210
1-19-77

Doc. # 654

LA-NUREG-6570-MS

Informal Report

NRC-8

LEAF:

**A Computer Program to Calculate Fission Product Release
from a Reactor Containment Building for
Arbitrary Radioactive Decay Chains**

Issued: November 1976

Los Alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

An Affirmative Action/Equal Opportunity Employer

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This work was supported by the US Nuclear Regulatory Commission,
Office of Nuclear Regulatory Research, Division of Reactor Safety Research.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy \$4.00 Microfiche \$3.00

NOTICE

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

LA-NUREG-6570-MS
Informal Report
NRC-8

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

LEAF:

**A Computer Program to Calculate Fission Product Release
from a Reactor Containment Building for
Arbitrary Radioactive Decay Chains**

by

Clarence E. Lee
Courtney E. Apperson, Jr.
John E. Foley

Manuscript completed: October 1976
Issued: November 1976

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

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

LEAF: A COMPUTER PROGRAM TO CALCULATE FISSION PRODUCT RELEASE
FROM A REACTOR CONTAINMENT BUILDING FOR ARBITRARY RADIOACTIVE DECAY CHAINS

by

Clarence E. Lee, Courtney E. Apperson, Jr., and
John E. Foley

ABSTRACT

This report describes an analytic containment building model that is used for calculating the leakage into the environment of each isotope of an arbitrary radioactive decay chain. The model accounts for the source, the buildup, the decay, the cleanup, and the leakage of isotopes that are gas-borne inside the containment building.

I. INTRODUCTION

The sources of the radioactive materials that are needed for the calculation of the consequences of postulated reactor accidents are obtained from estimates of the leakage of fission products from the reactor containment building. These estimates are obtained from a mathematical model of the reactor containment building that accounts for the source, the decay, the cleanup, and the leakage of each radionuclide in the building. A containment building model, which assumes that the gas in the building consists of a single, well mixed volume, is described in the Reactor Safety Study.¹ We have used a similar model^{2,3} to estimate the time-dependent release of ¹³¹I from the containment building of a High-Temperature Gas-Cooled Reactor (HTGR) during the Loss of Forced Circulation (LOFC) accident. The containment building model of References 2 and 3 is useful only for single isotopes because the radioactive decay chains are not included.

In this report we describe an analytic containment building model that is used for calculating the leakage into the environment of each isotope of an

arbitrary radioactive decay chain. The model accounts for the source, the build-up, the decay, the cleanup, and the leakage of the isotopes that are gas-borne inside the containment building. In the model, the source of an isotope inside the containment building (which is the result of leakage from the reactor vessel), its removal rate by the containment cleanup system, and its leakage from the containment building are all assumed to be constant during short time intervals. We assume, as is done in Ref. 1, that the gas inside the containment building is well mixed and all in one compartment. Natural deposition of gas-borne isotopes onto surfaces internal to the containment building was not included in the model.

Even though we use this containment building model to estimate the time-dependent release of fission products to the environment for postulated HTGR accidents, the model is quite general and can be used for other types of reactors.

II. LEAF MODEL EQUATIONS

We consider a system shown in Fig. 1, composed of a reactor vessel emitting a source of radioactive materials $\underline{S}$, surrounded by a containment building which leaks at a rate L (s^{-1}). Inside the containment building there is a cleanup system filter having a cleanup rate V (s^{-1}). Let $\underline{N}$ be the amount of an isotope of a chain in the containment building, and $\underline{F}$ the total amount of the isotope absorbed on the filter. $\underline{N}$, $\underline{F}$, and $\underline{S}$ are vectors, the elements of which are the values of the individual species in the chain.

Fig. 1. LEAF containment building model.

Denote $\bar{\lambda}$ the decay chain matrix, and L and V the diagonal leak and filter clean-up rate matrices. The negative off-diagonal elements of $\bar{\lambda}$ include the branching ratio factors; the diagonal elements of $\bar{\lambda}$ are positive. Noble gases will not be filtered by the cleanup system. This fact is represented by a matrix $\bar{\delta}$ of the form

$$\bar{\delta}_{ij} = \mu_i (1 - \delta_{ij}), \quad (1)$$

where

$$\mu_i = \begin{cases} 1 & \text{if the } i^{\text{th}} \text{ isotope is a noble gas} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

and δ_{ij} is the Kronecker delta, defined by

$$\delta_{ij} = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \neq j. \end{cases} \quad (3)$$

Defining the matrices λ , λ^* , and Λ by

$$\begin{aligned} \lambda &= \bar{\lambda} - \lambda^*, \\ \lambda^* &= \bar{\delta} \otimes \bar{\lambda}, \\ \Lambda &= \bar{\lambda} + V + L, \end{aligned} \quad (4)$$

where $\otimes$ denotes the Cartesian product, then the LEAF model equations are written as

$$\frac{dN}{dt} = -\Lambda N - \lambda^* F + S, \quad (5)$$

$$\frac{dF}{dt} = VN - \lambda F.$$

If we define new vectors $\underline{X}$ and $\underline{s}$ by

$$\underline{X} = \begin{pmatrix} N \\ F \end{pmatrix}, \quad \underline{s} = \begin{pmatrix} S \\ 0 \end{pmatrix}, \quad (6)$$

and a supermatrix A by

$$A = \begin{pmatrix} -\Lambda & -\lambda^* \\ V & -\lambda \end{pmatrix}, \quad (7)$$

then Eq. (5) may be rewritten as

$$\frac{dX}{dt} = A \underline{X} + \underline{s}. \quad (8)$$

We assume that the matrix A and the vector $\underline{s}$ are constant over the time interval $(0, \tau)$.

We are interested in calculating the integrated release to the environment by leakage from the containment building. This is given by

$$\begin{aligned}\underline{R}(\tau) &= \int_0^\tau dt' L(t') \underline{N}(t') \\ &= \bar{L} \int_0^\tau dt' \underline{N}(t'),\end{aligned}\tag{9}$$

where $\bar{L}$ is the average leakage in the time interval τ , defined by

$$\bar{L} = \frac{1}{\tau} (L(0) + L(\tau)).\tag{10}$$

If we define

$$\underline{Y}(\tau) = \begin{pmatrix} \underline{R}(\tau) \\ 0 \end{pmatrix}, \quad B = \begin{pmatrix} \bar{L} & 0 \\ L & 0 \end{pmatrix},\tag{11}$$

then Eq. (9) becomes

$$\underline{Y}(\tau) = B \int_0^\tau ds \underline{X}(s).\tag{12}$$

As we shall prove in detail below, if the matrix A is constant in the time interval $(0, \tau)$, the solutions to Eqs. (8) and (12) are given by

$$\underline{X}(\tau) = \underline{X}(0) + \tau D(A\tau) \left[A \underline{X}(0) + \underline{s} \right],\tag{13}$$

and

$$\underline{Y}(\tau) = B \left[\tau D(A\tau) \underline{X}(0) + \tau^2 Z(A\tau) \underline{s} \right],\tag{14}$$

where the matrix operators $D(C)$ and $Z(C)$ for $C = A\tau$ are evaluable using the methods of Ref. 4.

III. ANALYTIC SOLUTIONS TO THE LEAF MODEL EQUATIONS

Because the matrix A is constant in the time interval $(0, \tau)$, then following the Volterra method of the multiplicative integral,^{4,5} we may construct the matricant

$$\Omega_0^\tau(A) = \exp \left[\int_0^\tau A(s) ds \right] = \exp(A\tau).\tag{15}$$

The solution to Eq. (8) is given by

$$\underline{X}(\tau) = \Omega_0^\tau(A) \underline{X}(0) + \int_0^\tau dt' K(\tau, t') \underline{s}(t'),\tag{16}$$

where

$$K(\tau, t') \equiv \Omega_0^\tau(A) \left[\Omega_0^{t'}(A) \right]^{-1}.\tag{17}$$

As is readily proved,⁴ both the matrix A and $e^{A\tau}$ are non-negative.

Substituting Eq. (15) into Eqs. (16) and (17) gives

$$\underline{X}(\tau) = e^{A\tau} \underline{X}(0) + e^{A\tau} \int_0^\tau dt' e^{-At'} \underline{s}(t').\tag{18}$$

Assuming that $\underline{s}(t') = \underline{s}$ is constant over the interval $(0, \tau)$, Eq. (18) becomes

$$\underline{X}(\tau) = e^{A\tau} \underline{X}(0) + A^{-1}(e^{A\tau} - I)\underline{s}. \quad (19)$$

Defining the matrix operator $D(C)$ by⁴

$$D(C) = C^{-1}(e^C - I) \quad (20)$$

or

$$\tau D(A\tau) = A^{-1}(e^{A\tau} - I), \quad (21)$$

Eq. (19) becomes

$$\begin{aligned} \underline{X}(\tau) &= \underline{X}(0) + \tau A D(A\tau) \underline{X}(0) + \tau D(A\tau) \underline{s} \\ &= \underline{X}(0) + \tau D(A\tau) [A \underline{X}(0) + \underline{s}], \end{aligned} \quad (22)$$

which is Eq. (13).

In order to derive Eq. (14) we integrate Eq. (12) to obtain

$$\begin{aligned} \underline{Y}(\tau) &= B \{ A^{-1}(e^{A\tau} - I) \underline{X}(0) + [-A^{-1}\tau - A^{-1}A^{-1}(e^{A\tau} - I)] \underline{s} \} \\ &= B \{ \tau D(A\tau) \underline{X}(0) + \tau^2 [-C^{-1} + C^{-1} D(C)] \underline{s} \} \\ &= B \{ \tau D(A\tau) \underline{X}(0) + \tau^2 Z(A\tau) \underline{s} \}, \end{aligned} \quad (23)$$

where we have defined

$$CZ(C) = D(C) - I \quad (24)$$

for $C = A\tau$ and used Eq. (21). The last line of Eq. (23) is just Eq. (14).

Note that the matrix operators $D(C)$ and $Z(C)$ defined by

$$D(C) = C^{-1}(e^C - I) = \sum_{n=0}^{\infty} \frac{C^n}{(n+1)!} \quad \text{and} \quad (25)$$

$$Z(C) = C^{-1}(D(C) - I) = \sum_{n=0}^{\infty} \frac{C^n}{(n+2)!} \quad (26)$$

exist even if $C = A\tau$ is singular.* Although the eigenvalues of e^C are bounded by unity, and the eigenvalues of C are bounded, but not necessarily by unity, the direct evaluation of $D(C)$ and $Z(C)$ would prove difficult computationally if Eqs. (25) and (26) are used. We can scale the matrix C so that the eigenvalues are bounded by unity. Define

$$H = 2^{-p}C, \quad (27)$$

where p is determined by

$$||H|| < \frac{1}{2} \quad (28)$$

or^{4,6}

$$p > \ln \left(\sum_{ij} |C_{ij}|^2 \right) / (2 \ln 2). \quad (29)$$

*For example, a chain involving a stable isotope will lead to a matrix C that is singular.

We approximate the $D(H)$ and $Z(H)$ matrix operators by a finite number of terms M using Eqs.(25) and (26).

$$D^M(H) \approx \sum_{n=0}^M \frac{H^n}{(n+1)!} \quad (30)$$

$$Z^M(H) \approx \sum_{n=0}^M \frac{H^n}{(n+2)!} \quad (31)$$

M is determined⁴ such that the excluded terms have an error less than some ϵ , or

$$\frac{(|H|)^{M+1}}{(M+2)!} < \frac{1}{2^{M+1}(M+2)!} < \epsilon. \quad (32)$$

Knowing $D(H)$ and $Z(H)$, we may recur upwards by powers of 2 in H to find $D(C)$ and $Z(C)$ where $C = 2^p H$, using the recursion relations

$$D(2^p + 1 H) = D(2^p H) \left[I + \frac{1}{2} (2^p H) D(2^p H) \right] \text{ and} \quad (33)$$

$$Z(2^p + 1 H) = \frac{1}{2} Z(2^p H) + \frac{1}{4} \left[D(2^p H) \right]^2. \quad (34)$$

These recursion relationships are proved in Appendix A.

