subcritical and the excursion is considered over by the kinetics code. Boiling of sodium continues until 19.2 sec, when the temperature drops below the boiling point. Liquid fuel and sodium continue to burn.

C. Assumptions

The amount of radiologically hazardous material released to the atmosphere during the Design Basis Accident is calculated by dividing the

problem into small time intervals Δt_j (sec)* and making the following additional assumptions:

(1) Based on the DBA analysis, the fissions that release fission products to the cell occur at an average time of t = 6 sec. This assumption greatly simplifies the analysis by allowing use of tabulated values of fission product activities following instantaneous fission at t = 6 sec.

(2) Fission products are released and spread uniformly throughout the cell as soon as the fuel begins to burn at t = 13 sec. Two methods of fission product release are considered:

a. All of the fission products are released instantaneously at 13 sec. This allows for a simplified solution and a conservative answer.

b. The fission products are released as the fuel burns at a constant rate for one hour. The fraction of fission products available for release during a time interval Δt seconds is then $\Delta t/3600$.

There are two possible paths by which fission products released to the cell air can reach the atmosphere:

a. through the emergency exhaust system, and

b. leakage through the cell walls into the confinement shell, through the air filters in the shell, then out the stack.

Here we are concerned only with the first path and assume that the reactor cell is sealed except for the emergency exhaust system. Fission product release from the stack is based on two additional assumptions:

(3) All particulate fission products are held up in the filter. Only gaseous fission products are released.

(4) All precursors are considered particulate. As these precursor atoms decay into gas atoms they are released from the stack.

The piping and filter of the emergency exhaust system introduce a delay time during which fission product decay is considered. The delay time T associated with the travel time of fission products from the cell to the filter is given by

$$T = D/v; \quad v = k\overline{P},$$

*The choice of time intervals is discussed in Appendix B, p. 38.

where

$\overline{P}$ = average cell pressure, psig;

D = length of pipe;

v = velocity.

The constant k was determined by the flow characteristics of the emergency exhaust system to be 8.8 ft/sec-psig. Thus the delay time is

$$T = (D/8.8)/\overline{P}.$$

Gaseous fission products pass through the entire system (D = 1232 ft) without filter holdup. The delay time is then

$$T = 140/\overline{P}.$$

For particulate fission products that are held up in the filter, the time to reach the filter (D = 968 ft) is

$$T = 110/\overline{P}.$$

GASOUT has two methods of computing the number of gas atoms released from the stack, depending on the nature of the problem being solved.

The simplest case is to determine the total dose at a point downwind from the stack. In this case, it is only necessary to calculate the total number of gas atoms released from the stack. Since filter holdup of precursors does not affect the total number of gas atoms released, it can be neglected. All fission product atoms that leave the cell are assumed to leave the stack after a decay time of $T = 140/\overline{P}$ seconds. Note that the rate of release from the stack is not considered. Thus this is a time-independent problem.

In an actual situation, a man standing downwind from the stack will evacuate the area after some finite time. To determine the dose received for this finite time it is necessary to consider the rate of fission product release from the stack. In this case, the time of release of gas atoms due to precursor decay must be considered. Therefore, filter holdup of precursors must be accounted for in the calculation. This is a time-dependent problem.

II. DATA

A. Source of Nuclear Data

The data for the production and decay of the noble gas (krypton and xenon) and radioiodine* fission products is obtained from USNRDL-TR-757, Table VII.[2] The table gives the activities $\lambda_n N_n$ (dis/sec) of individual radionuclides at various decay times t' following instantaneous fission of 8.435×10^5 atoms of ^{235}U. Here λ_n is the decay constant and N_n the number of atoms present at time t'.

The USNRDL data for the fission products considered is listed in Appendix A. The decay chain for each Kr, Xe, and I fission product is also included along with the half-life $T_{1/2}$ and decay constant $\lambda_n = 0.6931/T_{1/2}$ for each isotope in the decay chain. Precursors with extremely short half-lives (<1 sec) have been omitted.

For the data in Appendix A, t' = 0 is the time of instantaneous fission. Since it is assumed that all fissions occur 6 sec after the start of the accident, t' = 0 in the data tables corresponds to t = 6 in the problem. Therefore, 6 sec is added to all times in the USNRDL data when used in GASOUT.

After reading the decay constant and activities for each isotope in the decay scheme, GASOUT obtains the number of atoms of each isotope at each time by dividing $\lambda_n N_n$ by λ_n.

B. Interpolation

Linear interpolation of the USNRDL data is used to obtain the number of isotope atoms that exist at time t, assuming instantaneous fission of 8.435×10^5 ^{235}U atoms at t = 6 sec and no nonradioactive losses. GASOUT uses this number to calculate the distribution of the isotope in the cell, filter, and stack after a nuclear excursion has released fission products to the air in the cell.

No attempt has been made to renormalize the data to a different number of original fissions. This is easily accomplished at the conclusion of GASOUT calculations.

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* Isotopes of krypton, xenon, and iodine are the only radioactive gases given off in significant quantities in this type of accident.

III. RELEASE OF AIR FROM THE REACTOR CELL

The nuclear excursion postulated for the DBA causes molten fuel to be expelled from the reactor. A metal fire begins as soon as the fuel starts to flow. Also, sodium vapor is generated at a rate proportional to the heat flow into the sodium after the sodium boiling temperature is reached. The sodium vapor burns instantaneously. The heat generated by the burning vapor and liquid then immediately raises the temperature and pressure of the cell air. Subsequently, air-borne fission products are expelled from the cell.

Fuel flows onto the reactor bed and begins to burn at t = 13.0 sec. Up until this time no energy is released to the cell.

From 13.0 to 19.2 sec, the energy released to the cell due to burning vapor and liquid is given by

$$\Delta Q = 5.1 \times 10^4 \Delta t^* \text{ Btu},$$

where Δt is the time interval between successive calculations.

At 19.2 sec the temperature of sodium drops below the boiling point and no more sodium vapor is produced. From then on, the energy released to the cell by the burning liquid fuel and sodium is

$$\Delta Q = 920 \ \Delta t \ \text{ Btu}.$$

The pressure routine in GASOUT then proceeds as follows:

(1) The pressure increase due to heat input during a time interval Δt is calculated assuming a constant-volume process (a negligible fraction of air escapes the cell during Δt). Based on the perfect gas law,

$$PV = mRT,$$

we have

$$\Delta P = (mR/V)\,\Delta T.$$

For constant volume,

$$T = Q/mC_v,$$

*The expressions for energy released to the cell are obtained from Ch. 12, Ref. 1.

so that

$$\Delta P = (R/C_v)(\Delta Q/V).$$

Therefore

$$\Delta P = 2.13\ \Delta Q/V,$$

where

ΔQ = heat input to cell during Δt (Btu);

ΔP = pressure increase due to ΔQ heat input, psi;

V = cell volume;

T = temperature;

m = mass of air.

(2) A new cell pressure P_2 and average cell pressure $\overline{P}$ for time interval Δt are calculated:

$$P_2 = P_1 + \Delta P;\quad \overline{P} = P_1 + 0.5\ \Delta P,$$

when P_1 is the cell pressure at beginning of Δt.

(3) The change in cell air temperature is given by

$$\Delta T = (T_1/P_1)\Delta P,$$

where T_1 is the cell temperature at start of Δt.

(4) The new temperature and average temperature for interval Δt are calculated:*

$$T_2 = T_1 + \Delta T;\quad T = T_1 + 0.5\ \Delta T.$$

(5) The volume of air which flows out of the cell during Δt is calculated:

$$\Delta V = B(\overline{P} - P_0)\ \Delta t,$$

*Heat transfer to surrounding materials is not directly calculated by GASOUT. If it is ignored completely, however, the calculated temperature within the cell rises to unrealistic values and affects the computed pressures. DBA analysis indicates that at 20 sec the temperature in the cell reaches a maximum value of 1400°R. Therefore, GASOUT allows the temperature in the cell to rise to 1400°R and then holds it at that value for the remainder of the problem.

where

P_0 = atmospheric pressure;

B = flow rate through filter.

(6) The average specific volume $\overline{v}$ is obtained:

$$\overline{P}V = mR\overline{T};\ V/m = \overline{v} = R\overline{T}/\overline{P};\ \overline{v} = 0.37\ \overline{T}/\overline{P}.$$

(7) The change in cell air weight and a new cell air weight are obtained:

$$\Delta W = \Delta V/\overline{v};\ W_3 = W_1 - \Delta W,$$

where

W_1 = weight of cell air at beginning of Δt;

W_3 = weight of cell air at end of Δt.

(8) The fraction of air exhausted out of the cell is calculated:

$$f = \Delta W/W_1.$$

This will later be used as the fraction of fission product atoms in the cell leaving the cell during time interval Δt.

(9) The new pressure following air flow out of the cell is then

$$P_3 = P_2(W_3/W_1),$$

assuming isothermal expansion of the air. The assumption is considered valid for the time intervals chosen.

(10) The final values P_3, T_2, and W_3 of time interval Δt then become the initial values of the next time interval $\Delta t'$:

$$P_1' = P_3;\ T_1' = T_2;\ W_1' = W_3.$$

Table I lists the parameters used in the pressure calculation. A plot of pressure versus time is shown in Fig. 3.

TABLE I. Parameters for Pressure Calculations

Flow rate through sand filters (B)	40 ft^3 psig-sec
Cell volume	36,500 ft^3
Initial air temperature	530°R
Initial cell pressure	14.7 psia
Atmospheric pressure	14.7 psia
Initial weight of cell air	2700 lbs

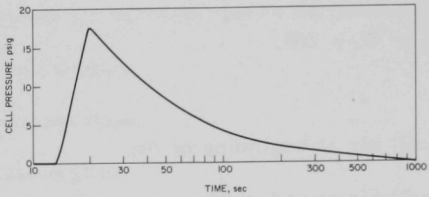

Fig. 3
Cell Pressure

IV. METHODS OF SOLUTION

GASOUT considers two methods of handling filter holdup of precursors, as discussed in Sect. I. The desired option is selected through the input parameter PATH as follows:

PATH=0 No holdup of precursors in filter; time-independent problem;

PATH=1 Precursors are held up in filter; time-dependent problem.

Another option discussed in Sect. I concerned the release of fission products to the air in the cell. The input parameter RATE selects the option as follows:

RATE=0 Instantaneous release of fission products at t = 13 sec;

RATE=1 Constant burning rate for one hour. Fraction of fuel burned in Δt_j sec is $\Delta t_j/3600$.

The options RATE and PATH allow for four different approaches to be taken. The simplest and most conservative approach is to consider instantaneous release of fission products to the cell with no filter holdup of precursors (RATE=0, PATH=0). If this does not give satisfactory results, more realistic approaches can be taken, the least conservative

being a constant burning rate with filter holdup of precursors (RATE=1, PATH=1). The simplest case is considered first.

A. Time-independent Problem; No Filter Holdup of Precursors

As an example of the calculational method consider the decay chain for radioiodine ^{134}I:

$$Sb(48\ sec) \rightarrow Te(42\ min) \rightarrow {}^{134}I(53\ min).$$

Let $I(t_j)$ be the average number of ^{134}I atoms during time interval Δt_j that would exist in the cell if there were no losses through the emergency exhaust system. Similar definitions hold for antimony and tellurium. These values are obtained from the USNRDL data described in Sect. II.

The calculation proceeds as follows:

(1) During the first time interval Δt_1, the fraction of air released from the cell is given by $f_1 = \Delta W(1)/W_1(1)$ (see Sect. III). The number of ^{134}I atoms released from the cell is therefore

$$f_1 I(t_1).$$

The number remaining in the cell is

$$(1 - f_1)\, I(t_1).$$

The corresponding numbers for the precursor atoms are

$$f_1[Sb(t_1) + Te(t_1)] \text{ released}$$

and

$$(1 - f_1)[Sb(t_1) + Te(t_1)] \text{ remaining.}$$

(2) After leaving the cell there is a delay time given by $T_1 = 140/P_1$ sec before the ^{134}I atoms leave the stack.

If $I(t_1 + T_1)$ is the number of ^{134}I atoms at time $t_1 + T_1$ (here t_1 represents the midpoint of interval Δt_1), then the fraction of ^{134}I atoms at time t_1 that exists at time $t_1 + T_1$ is $I(t_1 + T_1)/I(t_1)$. Thus the number of ^{134}I atoms released from the stack* due to the $f_1 I(t_1)$ atoms that leave the cell during Δt_1 is

$$G_g(t_1) = f_1 I(t_1)[I(t_1 + T_1)/I(t_1)] = f_1 I(t_1 + T_1).$$

*These atoms are released at time $t_1 + T_1$. Since only the total number of atoms released is important, the time of release is not considered here. However, it is important for the time-dependent problem and is discussed in Sect. IV-B.

In this method, filter holdup of precursors is not considered. The precursor atoms that leave the cell during Δt_1 will eventually decay into gas and be released from the stack. Again considering a delay time of $T = 140/\overline{P}_1$, the number of ^{134}I atoms released from the stack due to precursor atoms leaving the cell during Δt_1 is

$$G_p(t_1) = f_1[Sb(t_1 + T_1) + Te(t_1 + T_1)].$$

(3) The ^{134}I atoms left in the cell after time interval Δt_1 decay into

$$(1 - f_1)\, I(t_2)$$

atoms during the second interval Δt_1. The number of ^{134}I atoms released from the cell during the second interval is therefore

$$f_2(1 - f_1)\, I(t_2).$$

Similarly, the number of precursor atoms released from the cell during Δt_2 is

$$f_2(1 - f_1)[Sb(t_2) + Te(t_2)].$$

The number of ^{134}I atoms remaining in the cell after Δt_2 is then

$$(1 - f_2)(1 - f_1)\, I(t_2),$$

and the number of precursor atoms remaining is

$$(1 - f_2)(1 - f_1)[Sb(t_2) + Te(t_2)].$$

(4) The number of ^{134}I atoms leaving the stack due to ^{134}I atoms leaving the cell is

$$G_g(t_2) = f_2(1 - f_1)\, I(t_2 + T_2).$$

The number of ^{134}I atoms released from the stack due to precursor atoms leaving the cell is

$$G_p(t_2) = f_2(1 - f_1)[Sb(t_2 + T_2) + Te(t_2 + T_2)].$$

Here $T_2 = 140/\overline{P}_2$ is the piping delay time.

(5) In general, the number of ^{134}I atoms released from the cell during time interval Δt_j is

$$f_j \left[\prod_{i=1}^{j-1} (1 - f_i) \right] I(t_j).$$

The number remaining in the cell is

$$(1 - f_j) \left[\prod_{i=1}^{j-1} (1 - f_i) \right] I(t_j).$$

Similar expressions exist for the precursors.

(6) The number of ^{134}I atoms released from the stack due to ^{134}I atoms released from the cell during Δt_j is

$$G_g(t_j) = f_j \left[\prod_{i=1}^{j-1} (1 - f_i) \right] I(t_j + T_j).$$

The number of ^{134}I atoms released from the stack due to precursor atoms leaving the cell during Δt_j is

$$G_p(t_j) = f_j \left[\prod_{i=1}^{j-1} (1 - f_i) \right] \left[Sb(t_j + T_j) + Te(t_j + T_j) \right].$$

Again, $T_j = 140/\overline{P}_j$ is the delay time for interval Δt_j.

(7) Finally, the number of ^{134}I atoms remaining in the cell after a time period divided into J intervals is

$$(1 - f_J) \left[\prod_{i=1}^{J-1} (1 - f_i) \right] I(t_J).$$

The number of precursor atoms remaining is

$$(1 - f_J) \left[\prod_{i=1}^{J-1} (1 - f_i) \right] \left[Sb(t_J) + Te(t_J) \right].$$

The total number of ^{134}I atoms released from the stack due to ^{134}I atoms released from the cell is

$$\sum_{j=1}^{J} G_g(t_j) = \sum_{j=1}^{J} f_j \left[\prod_{i=1}^{j-1} (1 - f_i) \right] I(t_j + T_j).$$

The total number of ^{134}I atoms released from the stack due to precursor atoms released from the cell is

$$\sum_{j=1}^{J} G_p(t_j) = \sum_{j=1}^{J} f_j \left[\prod_{i=1}^{j-1} (1 - f_i)\right] \left[Sb(t_j + T_j) + Te(t_j + T_j)\right].$$

In this example the total number of ^{134}I atoms released from the stack is

$$\sum_{j=1}^{J} \left[G_g(t_j) + G_p(t_j)\right].$$

Consider, however, the decay chain for ^{89}Kr:

$$\begin{array}{lcl} & \overset{11.8\%}{\nearrow} & {}^{88}Kr \\ Se(2\ sec) \longrightarrow Br(4.4\ sec) & & \\ & \underset{88.2\%}{\longrightarrow} & {}^{89}Kr. \end{array}$$

Here only 88.2% of the precursor atoms that leave the cell will decay into ^{89}Kr atoms. Setting $\chi = 0.882$, the total number of ^{89}Kr atoms released from the stack is

$$\sum_{j=1}^{J} \left[G_g(t_j) + \chi G_p(t_j)\right].$$

The input parameter χ gives the fraction of precursor atoms that decay into gas atoms.

Reference to Fig. 3 indicates that the gauge pressure in the cell reaches 0.0 psig at t = 16 min. At this point $f_j = \Delta W/W = 0.0$, and fission product release from the cell is stopped. Thus, to obtain the total number of gas atoms released from the stack it is only necessary to continue the calculation until $\overline{P} = 0.0$.

B. Time-dependent Problem; Filter Holdup of Precursors

Consider the case where the man standing downwind leaves after some finite time. To determine the dose received during this time, the holdup of precursors in the filter must be accounted for. The rate of release of gas atoms out the stack is calculated.

The number of ^{134}I atoms leaving the cell during time interval Δt_j was shown to be

$$f_j \left[\prod_{i=1}^{j-1} (1 - f_i) \right] I(t_j).$$

After a delay time $T_j = 140/\overline{P}_j$,

$$G_g(t_j) = f_j \left[\prod_{i=1}^{j-1} (1 - f_i) \right] I(t_j + T_j).$$

^{134}I atoms are released from the stack. The time $t_j + T_j$ falls in some time interval denoted by $\Delta t_k (k \geq j)$. The number $G_g(t_j)$ is stored in the array O:

$$O(k) = O(k) + G_g(t_j).$$

Thus, the number of ^{134}I atoms released from the stack during the time interval Δt_k will be contained in the array element O(k). Note that O contains only the number of ^{134}I atoms released from the stack due to ^{134}I atoms released from the cell.

The number of precursor atoms leaving the cell during time interval Δt_j is

$$M = f_j \left[\prod_{i=1}^{j-1} (1 - f_i) \right] \left[Sb(t_j) + Te(t_j) \right].$$

The time for these precursor atoms to reach the filter is $\gamma_j = 110/\overline{P}_j$. The number of precursor atoms arriving at the filter is

$$N = f_j \left[\prod_{i=1}^{j-1} (1 - f_i) \right] \left[Sb(t_j + \gamma_j) + Te(t_j + \gamma_j) \right].$$

Thus, N precursor atoms arrive at the filter at time $t_j + \gamma_j$ which falls in some time interval $\Delta t_\ell (\ell \geq j)$. The number N is stored in the array F:

$$F(\ell) = F(\ell) + N.$$

If F_j' represents the number of precursor atoms in the filter at the beginning of time interval Δt_j, the number in the filter during Δt_j is taken to be

$$F_j = F_j' + F(j),$$

where F(j) is the number of precursor atoms arriving at the filter during Δt_j.

Once the number of precursor atoms in the filter for time interval Δt_j has been determined, the decay of these atoms into ^{134}I atoms can be considered. The fraction of precursor atoms decaying into ^{134}I atoms during Δt_j can be obtained from the USNRDL data. This fraction is given by

$$\phi_j = \{[Sb(t_{j-1}) + Te(t_{j-1})] - [Sb(t_j) + Te(t_j)]\}/[Sb(t_{j-1}) + Te(t_{j-1})].$$

Therefore, $\phi_j F_j$ precursor atoms in the filter decay into ^{134}I atoms during Δt_j. These ^{134}I atoms are assumed to leave the stack during Δt_j. Thus,

$$G_P(t_j) = \phi_j F_j.$$

The total number of ^{134}I atoms released from the stack during time interval Δt_j is then

$$O(j) + \phi_j F_j.$$

For a finite time interval divided into J intervals the total number of ^{134}I atoms released from the stack is

$$\sum_{j=1}^{J} \left[O(j) + \phi_j F_j \right].$$

Now consider the decay chain for ^{89}Kr, for which only 88.2% of the precursors decay into ^{89}Kr:

$$\text{Se(2 sec)} \longrightarrow \text{Br(4.4 sec)} \begin{array}{l} \xrightarrow{11.8\%} {}^{88}\text{Kr} \\ \xrightarrow[88.2\%]{} {}^{89}\text{Kr}. \end{array}$$

In this case the total number of ^{89}Kr atoms released from the stack during T_J is

$$\sum_{j=1}^{J} \left[O(j) + \chi \phi_j F_j \right],$$

where $\chi = 0.882$.

C. Constant Burning Rate

The methods discussed so far have assumed instantaneous release of all fission products to the cell air at t = 13 sec. This gives a conservative estimate of the amount released out the stack since the total number

of atoms is immediately available for release from the cell. Actually, fission products are released to the cell air only after the fuel burns. Assume that it takes one hour to burn all the fuel at a constant burning rate. Then the fraction of available fuel burned in time interval Δt_j sec is $B_j = \Delta t_j/3600$.