Using the above equations, we wrote and debugged a computer program called LEAF. The LEAF program listing is given in Appendix B.

We next discuss the program logic of LEAF, the input structure, and then we examine some of the comparisons that were made for the validation of the LEAF program.

IV. LEAF PROGRAM LOGIC

The LEAF program consists of a driver routine which controls the program flow (LEAF); nine primary subroutines (INPA, INPC, MAKEA, SOLVER, FSOLVE, PREP, PAPER, TERM, and PRMAT), which perform input/output tasks; and five secondary subroutines (SCALAR, MULTI, EQUAL, MVMUL, VADD), which are called by the primary subroutines to evaluate matrix and vector operations in double precision.

The dimensions of arrays are set by a parameter statement. The meaning and the current values of the four parameters in LEAF are

NNT = 10 : Maximum number of nuclides allowed a problem,

NN = 2*NNT: Twice NNT,

NIT = 25 : Maximum number of time intervals plus one, and

NBR = 10 : Maximum number of branching ratios allowed.

These parameters can be increased as long as $NN = 2 * NNT$. No use is made of Large Core Memory in this version of the code. The code runs using both CROS-CDC-7600 BATCH mode and NOS-CDC-6600 time-sharing terminal mode.

The nine primary subroutines are discussed in the order in which they are called by the driver routine LEAF.

A. INPA

The subroutine INPA reads and prints the basic nuclear data used in constructing the decay chain matrices. The input is stored so that it may be recalled in subsequent subroutines. The printing of this data is controlled by the value of NSKIP. If NSKIP is greater than zero, the input read by INPA is not printed.

B. INPC

The subroutine INPC reads and prints the time-dependent data, the initial concentrations, and the time-dependent source data. The initial concentrations and time-dependent sources are input in atoms and atoms/s if $IAC = 0$. If $IAC > 0$, the input is in Ci and Ci/s for radioactive isotopes ($\lambda \neq 0$), and in g and g/s for stable isotopes ($\lambda = 0$). As in INPA, the printing of the input is controlled by the value of NSKIP.

At this point all of the required inputs have been read and stored.

C. MAKEA

The subroutine MAKEA constructs the main solution matrix A defined in Eq. (7). The size of the A matrix is NN by NN . The upper half of the A matrix models the behavior of the nuclides in the containment building. The lower half of the A matrix models the behavior in the containment building filter system.

The subroutine MAKEA also constructs the matrix B , Eq. (11). B is called BL in MAKEA, and premultiplies the integrated containment concentration vector to calculate the integrated release to the environment.

D. SOLVER

The subroutine SOLVER uses the matrix A to calculate three matrix operators: $D(A\tau)$, $I + A\tau D(A\tau)$, and $Z(A\tau)$ as used in Eqs. (13) and (14). The value of p is determined using Eq. (29) to insure that $||H|| < \frac{1}{2}$, where $H = 2^{-p}C$ and $C = A\tau$. Then the power series representations for $D(H)$ and $Z(H)$ are evaluated, Eqs. (30) and (31). Finally, the recursion relations, Eqs. (33) and (34), are used to determine the $D(C)$, $I + CD(C)$ and $Z(C)$ matrix operators needed by FSOLVE to establish the solution for a given time interval.

E. FSOLVE

The subroutine FSOLVE calculates the concentrations of the nuclides in the containment building and filter as well as the integrated release to the environment for the specified time interval, Eqs. (13) and (14), using the matrix operators determined in SOLVER.

The system of subroutines (MAKEA, SOLVER, and FSOLVE) is repeatedly evaluated for each time interval as specified by the input read by subroutine INPC.

F. PREP

Upon completion of the calculation of all the time intervals, the subroutine PREP is used to prepare the results for final output display. This subroutine converts the calculated results in atoms into curies for radioactive nuclides and into grams for stable nuclides.

G. PAPER, TERM

The results of the LEAF calculations are printed by either the subroutine PAPER or TERM. The subroutine PAPER provides a detailed and labeled presentation of the results for each time interval in atoms and in curies or grams. The subroutine TERM produces an abbreviated output for each time interval in atoms. This routine is intended for use when the output is to be displayed on an interactive terminal and is chosen when NSKIP is greater than zero.

H. PRMAT

The subroutine PRMAT prints the matrix A for each time interval if the variable MATRIX is greater than zero. The A matrix is printed by quadrant in the trigonometric convention

$$A = \begin{pmatrix} -\Lambda & -\lambda^* \\ V & -\lambda \end{pmatrix}, \quad (35)$$

where quadrant 1 = $-\lambda^*$, quadrant 2 = $-\Lambda$, quadrant 3 = V , quadrant 4 = $-\lambda$, as defined by Eqs. (1) through (4).

Finally, there are five secondary subroutines in LEAF which perform matrix and vector operations in double precision. These routines and their functions are as follows.

1. SCALAR: Multiplies a scalar times a matrix.
2. MULTI : Multiplies two matrices.
3. EQUAL : Sets one matrix equal to another.
4. MVMUL : Multiplies a matrix times a vector.
5. VADD : Adds two vectors.

V. LEAF INPUT STRUCTURE

The input for LEAF is contained in seven cards, which are divided into three sets. The first set consists of card 0, which establishes the print options. The second set consists of cards 1 and 2 and is used to define the decay chains. The third set is composed of four cards, which define the time-dependent case data.

The specific data for each of the three sets is detailed in Table I. Note the use of negative numbers in words 2, 3, and 4 of card 1. If card 1 word 2 is negative, the nuclide is not retained by the filter; for example, a noble gas. If words 3 and/or 4 of card 1 are negative, then one or two branching ratio cards, card 2, must follow the card 1 on which the negative values appeared. It should also be noted that cards 5 and 6 are entered as pairs for each time interval.

Finally, we remark that the parameter IAC in word 3 card 3 controls the units used on the input of the initial concentrations and source terms.

VI. COMPARISONS

Extensive testing of the D(C) and Z(C) algorithms was performed and compared with analytic solutions to validate the programming. Problems involving off-diagonal elements above and below the diagonal, as well as a constant times the identity matrix, were solved successfully.

Finally, as an independent test of the LEAF model equation solutions, several problems were solved analytically using a Laplace transform technique on MACSYMA.⁷ We report here three such tests. These test problems are not intended to represent a real accident sequence; they were designed to test the accuracy of the LEAF solutions when compared to independently constructed analytic solutions.

The first two problems use the simple decay chain defined by⁸

The basic data involved is given in Table II.

In these first two sample problems the source was held constant in time, either zero or a fixed value. The filtration rate and leakage rate were held constant during the course of the problem:

$$V = \text{filtration rate} = 2.5 \times 10^{-4} \text{ s}^{-1}$$

$$\bar{L} = \text{leakage rate} = 1.157 \times 10^{-8} \text{ s}^{-1}.$$

The containment building inventory, filter inventory, and the integrated release were evaluated at 0, 2, 4, 6, 8, and 24 h.

TABLE I
LEAF INPUT CARDS

CARD	WORD	FORMAT	SYMBOL	DESCRIPTION
0	1	I4	NSKIP	NSKIP = 0: Unabridged output NSKIP = 1: Abbreviated terminal output
	2	I4	MATRIX	MATRIX = 0: Do not print A matrix MATRIX = 1: Print A matrix
1	1	A7	HANMAT(I, 1)	Alphanumeric nuclide name
	2	F4	HANMAT(I, 2)	Nuclide ID No., negative if nuclide not retained by filter
	3	F4	HANMAT(I, 3)	Decay Parent No. 1, negative if branching ratio involved
	4	F4	HANMAT(I, 4)	Decay Parent No. 2, negative if branching ratio involved
	5	E 12.5	ANMAT(I, 1)	Nuclear decay constant (s^{-1})
	6	E 12.5	ANMAT(I, 2)	Atomic mass in gram-atoms
2	1	E 12.5	BRV(M)	Branching ratio associated with first negative decay parent, if applicable
2'	1	E 12.5	BRV(M + 1)	Branching ratio associated with second negative decay parent, if applicable
A BLANK CARD MUST FOLLOW THE LAST PAIR OF CARDS 1 AND 2				
3	1	I4	INT	Number of time intervals
	2	I4	ITP	PRINTING FREQUENCY ITP = 1: Print every interval ITP = 2: Print every second interval ITP = N: Print every Nth interval
	3	I4	IAC	Input units of initial concentration and source terms IAC = 0: Atoms and atoms/s IAC = 1: Curies and curies/s if radioactive, grams if stable
	4	E 12.5	TEND(INT + 1)	Time at end of problem in hours
4	1	E 12.5	CONTIC(1)	Initial concentration (atoms) of nuclide 1 in the containment building
	2	E 12.5	CONTIC(2)	Initial concentration (atoms) of nuclide 2 in the containment building
	.	.	.	.
	I	E 12.5	CONTIC(I)	Initial concentration (atoms) of nuclide I in the containment building
5	1	E 12.5	TEND(N)	Beginning time in hours of the Nth time step
	2	E 12.5	LAMDAV(N)	Clean-up rate (s^{-1}) for Nth time step
	3	E 12.5	LAMDAL(N)	Leakage rate (s^{-1}) for Nth time step
6	1	E 12.5	SOURCE(1,N)	Source term (atoms/s) for nuclide 1 in Nth time step
	2	E 12.5	SOURCE(2,N)	Source term (atoms/s) for nuclide 2 in Nth time step
	.	.	.	.
	I	E 12.5	SOURCE(I, N)	Source term (atoms/s) for nuclide I in Nth time step
CARDS 5 AND 6 ARE ENTERED AS A PAIR				

TABLE II
BASIC DATA FOR LEAF
Tests 1 and 2

NUCLIDE	DECAY CONSTANT (s ⁻¹)	CONTAINMENT BUILDING CONCENTRATION At T = 0 (atoms)	SOURCE (atoms/s)	
			Test 1	Test 2
⁸⁸ Br	4.359 x 10 ⁻²	1.912 x 10 ¹³	0	1 x 10 ¹⁸
⁸⁸ Kr	6.876 x 10 ⁻⁵	1.090 x 10 ¹⁸	0	2 x 10 ¹⁸
⁸⁸ Rb	6.527 x 10 ⁻⁴	1.213 x 10 ¹⁴	0	3 x 10 ¹⁸

In order to verify the LEAF results, the same two test problems were solved analytically using MACSYMA.⁷ The problem solved by LEAF and on MACSYMA is defined as follows.

$$\frac{d\mathbf{N}}{dt} = \mathbf{A}\mathbf{N} + \mathbf{S}, \quad (37)$$

where

$$\mathbf{N} = \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ F_1 \\ F_2 \\ F_3 \end{bmatrix}, \quad \mathbf{S} = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad \mathbf{N}_0 = \begin{bmatrix} 1.912 \times 10^{13} \\ 1.090 \times 10^{18} \\ 1.213 \times 10^{14} \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (38)$$

and

$$\mathbf{R}(\tau) = \mathbf{L} \int_0^\tau dt' \mathbf{N}(t') \quad (39)$$

with

$$R = \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad \bar{L} = \begin{bmatrix} 1.157 \times 10^{-8} & 0 & 0 & 0 & 0 & 0 \\ 0 & 1.157 \times 10^{-8} & 0 & 0 & 0 & 0 \\ 0 & 0 & 1.157 \times 10^{-8} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, \quad (40)$$

and the A matrix given by

$$A = \begin{bmatrix} -4.384 \times 10^{-2} & 0 & 0 & 0 & 0 & 0 \\ 4.359 \times 10^{-2} & -6.8772 \times 10^{-5} & 0 & 4.359 \times 10^{-2} & 0 & 0 \\ 0 & -6.8760 \times 10^{-5} & -9.02712 \times 10^{-4} & 0 & 0 & 0 \\ 2.500 \times 10^{-4} & 0 & 0 & -4.359 \times 10^{-2} & 0 & 0 \\ 0 & 0 & 0 & 0 & -6.876 \times 10^{-5} & 0 \\ 0 & 0 & 2.5 \times 10^{-4} & 0 & 6.876 \times 10^{-5} & -6.527 \times 10^{-4} \end{bmatrix}. \quad (41)$$

Comparisons of the LEAF and MACSYMA solutions are given in Tables III and IV. We note that in most instances six-digit agreement occurs, with the maximum discrepancy in the fifth digit.

The third test problem was the mass-85 chain defined by⁸

As an illustration of the LEAF program, the problem cards for Eq. (42) are listed in Table V for a BATCH CROS-CDC-7600 run. In Table VI the decay chain⁸ and nuclide data LEAF output are displayed.

Table VII lists the filtration removal rate, leakage removal rate and source terms for the various time intervals. Note in Table VII that a source to the containment building was non zero for all times. At 42 hours it was changed and again held constant.

Table VIII displays the A matrix constructed from the input (see Eq. 35) in quadrant form. Finally in Table IX the fission product inventories are given at $t = 0, 2, 4, 6, 8, 24, 30, 36, 42, 48, 54,$ and 60 hours. Note in Table IX that ${}^{85}\text{Rb}$ is stable and the listing is marked with an * indicating that the inventory is given in atoms and grams, not atoms and curies.

TABLE III
Test Problem 1
88 CHAIN - ZERO SOURCE
(All results in atoms)

TIME (hours)	NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
		LEAF	MACSYMA	LEAF	MACSYMA	LEAF	MACSYMA
0	⁸⁸ Br	1.9120×10^{13}	1.9120×10^{13}	0	0	0	0
	⁸⁸ Kr	1.0900×10^{18}	1.0900×10^{18}	0	0	0	0
	⁸⁸ Rb	1.2130×10^{14}	1.2130×10^{14}	0	0	0	0
2	⁸⁸ Br	0	0	3.77076×10^{-18}	0	5.04604×10^6	5.04604×10^6
	⁸⁸ Kr	6.64341×10^{17}	6.64339×10^{17}	0	0	7.16153×10^{13}	7.16152×10^{13}
	⁸⁸ Rb	5.46412×10^{16}	5.46410×10^{16}	2.24197×10^{16}	2.24196×10^{16}	4.75620×10^{12}	4.75619×10^{12}
4	⁸⁸ Br	0	0	0	0	5.04604×10^6	5.04604×10^6
	⁸⁸ Kr	4.04900×10^{17}	4.04897×10^{17}	0	0	1.15263×10^{14}	1.15263×10^{14}
	⁸⁸ Rb	3.33846×10^{16}	3.33844×10^{16}	1.42828×10^{16}	1.42827×10^{16}	8.35332×10^{12}	8.35329×10^{12}
6	⁸⁸ Br	0	0	0	0	5.04604×10^6	5.04604×10^6
	⁸⁸ Kr	2.46777×10^{17}	2.46774×10^{17}	0	0	1.41865×10^{14}	1.41865×10^{14}
	⁸⁸ Rb	2.03472×10^{16}	2.03470×10^{16}	8.71126×10^{15}	8.71119×10^{15}	1.05467×10^{13}	1.05467×10^{13}
8	⁸⁸ Br	0	0	0	0	5.04604×10^6	5.04604×10^6
	⁸⁸ Kr	1.50405×10^{17}	1.50403×10^{17}	0	0	1.58079×10^{14}	1.58078×10^{14}
	⁸⁸ Rb	1.24012×10^{16}	1.24010×10^{16}	5.30937×10^{15}	5.30930×10^{15}	1.18836×10^{13}	1.18835×10^{13}
24	⁸⁸ Br	0	0	0	0	5.04604×10^6	5.04604×10^6
	⁸⁸ Kr	2.86362×10^{15}	2.86351×10^{15}	0	0	1.82901×10^{14}	1.82900×10^{14}
	⁸⁸ Rb	2.36111×10^{14}	2.36102×10^{14}	1.01087×10^{14}	1.01084×10^{14}	1.39302×10^{13}	1.39301×10^{13}

TABLE IV
 Test Problem 2
 88 CHAIN - NON ZERO
 SOURCES
 (All results in atoms)

TIME (hours)	NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
		LEAF	MACSYMA	LEAF	MACSYMA	LEAF	MACSYMA
0	^{88}Br	1.91200×10^{13}	1.91200×10^{13}	0	0	0	0
	^{88}Kr	1.09000×10^{18}	1.09000×10^{18}	0	0	0	0
	^{88}Rb	1.21300×10^{14}	1.21300×10^{14}	0	0	0	0
2	^{88}Br	2.28102×10^{19}	2.28102×10^{19}	1.30823×10^{17}	1.30822×10^{17}	1.89416×10^{15}	1.89416×10^{15}
	^{88}Kr	1.70224×10^{22}	1.70223×10^{22}	0	0	7.66459×10^{17}	7.66458×10^{17}
	^{88}Rb	4.44825×10^{21}	4.44824×10^{21}	1.57431×10^{21}	1.57431×10^{21}	2.78215×10^{17}	2.78214×10^{17}
4	^{88}Br	2.28102×10^{19}	2.28102×10^{19}	1.30823×10^{17}	1.30822×10^{17}	3.79434×10^{15}	3.79434×10^{15}
	^{88}Kr	2.74104×10^{22}	2.74103×10^{22}	0	0	2.65273×10^{18}	2.65273×10^{18}
	^{88}Rb	5.30934×10^{21}	5.30933×10^{21}	1.97298×10^{21}	1.97298×10^{21}	6.87702×10^{17}	6.87702×10^{17}
6	^{88}Br	2.28102×10^{19}	2.28102×10^{19}	1.30823×10^{17}	1.30822×10^{17}	5.69453×10^{15}	5.69453×10^{15}
	^{88}Kr	3.37417×10^{22}	3.37416×10^{22}	0	0	5.22152×10^{18}	5.22150×10^{18}
	^{88}Rb	5.83137×10^{21}	5.83136×10^{21}	2.19680×10^{21}	2.19680×10^{21}	1.15352×10^{18}	1.15352×10^{18}
8	^{88}Br	2.28102×10^{19}	2.28102×10^{19}	1.30823×10^{17}	1.30822×10^{17}	7.59471×10^{15}	7.59471×10^{15}
	^{88}Kr	3.76004×10^{22}	3.76003×10^{22}	0	0	8.20627×10^{18}	8.20624×10^{18}
	^{88}Rb	6.14954×10^{21}	6.14952×10^{21}	2.33302×10^{21}	2.33302×10^{21}	1.65364×10^{18}	1.65364×10^{18}
24	^{88}Br	2.28102×10^{19}	2.28102×10^{19}	1.30823×10^{17}	1.30822×10^{17}	2.27962×10^{16}	2.27962×10^{16}
	^{88}Kr	4.35080×10^{22}	4.35077×10^{22}	0	0	3.62839×10^{19}	3.62838×10^{19}
	^{88}Rb	6.63663×10^{21}	6.63660×10^{21}	2.54156×10^{21}	2.54155×10^{21}	6.00086×10^{18}	6.00084×10^{18}

TABLE V

LIST OF TEST PROBLEM 3 DECK FOR BATCH CROS CDC-7600

```

$JOB(NAME=YSAPP,AC=ADOT,CL=U,UA=9R04R401,PK=22,PL=50,TL=305)
$PWINO(JOBIN)
$COPYSF(I=JOBIN,O=DUM,N=3)
$AFSREL(FS=DUM,ADISP=PRT)
$CLOSER(FS=JOBIN)
$OPERM(FS=MACLIB2,OAC=Z00,FS1=ZFS1)
$MACRO(MDF=MACLIB2,OAC=Z00)
$PHOTOR(FS=LEAF)
$UPDATE(F,P=LEAF)
$RUN(I=COMPILE)
$LDGO(SETA=I)
$FM.
*COMPILE,LEAF
$FM.

```

```

0 1
AS 85 1 0 0 3.415 E-01 85.0
SE 85 2 -1 0 1.777 E-02 85.0
.800
SE 85M 3 0 0 3.648 E-02 85.0
BR 85 4 2 3 4.025 E-03 85.0
KR 85M -5 4 0 4.298 E-05 85.0
KR 85 -6 -5 0 2.047 E-09 85.0
.212
RB 85 7 -5 6 0.0 85.0
.788

```

```

11 1 0 60.0

```

```

0.0 2.5 E-04 1.157 E-08
1.0 E+18 1.5 E+18 2.0 E+18 2.5 E+18 3.0 E+18 3.5 E+18
4.0 E+18
2.0 2.5 E-04 1.157 E-08
1.0 E+18 1.5 E+18 2.0 E+18 2.5 E+18 3.0 E+18 3.5 E+18
4.0 E+18
4.0 2.5 E-04 1.157 E-08
1.0 E+18 1.5 E+18 2.0 E+18 2.5 E+18 3.0 E+18 3.5 E+18
4.0 E+18
6.0 2.5 E-04 1.157 E-08
1.0 E+18 1.5 E+18 2.0 E+18 2.5 E+18 3.0 E+18 3.5 E+18
4.0 E+18
8.0 2.5 E-04 1.157 E-08
1.0 E+18 1.5 E+18 2.0 E+18 2.5 E+18 3.0 E+18 3.5 E+18
4.0 E+18
24.0 2.5 E-04 1.157 E-08
1.0 E+18 1.5 E+18 2.0 E+18 2.5 E+18 3.0 E+18 3.5 E+18
4.0 E+18
30.0 2.5 E-04 1.157 E-08
1.0 E+18 1.5 E+18 2.0 E+18 2.5 E+18 3.0 E+18 3.5 E+18
4.0 E+18
36.0 2.5 E-04 1.157 E-08
1.0 E+18 1.5 E+18 2.0 E+18 2.5 E+18 3.0 E+18 3.5 E+18
4.0 E+18
42.0 2.5 E-04 1.157 E-08
4.0 E+18 3.5 E+18 3.0 E+18 2.5 E+18 2.0 E+18 1.0 E+18
1.0 E+18
48.0 2.5 E-04 1.157 E-08
4.0 E+18 3.5 E+18 3.0 E+18 2.5 E+18 2.0 E+18 1.0 E+18
1.0 E+18
54.0 2.5 E-04 1.157 E-08
4.0 E+18 3.5 E+18 3.0 E+18 2.5 E+18 2.0 E+18 1.0 E+18
1.0 E+18
$EJ.

```

TABLE VI
DECAY CHAINS AND NUCLIDE RELATED DATA

NUCLIDE	ID	PARENT		DECAY CONSTANT	ATOMIC MASS
		1	2		
AS 85	1	0	0	3.41500D-01	8.50000D+01
SE 85	2	-1	0	1.77700D-02	8.50000D+01
SE 85M	3	0	0	3.64800D-02	8.50000D+01
BR 85	4	2	3	4.02500D-03	8.50000D+01
KR 85M	-5	4	0	4.29800D-05	8.50000D+01
KR 85	-6	-5	0	2.04700D-09	8.50000D+01
RB 85	7	-5	6	0.	8.50000D+01