In time interval Δt_1 the number of ^{134}I atoms released to the cell air is then

$$B_1 I(t_1),$$

and the number released from the cell is

$$f_1 B_1 I(t_1).$$

Also,

$$(1 - f_1)\ B_1 I(t_1)$$

is the number remaining in the cell.

In time interval Δt_2, $B_2 I(t_2)$ additional ^{134}I atoms are released to the cell air and are added to those remaining from interval Δt_1. The number of ^{134}I atoms in the cell is then

$$(1 - f_1)\ B_1 I(t_1) + B_2 I(t_2).$$

Therefore, the amount released from the cell during interval Δt_2 is

$$f_2[(1 - f_1)\ B_1 I(t_1) + B_2 I(t_2)],$$

and the amount remaining is

$$(1 - f_2)[(1 - f_1)\ B_1 I(t_1) + B_2 I(t_2)].$$

This process is then continued for all time intervals. If X is the number of ^{134}I atoms in the cell after interval Δt_{j-1}, the number during interval Δt_j is

$$X + B_j I(t_j),$$

and the number released from the cell is

$$f_j[X + B_j I(t_j)].$$

Similar expressions hold for the precursor atoms. Once the number of atoms out the cell has been determined, the number out the stack is determined as in one of the two previous methods.

V. INPUT AND OUTPUT

A. Input

The input required by GASOUT defining problem type and providing isotope decay data is listed in Table II.

TABLE II. GASOUT Input Data

Card Type	Format	Item	Description
1	20A4	IDENT	Problem identification.
2	4I6	N1	Number of activities to be read in for each isotope.
		RATE	=0, instantaneous release of fission products to cell.
			=1, constant burning rate for one hour.
		PATH	=0, no filter holdup of precursor atoms.
			=1, filter holdup of precursor atoms.
		J	Print output every Jth time step.
3	3E12.5	DTX	Time interval Δt_j.
		FINTIM	Total problem time.
		CHI	Fraction of precursor atoms that decay into gas.
4	A4, E12.5	NAMEA	Isotope name.
		LAMBA	Decay constant $\lambda \neq 0$.
5	6E12.5	A1(I), I=1, N1	Activities $\lambda_n N_n$ at each time t(I).
Card sets 4 and 5 are repeated for six isotopes in a decay chain. If there are less than six, dummy isotopes must be provided. Input the noble gas or radioiodine isotope first.			
6	I6	EOF	$\neq 0$, stop. =0, continue.

The isotope data consist of the name, decay constant λ_n, and activities $\lambda_n N_n(I)$ at decay times t(I) for each isotope in the decay chain of the noble gas or radioiodine fission product. GASOUT has provision for six isotopes in a decay chain. If there are less than six, dummy isotopes must be provided. The λ_n input for the dummy isotopes must be nonzero.

The data as described in Sect. II are listed in Appendix A. The number of activities to be input for each isotope is given by the parameter N1, which must be chosen so that the time t(N1) is greater than or equal to the total time of the problem:

$$t(N1) \geq FINTIM.$$

B. Output

For every Jth time interval (see Table II), GASOUT lists the following quantities concerning the release of fission products from the cell:

(1) the time at the end of the time interval;

(2) the number of gas atoms remaining in the cell at the end of the time interval;

(3) the total number of precursor atoms remaining in the cell at the end of the time interval;

(4) the number of gas atoms released from the cell during the time interval;

(5) the total number of precursor atoms released from the cell during the time interval.

The total number of gas atoms and precursor atoms released during the problem is also listed.

Two numbers are listed for the release of gas atoms from the stack for each every Jth time interval:

GG_j = gas atoms released from the stack due to gas atoms released from the cell;

GP_j = gas atoms released from the stack due to precursor atoms released from the cell.

The totals of the GG and GP are then listed along with the final number of gas atoms released from the stack:

$$\sum_{j=1}^{J} GG_j + \chi \left[\sum_{j=1}^{J} GP_j \right].$$

Recall that these numbers correspond to the instantaneous fission of 8.435×10^5 ^{235}U atoms at t = 6 sec. Normalization to other initial conditions can take place at this time.

Appendix B contains a sample problem including examples of GASOUT input and output. Results obtained for the noble gas and radioiodine fission products listed in Table A1 are also included.

A listing of the code is included in Appendix C.

APPENDIX A

Data

Table A1 lists the decay chains for each of the Kr, Xe, and I fission products considered by GASOUT. The half-life for each isotope appears in parentheses.

TABLE A1. Noble Gas and Radioiodine Decay Chains

(half-lives in parentheses)

^{83}Kr	Ge(2.0 sec) → As(7.0 sec) → 44% Se_1(69.0 sec) 90% → Br(2.4 hr) → Kr(1.9 hr); Se_1 → 10% → Se_2(25.0 min) → Br(2.4 hr); As(7.0 sec) → 56% Se_2(25.0 min)
^{85}Kr	Se(39.0 sec) → Br(3.0 min) → Kr(4.4 hr)
^{87}Kr	As(1.5 sec) → Se(16.0 sec) → Br(54.5 sec) → 97% Kr(78.0 min); Br(54.5 sec) → 3% n
^{88}Kr	Se(2.5 sec) → Br(16.3 sec) → 7% ^{87}Kr + n; Br(16.3 sec) → 93% ^{88}Kr(2.8 hr)
^{89}Kr	Se(2.0 sec) → Br(4.4 sec) → 11.8% ^{88}Kr + n; Br(4.4 sec) → 88.2% ^{89}Kr(3.2 min)
^{90}Kr	Br(1.6 sec) → 15% ^{89}Kr + n; Br(1.6 sec) → 85% ^{90}Kr(33.0 sec)
^{91}Kr	Br(2.0 sec) → Kr(10.0 sec)
^{135}Xe I and II	Sb(6.0 sec) → Te(1.4 min) → I(6.7 hr) → 30% Xe_I(15.3 min); I(6.7 hr) → 70% Xe_{II}(9.2 hr); Xe_I → Xe_{II}
^{137}Xe	Te(3.0 sec) → I(24.4 sec) → 96% Xe(3.9 min); I(24.4 sec) → 4% n
^{138}Xe	Te(2.0 sec) → I(6.3 sec) → 3% ^{137}Xe + n; I(6.3 sec) → 97% ^{138}Xe(17.0 min)

TABLE A1 (Contd.)

^{139}Xe I(2.0 sec) $\xrightarrow{4\%}$ ^{138}Xe + n ; I(2.0 sec) $\xrightarrow{96\%}$ ^{139}Xe(41.0 sec)

^{140}Xe I(1.5 sec) $\longrightarrow$ Xe(16.0 sec)

^{131}I In(1.0 sec) $\longrightarrow$ Sn(3.4 min) $\longrightarrow$ Sb(23.0 min) $\xrightarrow{15\%}$ Te$_1$(30.0 hr) $\xrightarrow{80\%}$ I(8.05 d) ; Te$_1$(30.0 hr) $\xrightarrow{20\%}$ Te$_2$(24.0 min) ; Sb(23.0 min) $\xrightarrow{85\%}$ Te$_2$(24.0 min) $\longrightarrow$ I(8.05 d)

^{132}I Sn(2.2 min) $\longrightarrow$ Sb(2.1 min) $\longrightarrow$ Te(78.0 hr) $\longrightarrow$ I(2.3 hr)

^{133}I Sn(2.0 sec) $\longrightarrow$ Sb(4.1 min) $\xrightarrow{72\%}$ Te$_1$(52.0 min) $\xrightarrow{87\%}$ I(20.8 hr) ; Te$_1$(52.0 min) $\xrightarrow{13\%}$ Te$_2$(2.0 min) ; Sb(4.1 min) $\xrightarrow{28\%}$ Te$_2$(2.0 min) $\longrightarrow$ I(20.8 hr)

^{134}I Sb(48.0 sec) $\longrightarrow$ Te(42.0 min) $\longrightarrow$ I(53.0 min)

^{135}I Sb(6.0 sec) $\longrightarrow$ Te(1.4 min) $\longrightarrow$ I(6.7 hr)

Table A2 gives the activities $\lambda_n N_n$ of individual radionuclides at various decay times following instantaneous fission of 8.435×10^5 atoms of ^{235}U.[2] The decay times listed are in seconds. The unit of activity is d/sec per 8.435×10^5 fissions. Listed immediately under each isotope name is its decay constant $\lambda_n = 0.6931/T_{1/2}$.

TABLE A2. Activities vs Decay Time

KR-83

TIME	GE	AS	SE1	SE2
	0.347E 00	0.990E-01	0.100E-01	0.460E-03
0.	0.591E 03	0.191E 03	0.282E 01	0.130E 00
1.	0.510E 03	0.230E 03	0.373E 01	0.185E 00
10.	0.225E 02	0.169E 03	0.119E 02	0.710E 00
25.	0.124E 00	0.403E 02	0.158E 02	0.107E 01
40.	0.687E-03	0.913E 01	0.148E 02	0.115E 01
63.	0.237E-06	0.936E 00	0.121E 02	0.117E 01
100.	0.000E 00	0.240E-01	0.837E 01	0.117E 01
160.	0.000E 00	0.631E-04	0.458E 01	0.116E 01
250.	0.000E 00	0.850E-08	0.185E 01	0.112E 01
400.	0.000E 00	0.000E 00	0.411E 00	0.106E 01
630.	0.000E 00	0.000E 00	0.908E-01	0.951E 00
1000.	0.000E 00	0.000E 00	0.991E-03	0.802E 00
1600.	0.000E 00	0.000E 00	0.239E-05	0.607E 00
2500.	0.000E 00	0.000E 00	0.283E-09	0.401E 00
4000.	0.000E 00	0.000E 00	0.000E 00	0.200E 00
6300.	0.000E 00	0.000E 00	0.000E 00	0.692E-01
10000.	0.000E 00	0.000E 00	0.000E 00	0.125E-01
16000.	0.000E 00	0.000E 00	0.000E 00	0.783E-03
25000.	0.000E 00	0.000E 00	0.000E 00	0.122E-04
40000.	0.000E 00	0.000E 00	0.000E 00	0.119E-07
63000.	0.000E 00	0.000E 00	0.000E 00	0.000E 00

TIME	BR	KR83
	0.800E-04	0.101E-03
0.	0.483E-03	0.000E 00
1.	0.731E-03	0.598E-07
10.	0.637E-02	0.285E-05
25.	0.233E-01	0.248E-04
40.	0.413E-01	0.740E-04
63.	0.653E-01	0.199E-03
100.	0.961E-01	0.505E-03
160.	0.128E 00	0.119E-02
250.	0.155E 00	0.248E-02
400.	0.177E 00	0.497E-02
630.	0.194E 00	0.414E-02
1000.	0.215E 00	0.163E-01
1600.	0.237E 00	0.288E-01
2500.	0.255E 00	0.479E-01
4000.	0.259E 00	0.777E-01
6300.	0.236E 00	0.113E 00
10000.	0.183E 00	0.143E 00
16000.	0.115E 00	0.143E 00
25000.	0.558E-01	0.104E 00
40000.	0.168E-01	0.445E-01
63000.	0.265E-02	0.922E-02

TABLE A2 (Contd.)

KR-85

TIME	SE	BR	KR85
	0.178E-01	0.384E-02	0.438E-04
0.	0.913E 02	0.812E 01	0.205E-02
1.	0.137E 03	0.855E 01	0.241E-02
10.	0.132E 03	0.131E 02	0.669E-02
25.	0.101E 03	0.189E 02	0.173E-01
40.	0.777E 02	0.228E 02	0.310E-01
63.	0.516E 02	0.263E 02	0.559E-01
100.	0.268E 02	0.278E 02	0.100E 00
160.	0.921E 01	0.254E 02	0.170E 00
250.	0.186E 01	0.192E 02	0.257E 00
400.	0.129E 00	0.110E 02	0.352E 00
630.	0.217E-02	0.457E 01	0.422E 00
1000.	0.302E-05	0.110E 01	0.454E 00
1600.	0.707E-10	0.109E 00	0.454E 00
2500.	0.000E 00	0.341E-02	0.437E 00
4000.	0.000E 00	0.106E-04	0.410E 00
6300.	0.000E 00	0.150E-08	0.370E 00
10000.	0.000E 00	0.000E 00	0.315E 00
16000.	0.000E 00	0.000E 00	0.242E 00
25000.	0.000E 00	0.000E 00	0.163E 00
40000.	0.000E 00	0.000E 00	0.848E-01
63000.	0.000E 00	0.000E 00	0.310E-01

KR-87

TIME	AS	SE	BR	KR87
	0.462E 00	0.433E-01	0.127E-01	0.148E-03
0.	0.725E 03	0.329E 03	0.115E 03	0.410E 00
1.	0.457E 03	0.340E 03	0.118E 03	0.433E 00
10.	0.714E 01	0.261E 03	0.138E 03	0.663E 00
25.	0.697E-02	0.137E 03	0.147E 03	0.105E 01
40.	0.681E-05	0.715E 02	0.139E 03	0.139E 01
63.	0.165E-09	0.264E 02	0.115E 03	0.184E 01
100.	0.000E 00	0.531E 01	0.765E 02	0.234E 01
160.	0.000E 00	0.395E 00	0.365E 02	0.279E 01
250.	0.000E 00	0.800E-02	0.117E 02	0.303E 01
400.	0.000E 00	0.120E-04	0.173E 01	0.308E 01
630.	0.000E 00	0.567E-09	0.930E-01	0.299E 01
1000.	0.000E 00	0.000E 00	0.841E-03	0.284E 01
1600.	0.000E 00	0.000E 00	0.408E-06	0.259E 01
2500.	0.000E 00	0.000E 00	0.000E 00	0.227E 01
4000.	0.000E 00	0.000E 00	0.000E 00	0.182E 01
6300.	0.000E 00	0.000E 00	0.000E 00	0.129E 01
10000.	0.000E 00	0.000E 00	0.000E 00	0.748E 00
16000.	0.000E 00	0.000E 00	0.000E 00	0.307E 00
25000.	0.000E 00	0.000E 00	0.000E 00	0.811E-01
40000.	0.000E 00	0.000E 00	0.000E 00	0.879E-02
63000.	0.000E 00	0.000E 00	0.000E 00	0.291E-03

KR-88

TIME	SE	BR	KR88
	0.277E 00	0.425E-01	0.688E-04
0.	0.193E 04	0.610E 03	0.504E 00
1.	0.160E 04	0.661E 03	0.566E 00
10.	0.132E 03	0.625E 03	0.107E 01
25.	0.207E 01	0.343E 03	0.156E 01
40.	0.323E-01	0.181E 03	0.181E 01
63.	0.549E-04	0.682E 02	0.198E 01
100.	0.193E-08	0.141E 02	0.205E 01
160.	0.000E 00	0.110E 01	0.206E 01
250.	0.000E 00	0.240E-01	0.205E 01
400.	0.000E 00	0.407E-04	0.203E 01
630.	0.000E 00	0.230E-08	0.200E 01
1000.	0.000E 00	0.000E 00	0.195E 01
1600.	0.000E 00	0.000E 00	0.187E 01
2500.	0.000E 00	0.000E 00	0.176E 01
4000.	0.000E 00	0.000E 00	0.159E 01
6300.	0.000E 00	0.000E 00	0.135E 01
10000.	0.000E 00	0.000E 00	0.105E 01
16000.	0.000E 00	0.000E 00	0.695E 00
25000.	0.000E 00	0.000E 00	0.374E 00
40000.	0.000E 00	0.000E 00	0.133E 00
63000.	0.000E 00	0.000E 00	0.274E-01

KR-89

TIME	SE	BR	KR89
	0.347E 00	0.157E 00	0.361E-02
0.	0.164E 04	0.266E 04	0.533E 02
1.	0.120E 04	0.248E 04	0.646E 02
10.	0.529E 02	0.798E 03	0.112E 03
25.	0.292E 00	0.790E 02	0.121E 03
40.	0.161E-01	0.746E 01	0.116E 03
63.	0.558E-06	0.199E 00	0.107E 03
100.	0.150E-11	0.586E-03	0.934E 02
160.	0.000E 00	0.460E-07	0.752E 02
250.	0.000E 00	0.000E 00	0.544E 02
400.	0.000E 00	0.000E 00	0.316E 02
630.	0.000E 00	0.000E 00	0.138E 02
1000.	0.000E 00	0.000E 00	0.363E 01
1600.	0.000E 00	0.000E 00	0.416E 00
2500.	0.000E 00	0.000E 00	0.161E-01
4000.	0.000E 00	0.000E 00	0.717E-04
6300.	0.000E 00	0.000E 00	0.178E-07
10000.	0.000E 00	0.000E 00	0.000E 00
16000.	0.000E 00	0.000E 00	0.000E 00
25000.	0.000E 00	0.000E 00	0.000E 00
40000.	0.000E 00	0.000E 00	0.000E 00
63000.	0.000E 00	0.000E 00	0.000E 00

TABLE A2 (Contd.)

KR-90

TIME	BR	KR90
	0.433E 00	0.210E-01
0.	0.658E 04	0.466E 03
1.	0.499E 04	0.566E 03
10.	0.101E 03	0.643E 03
25.	0.152E 00	0.472E 03
40.	0.229E-03	0.345E 03
63.	0.108E-07	0.213E 03
100.	0.000E 00	0.978E 02
160.	0.000E 00	0.277E 02
250.	0.000E 00	0.419E 01
400.	0.000E 00	0.179E 00
630.	0.000E 00	0.143E-02
1000.	0.000E 00	0.603E-06
1600.	0.000E 00	0.203E-11
2500.	0.000E 00	0.000E 00
4000.	0.000E 00	0.000E 00
6300.	0.000E 00	0.000E 00
10000.	0.000E 00	0.000E 00
16000.	0.000E 00	0.000E 00
25000.	0.000E 00	0.000E 00
40000.	0.000E 00	0.000E 00
63000.	0.000E 00	0.000E 00

KR-91

TIME	BR	KR91
	0.347E 00	0.693E-01
0.	0.322E 04	0.158E 04
1.	0.237E 04	0.166E 04
10.	0.105E 03	0.118E 04
25.	0.578E 00	0.427E 03
40.	0.319E-02	0.151E 03
63.	0.110E-05	0.307E 02
100.	0.297E-11	0.236E 01
160.	0.000E 00	0.369E-01
250.	0.000E 00	0.720E-04
400.	0.000E 00	0.220E-08
630.	0.000E 00	0.000E 00
1000.	0.000E 00	0.000E 00
1600.	0.000E 00	0.000E 00
2500.	0.000E 00	0.000E 00
4000.	0.000E 00	0.000E 00
6300.	0.000E 00	0.000E 00
10000.	0.000E 00	0.000E 00
16000.	0.000E 00	0.000E 00
25000.	0.000E 00	0.000E 00
40000.	0.000E 00	0.000E 00
63000.	0.000E 00	0.000E 00

TABLE A2 (Contd.)

XE-135, 1 AND 2

TIME	SB	TE	I	XE1
	0.115E 00	0.825E-02	0.287E-04	0.755E-03
0.	0.426E 03	0.157E 03	0.691E 00	0.296E 01
1.	0.379E 03	0.159E 03	0.695E 00	0.296E 01
10.	0.134E 03	0.164E 03	0.737E 00	0.294E 01
25.	0.237E 02	0.152E 03	0.806E 00	0.291E 01
40.	0.419E 01	0.136E 03	0.867E 00	0.288E 01
63.	0.294E 00	0.113E 03	0.949E 00	0.284E 01
100.	0.409E-02	0.830E 02	0.105E 01	0.277E 01
160.	0.400E-05	0.506E 02	0.116E 01	0.266E 01
250.	0.122E-09	0.241E 02	0.125E 01	0.251E 01
400.	0.000E 00	0.698E 01	0.130E 01	0.228E 01
630.	0.000E 00	0.105E 01	0.132E 01	0.198E 01
1000.	0.000E 00	0.494E-01	0.131E 01	0.159E 01
1600.	0.000E 00	0.349E-03	0.128E 01	0.115E 01
2500.	0.000E 00	0.208E-06	0.125E 01	0.772E 00
4000.	0.000E 00	0.000E 00	0.120E 01	0.497E 00
6300.	0.000E 00	0.000E 00	0.112E 01	0.372E 00
10000.	0.000E 00	0.000E 00	0.101E 01	0.316E 00
16000.	0.000E 00	0.000E 00	0.849E 00	0.265E 00
25000.	0.000E 00	0.000E 00	0.655E 00	0.204E 00
40000.	0.000E 00	0.000E 00	0.426E 00	0.133E 00
63000.	0.000E 00	0.000E 00	0.220E 00	0.686E-01

TIME	XE2
	0.209E-04
0.	0.821E-01
1.	0.822E-01
10.	0.828E-01
25.	0.839E-01
40.	0.849E-01
63.	0.866E-01
100.	0.892E-01
160.	0.935E-01
250.	0.998E-01
400.	0.110E 00
630.	0.124E 00
1000.	0.144E 00
1600.	0.170E 00
2500.	0.201E 00
4000.	0.240E 00
6300.	0.287E 00
10000.	0.346E 00
16000.	0.416E 00
25000.	0.474E 00
40000.	0.490E 00
63000.	0.420E 00

TABLE A2 (Contd.)