BRANCHING RATIO		
FROM	TO	RATIO
1	2	.8000
5	6	.2120
5	7	.7880

TABLE VII
FILTRATION REMOVAL RATE, LEAKAGE REMOVAL RATE, AND
SOURCE TERMS FOR TIME INTERVALS

	TIME STEP DATA						
	TIME PERIOD IN HOURS						
	0.0- 2.0	2.0- 4.0	4.0- 6.0	6.0- 8.0	8.0- 24.0	24.0- 30.0	30.0- 36.0
FILTRATION REMOVAL RATE	2.50000D-04	2.50000D-04	2.50000D-04	2.50000D-04	2.50000D-04	2.50000D-04	2.50000D-04
LEAKAGE REMOVAL RATE	1.15700D-08	1.15700D-08	1.15700D-08	1.15700D-08	1.15700D-08	1.15700D-08	1.15700D-08
SOURCE TERMS							
AS AS	1.00000D+18	1.00000D+18	1.00000D+18	1.00000D+18	1.00000D+18	1.00000D+18	1.00000D+18
SE AS	1.50000D+18	1.50000D+18	1.50000D+18	1.50000D+18	1.50000D+18	1.50000D+18	1.50000D+18
SE ASM	2.00000D+18	2.00000D+18	2.00000D+18	2.00000D+18	2.00000D+18	2.00000D+18	2.00000D+18
BR AS	2.50000D+18	2.50000D+18	2.50000D+18	2.50000D+18	2.50000D+18	2.50000D+18	2.50000D+18
KR ASM	3.00000D+18	3.00000D+18	3.00000D+18	3.00000D+18	3.00000D+18	3.00000D+18	3.00000D+18
KR AS	3.50000D+18	3.50000D+18	3.50000D+18	3.50000D+18	3.50000D+18	3.50000D+18	3.50000D+18
RB AS	4.00000D+18	4.00000D+18	4.00000D+18	4.00000D+18	4.00000D+18	4.00000D+18	4.00000D+18
	36.0- 62.0	42.0- 48.0	48.0- 54.0	54.0- 60.0			
FILTRATION REMOVAL RATE	2.50000D-04	2.50000D-04	2.50000D-04	2.50000D-04			
LEAKAGE REMOVAL RATE	1.15700D-08	1.15700D-08	1.15700D-08	1.15700D-08			
SOURCE TERMS							
AS AS	1.00000D+18	4.00000D+18	4.00000D+18	4.00000D+18			
SE AS	1.50000D+18	3.50000D+18	3.50000D+18	3.50000D+18			
SE ASM	2.00000D+18	3.00000D+18	3.00000D+18	3.00000D+18			
BR AS	2.50000D+18	2.50000D+18	2.50000D+18	2.50000D+18			
KR ASM	3.00000D+18	2.00000D+18	2.00000D+18	2.00000D+18			
KR AS	3.50000D+18	1.00000D+18	1.00000D+18	1.00000D+18			
RB AS	4.00000D+18	1.00000D+18	1.00000D+18	1.00000D+18			

TABLE VIII
THE A MATRIX PRINTED BY QUADRANTS

QUADRANT 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.	0.	0.	0.
0.	0.	0.	4.02500D-03	0.	0.	0.
0.	0.	0.	0.	9.11176D-06	0.	0.
0.	0.	0.	0.	0.	0.	0.

QUADRANT 2

-3.41750D-01	0.	0.	0.	0.	0.	0.
2.73200D-01	-1.80200D-02	0.	0.	0.	0.	0.
0.	0.	-3.67300D-02	0.	0.	0.	0.
0.	1.77700D-02	3.64800D-02	-4.27501D-03	0.	0.	0.
0.	0.	0.	4.02500D-03	-4.29916D-05	0.	0.
0.	0.	0.	0.	9.11176D-06	-1.36170D-08	0.
0.	0.	0.	0.	3.38682D-05	2.04700D-09	-2.50012D-04

QUADRANT 3

2.50000D-04	0.	0.	0.	0.	0.	0.
0.	2.50000D-04	0.	0.	0.	0.	0.
0.	0.	2.50000D-04	0.	0.	0.	0.
0.	0.	0.	2.50000D-04	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	2.50000D-04

QUADRANT 4

-3.41500D-01	0.	0.	0.	0.	0.	0.
2.73200D-01	-1.77700D-02	0.	0.	0.	0.	0.
0.	0.	-3.64800D-02	0.	0.	0.	0.
0.	1.77700D-02	3.64800D-02	-4.02500D-03	0.	0.	0.
0.	0.	0.	0.	-4.29800D-05	0.	0.
0.	0.	0.	0.	0.	-2.04700D-09	0.
0.	0.	0.	0.	3.38682D-05	2.04700D-09	-0.

TABLE IX
FISSION PRODUCT INVENTORIES

FISSION PRODUCT INVENTORY AT 0.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES,GM	ATOMS	CURIES,GM	ATOMS	CURIES,GM
AS 85	-0.	0.	0.	0.	0.	0.
SE 85	-0.	0.	0.	0.	0.	0.
SE 85M	-0.	0.	0.	0.	0.	0.
BK 85	-0.	0.	0.	0.	0.	0.
KR 85M	-0.	0.	0.	0.	0.	0.
KR 85	-0.	0.	0.	0.	0.	0.
* RB 85	-0.	0.	0.	0.	0.	0.

FISSION PRODUCT INVENTORY AT 2.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES,GM	ATOMS	CURIES,GM	ATOMS	CURIES,GM
AS 85	2.92612D+18	2.70073D+07	2.14211D+15	1.97711D+04	2.43658D+14	2.24890D+03
SE 85	1.27603D+20	6.12841D+07	1.82814D+18	8.78002D+05	1.05464D+16	5.06514D+03
SE 85M	5.44514D+19	5.36861D+07	3.73159D+17	3.67915D+05	4.51887D+15	4.45536D+03
BK 85	1.57986D+21	1.71863D+08	1.09581D+20	1.19206D+07	1.26839D+17	1.37981D+04
KR 85M	5.92923D+22	6.83752D+07	0.	0.	2.52747D+18	2.93597D+03
KR 85	2.71892D+22	1.50422D+03	0.	0.	1.10485D+18	6.11250D-02
* RB 85	1.77564D+22	2.50609D+00	1.84415D+22	2.60278D+00	8.53471D+17	1.20457D-04

FISSION PRODUCT INVENTORY AT 4.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES,GM	ATOMS	CURIES,GM	ATOMS	CURIES,GM
AS 85	2.92612D+18	2.70073D+07	2.14211D+15	1.97711D+04	4.87415D+14	4.49871D+03
SE 85	1.27603D+20	6.12841D+07	1.82814D+18	8.78002D+05	2.11763D+16	1.01704D+04
SE 85M	5.44514D+19	5.36861D+07	3.73159D+17	3.67915D+05	9.05488D+15	8.92763D+03
BR 85	1.57986D+21	1.71863D+08	1.09581D+20	1.19206D+07	2.58448D+17	2.81149D+04
KR 85M	1.04192D+23	1.21031D+08	0.	0.	9.43324D+18	1.09579D+04
KR 85	5.78235D+22	3.19905D+03	0.	0.	4.62540D+18	2.55897D-01
* RB 85	2.63796D+22	3.72314D+00	5.88320D+22	8.30339D+00	2.72274D+18	3.84281D-04

FISSION PRODUCT INVENTORY AT 6.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES,GM	ATOMS	CURIES,GM	ATOMS	CURIES,GM
AS 85	2.92612D+18	2.70073D+07	2.14211D+15	1.97711D+04	7.31772D+14	6.74852D+03
SE 85	1.27603D+20	6.12841D+07	1.82814D+18	8.78002D+05	3.18662D+16	1.52756D+04
SE 85M	5.44514D+19	5.36861D+07	3.73159D+17	3.67915D+05	1.35009D+16	1.33999D+04
BR 85	1.57986D+21	1.71863D+08	1.09581D+20	1.19206D+07	3.90656D+17	4.24317D+04
KR 85M	1.04192D+23	1.59303D+08	0.	0.	1.95558D+19	2.27165D+04
KR 85	9.69881D+22	5.63386D+03	0.	0.	1.08687D+19	5.97987D-01
* RB 85	3.79810D+22	4.51371D+00	1.11660D+23	1.57595D+01	5.16765D+18	7.29348D-04

FISSION PRODUCT INVENTORY AT 8.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES.GM	ATOMS	CURIES.GM	ATOMS	CURIES.GM
AS 85	2.92612D+18	2.70073D+07	2.14211D+15	1.97711D+04	9.74929D+14	8.99834D+03
SE 85	1.27663D+20	6.12841D+07	1.82814D+18	8.78002D+05	4.24361D+16	2.03808D+04
SE 85M	5.44514D+19	5.36861D+07	3.73159D+17	3.67915D+05	1.81269D+16	1.78722D+04
BR 85	1.57986D+21	1.71863D+08	1.09581D+20	1.19209D+07	5.21264D+17	5.67486D+04
KR 85M	1.61314D+23	1.87386D+08	0.	0.	3.20388D+19	3.72170D+04
KR 85	1.26068D+23	6.97132D+03	0.	0.	1.98361D+19	1.09742D+00
* RB 85	3.59713D+22	5.67689D+00	1.73010D+23	2.44181D+01	8.00689D+18	1.13007D+03

FISSION PRODUCT INVENTORY AT 24.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES.GM	ATOMS	CURIES.GM	ATOMS	CURIES.GM
AS 85	2.92612D+18	2.70073D+07	2.14211D+15	1.97711D+04	2.92499D+15	2.69968D+04
SE 85	1.27663D+20	6.12841D+07	1.82814D+18	8.78002D+05	1.27475D+17	6.12225D+04
SE 85M	5.44514D+19	5.36861D+07	3.73159D+17	3.67915D+05	5.44151D+16	5.36503D+04
BR 85	1.57986D+21	1.71863D+08	1.09581D+20	1.19209D+07	1.57453D+18	1.71283D+05
KR 85M	2.22350D+23	2.52287D+08	0.	0.	1.67527D+20	1.94603D+05
KR 85	4.24092D+23	2.40158D+04	0.	0.	2.04864D+20	1.13339D+01
* RB 85	4.59641D+22	6.48754D+00	7.90025D+23	1.11502D+02	3.65240D+19	5.16032D+03

FISSION PRODUCT INVENTORY AT 30.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES.GM	ATOMS	CURIES.GM	ATOMS	CURIES.GM
AS 85	2.92612D+18	2.70073D+07	2.14211D+15	1.97711D+04	3.65626D+15	3.37463D+04
SE 85	1.27603D+20	6.12841D+07	1.82814D+18	8.78002D+05	1.59365D+17	7.65381D+04
SE 85M	5.44514D+19	5.36861D+07	3.73159D+17	3.67915D+05	6.80331D+16	6.70671D+04
BR 85	1.57986D+21	1.71863D+08	1.09581D+20	1.19209D+07	1.96935D+18	2.14234D+05
KR 85M	2.55738D+23	2.62222D+08	0.	0.	2.23683D+20	2.59718D+05
KR 85	5.63692D+23	3.06327D+04	0.	0.	3.28280D+20	1.81619D+01
* RB 85	4.65214D+22	6.56591D+00	1.03997D+24	1.46779D+02	4.81298D+19	6.79292D-03

FISSION PRODUCT INVENTORY AT 36.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES.GM	ATOMS	CURIES.GM	ATOMS	CURIES.GM
AS 85	2.92612D+18	2.70073D+07	2.14211D+15	1.97711D+04	4.38753D+15	4.04957D+04
SE 85	1.27603D+20	6.12841D+07	1.82814D+18	8.78002D+05	1.91254D+17	9.18538D+04
SE 85M	5.44514D+19	5.36861D+07	3.73159D+17	3.67915D+05	8.16312D+16	8.04839D+04
BR 85	1.57986D+21	1.71863D+08	1.09581D+20	1.19209D+07	2.36418D+18	2.57184D+05
KR 85M	2.57077D+23	2.63777D+08	0.	0.	2.80190D+20	3.25475D+05
KR 85	6.73692D+23	3.72716D+04	0.	0.	4.81445D+20	2.66467D+01
* RB 85	4.67413D+22	6.59695D+00	1.29187D+24	1.82331D+02	5.97877D+19	8.43828D-03

FISSION PRODUCT INVENTORY AT 42.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES.GM	ATOMS	CURIES.GM	ATOMS	CURIES.GM
AS 85	2.92612D+18	2.70073D+07	2.14211D+15	1.97711D+04	5.11880D+15	4.72451D+04
SE 85	1.27603D+20	6.12841D+07	1.82814D+18	8.78002D+05	2.23144D+17	1.07169D+05
SE 85M	5.44514D+19	5.36861D+07	3.73159D+17	3.67915D+05	9.52392D+16	9.39007D+04
BR 85	1.57986D+21	1.71863D+08	1.09581D+20	1.19206D+07	2.75900D+18	3.00135D+05
KR 85M	2.27606D+23	2.64392D+08	0.	0.	3.37015D+20	3.91484D+05
KR 85	7.03828D+23	4.39180D+04	0.	0.	6.65019D+20	3.67917D+01
* RB 85	4.48289D+22	6.60930D+00	1.54454D+24	2.17993D+02	7.14815D+19	1.00887D-02