XE-137

TIME	TE	I	XE
	0.231E 00	0.284E-01	0.296E-02
0.	0.897E 03	0.527E 03	0.665E 02
1.	0.712E 03	0.535E 03	0.679E 02
10.	0.889E 02	0.479E 03	0.798E 02
25.	0.278E 01	0.321E 03	0.931E 02
40.	0.869E-01	0.210E 03	0.100E 03
63.	0.427E-03	0.109E 03	0.103E 03
100.	0.828E-07	0.381E 02	0.991E 02
160.	0.000E 00	0.693E 01	0.857E 02
250.	0.000E 00	0.538E 00	0.662E 02
400.	0.000E 00	0.758E-02	0.425E 02
630.	0.000E 00	0.110E-04	0.215E 02
1000.	0.000E 00	0.300E-09	0.719E 01
1600.	0.000E 00	0.000E 00	0.122E 01
2500.	0.000E 00	0.000E 00	0.845E-01
4000.	0.000E 00	0.000E 00	0.993E-03
6300.	0.000E 00	0.000E 00	0.109E-05
10000.	0.000E 00	0.000E 00	0.190E-10
16000.	0.000E 00	0.000E 00	0.000E 00
25000.	0.000E 00	0.000E 00	0.000E 00
40000.	0.000E 00	0.000E 00	0.000E 00
63000.	0.000E 00	0.000E 00	0.000E 00

XE-138

TIME	TE	I	XE
	0.347E 00	0.110E 00	0.679E-03
0.	0.371E 03	0.123E 04	0.158E 02
1.	0.263E 03	0.114E 04	0.166E 02
10.	0.116E 02	0.463E 03	0.211E 02
25.	0.641E-01	0.899E 02	0.231E 02
40.	0.354E-03	0.173E 02	0.233E 02
63.	0.122E-06	0.137E 01	0.231E 02
100.	0.000E 00	0.234E-01	0.225E 02
160.	0.000E 00	0.318E-04	0.216E 02
250.	0.000E 00	0.159E-08	0.203E 02
400.	0.000E 00	0.000E 00	0.184E 02
630.	0.000E 00	0.000E 00	0.157E 02
1000.	0.000E 00	0.000E 00	0.122E 02
1600.	0.000E 00	0.000E 00	0.812E 01
2500.	0.000E 00	0.000E 00	0.441E 01
4000.	0.000E 00	0.000E 00	0.159E 01
6300.	0.000E 00	0.000E 00	0.333E 00
10000.	0.000E 00	0.000E 00	0.270E-01
16000.	0.000E 00	0.000E 00	0.457E-03
25000.	0.000E 00	0.000E 00	0.101E-05
40000.	0.000E 00	0.000E 00	0.377E-10
63000.	0.000E 00	0.000E 00	0.000E 00

TABLE A2 (Contd.)

XE-139

TIME	I	XE
	0.347E 00	0.169E-01
0.	0.227E 04	0.392E 03
1.	0.162E 04	0.417E 03
10.	0.717E 02	0.423E 03
25.	0.396E 00	0.331E 03
40.	0.219E-02	0.257E 03
63.	0.755E-06	0.174E 03
100.	0.204E-11	0.931E 02
160.	0.000E 00	0.338E 02
250.	0.000E 00	0.738E 01
400.	0.000E 00	0.584E 00
630.	0.000E 00	0.120E-01
1000.	0.000E 00	0.230E-04
1600.	0.000E 00	0.903E-09
2500.	0.000E 00	0.000E 00
4000.	0.000E 00	0.000E 00
6300.	0.000E 00	0.000E 00
10000.	0.000E 00	0.000E 00
16000.	0.000E 00	0.000E 00
25000.	0.000E 00	0.000E 00
40000.	0.000E 00	0.000E 00
63000.	0.000E 00	0.000E 00

XE-140

TIME	I	XE
	0.462E 00	0.433E-01
0.	0.111E 04	0.738E 03
1.	0.702E 03	0.745E 03
10.	0.110E 02	0.552E 03
25.	0.107E-01	0.289E 03
40.	0.105E-04	0.151E 03
63.	0.253E-09	0.557E 02
100.	0.000E 00	0.112E 02
160.	0.000E 00	0.833E 00
250.	0.000E 00	0.169E-01
400.	0.000E 00	0.254E-04
630.	0.000E 00	0.120E-08
1000.	0.000E 00	0.000E 00
1600.	0.000E 00	0.000E 00
2500.	0.000E 00	0.000E 00
4000.	0.000E 00	0.000E 00
6300.	0.000E 00	0.000E 00
10000.	0.000E 00	0.000E 00
16000.	0.000E 00	0.000E 00
25000.	0.000E 00	0.000E 00
40000.	0.000E 00	0.000E 00
63000.	0.000E 00	0.000E 00

TABLE A2 (Contd.)

I_{-131}

TIME	IN	SN	SB	TE1
	0.693E 00	0.340E-02	0.502E-03	0.642E-05
0.	0.103E 04	0.279E 02	0.555E 01	0.125E-01
1.	0.517E 03	0.304E 02	0.556E 01	0.125E-01
10.	0.101E 01	0.319E 02	0.568E 01	0.125E-01
25.	0.308E-04	0.303E 02	0.587E 01	0.126E-01
40.	0.941E-09	0.288E 02	0.605E 01	0.127E-01
63.	0.000E 00	0.267E 02	0.630E 01	0.128E-01
100.	0.000E 00	0.235E 02	0.664E 01	0.130E-01
160.	0.000E 00	0.192E 02	0.708E 01	0.134E-01
250.	0.000E 00	0.141E 02	0.749E 01	0.141E-01
400.	0.000E 00	0.848E 01	0.775E 01	0.151E-01
630.	0.000E 00	0.388E 01	0.754E 01	0.168E-01
1000.	0.000E 00	0.110E 01	0.663E 01	0.193E-01
1600.	0.000E 00	0.144E 00	0.502E 01	0.226E-01
2500.	0.000E 00	0.675E-02	0.321E 01	0.260E-01
4000.	0.000E 00	0.413E-02	0.151E 01	0.289E-01
6300.	0.000E 00	0.167E-07	0.476E 00	0.305E-01
10000.	0.000E 00	0.000E 00	0.742E-01	0.305E-01
16000.	0.000E 00	0.000E 00	0.365E-02	0.295E-01
25000.	0.000E 00	0.000E 00	0.397E-04	0.279E-01
40000.	0.000E 00	0.000E 00	0.212E-07	0.253E-01
63000.	0.000E 00	0.000E 00	0.000E 00	0.218E-01

TIME	TE2	I131
	0.481E-03	0.996E-06
0.	0.934E 00	0.794E-04
1.	0.936E 00	0.804E-04
10.	0.952E 00	0.889E-04
25.	0.981E 00	0.104E-03
40.	0.101E 01	0.119E-03
63.	0.106E 01	0.142E-03
100.	0.114E 01	0.183E-03
160.	0.127E 01	0.256E-03
250.	0.148E 01	0.380E-03
400.	0.183E 01	0.629E-03
630.	0.232E 01	0.111E-02
1000.	0.293E 01	0.209E-02
1600.	0.343E 01	0.402E-02
2500.	0.341E 01	0.715E-02
4000.	0.260E 01	0.117E-01
6300.	0.132E 01	0.162E-01
10000.	0.345E 00	0.189E-01
16000.	0.344E-01	0.197E-01
25000.	0.618E-02	0.199E-01
40000.	0.513E-02	0.200E-01
63000.	0.443E-02	0.201E-01

TABLE A2 (Contd.)

I-132

TIME	SN	SB	TE	I132
	0.525E-02	0.550E-02	0.247E-05	0.837E-04
0.	0.391E 02	0.956E 02	0.254E-01	0.118E 00
1.	0.410E 02	0.953E 02	0.256E-01	0.118E 00
10.	0.392E 02	0.926E 02	0.277E-01	0.118E 00
25.	0.362E 02	0.883E 02	0.311E-01	0.118E 00
40.	0.334E 02	0.840E 02	0.343E-01	0.118E 00
63.	0.296E 02	0.778E 02	0.389E-01	0.117E 00
100.	0.244E 02	0.684E 02	0.455E-01	0.117E 00
160.	0.178E 02	0.550E 02	0.546E-01	0.117E 00
250.	0.111E 02	0.390E 02	0.650E-01	0.116E 00
400.	0.505E 01	0.212E 02	0.758E-01	0.116E 00
630.	0.151E 01	0.783E 01	0.834E-01	0.115E 00
1000.	0.216E 00	0.144E 01	0.868E-01	0.114E 00
1600.	0.926E-02	0.816E-01	0.873E-01	0.113E 00
2500.	0.821E-04	0.941E-03	0.872E-01	0.111E 00
4000.	0.311E-07	0.460E-06	0.869E-01	0.108E 00
6300.	0.000E 00	0.317E-11	0.864E-01	0.104E 00
10000.	0.000E 00	0.000E 00	0.856E-01	0.996E-01
16000.	0.000E 00	0.000E 00	0.843E-01	0.938E-01
25000.	0.000E 00	0.000E 00	0.825E-01	0.882E-01
40000.	0.000E 00	0.000E 00	0.795E-01	0.828E-01
63000.	0.000E 00	0.000E 00	0.751E-01	0.775E-01

TABLE A2 (Contd.)

I-133

TIME	SN	SB	TE1	TE2
	0.347E 00	0.282E-02	0.222E-03	0.578E-02
0.	0.194E 04	0.632E 02	0.245E 01	0.636E 02
1.	0.137E 04	0.677E 02	0.246E 01	0.633E 02
10.	0.607E 02	0.764E 02	0.256E 01	0.612E 02
25.	0.335E 00	0.737E 02	0.273E 01	0.579E 02
40.	0.185E-02	0.707E 02	0.289E 01	0.548E 02
63.	0.639E-06	0.663E 02	0.313E 01	0.504E 02
100.	0.172E-11	0.547E 02	0.347E 01	0.442E 02
160.	0.000E 00	0.504E 02	0.395E 01	0.359E 02
250.	0.000E 00	0.391E 02	0.451E 01	0.265E 02
400.	0.000E 00	0.256E 02	0.511E 01	0.166E 02
630.	0.000E 00	0.134E 02	0.553E 01	0.852E 01
1000.	0.000E 00	0.473E 01	0.557E 01	0.337E 01
1600.	0.000E 00	0.872E 00	0.507E 01	0.116E 01
2500.	0.000E 00	0.690E-01	0.419E 01	0.604E 00
4000.	0.000E 00	0.101E-02	0.301E 01	0.407E 00
6300.	0.000E 00	0.155E-05	0.180E 01	0.244E 00
10000.	0.000E 00	0.458E-10	0.793E 00	0.107E 00
16000.	0.000E 00	0.000E 00	0.209E 00	0.233E-01
25000.	0.000E 00	0.000E 00	0.283E-01	0.383E-02
40000.	0.000E 00	0.000E 00	0.101E-02	0.137E-03
63000.	0.000E 00	0.000E 00	0.610E-05	0.825E-06

TIME	I^{133}
	0.926E-05
0.	0.503E-01
1.	0.509E-01
10.	0.563E-01
25.	0.648E-01
40.	0.730E-01
63.	0.847E-01
100.	0.102E 00
160.	0.126E 00
250.	0.154E 00
400.	0.189E 00
630.	0.224E 00
1000.	0.259E 00
1600.	0.294E 00
2500.	0.332E 00
4000.	0.377E 00
6300.	0.419E 00
10000.	0.446E 00
16000.	0.446E 00
25000.	0.417E 00
40000.	0.364E 00
63000.	0.294E 00

TABLE A2 (Contd.)