FISSION PRODUCT INVENTORY AT 48.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES.GM	ATOMS	CURIES.GM	ATOMS	CURIES.GM
AS 85	1.17045D+19	1.08029D+08	8.56842D+15	7.90842D+04	8.04359D+15	7.42402D+04
SE 85	3.71679D+20	1.78506D+08	5.36076D+18	2.57461D+04	3.15870D+17	1.51703D+05
SE 85M	8.16771D+19	8.05292D+07	5.59739D+17	5.51872D+05	1.15643D+17	1.14017D+05
BR 85	2.62673D+21	3.07503D+08	2.04314D+20	2.22260D+07	3.46132D+18	3.76536D+05
KR 85M	2.89075D+23	3.35795D+08	0.	0.	4.02681D+20	4.67647D+05
KR 85	8.46819D+23	4.79562D+04	0.	0.	8.72272D+20	4.82579D+01
* RB 85	4.20756D+22	5.93844D+00	1.76285D+24	2.48804D+02	8.15847D+19	1.15147D-02

FISSION PRODUCT INVENTORY AT 54.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES/GM	ATOMS	CURIES/GM	ATOMS	CURIES/GM
AS 85	1.170450+19	1.680290+08	8.568420+15	7.908420+04	1.092870+16	1.012380+05
SE 85	3.716790+20	1.785060+08	5.360760+18	2.574610+04	4.087570+17	1.963140+05
SE 85M	8.167710+19	8.052920+07	5.597390+17	5.518720+05	1.360550+17	1.341430+05
BR 85	2.826730+21	3.075030+08	2.043140+20	2.222600+07	4.167760+18	4.533840+05
KR 85M	3.140100+23	3.647410+08	0.	0.	4.784150+20	5.557380+05
KR 85	9.478750+23	5.244050+04	0.	0.	1.098930+21	6.079750+01
* RB 85	4.408740+22	6.504660+00	2.002450+24	2.826210+02	9.267360+19	1.307970-02

FISSION PRODUCT INVENTORY AT 60.00 HOURS

STABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND ARE NOTED BY A * IN THE MARGIN

NUCLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES/GM	ATOMS	CURIES/GM	ATOMS	CURIES/GM
AS 85	1.170450+19	1.680290+08	8.568420+15	7.908420+04	1.389380+16	1.282360+05
SE 85	3.716790+20	1.785060+08	5.360760+18	2.574610+04	5.014440+17	2.409250+05
SE 85M	8.167710+19	8.052920+07	5.597390+17	5.518720+05	1.564670+17	1.542680+05
BR 85	2.826730+21	3.075030+08	2.043140+20	2.222600+07	4.874190+18	5.302330+05
KR 85M	3.238620+23	3.742050+08	0.	0.	5.583090+20	6.485440+05
KR 85	1.632100+24	5.710040+04	0.	0.	1.346300+21	7.448310+01
* RB 85	4.769960+22	6.732190+00	2.286340+24	3.184540+02	1.044240+20	1.473810-02

The MACSYMA analytic solution agreed in all instances to within two digits in the sixth place. This difference is judged insignificant.

The total running time on the CDC-7600 for example 3 with LEAF was 15.3 s; the problem solution time was 5.5 s.

VII. CONCLUSIONS

An analytic solution has been obtained for a containment building model to calculate the leakage into the environment of each isotope of an arbitrary radioactive decay chain. The model accounts for the source, the buildup, the decay, the cleanup and the leakage of isotopes that are gas-borne inside the containment building.

Three assumptions were made in the model: (1) the gas inside the containment building is well mixed and all in one compartment; (2) that natural deposition of gas-borne isotopes internal to the containment building is ignored; and (3) that the source of an isotope inside the containment building which is a result of leakage from the reactor vessel, its removal rate by the containment cleanup system, and its leakage from the containment building are all assumed constant during short time intervals.

With these assumptions the model is representable by a system of linear differential equations. An analytic solution is obtained to these equations in terms of matrix operators using the Volterra method of the multiplicative integral. Recursion formulae are developed to accurately evaluate the matrix operators for arbitrary matrix element values.

A computer program LEAF was written, debugged, and described. Comparisons of LEAF with those achieved by Laplace transform techniques on MACSYMA⁷ indicate that the LEAF model is accurate. Computationally LEAF is fast.

REFERENCE

1. "Reactor Safety Study -- Assessment of Accident Risks in Commercial Nuclear Power Plants," United States Nuclear Regulatory Commission report WASH-1400 (NUREG-75-014), Appendix VII (October 1975), p. 23.
2. John E. Foley, "¹³¹I Release from an HTGR During the LOFC Accident," Los Alamos Scientific Laboratory report LA-5893-MS (March 1975), p. 6.
3. L. M. Carruthers and C. E. Lee, "LARC-1: A Los Alamos Release Calculation Program for Fission Product Transport in HTGRs During the LOFC Accident," Los Alamos Scientific Laboratory report LA-NUREG-6563-MS (November 1976).
4. C. E. Lee, "The Calculation of Isotopic Mass and Energy Production by a Matrix Operator Method," Los Alamos Scientific Laboratory report LA-6483-MS (September 1976).
5. F. R. Gantmacher, The Theory of Matrices, (Chelsea Publishing Company, New York, 1960), pp. 125ff, 185ff.
6. E. Bodewig, Matrix Calculus, (Interscience Publishers, New York, 1963), p. 67ff.
7. The MATHLAB GROUP, MASCYMA Reference Manual, Version 8, Project MAC-MIT, Cambridge, Mass. (1975) supported by the Defense Advanced Research Projects Agency work order No. 2095, under Office of Naval Research contract No. N00014-75-0661.
8. T. R. England and R. E. Schenter, "ENDF/B-IV Fission Product Files: Summary of Major Nuclide Data," Los Alamos Scientific Laboratory report LA-6116-MS (October 1975).

APPENDIX A

$D(2^p H)$ AND $Z(2^p H)$ RECURSION RELATIONS

We demonstrate here an induction proof of the recursion relations for Eqs. (33) and (34) of the text.

$D(2^p H)$: Define

$$D(H) = H^{-1}(e^H - I) \quad (A-1)$$

and

$$C = 2^p H. \quad (A-2)$$

Clearly if $p = 0$

$$D(C) = D(H). \quad (A-3)$$

If $p = 1$

$$\begin{aligned} D(C) &= D(2H) = (2H)^{-1}(e^{2H} - I) \\ &= H^{-1}(e^H - I) \left(\frac{e^H + I}{2} \right) \\ &= D(H) \left[I + \frac{1}{2} H D(H) \right]. \end{aligned} \quad (A-4)$$

By induction we may write

$$D(2^p H) = D(2^{p-1} H) \left[I + \frac{1}{2} (2^{p-1} H) D(2^{p-1} H) \right]. \quad (A-5)$$

We assume Eq. (A-5), which is true for $p = 0$ and 1 , is true for $p = n$. Evaluate $D(2^{n+1} H)$ as

$$\begin{aligned} D(2^{n+1} H) &= (2^{n+1} H)^{-1}(e^{2^{n+1} H} - I) \\ &= (2^n H)^{-1}(e^{2^n H} - I) \frac{1}{2} (e^{2^n H} + I) \\ &= D(2^n H) \left[I + \frac{1}{2} (2^n H) D(2^n H) \right]. \end{aligned} \quad (A-6)$$

Since Eq. (A-5) is true for $p = 0$ and 1 and if it is assumed true for $p = n$, it is true for $p = n + 1$; then by transfinite induction it is true for all p .

$Z(2^p H)$: Define

$$HZ(H) + I = D(H). \quad (A-7)$$

Assume Eq. (A-5) is true, as was proved. Then using Eqs. (A-5) and (A-6) we may write

$$2^p + 1_H Z(2^p + 1_H) + I = D(2^p + 1_H) \\ = D(2^{p_H}) \left[I + \frac{1}{2} (2^{p_H}) D(2^{p_H}) \right], \quad (A-8)$$

$$2^{p_H} Z(2^{p_H}) + I = D(2^{p_H}) \quad (A-9)$$

or substituting the LHS of Eq. (A-9) into the RHS of Eq. (A-8) for $D(2^{p_H})$ we have

$$H Z(2^p + 1_H) = H \left\{ \frac{1}{2} Z(2^{p_H}) + \left[\frac{I}{2} + \frac{1}{2} (2^{p_H}) Z(2^{p_H}) \right]^2 \right\} \quad (A-10)$$

or

$$Z(2^p + 1_H) = \frac{1}{2} Z(2^{p_H}) + \left[\frac{I}{2} + \frac{1}{2} (2^{p_H}) Z(2^{p_H}) \right]^2. \quad (A-11)$$

If H is singular, we may define a non-singular matrix H' such that

$$H' = H - \epsilon I, \quad \epsilon \ll 1 \quad (A-12)$$

and

$$|H'| \neq 0, \quad (A-13)$$

which permits Eq. (A-11) to be written with H' , since $(H')^{-1}$ exists and yet is arbitrarily close to H . The H matrices in LEAF will be singular if a stable isotope is in a chain.

Since $Z(H)$ exists even if H is singular [see Eq. (26)], an alternate proof of the validity of Eq. (A-11) can be made by direct evaluation of the power series. That tedious process will not be repeated here; however, term by term comparison indicates that Eq. (A-11) is indeed correct.

Computationally, Eq. (A-11) is subject to round-off errors even in double precision arithmetic. Using Eq. (A-9) in Eq. (A-11) we can eliminate that difficulty and obtain

$$Z(2^p + 1_H) = \frac{1}{2} Z(2^{p_H}) + \frac{1}{4} [D(2^{p_H})]^2, \quad (A-14)$$

which involves evaluating $Z(C)$ after $D(C)$ at each point in the recursion.

LASL Identification Code: LP-0722
APPENDIX B: LEAF PROGRAM LISTING

PROGRAM LEAF (INP,OUT)	LEAF	2
LEAF - A COMPUTER PROGRAM TO CALCULATE FISSION PRODUCT RELEASE	LEAF	3
FROM A REACTOR CONTAINMENT BUILDING FOR ARBITRARY RADIOACTIVE	LEAF	4
DECAY CHAINS	LEAF	5
BY CLARENCE E. LEE	LEAF	6
COURTNEY E. APPERSON, JR.	LEAF	7
JOHN E. FOLEY	LEAF	8
REACTOR TECHNOLOGY DIVISION	LEAF	9
LOS ALAMOS SCIENTIFIC LABORATORY	LEAF	10
NOVEMBER 1976	LEAF	11
THIS IS THE EIGHTH VERSION OF LEAF. IT WAS CREATED ON	LEAF	12
11 NOVEMBER 1976. THE CHANGES INCORPORATED IN VERSION	LEAF	13
EIGHT REMOVE A DIMENSION ERROR.	LEAF	14
INPLT INSTRUCTIONS FOR THE CODE FOLLOW	LEAF	15
CARD WORD SYMBOL FORMAT INFORMATION	LEAF	16
0 PRINT OPTION	LEAF	17
1 NSKIP I4 0/1 LINE PRINTER/TERMINAL	LEAF	18
2 MATRIX I4 0/1 PRINT A MATRIX NO/YES	LEAF	19
1 NUCLIDE BASIC DATA - ONE CARD PER NUCLIDE	LEAF	20
1 HANMAT(I,1) A7 NUCLIDE NAME	LEAF	21
2 HANMAT(I,2) F4 ID NUMBER (NEGATIVE IF NOT	LEAF	22
RETAINED BY FILTER)	LEAF	23
3 HANMAT(I,3) F4 DECAY PARENT 1	LEAF	24
4 HANMAT(I,4) F4 DECAY PARENT 2	LEAF	25
5 ANMAT(I,1) E12.5 NUCLEAR DECAY CONSTANT	LEAF	26
6 ANMAT(I,2) E12.5 ATOMIC MASS	LEAF	27
2 BRANCHING RATIO - ONE CARD PER BRANCH AFTER CARD ONE	LEAF	28
FOR EACH NEGATIVE DECAY PARENT	LEAF	29
1 BRV(IBR) E12.5 BRANCHING RATIO	LEAF	30
BLANK CARD AFTER LAST SET OF CARDS ONE AND TWO	LEAF	31
3 NUMBER OF TIME STEPS	LEAF	32
1 INT I4 NUMBER OF TIME INTERVALS	LEAF	33
2 ITP I4 PRINT FREQUENCY	LEAF	34
3 IAC I4 UNITS OF CONTIC AND SOURCE	LEAF	35
0 - ATOMS AND ATOMS/SEC	LEAF	36
1 - CURIES OR GRAMS AND	LEAF	37
CURIES/SEC OR GRAMS/SEC	LEAF	38
4 TEND(INT+1) E12.5 MAXIMUM TIME IN HOURS	LEAF	39
4 INITIAL VALUE OF ALL NUCLIDE CONCENTRATIONS IN CONTAINMENT	LEAF	40
1 CONTIC(1) E12.5 INITIAL CONCENTRATION OF NUCLIDE	LEAF	41
2 CONTIC(2) E12.5 INITIAL CONCENTRATION OF NUCLIDE	LEAF	42
N CONTIC(N) E12.5 INITIAL CONCENTRATION OF NUCLIDE	LEAF	43
5 TIME STEP DATA - INT CARDS	LEAF	44
1 TEND(N) E12.5 BEGINNING OF NTH TIME STEP	LEAF	45
IN HOURS	LEAF	46
2 LAMDAV(N) E12.5 CLEAN UP RATE DURING INTERVAL	LEAF	47
3 LAMDAL(N) E12.5 LEAKAGE RATE DURING INTERVAL	LEAF	48
6 TIME STEP SOURCE DATA - CARDS FIVE AND SIX ARE ENTERED AS A SET	LEAF	49
1 SOURCE(1,INT) E12.5 SOURCE TERM FOR NUCLIDE 1	LEAF	50
2 SOURCE(2,INT) E12.5 SOURCE TERM FOR NUCLIDE 2	LEAF	51
N SOURCE(N,INT) E12.5 SOURCE TERM FOR NUCLIDE N	LEAF	52
PROGRAM LOGIC OF LEAF	LEAF	53

C		LEAF	62	
C	INPA	LEAF	63	
C	INPC	LEAF	64	
C	MAKEA	LEAF	65	
C	SOLVER	LEAF	66	
C	FSOLVE	LEAF	67	
C	PREP	LEAF	68	
C	PAPER OR TERM	LEAF	69	
C		LEAF	70	
C		LEAF	71	
C	NN=20	NUMBER OF NUCLIDES TIMES TWO	LEAF	72
C	NNT=10	NUMBER OF NUCLIDES	LEAF	73
C	NIT=25	NUMBER OF TIME INTERVALS PLUS ONE	LEAF	74
C	NBR=10	NUMBER OF BRANCHING RATIOS	LEAF	75
C		LEAF	76	
	IMPLICIT DOUBLE(A-G,P-Z)	PARAM1	2	
	PARAMETER (NNT=10),(NN=2*NN1),(NIT=25),(NBR=10),(NNP=NNT+1)	PARAM1	3	
	COMMON /BASIS1/ I,IBR,NSKIP	PARAM1	4	
	DOUBLE LAMDV,LAMD	PARAM1	5	
	DOUBLE LAMDAV(NIT),LAMDAL(NIT)	LEAF	78	
	DIMENSION A(NN,NN),SOURCE(NNT,NIT),CONTIC(NN),XNTOT(NN),	LEAF	79	
	1 XOUT(NNT,6,NIT),XIENV(NN),TEND(NIT),ANMAT(NNP,2),BRV(NBR),	LEAF	80	
	2 B(NN,NN),D(NN,NN),E(NN,NN),BL(NN,NN),CSOURC(NN),HANMAT(NNP,4),	LEAF	81	
	3 XENVIC(NN)	LEAF	82	
		LEAF	83	
C	*** READ LEAF INPUT DATA	LEAF	84	
C	*** ASKIP GREATER THAN ZERO - DO NOT PRINT INPUT DATA AND USE	LEAF	85	
C	*** TERMINAL OUTPUT FORMAT	LEAF	86	
	READ 90, NSKIP,MATRIX	LEAF	87	
	CALL INPA(ANMAT,HANMAT,BRV)	LEAF	88	
	I2=I*2	LEAF	89	
	DO 10 IK=1,I2	LEAF	90	
	XNTOT(IK)=0.000	LEAF	91	
	XIENV(IK)=0.000	LEAF	92	
	XENVIC(IK)=0.000	LEAF	93	
	CSOURC(IK)=0.000	LEAF	94	
	CONTIC(IK)=0.000	LEAF	95	
10	CONTINUE	LEAF	96	
	CALL INPC(INT,CONTIC,TEND,LAMDAV,LAMDAL,SOURCE,HANMAT,ITP,ANMAT)	LEAF	97	
	DO 20 J=1,I	LEAF	98	
	XOUT(J,1,1)=CONTIC(J)	LEAF	99	
	XOUT(J,3,1)=0.000	LEAF	100	
	XOUT(J,5,1)=0.000	LEAF	101	
20	CONTINUE	LEAF	102	
	DO 50 IT=1,INT	LEAF	103	
	TINC0=(TEND(IT+1)-TEND(IT))*3600.000	LEAF	104	
	DO 30 IN=1,I	LEAF	105	
	CSOURC(IN)=SOURCE(IN,IT)	LEAF	106	
30	CONTINUE	LEAF	107	
	LAMDV=LAMDAV(IT)	LEAF	108	
	LAMD0=LAMDAL(IT)	LEAF	109	
	CALL MAKEA(ANMAT,HANMAT,BRV,A,BL,LAMDV,LAMD0)	LEAF	110	
	IF(MATRIX.EQ.1) CALL PRMAT(A,IT)	LEAF	111	
	CALL SOLVER(A,B,D,E,TINC0)	LEAF	112	
	CALL FSOLVE(BL,B,D,E,CONTIC,CSOURC,XNTOT,XIENV,TINC0,XENVIC)	LEAF	113	
	DO 40 J=1,I	LEAF	114	
	XOUT(J,1,IT+1)=XNTOT(J)	LEAF	115	
	XOUT(J,3,IT+1)=XNTOT(J+I)	LEAF	116	
	XOUT(J,5,IT+1)=XIENV(J)	LEAF	117	
40	CONTINUE	LEAF	118	
50	CONTINUE	LEAF	119	
	INT=INT+1	LEAF	120	
	CALL PREP(XOUT,ANMAT,INT)	LEAF	121	

IF (NSKIP) 60,60,70	LEAF	122
60 CALL PAPER(XOUT,ANMAT,HANMAI,INT,ITP,TEND)	LEAF	123
GO TO 80	LEAF	124
70 CALL TERM(XOUT,HANMAT,INT,I!P,TEND)	LEAF	125
80 CONTINUE	LEAF	126
C	LEAF	127
90 FORMAT(2I4)	LEAF	128
END	LEAF	129
SUBROUTINE INPA(ANMAT,HANMAI,BRV)	LEAF	130
C *** INPA READS AND PRINTS THE NUCLEAR DATA	LEAF	131
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10),(NN=2*NNI),(NIT=25),(NBR=10),(NNP=NNI+1)	PARAM2	3
COMMON /BASIS/ I,IBR,NSKIP	PARAM2	4
DIMENSION ANMAT(NNP,2),HANMAT(NNP,4),BRV(NBR),HBRP(3,NBR)	LEAF	133
HJ=(7H)	LEAF	134
I=1	LEAF	135
IBR=1	LEAF	136
C *** READ NUCLEAR DATA	LEAF	137
10 READ 110, (HANMAT(I,J),J=1,4),(ANMAT(I,K),K=1,2)	LEAF	138
IF (HANMAT(I,1).EQ.HJ) GO TO 70	LEAF	139
DO 20 J=3,4	LEAF	140
IF (ABS(HANMAT(I,J))-1) 20,20,30	LEAF	141
20 CONTINUE	LEAF	142
GO TO 40	LEAF	143
30 PRINT 120, I	LEAF	144
CALL EXIT	LEAF	145
C *** TEST FOR BRANCHING RATIOS	LEAF	146
40 DO 60 J=3,4	LEAF	147
IF (HANMAT(I,J)-0.0) 50,60,60	LEAF	148
50 READ 130, BRV(IBR)	LEAF	149
HBRP(1,IBR)=ABS(HANMAT(I,J))	LEAF	150
HBRP(2,IBR)=1	LEAF	151
HBRP(3,IBR)=BRV(IBR)	LEAF	152
IBR=IBR+1	LEAF	153
60 CONTINUE	LEAF	154
I=I+1	LEAF	155
GO TO 10	LEAF	156
70 I=I-1	LEAF	157
IBR=IBR-1	LEAF	158
IF (NSKIP.EQ.1) GO TO 100	LEAF	159
C *** PRINT DECAY DATA	LEAF	160
PRINT 140	LEAF	161
PRINT 150	LEAF	162
PRINT 160	LEAF	163
PRINT 150	LEAF	164
PRINT 170	LEAF	165
LCNT=13	LEAF	166
DO 80 J=1,I	LEAF	167
PRINT 180, (HANMAT(J,JJ),JJ=1,4),(ANMAT(J,JJ),JJ=1,2)	LEAF	168
LCNT=LCNT+1	LEAF	169
IF (LCNT.GE.60) PRINT 140	LEAF	170
80 CONTINUE	LEAF	171
LCNT=LCNT+IBR*8	LEAF	172
IF (LCNT.GT.60) PRINT 140	LEAF	173
C *** PRINT BRANCHING RATIOS	LEAF	174
IF (IBR.EQ.0) GO TO 100	LEAF	175
PRINT 150	LEAF	176
PRINT 190	LEAF	177
DO 90 J=1,IBR	LEAF	178
PRINT 200, HBRP(1,J),HBRP(2,J),HBRP(3,J)	LEAF	179
90 CONTINUE	LEAF	180
100 CONTINUE	LEAF	181
RETURN	LEAF	182

C		LEAF	183
110	FORMAT (A7,3F4,2D12.5)	LEAF	184
120	FORMAT (1H0,4X,*THERE IS AN ERROR IN NUCLIDE *,I3)	LEAF	185
130	FORMAT (6D12.5)	LEAF	186
140	FORMAT (1H1)	LEAF	187
150	FORMAT (////////)	LEAF	188
160	FORMAT (51X,*DECAY CHAINS AND NUCLIDE RELATED DATA*)	LEAF	189
170	FORMAT (61X,*PARENT*,7X,*DECAY*,/,45X,*NUCLIDE ID*,4X,*1 2*,5	LEAF	190
	1X,*CONSTANT*,4X,*ATOMIC MASS*,/)	LEAF	191
180	FORMAT (45X,A7,1X,F4,2X,F4,1X,F4,2X,1PD12.5,1X,1PD12.5)	LEAF	192
190	FORMAT (61X,*BRANCHING RATIOS*,/,58X,*FROM*,5X,*TO*,5X,*RATIO*,/)	LEAF	193
200	FORMAT (57X,F4,4X,F4,3X,F7.4)	LEAF	194
	END	LEAF	195
	SUBROUTINE INPC(INT,CONTIC,LEND,LAMDAV,LAMDAL,SOURCE,HANMAT,ITP,AN	LEAF	196
	1MAT)	LEAF	197
C ***	INPC READS THE CASE DATA	LEAF	198
	IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
	PARAMETER (NNT=10), (NN=2*NN), (NIT=25), (NBR=10), (NNP=NN+1)	PARAM2	3
	COMMON /BASIS1/ I,IHR,NSKIP	PARAM2	4
	DOUBLE PRECISION LAMDAV(NIT),LAMDAL(NIT)	LEAF	200
	DIMENSION SOURCE(NNT,NIT), HANMAT(NNP,4), CONTIC(NN), TEND(NIT)	LEAF	201
	DIMENSION HTEND(8), ANMAT(NNP,2)	LEAF	202
C ***	READ BASIC TIME DATA	LEAF	203
	READ 120, INT,ITP,IAC,HTIME	LEAF	204
	INT1=INT+1	LEAF	205
	TEND(INT1)=HTIME	LEAF	206
C ***	READ INITIAL CONCENTRATION OF CONTAINMENT	LEAF	207
	READ 130, (CONTIC(J),J=1,I)	LEAF	208
C ***	READ TIME STEP DATA	LEAF	209
	DO 10 J=1,INT	LEAF	210
	READ 130, TEND(J),LAMDAV(J),LAMDAL(J)	LEAF	211
	READ 130, (SOURCE(M,J),M=1,I)	LEAF	212
	10 CONTINUE	LEAF	213
C ***	CONVERT CONTIC AND SOURCE TO ATOMS AND ATOMS/SEC	LEAF	214
	IF (IAC.EQ.0) GO TO 60	LEAF	215
	DO 50 M=1,I	LEAF	216
	IF (ANMAT(M,1)) 20,20,30	LEAF	217
20	CF=6.0225D+23/ANMAT(M,2)	LEAF	218
	GO TO 40	LEAF	219
30	CF=3.7D+10/ANMAT(M,1)	LEAF	220
40	CONTINUE	LEAF	221
	CONTIC(M)=CONTIC(M)*CF	LEAF	222
	DO 50 J=1,INT	LEAF	223
	SOURCE(M,J)=SOURCE(M,J)*CF	LEAF	224
50	CONTINUE	LEAF	225
60	CONTINUE	LEAF	226
C ***	PRINT INPUT DATA	LEAF	227
	IF (NSKIP.EQ.1) GO TO 110	LEAF	228
	PRINT 140	LEAF	229
	PRINT 160	LEAF	230
	PRINT 170	LEAF	231
	PRINT 180	LEAF	232
	LIN1=1	LEAF	233
	LIN2=MIN0(7,INT)	LEAF	234
	LIN2P=LIN2+1	LEAF	235
	LIN=INT/7.0+0.99	LEAF	236
	LNCT=9	LEAF	237
	NLN=6+1	LEAF	238
	DO 100 JK=1,LIN	LEAF	239
	PRINT 190	LEAF	240
	L=LIN2P-LIN1+1	LEAF	241
	L=MIN0(8,L)	LEAF	242
	DO 70 J=1,L	LEAF	243