I-134

TIME	SB	TE	I134
	0.144E-01	0.275E-03	0.218E-03
0.	0.207E 03	0.877E 01	0.399E 01
1.	0.217E 03	0.883E 01	0.399E 01
10.	0.190E 03	0.931E 01	0.400E 01
25.	0.153E 03	0.997E 01	0.402E 01
40.	0.123E 03	0.105E 02	0.404E 01
63.	0.885E 02	0.111E 02	0.407E 01
100.	0.519E 02	0.117E 02	0.413E 01
160.	0.218E 02	0.121E 02	0.423E 01
250.	0.595E 01	0.121E 02	0.439E 01
400.	0.682E 00	0.117E 02	0.463E 01
630.	0.246E-01	0.110E 02	0.495E 01
1000.	0.118E-03	0.990E 01	0.538E 01
1600.	0.203E-07	0.840E 01	0.584E 01
2500.	0.000E 00	0.656E 01	0.612E 01
4000.	0.000E 00	0.434E 01	0.589E 01
6300.	0.000E 00	0.231E 01	0.480E 01
10000.	0.000E 00	0.833E 00	0.289E 01
16000.	0.000E 00	0.160E 00	0.103E 01
25000.	0.000E 00	0.135E-01	0.180E 00
40000.	0.000E 00	0.217E-03	0.795E-02
63000.	0.000E 00	0.389E-06	0.569E-04

I-135

TIME	SB	TE	I135
	0.115E 00	0.825E-02	0.287E-04
0.	0.426E 03	0.157E 03	0.691E 00
1.	0.379E 03	0.159E 03	0.695E 00
10.	0.134E 03	0.164E 03	0.737E 00
25.	0.237E 02	0.152E 03	0.806E 00
40.	0.419E 01	0.136E 03	0.867E 00
63.	0.294E 00	0.113E 03	0.949E 00
100.	0.409E-02	0.830E 02	0.105E 01
160.	0.400E-05	0.506E 02	0.116E 01
250.	0.122E-09	0.241E 02	0.125E 01
400.	0.000E 00	0.698E 01	0.130E 01
630.	0.000E 00	0.105E 01	0.132E 01
1000.	0.000E 00	0.494E-01	0.131E 01
1600.	0.000E 00	0.349E-03	0.128E 01
2500.	0.000E 00	0.208E-06	0.125E 01
4000.	0.000E 00	0.000E 00	0.120E 01
6300.	0.000E 00	0.000E 00	0.112E 01
10000.	0.000E 00	0.000E 00	0.101E 01
16000.	0.000E 00	0.000E 00	0.849E 00
25000.	0.000E 00	0.000E 00	0.655E 00
40000.	0.000E 00	0.000E 00	0.426E 00
63000.	0.000E 00	0.000E 00	0.220E 00

APPENDIX B

Sample Problem

The sample problem is a calculation of the number of ^{134}I atoms released from the stack for 15 min (FINTIM=900 sec) following the start of the accident. Instantaneous release of fission products to the cell air (RATE=0) and filter holdup of precursor atoms (PATH=1) are considered.

GASOUT uses a time interval, Δt_j, of 0.5 sec for the first 30 sec following the start of the accident. During this time the cell pressure builds up, peaks, and begins to decay. This time interval adequately reproduces the pressure curve reported for the DBA analysis in Ref. 1 in which smaller time intervals (~0.01 sec) were used. For times greater than 30 sec, when the pressure varies slowly, a longer time interval (input parameter DTX) can be used. For this example DTX=4.0 sec was chosen. Stability of the numerical method for these time intervals was checked by dividing all time intervals in half and verifying that the same answer was obtained.

Table B1 lists the total number of gas atoms released from the stack after 15 min for each of the Kr, Xe, and I fission products considered.

TABLE B1. Total Number of Gas Atoms Released from Stack after 15 min

(normalized to 8.4351×10^5 fissions)

A = Instantaneous release of fission products with no filter holdup.

B = Instantaneous release of fission products with filter holdup.

C = Constant burning rate release of fission products with filter holdup.

Isotope	A	B	C
^{83}Kr	4.3×10^3	1.3×10^2	1.4×10^1
^{85}Kr	1.0×10^4	1.0×10^4	1.1×10^3
^{87}Kr	2.0×10^4	2.0×10^4	2.2×10^3
^{88}Kr	2.8×10^4	2.8×10^4	3.1×10^3
^{89}Kr	2.3×10^4	2.3×10^4	9.8×10^2
^{90}Kr	9.7×10^3	9.7×10^3	1.2×10^2
^{91}Kr	2.2×10^3	2.2×10^3	1.7×10^1
$^{135}Xe_I$	1.8×10^4	3.3×10^3	3.1×10^2
$^{135}Xe_{II}$	3.7×10^4	5.6×10^3	6.7×10^2
^{137}Xe	3.0×10^4	3.0×10^4	1.5×10^3
^{138}Xe	3.0×10^4	3.0×10^4	2.8×10^3
^{139}Xe	8.9×10^3	8.9×10^3	1.2×10^2
^{140}Xe	2.4×10^3	2.4×10^3	2.2×10^1
^{131}I	2.3×10^4	1.7×10^3	2.0×10^2
^{132}I	3.5×10^4	1.4×10^3	1.5×10^2
^{133}I	5.2×10^4	2.6×10^4	2.9×10^3
^{134}I	6.1×10^4	2.6×10^4	2.8×10^3
^{135}I	4.4×10^4	4.4×10^4	5.0×10^3

For some gas isotopes (e.g., ^{85}Kr), including filter holdup of precursor atoms (Case B) gives the same number of atoms released from the stack as the number obtained with no filter holdup (Case A). For these isotopes the precursor atoms have a short half-life so that the time holdup in the filter is small compared to the time of the problem. Filter holdup of precursor atoms can then be neglected.

Sample Problem--Input

```
 (I134)  ISOTOPE CHAIN SB-TE-I
    12      0      1     10
 4.0          900.0        1.0
I134      2.18E-4
 3.99         3.99         4.0          4.02         4.04         4.07
 4.13         4.23         4.39         4.63         4.95         5.38
SB    .01444
 207.         217.         190.         153.         123.         88.5
 51.9         21.8         5.95         .682         .0246        .000118
TE        2.75E-4
 8.77         8.83         9.31         9.97         10.5         11.1
 11.7         12.1         12.1         11.7         11.0         9.90
XXXX  1.0
 0.0          0.0          0.0          0.0          0.0          0.0
 0.0          0.0          0.0          0.0          0.0          0.0
XXXX  1.0
 0.0          0.0          0.0          0.0          0.0          0.0
 0.0          0.0          0.0          0.0          0.0          0.0
XXXX  1.0
 0.0          0.0          0.0          0.0          0.0          0.0
 0.0          0.0          0.0          0.0          0.0          0.0
     1
```

Sample Problem--Output

```
PROGRAM GASOUT

(I134)  ISOTOPE CHAIN SB-TE-I

RATE=0, THIS PROBLEM CONSIDERS INSTANTANEOUS BURNING
PATH=1, THIS PATH INCLUDES FILTER HOLDUP OF PRECURSORS

DECAY CHAIN

  ISOTOPE        LAMBDA

     I134      2.18000E-04
     SB        1.44400E-02
     TE        2.75000E-04
     XXXX      1.00000E 00
     XXXX      1.00000E 00
     XXXX      1.00000E 00

INTERPOLATION TABLE FOR TOTAL NO. OF ATOMS

          J            TIME       I134 ATOMS   PRECURSOR ATOMS

          1            6.00      1.83028E 04      4.62261E 04
          2            7.00      1.83028E 04      4.71368E 04
          3           16.00      1.83486E 04      4.70124E 04
          4           31.00      1.84404E 04      4.68501E 04
          5           46.00      1.85321E 04      4.66998E 04
          6           69.00      1.86697E 04      4.64924E 04
          7          106.00      1.89449E 04      4.61396E 04
          8          166.00      1.94037E 04      4.55097E 04
          9          256.00      2.01376E 04      4.44120E 04
         10          406.00      2.12385E 04      4.25927E 04
         11          636.00      2.27064E 04      4.00017E 04
         12         1006.00      2.46789E 04      3.60000E 04

TIME INTERVALS

  FOR TIME LESS THAN 30 SEC, DT= 0.5 SEC

  FOR TIME GREATER THAN 30 SEC, DT= 4.00 SEC

PRINT OUTPUT EVERY 10 TIME STEP
```

(I134) ISOTOPE CHAIN SB-TE-I

OUTPUT

OUT OF CELL

J	TIME	GAS IN	PREC IN	GAS OUT	PREC OUT
1	0.500	1.83028E 04	4.09895E 04	0.0	0.0
11	5.500	1.83028E 04	4.55431E 04	0.0	0.0
21	10.500	1.83193E 04	4.70919E 04	0.0	0.0
31	15.500	1.82250E 04	4.67156E 04	5.21172E 01	1.33591E 02
41	20.500	1.70462E 04	4.35710E 04	1.53637E 02	3.92703E 02
51	25.500	1.57204E 04	4.00691E 04	1.21994E 02	3.10946E 02
61	34.000	1.39628E 04	3.54550E 04	8.01293E 02	2.03468E 03
71	74.000	9.97374E 03	2.47923E 04	2.51325E 02	6.24733E 02
81	114.000	8.29651E 03	2.01295E 04	1.47892E 02	3.58824E 02
91	154.000	7.16210E 03	1.69458E 04	1.11826E 02	2.64586E 02
101	194.000	6.26706E 03	1.44387E 04	9.28270E 01	2.13864E 02
111	234.000	5.50881E 03	1.23494E 04	8.02562E 01	1.79915E 02
121	274.000	4.84331E 03	1.05732E 04	7.03665E 01	1.53614E 02
131	314.000	4.25312E 03	9.05175E 03	6.18820E 01	1.31701E 02
141	354.000	3.73301E 03	7.74600E 03	5.44350E 01	1.12953E 02
151	394.000	3.27482E 03	6.62571E 03	4.78520E 01	9.68155E 01
161	434.000	2.86822E 03	5.66822E 03	4.19805E 01	8.29625E 01
171	474.000	2.50964E 03	4.84891E 03	3.67788E 01	7.10610E 01
181	514.000	2.19523E 03	4.14689E 03	3.22024E 01	6.08320E 01
191	554.000	1.91970E 03	3.54564E 03	2.81835E 01	5.20541E 01
201	594.000	1.67837E 03	3.03090E 03	2.46549E 01	4.45231E 01
211	634.000	1.46708E 03	2.59037E 03	2.15605E 01	3.80685E 01
221	674.000	1.28005E 03	2.21438E 03	1.88180E 01	3.25538E 01
231	714.000	1.11651E 03	1.89275E 03	1.64180E 01	2.78325E 01
241	754.000	9.73746E 02	1.61758E 03	1.43215E 01	2.37908E 01
251	794.000	8.49149E 02	1.38222E 03	1.24907E 01	2.03320E 01
261	834.000	7.40420E 02	1.18093E 03	1.08926E 01	1.73730E 01
271	874.000	6.45553E 02	1.00880E 03	9.49767E 00	1.48420E 01

TOTAL GAS ATOMS OUT OF CELL = 1.89558E 04
TOTAL PRECURSOR ATOMS OUT OF CELL = 4.42368E 04
TOTAL NUMBER OF ATOMS OUT OF CELL = 6.31926E 04

(I134) ISOTOPE CHAIN SB-TE-I

OUT OF STACK

GG = GAS OUT OF STACK DUE TO GAS OUT OF CELL
GP = GAS OUT OF STACK DUE TO PRECURSORS OUT OF CELL

J	GG	GP
1	0.0	0.0
11	0.0	0.0
21	0.0	0.0
31	0.0	0.0
41	0.0	0.0
51	0.0	0.0
61	1.11438E 03	3.43290E 00
71	4.04868E 02	1.52065E 01
81	2.05204E 02	2.14435E 01
91	0.0	2.42357E 01
101	1.19364E 02	3.06564E 01
111	1.01550E 02	3.29435E 01
121	0.0	3.44953E 01
131	7.91070E 01	3.62005E 01
141	7.14071E 01	3.75387E 01
151	6.46032E 01	3.87321E 01
161	0.0	3.69614E 01
171	5.34382E 01	3.78439E 01
181	4.88892E 01	3.86309E 01
191	0.0	3.92491E 01
201	4.09063E 01	3.98833E 01
211	3.74160E 01	4.03812E 01
221	0.0	3.91405E 01
231	3.16006E 01	3.95401E 01
241	2.92331E 01	3.98453E 01
251	0.0	4.01695E 01
261	2.53530E 01	4.04252E 01
271	0.0	4.06218E 01