K=LIN1-1+J	LEAF	244
HTEND(J)=TEND(K)	LEAF	245
70 CONTINUE	LEAF	246
LM=L-1	LEAF	247
PRINT 200, (HTEND(J),J=1,LM)	LEAF	248
PRINT 210, (HTEND(J),J=2,L)	LEAF	249
PRINT 220, (LAMDAV(J),J=LIN1,LIN2)	LEAF	250
PRINT 230, (LAMDAL(J),J=LIN1,LIN2)	LEAF	251
PRINT 240	LEAF	252
DO 80 JL=1,I	LEAF	253
PRINT 250, HANMAT(JL,1), (SOURCE(JL,J),J=LIN1,LIN2)	LEAF	254
80 CONTINUE	LEAF	255
LIN1=LIN1+7	LEAF	256
LIN2=LIN2+7	LEAF	257
LIN2=MIN0(LIN2,INT)	LEAF	258
LIN2P=LIN2+1	LEAF	259
PRINT 150	LEAF	260
LNCT=LNCT+NLN+3	LEAF	261
LNTST=60-LNCT	LEAF	262
IF (LNTST-NLN) 90,100,100	LEAF	263
90 PRINT 140	LEAF	264
LNCT=0	LEAF	265
100 CONTINUE	LEAF	266
110 CONTINUE	LEAF	267
RETURN	LEAF	268
C	LEAF	269
120 FORMAT (3I4,E12.5)	LEAF	270
130 FORMAT (6D12.5)	LEAF	271
140 FORMAT (1H1)	LEAF	272
150 FORMAT (////)	LEAF	273
160 FORMAT (////////)	LEAF	274
170 FORMAT (62X,*TIME STEP DATA*,/)	LEAF	275
180 FORMAT (59X,*TIME PERIOD IN HOURS*,/)	LEAF	276
190 FORMAT (23X,7(12X,*-*))	LEAF	277
200 FORMAT (1H*,21X,7(8X,F6.1))	LEAF	278
210 FORMAT (1H*,27X,7(8X,F6.1))	LEAF	279
220 FORMAT (/5X,*FILTRATION REMOVAL RATE*,7(2X,1PD12.5))	LEAF	280
230 FORMAT (/5X,*LEAKAGE REMOVAL RATE *,7(2X,1PD12.5))	LEAF	281
240 FORMAT (/5X,*SOURCE TERMS*)	LEAF	282
250 FORMAT (7X,A7,14X,7(2X,1PD12.5))	LEAF	283
END	LEAF	284
SUBROUTINE MAKEA(ANMAT,HANMAT,BRV,A,BL,LAMDV,LAMDUL)	LEAF	285
C *** MAKEA CONSTRUCTS THE MAIN SOLUTION MATRIX	LEAF	286
IMPLICIT DOUBLE(A-G,P-Z)	PARAM1	2
PARAMETER (NNT=10),(NN=2*NNT),(NIT=25),(NBR=10),(NNP=NN+1)	PARAM1	3
COMMON /BASIS1/ I,IBR,NSKIP	PARAM1	4
DOUBLE LAMDV,LAMDUL	PARAM1	5
DIMENSION ANMAT(NNP,2),BRV(NBR),A(NN,NN),BB(NNT,NNT),BL(NN,NN)	LEAF	288
DIMENSION HANMAT(NNP,4)	LEAF	289
I2=I+2	LEAF	290
IP=I+1	LEAF	291
DO 10 IK=1,I2	LEAF	292
DO 10 JK=1,I2	LEAF	293
A(IK,JK)=0.0D0	LEAF	294
BL(IK,JK)=0.0D0	LEAF	295
10 CONTINUE	LEAF	296
DO 20 IK=1,I	LEAF	297
DO 20 JK=1,I	LEAF	298
BB(IK,JK)=0.0D0	LEAF	299
20 CONTINUE	LEAF	300
IBR=1	LEAF	301
DO 70 IK=1,I	LEAF	302
DO 60 JK=1,I	LEAF	303

DO 50 IDX=3,4	LEAF	304
C *** IDENTIFY SOURCE TERMS	LEAF	305
IF (ABS(HANMAT(IK,IDX)).NE.0) GO TO 50	LEAF	306
IF (HANMAT(IK,IDX)) 30,30,40	LEAF	307
30 BB(IK,JK)=BRV(1BR)*ANMAT(JK,1)	LEAF	308
1BR=1BR+1	LEAF	309
GO TO 50	LEAF	310
40 BB(IK,JK)=ANMAT(JK,1)	LEAF	311
50 CONTINUE	LEAF	312
A(IK,JK)=BB(IK,JK)	LEAF	313
60 CONTINUE	LEAF	314
BB(IK,IK)=ANMAT(IK,1)	LEAF	315
A(IK,IK)=-BB(IK,IK)-LAMDL	LEAF	316
IF (HANMAT(IK,2).GT.0.0) A(IK,IK)=A(IK,IK)-LAMDV	LEAF	317
70 CONTINUE	LEAF	318
DO 80 IK=IP,I2	LEAF	319
JK=IK-1	LEAF	320
IF (HANMAT(JK,2).GT.0.0) A(IK,JK)=LAMDV	LEAF	321
80 CONTINUE	LEAF	322
DO 130 IK=1,I	LEAF	323
JJ=IK-1	LEAF	324
IL=I+IK	LEAF	325
IF (JJ.EQ.0) GO TO 120	LEAF	326
DO 110 JK=1,JJ	LEAF	327
JL=I+JK	LEAF	328
IF (HANMAT(IK,2)) 90,90,100	LEAF	329
90 A(IK,JL)=BB(IK,JK)	LEAF	330
GO TO 110	LEAF	331
100 A(IL,JL)=BB(IK,JK)	LEAF	332
110 CONTINUE	LEAF	333
120 CONTINUE	LEAF	334
A(IL,IL)=-BB(IK,IK)	LEAF	335
130 CONTINUE	LEAF	336
DO 140 J=1,I	LEAF	337
BL(J,J)=LAMDL	LEAF	338
140 CONTINUE	LEAF	339
RETURN	LEAF	340
END	LEAF	341
SUBROUTINE SOLVER(A,B,D,E,TINCD)	LEAF	342
C *** SOLVER EVALUATES D(A), I+A*D(A), AND Z(A)	LEAF	343
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10),(NN=2*NNT),(NIT=25),(NBR=10),(NNP=NN+1)	PARAM2	3
COMMON /BASIS/ I,1BR,NSKIP	PARAM2	4
DIMENSION A(NN,NN), B(NN,NN), C(NN,NN), D(NN,NN), E(NN,NN)	LEAF	345
DIMENSION F(NN,NN), G(NN,NN)	LEAF	346
M=20	LEAF	347
SUM=0.000	LEAF	348
I2=I*2	LEAF	349
DO 20 J=1,I2	LEAF	350
DO 10 JJ=1,I2	LEAF	351
SUM=SUM+A(J,JJ)*A(J,JJ)	LEAF	352
10 CONTINUE	LEAF	353
20 CONTINUE	LEAF	354
F=(DLOG(SUM)+2.000*DLOG(TINCD))/(2.000*DLOG(2.000))	LEAF	355
IF (P) 30,30,40	LEAF	356
30 NP=1	LEAF	357
GO TO 50	LEAF	358
40 NP=NP+1.000	LEAF	359
50 CONTINUE	LEAF	360
T=TINCD/(2.000**NP)	LEAF	361
CALL SCALAR(A,T,C)	LEAF	362
DO 70 J=1,I2	LEAF	363
DO 60 JJ=1,I2	LEAF	364

B(J,JJ)=0.000	LEAF	365
60 CONTINUE	LEAF	366
B(J,J)=1.000	LEAF	367
70 CONTINUE	LEAF	368
C *** CALCULATE U(H) AND Z(H)	LEAF	369
DO 90 J=1,M	LEAF	370
FM=1.000/(M+2.000-J)	LEAF	371
CALL SCALAR(B,FM,D)	LEAF	372
CALL MULTI(C,D,E)	LEAF	373
DO 80 JJ=1,I2	LEAF	374
E(JJ,JJ)=E(JJ,JJ)+1.000	LEAF	375
80 CONTINUE	LEAF	376
CALL EQUAL(E,B)	LEAF	377
90 CONTINUE	LEAF	378
S=1.000	LEAF	379
DO 120 J=1,NP	LEAF	380
G=S/2.000	LEAF	381
S=S*2.000	LEAF	382
CALL SCALAR(C,Q,F)	LEAF	383
CALL MULTI(F,B,E)	LEAF	384
DO 100 JJ=1,I2	LEAF	385
E(JJ,JJ)=E(JJ,JJ)+1.000	LEAF	386
100 CONTINUE	LEAF	387
CALL MULTI(B,E,F)	LEAF	388
CALL EQUAL(B,G)	LEAF	389
CALL EQUAL(F,B)	LEAF	390
C *** D(A)	LEAF	391
CALL EQUAL(G,E)	LEAF	392
CALL MULTI(G,E,F)	LEAF	393
CALL SCALAR(F,0.2500,G)	LEAF	394
CALL SCALAR(D,0.5000,E)	LEAF	395
DO 110 JI=1,I2	LEAF	396
DO 110 JJ=1,I2	LEAF	397
110 D(JI,JJ)=E(JI,JJ)+G(JI,JJ)	LEAF	398
C *** Z(A)	LEAF	399
120 CONTINUE	LEAF	400
CALL SCALAR(A,TINCD,F)	LEAF	401
CALL MULTI(F,B,E)	LEAF	402
DO 130 JJ=1,I2	LEAF	403
130 E(JJ,JJ)=E(JJ,JJ)+1.000	LEAF	404
C *** I = A * D(A)	LEAF	405
RETURN	LEAF	406
END	LEAF	407
SUBROUTINE FSOLVE(BL,B,D,E,CONTIC,CSOURC,XNTOT,XIENV,TINCD,XENVIC)	LEAF	408
C *** FSOLVE CALCULATES THE FINAL CONCENTRATIONS AND INTEGRALS	LEAF	409
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10),(NN=2*NNT),(NIT=25),(NBH=10),(NNP=NNT+1)	PARAM2	3
COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
DIMENSION B(NN,NN), BL(NN,NN), D(NN,NN), E(NN,NN), F(NN,NN), X(NN)	LEAF	411
I, Y(NN), XENVIC(NN)	LEAF	412
DIMENSION CONTIC(NN),CSOURC(NN),XNTOT(NN),XIENV(NN)	LEAF	413
I2=I*2	LEAF	414
C *** CALCULATE CONTAINMENT AND FILTER INVENTORY	LEAF	415
CALL MVMUL(E,CONTIC,X)	LEAF	416
CALL SCALAR(B,TINCD,F)	LEAF	417
CALL MVMUL(F,CSOURC,Y)	LEAF	418
CALL VADD(X,Y,XNTOT)	LEAF	419
C *** CALCULATE INTEGRATED RELEASE	LEAF	420
TINC02=TINCD*TINCD	LEAF	421
CALL SCALAR(B,TINCD,F)	LEAF	422
CALL MVMUL(F,CONTIC,XIENV)	LEAF	423
CALL SCALAR(D,TINC02,F)	LEAF	424
CALL MVMUL(F,CSOURC,Y)	LEAF	425

CALL VADD(XIENV,Y,X)	LEAF	426
CALL MVMUL(BL,X,Y)	LEAF	427
CALL VADD(Y,XENVIC,XIENV)	LEAF	428
DO 10 J=1,12	LEAF	429
CONTIC(J)=XNTOT(J)	LEAF	430
XENVIC(J)=XIENV(J)	LEAF	431
10 CONTINUE	LEAF	432
RETURN	LEAF	433
END	LEAF	434
SUBROUTINE PREP(XOUT,ANMAT,INT)	LEAF	435
C *** PREP CONVERTS DENSITIES TO CURIES OR GRAMS	LEAF	436
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10),(NN=2*NNI),(NIT=25),(NBH=10),(NNP=NN+1)	PARAM2	3
COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
DIMENSION XOUT(NNT,6,NIT),ANMAT(NNP,2)	LEAF	438
DO 50 J=1,INT	LEAF	439
DO 40 JJ=1,I	LEAF	440
IF (ANMAT(JJ,1).EQ.0.0) GO 10 20	LEAF	441
CURIES=ANMAT(JJ,1)/3.7D+10	LEAF	442
DO 10 JX=1,5,2	LEAF	443
XOUT(JJ,JX+1,J)=XOUT(JJ,JX,J)*CURIES	LEAF	444
10 CONTINUE	LEAF	445
GO TO 40	LEAF	446
20 GRAMS=ANMAT(JJ,2)/6.0225D+23	LEAF	447
DO 30 JX=1,5,2	LEAF	448
XOUT(JJ,JX+1,J)=XOUT(JJ,JX,J)*GRAMS	LEAF	449
30 CONTINUE	LEAF	450
40 CONTINUE	LEAF	451
50 CONTINUE	LEAF	452
RETURN	LEAF	453
END	LEAF	454
SUBROUTINE PAPER(XOUT,ANMAT,HANMAT,INT,ITP,TEND)	LEAF	455
C *** PAPER PRINTS THE RESULTS OF LEAF	LEAF	456
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10),(NN=2*NNI),(NIT=25),(NBH=10),(NNP=NN+1)	PARAM2	3
COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
DIMENSION XOUT(NNT,6,NIT),HANMAT(NNP,4),TEND(NIT),ANMAT(NNP,2)	LEAF	458
DO 30 J=1,INT,ITP	LEAF	459
HTIME=TEND(J)	LEAF	460
PRINT 40	LEAF	461
PRINT 50, HTIME	LEAF	462
PRINT 60	LEAF	463
PRINT 70	LEAF	464
PRINT 80	LEAF	465
DO 20 JK=1,I	LEAF	466
IF (ANMAT(JK,1).EQ.0.0) GO 10 10	LEAF	467
PRINT 90, HANMAT(JK,1),(XOUT(JK,JT,J),JT=1,6)	LEAF	468
GO TO 20	LEAF	469
10 PRINT 100, HANMAT(JK,1),(XOUT(JK,JT,J),JT=1,6)	LEAF	470
20 CONTINUE	LEAF	471
30 CONTINUE	LEAF	472
RETURN	LEAF	473
C	LEAF	474
40 FORMAT (1H1)	LEAF	475
50 FORMAT (47X,*FISSION PRODUCT INVENTORY AT *,F7.2,* HOURS*,/)	LEAF	476
60 FORMAT (29X,80HSTABLE NUCLIDE INVENTORIES ARE GIVEN IN GRAMS AND A	LEAF	477
1FE NOTED BY A * IN THE MARGIN,//)	LEAF	478
70 FORMAT (20X,*NUCLIDE*,9X,*CONTAINMENT INVENTORY*,10X,*FILTER INVEN	LEAF	479
1TORY*,11X,*INTEGRATED RELEASE*,/)	LEAF	480
80 FORMAT (30X,3(RX,*ATOMS CURIES,GM*),/)	LEAF	481
90 FORMAT (20X,A7.4X,3(3X,1PD12.5,1X,1PD12.5))	LEAF	482
100 FORMAT (18X,1H*,1X,A7.4X,3(3X,1PD12.5,1X,1PD12.5))	LEAF	483
END	LEAF	484

	SUBROUTINE TERM(XOUT,HANMAT,INT,ITP,TEND)	LEAF	485
C ***	TERM CREATES IT 700 OUTPUT FORMAT	LEAF	486
	IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
	PARAMETER (NNT=10),(NN=2*NNI),(NIT=25),(NBR=10),(NNP=NN+1)	PARAM2	3
	COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
	DIMENSION XOUT(NNT,6,NIT),HANMAT(NNP,4),TEND(NIT)	LEAF	488
	DO 20 J=1,INT,ITP	LEAF	489
	HTIME=TEND(J)	LEAF	490
	PRINT 30, HTIME	LEAF	491
	PRINT 40	LEAF	492
	DO 10 JK=1,I	LEAF	493
	PRINT 50, HANMAT(JK,1),(XOUT(JK,JT,J),JT=1,5,2)	LEAF	494
10	CONTINUE	LEAF	495
20	CONTINUE	LEAF	496
	RETURN	LEAF	497
C		LEAF	498
30	FORMAT (//,2X,*FISSION PRODUCT INVENTORY A1*,F7.2,* HOURS IN ATOMS	LEAF	499
	1*,//)	LEAF	500
40	FORMAT (2X,*NUCLIDE*,3X,*CONTAINMENT INVENTORY*,3X,*FILTER INVENTO	LEAF	501
	RY*,3X,*INTEGRATED RELEASE*,//)	LEAF	502
50	FORMAT (2X,A7,7X,D12.5,10X,D12.5,8X,D12.5)	LEAF	503
	END	LEAF	504
	SUBROUTINE PRMAT(A,IT)	LEAF	505
C ***	PRMAT PRINTS THE A MATRIX	LEAF	506
	IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
	PARAMETER (NNT=10),(NN=2*NNI),(NIT=25),(NBR=10),(NNP=NN+1)	PARAM2	3
	COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
	DIMENSION A(NN,NN)	LEAF	508
	IP=I+1	LEAF	509
	I2=I*2	LEAF	510
	N=1	LEAF	511
	PRINT 50,IT	LEAF	512
	PRINT 60,N	LEAF	513
	DO 10 J=1,I	LEAF	514
10	PRINT 70,(A(J,JJ),JJ=IP,I2)	LEAF	515
	N=N+1	LEAF	516
	PRINT 60,N	LEAF	517
	DO 20 J=1,I	LEAF	518
20	PRINT 70,(A(J,JJ),JJ=1,I)	LEAF	519
	N=N+1	LEAF	520
	PRINT 60,N	LEAF	521
	DO 30 J=1P,I2	LEAF	522
30	PRINT 70,(A(J,JJ),JJ=1,I)	LEAF	523
	N=N+1	LEAF	524
	PRINT 60,N	LEAF	525
	DO 40 J=IP,I2	LEAF	526
40	PRINT 70,(A(J,JJ),JJ=IP,I2)	LEAF	527
	RETURN	LEAF	528
C		LEAF	529
50	FORMAT(1H,5X,*A MATRIX PRINTED BY QUADRANTS FOR TIME INTERVAL*,	LEAF	530
	1 I3,//)	LEAF	531
60	FORMAT(/,5X,*QUADRANT*,I3,//)	LEAF	532
70	FORMAT(2X,12(1X,1PD10.3))	LEAF	533
	END	LEAF	534
	SUBROUTINE SCALAR(A,S,B)	LEAF	535
C ***	SCALAR MULTIPLIES A SCALAR TIMES A MATRIX IN DOUBLE	LEAF	536
	IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
	PARAMETER (NNT=10),(NN=2*NNI),(NIT=25),(NBR=10),(NNP=NN+1)	PARAM2	3
	COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
	DIMENSION A(NN,NN), B(NN,NN)	LEAF	538
	I2=I*2	LEAF	539
	DO 20 J=1,I2	LEAF	540
	DO 10 JJ=1,I2	LEAF	541

B(J,JJ)=S*A(J,JJ)	LEAF	542
10 CONTINUE	LEAF	543
20 CONTINUE	LEAF	544
RETURN	LEAF	545
END	LEAF	546
SUBROUTINE MULTI(A,B,C)	LEAF	547
C *** MULTI MULTIPLIES TWO MATRICES IN DOUBLE	LEAF	548
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10), (NN=2*NN!), (NIT=25), (NBH=10), (NNP=NN+1)	PARAM2	3
COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
DIMENSION A(NN,NN), B(NN,NN), C(NN,NN)	LEAF	550
I2=I*2	LEAF	551
DO 20 K=1,I2	LEAF	552
DO 20 KK=1,I2	LEAF	553
AM=0.000	LEAF	554
DO 10 J=1,I2	LEAF	555
10 AM=AM+A(K,J)*B(J,KK)	LEAF	556
20 C(K,KK)=AM	LEAF	557
RETURN	LEAF	558
END	LEAF	559
SUBROUTINE EQUAL(A,B)	LEAF	560
C *** EQUAL SETS A MATRIX EQUAL TO A MATRIX IN DOUBLE	LEAF	561
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10), (NN=2*NN!), (NIT=25), (NBH=10), (NNP=NN+1)	PARAM2	3
COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
DIMENSION A(NN,NN), B(NN,NN)	LEAF	563
I2=I*2	LEAF	564
DO 20 K=1,I2	LEAF	565
DO 10 KK=1,I2	LEAF	566
B(K,KK)=A(K,KK)	LEAF	567
10 CONTINUE	LEAF	568
20 CONTINUE	LEAF	569
RETURN	LEAF	570
END	LEAF	571
SUBROUTINE MVMUL(A,B,C)	LEAF	572
C *** MVMUL DOES PRODUCT OF MATRIX AND VECTOR	LEAF	573
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10), (NN=2*NN!), (NIT=25), (NBH=10), (NNP=NN+1)	PARAM2	3
COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
DIMENSION A(NN,NN), B(NN), C(NN)	LEAF	575
I2=I*2	LEAF	576
DO 20 KI=1,I2	LEAF	577
AM=0.000	LEAF	578
DO 10 KJ=1,I2	LEAF	579
10 AM=AM+A(KI,KJ)*B(KJ)	LEAF	580
20 C(KI)=AM	LEAF	581
RETURN	LEAF	582
END	LEAF	583
SUBROUTINE VADD(A,B,C)	LEAF	584
C *** VADD DOES VECTOR ADDITION	LEAF	585
IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
PARAMETER (NNT=10), (NN=2*NN!), (NIT=25), (NBH=10), (NNP=NN+1)	PARAM2	3
COMMON /BASIS1/ I,IBR,NSKIP	PARAM2	4
DIMENSION A(NN), B(NN), C(NN)	LEAF	587
I2=I*2	LEAF	588
DO 10 KI=1,I2	LEAF	589
C(KI)=A(KI)+B(KI)	LEAF	590
10 CONTINUE	LEAF	591
RETURN	LEAF	592
END	LEAF	593