TOTAL GG OUT STACK = 1.83359E 04
TOTAL GP OUT STACK = 7.57694E 03

CHI= 1.000
CHI*GP= 7.57694E 03
(1-CHI)*GP= 0.0

FINAL NUMBER OF I134 ATOMS OUT STACK = GG + CHI*GP = 2.59129E 04

APPENDIX C

Code Listing

```
LEVEL 16 ( 1 JULY 68)                          OS/360  FORTRAN H          DATE  70.012/15.04.24

        COMPILER OPTIONS - NAME=  MAIN,OPT=00,LINECNT=57,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,
              C      PROGRAM GASOUT                          MAP,NOEDIT,ID,NOXREF                1
              C                                                                                  1
              C      JANUARY 1970
              C
              C      CALCULATES AMOUNTS OF ISOTOPES EXPELLED FROM CELL IN A DBA                  1
              C                                                                                  1
              C      RATE=0 MEANS INSTANTANEOUS RELEASE OF FISSION PRODUCTS
              C      RATE=1 MEANS CONSTANT RELEASE RATE FOR ONE HOUR
              C      PATH=0 MEANS NO HOLDUP IN FILTER, TIME INDEPENDENT                          1
              C      PATH=1 MEANS INCLUDE FILTER HOLDUP, TIME DEPENDENT                          1
              C                                                                                  1
ISN 0002            DIMENSION     B1(20),C1(20),D1(20),E1(20),PREOUT(999),F(999),
                   XPRESTK(999),FP(999),TEND(999),DT(999),IDENT(20),        T2(999),            2
                   XA1(20),  OUTCEL(999),OUTSTK(999),TOT(20),INCELL(999),PREIN(999),
                   XD(999),E(999),F1(20),A(999),B(999),C(999),T1(21)
ISN 0003            REAL INCELL,LAMBA,LAMBB,LAMBC,LAMBD,LAMBE,LAMBF,MU                          4
ISN 0004            INTEGER RATE,PATH                                                           5
ISN 0005            DATA T1/6.,7.,16.,31.,46.,69.,106.,166.,256.,
                   X400.,636.,1000.,1600.,2500.,4000.,6300.,10000.,16000.,25000.,40000
                   X.,63000./
ISN 0006          1 FORMAT (6E12.5)                                                             7
ISN 0007          2 FORMAT (A4,E12.5)                                                           8
ISN 0008          7 FORMAT (20A4)                                                               9
ISN 0009         10 FORMAT (12I6)                                                              10
ISN 0010        115 READ (3,7) IDENT
ISN 0011            READ (3,10) N1,RATE,PATH,JOT
ISN 0012            READ (3,1) DTX,FINTIM,CHI
              C                                                                                12
ISN 0013            DT(1)=0.5
ISN 0014            TEND(1)=DT(1)                                                               13
ISN 0015            T2(1)=0.25
ISN 0016            DO 114 J=2,60
ISN 0017            DT(J)=0.5
ISN 0018            JJ=J-1                                                                      16
ISN 0019            T2(J)=TEND(JJ)+0.5*DT(J)                                                    17
ISN 0020        114 TEND(J)=TEND(JJ)+DT(J)                                                      18
ISN 0021            JT=61
ISN 0022        113 J=JT
ISN 0023            DT(J)=DTX
ISN 0024            JJ=J-1
ISN 0025            T2(J)=TEND(JJ)+0.5*DT(J)
ISN 0026            TEND(J)=TEND(JJ)+DT(J)
ISN 0027            JT=J+1
ISN 0028            IF (TEND(J).LT.FINTIM) GO TO 113
ISN 0030            N2=J
              C                                                                                18
              C      READ IN ATOM NUMBERS AT TIMES T1(I)                                       18
              C      ALWAYS INPUT NOBLE GAS DESIRED FIRST                                      18
              C                                                                                20
ISN 0031            READ (3,2) NAMEA,LAMBA                                                      21
ISN 0032            READ (3,1) (A1(I),I=1,N1)                                                   22
ISN 0033            READ (3,2) NAMEB,LAMBB                                                      23
ISN 0034            READ (3,1) (B1(I),I=1,N1)                                                   24
ISN 0035            READ (3,2) NAMEC,LAMBC                                                      25
ISN 0036            READ (3,1) (C1(I),I=1,N1)                                                   26
ISN 0037            READ (3,2) NAMED,LAMBD                                                      27
ISN 0038            READ (3,1) (D1(I),I=1,N1)                                                   28
ISN 0039            READ (3,2) NAMEE,LAMBE                                                      29
ISN 0040            READ (3,1) (E1(I),I=1,N1)                                                   30
ISN 0041            READ (3,2) NAMEF,LAMBF                                                      31
ISN 0042            READ (3,1) (F1(I),I=1,N1)                                                   32
ISN 0043            WRITE (4,19)                                                                33
ISN 0044         19 FORMAT (1H1)                                                                34
ISN 0045            WRITE (4,35)                                                                35
ISN 0046         35 FORMAT (15H PROGRAM GASOUT//)                                               36
ISN 0047            WRITE (4,7) (IDENT(I),I=1,20)                                               37
ISN 0048            IF (RATE) 31,31,34                                                          38
ISN 0049         31 WRITE (4,36)                                                                39
ISN 0050         36 FORMAT(//53H RATE=0, THIS PROBLEM CONSIDERS INSTANTANEOUS BURNING)          40
```

```
ISN 0051          GO TO 95
ISN 0052       34 WRITE (4,92)
ISN 0053       92 FORMAT(//52H RATE=1,THIS PROBLEM CONSIDERS CONSTANT BURNING RATE)
ISN 0054       95 IF (PATH) 80,80,81
ISN 0055       80 WRITE (4,82)
ISN 0056       82 FORMAT (49H PATH=0, THIS PATH DOES NOT INCLUDE FILTER HOLDUP)
ISN 0057          GO TO 6
ISN 0058       81 WRITE (4,83)
ISN 0059       83 FORMAT(55H PATH=1, THIS PATH INCLUDES FILTER HOLDUP OF PRECURSORS)
ISN 0060        6 WRITE (4,8)
ISN 0061        8 FORMAT (//12H DECAY CHAIN//2X,22H ISOTOPE          LAMBDA//)
ISN 0062        9 FORMAT (6X,A4,4X,1PE12.5)
ISN 0063          WRITE (4,9) NAMEA,LAMBA
ISN 0064          WRITE (4,9) NAMEB,LAMBB
ISN 0065          WRITE (4,9) NAMEC,LAMBC
ISN 0066          WRITE (4,9) NAMED,LAMBD
ISN 0067          WRITE (4,9) NAMEE,LAMBE
ISN 0068          WRITE (4,9) NAMEF,LAMBF
ISN 0069          DO 16 J=1,N1
ISN 0070          A1(J)=A1(J)/LAMBA
ISN 0071          B1(J)=B1(J)/LAMBB
ISN 0072          C1(J)=C1(J)/LAMBC
ISN 0073          D1(J)=D1(J)/LAMBD
ISN 0074          E1(J)=E1(J)/LAMBE
ISN 0075       16 F1(J)=F1(J)/LAMBF
ISN 0076          DO 57 J=1,N1
ISN 0077       57 TOT(J)=B1(J)+C1(J)+D1(J)+E1(J)+F1(J)
ISN 0078          WRITE (4,58) NAMEA
ISN 0079       58 FORMAT (///43H INTERPOLATION TABLE FOR TOTAL NO. OF ATOMS//
                 X6X,6H      J,16H              TIME,6X,A4,8H ATOMS  ,16H PRECURSOR ATO
                 XMS//)
ISN 0080          WRITE (4,59) (J,T1(J),A1(J),TOT(J),J=1,N1)
ISN 0081       59 FORMAT (6X,I6,CPF16.2,1PE16.5,1PE16.5)
ISN 0082          WRITE (4,74) DTX,JUT
ISN 0083       74 FORMAT (////15H TIME INTERVALS//41H   FOR TIME LESS THAN 30 SEC, D
                 1T= 0.5 SEC//36H   FOR TIME GREATER THAN 30 SEC, DT=F5.2,4H SEC////
                 219H PRINT OUTPUT EVERYI3,10H TIME STEP)
C
C         INTERPOLATION
C
C         GIVEN ATOM NUMBERS AT TIMES T1(I), FIND VALUES AT TIMES T2(J)
C         REQUIRES T1(1).LE.T2(1) AND T1(N1).GT.T2(N2)
C
ISN 0084          I=1
ISN 0085          DO 15 J=1,N2
ISN 0086       11 II=I+1
ISN 0087          IF (T2(J).GT.T1(II)) GO TO 12
ISN 0089          DT1=T1(II)-T1(I)
ISN 0090          DT2=T2(J)-T1(I)
ISN 0091          ALPHA=DT2/DT1
ISN 0092          A(J)=A1(I)+ALPHA*(A1(II)-A1(I))
ISN 0093          B(J)=B1(I)+ALPHA*(B1(II)-B1(I))
ISN 0094          C(J)=C1(I)+ALPHA*(C1(II)-C1(I))
ISN 0095          D(J)=D1(I)+ALPHA*(D1(II)-D1(I))
ISN 0096          E(J)=E1(I)+ALPHA*(E1(II)-E1(I))
ISN 0097          F(J)=F1(I)+ALPHA*(F1(II)-F1(I))
ISN 0098          GO TO 15
ISN 0099       12 I=I+1
ISN 0100          GO TO 11
ISN 0101       15 CONTINUE
C
C         SET INITIAL CONDITIONS
C
ISN 0102          CFSP=40.0
ISN 0103          V=3650.0
ISN 0104          TIME=0.0
ISN 0105          DKTIME=0.0
ISN 0106          REMAIN=1.0
ISN 0107          TR2=530.
ISN 0108          PA3=14.7
ISN 0109          PG3=0.0
ISN 0110          W3=2700.
ISN 0111          FILIN=0.0
ISN 0112          DO 110 J=1,N2
ISN 0113          OUTSTK(J)=0.0
ISN 0114          PRESTK(J)=0.0
ISN 0115      110 FP(J)=0.0
```

```
ISN 0116          DELTA=0.0
            C
            C     COMPUTE PRESSURE,FACT=Dw/W1
            C
ISN 0117          DO 73 L=1,N2
ISN 0118          LK=L
ISN 0119          IF (TIME.GT.13.0) GO TO 21
ISN 0121          DP=0.0
ISN 0122          GO TO 30
ISN 0123       21 IF (TIME.GE.19.235) GO TO 23
ISN 0125          Q=(5.1E04)*DT(L)
ISN 0126          DP=2.13*Q/V
ISN 0127          GO TO 30
ISN 0128       23 Q=920.0*DT(L)
ISN 0129          DP=2.13*Q/V
ISN 0130       30 TR1=TR2
ISN 0131          PA1=PA3
ISN 0132          PG1=PG3
ISN 0133          PA2=PA1+DP
ISN 0134          PG2=PA2-14.7
ISN 0135          PAM=(.5*DP)+PA1
ISN 0136          PGM=PAM-14.7
ISN 0137          IF (TIME.LT.20.) GO TO 302
ISN 0139          IF (PGM.LE.0.0) GO TO 71
ISN 0141      302 DTEMP=TR1*DP/PA1
ISN 0142          TR2=TR1+DTEMP
ISN 0143          TM=(.5*DTEMP)+TR1
ISN 0144      303 IF (TR2.GE.1400.0) GO TO 51
ISN 0146          GO TO 52
ISN 0147       51 TR2=1400.0
ISN 0148          TM=1400.0
ISN 0149       52 DVOL=CFSP*DT(L)*PGM
ISN 0150          VM=TM/(2.7*PAM)
ISN 0151          DW=DVOL/VM
ISN 0152          W1=W3
ISN 0153          FACT=DW/W1
ISN 0154          R=1.0-FACT
ISN 0155          W3=W1-DW
ISN 0156          PA3=PA2*W3/W1
ISN 0157          PG3=PA3-14.7
ISN 0158          TIME=TIME+DT(L)
            C
            C     NOW DO ISOTOPE CALCULATIONS
            C
ISN 0159          ATOMS=B(L)+C(L)+D(L)+E(L)+F(L)
ISN 0160          IF (RATE) 45,45,46
ISN 0161       45 BETA=FACT*REMAIN
ISN 0162          REMAIN=REMAIN*R
ISN 0163          INCELL(L)=REMAIN*A(L)
ISN 0164          PREIN(L)=REMAIN*ATOMS
ISN 0165          GO TO 47
ISN 0166       46 BURN=DT(L)/3600.0
ISN 0167          DELTA=MU*DELTA+BURN
ISN 0168          MU=R
ISN 0169          BETA=FACT*DELTA
ISN 0170          INCELL(L)=R*DELTA*A(L)
ISN 0171          PREIN(L)=R*DELTA*ATOMS
ISN 0172       47 OUTCEL(L)=BETA*A(L)
ISN 0173          PREOUT(L)=BETA*ATOMS
ISN 0174          IF (PGM.LT.0.1) GO TO 73
            C
ISN 0176          DKTIME=140.4/PGM
ISN 0177          THETA=T2(L)+DKTIME
ISN 0178          IF (THETA.GT.TEND(N2)) GO TO 72
ISN 0180          DO 62 K=1,N2
ISN 0181          IF (THETA.LE.T1(K)) GO TO 63
ISN 0183       62 CONTINUE
ISN 0184       63 KK=K-1
ISN 0185          DT1=T1(K)-T1(KK)
ISN 0186          DT2=THETA-T1(KK)
ISN 0187          ALPHA=DT2/DT1
ISN 0188          GAS=A1(KK)+ALPHA*(A1(K)-A1(KK))
ISN 0189          GG=BETA*GAS
ISN 0190          DO 53 J=L,N2
ISN 0191          IF (THETA.LT.TEND(J)) GO TO 54
ISN 0193       53 CONTINUE
```

```
ISN 0194        54 OUTSTK(J)=OUTSTK(J)+GG
ISN 0195           IF (PATH) 139,139,141
ISN 0196        72 IF (PATH) 73,73,141
ISN 0197       139 PREC=TOT(KK)+ALPHA*(TOT(K)-TOT(KK))
ISN 0198           GP=BETA*PREC
ISN 0199           PRESTK(J)=PRESTK(J)+GP
ISN 0200           GO TO 73
ISN 0201       141 FTIME=110./PGM
ISN 0202           GAMMA=T2(L)+FTIME
ISN 0203           DO 140 K=1,21
ISN 0204           IF (GAMMA.GT.T1(K)) GO TO 140
ISN 0206           KK=K-1
ISN 0207           DT1=T1(K)-T1(KK)
ISN 0208           DT2=GAMMA-T1(KK)
ISN 0209           ALPHA=DT2/DT1
ISN 0210           PREC=TOT(KK)+ALPHA*(TOT(K)-TOT(KK))
ISN 0211           FILTER=BETA*PREC
ISN 0212           DO 105 J=L,N2
ISN 0213           IF (GAMMA.LT.TEND(J)) GO TO 106
ISN 0215       105 CONTINUE
ISN 0216           GO TO 116
ISN 0217       106 FP(J)=FP(J)+FILTER
ISN 0218       116 M=L-1
ISN 0219           TOY=B(M)+C(M)+D(M)+E(M)+F(M)
ISN 0220           FILIN=FILIN+FP(L)
ISN 0221           IF (TOY) 117,117,66
ISN 0222        66 PHI=(TOY-ATOMS)/TOY
ISN 0223           IF (PHI) 117,117,118
ISN 0224       117 PHI=0.0
ISN 0225       118 PRESTK(L)=PHI*FILIN
ISN 0226           FILIN=FILIN-PRESTK(L)
ISN 0227           GO TO 73
ISN 0228       140 CONTINUE
ISN 0229        73 CONTINUE
              C
ISN 0230           DO 75 I=1,30
ISN 0231           IF (OUTCEL(I).GE.0.0) GO TO 75
ISN 0233           OUTCEL(I)=0.0
ISN 0234           PREOUT(I)=0.0
ISN 0235        75 CONTINUE
ISN 0236        71 S1=0.0
ISN 0237           S2=0.0
ISN 0238           S3=0.0
ISN 0239           S4=0.0
ISN 0240           DO 41 J=1,LK
ISN 0241           S1=S1+OUTCEL(J)
ISN 0242           S2=S2+PREOUT(J)
ISN 0243           S3=S3+OUTSTK(J)
ISN 0244        41 S4=S4+PRESTK(J)
ISN 0245           S5=S1+S2
              C
              C    WRITE OUTPUT
              C
ISN 0246           WRITE (4,19)
ISN 0247           WRITE (4,7) IDENT
ISN 0248           WRITE (4,93)
ISN 0249        93 FORMAT (///7H OUTPUT//12H OUT OF CELL///6H      J,12H        TIME .
                  X13H       GAS IN ,13H      PREC IN ,13H      GAS OUT   ,13H     PREC OU
                  XT //)
ISN 0250           WRITE (4,94) (J,TEND(J),INCELL(J),PREIN(J),OUTCEL(J),PREOUT(J),J=1
                  X,LK,JOT)
ISN 0251        94 FORMAT (I6,0PF12.3,1PE15.5,1PE15.5,1PE15.5,1PE15.5)
ISN 0252           WRITE (4,50) S1,S2,S5
ISN 0253        50 FORMAT (37H TOTAL GAS ATOMS OUT OF CELL          =1PE12.5/
                  X37H TOTAL PRECURSOR ATOMS OUT OF CELL  =1PE12.5/36H TOTAL NUMBER O
                  XF ATOMS OUT OF CELL =1PE12.5)
ISN 0254           WRITE (4,19)
ISN 0255           WRITE (4,7) IDENT
ISN 0256           WRITE (4,38)
ISN 0257        38 FORMAT (///13H OUT OF STACK//6X,45H GG = GAS OUT OF STACK DUE TO G
                  XAS OUT OF CELL/6X,52H GP = GAS OUT OF STACK DUE TO PRECURSORS OUT
                  XOF CELL///6H      J,16H          GG      ,16H          GP      //)
ISN 0258           WRITE (4,39) (J,OUTSTK(J),PRESTK(J),J=1,LK,JOT)
ISN 0259        39 FORMAT (I6,1PE16.5,1PE16.5)
ISN 0260           WRITE (4,42) S3,S4
ISN 0261        42 FORMAT (///21H TOTAL GG OUT STACK =1PE12.5/21H TOTAL GP OUT STACK
```

```
                    X=1PE12.5)
  ISN 0262            XX=CHI*S4
  ISN 0263            YY=S4-XX
  ISN 0264            S6=S3+XX
  ISN 0265            WRITE (4.43) CHI,XX,YY
  ISN 0266         43 FORMAT (//5H CHI=0PF6.3/8H CHI*GP=1PE12.5/12H (1-CHI)*GP=1PE12.5)
  ISN 0267            WRITE (4,44) NAMEA,S6
  ISN 0268         44 FORMAT (//17H FINAL NUMBER OF A4,32H ATOMS OUT STACK = GG + CHI*GP
                    X =1PE12.5)
  ISN 0269            READ (3,10) IOF
  ISN 0270            IF (IOF) 13,115,13
  ISN 0271         13 STOP
  ISN 0272            END
ADCONS FOR EXTERNAL REFERENCES
```

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