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LEAF:

A Computer Program to Calculate Fission Product Release from a Reactor Containment Building for

Arbitrary Radioactive Decay Chains



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by

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

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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 timedependent release of 131 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 buildup, 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 timedependent 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 cleanup 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

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

where

$$\begin{array}{l}
\overset{\text{re}}{\mu_{i}} = \begin{cases}
1 & \text{if the i}^{\text{th}} & \text{isotope is a noble gas} \\
\end{array} \tag{2}$$

and
$$\delta_{ij}$$
 is the Kronecker delta, defined by $\int I if i = j$

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

Defining the matrices
$$\lambda$$
, λ^* , and Λ by
 $\lambda = \overline{\lambda} - \lambda^*$,
 $\lambda^* = \overline{\delta} \otimes \overline{\lambda}$,
 $\Lambda = \overline{\lambda} + V + L$,
(4)

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

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

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

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

$$\underline{X} = \left(\frac{\underline{N}}{\underline{F}}\right), \ \underline{s} = \left(\frac{\underline{S}}{\underline{0}}\right), \tag{6}$$

and a supermatrix A by

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

then Eq. (5) may be rewritten as

$$\frac{\mathrm{d}X}{\mathrm{d}t} = A \ \underline{X} + \underline{s}. \tag{8}$$

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

$$\underline{R}(\tau) = \int_{0}^{\tau} dt' L(t') \underline{N}(t')$$

$$= \overline{L} \int_{0}^{\tau} dt' \underline{N}(t'),$$
(9)

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

$$\bar{L} = \frac{1}{2} (L(0) + L(\tau)) .$$
 (10)

If we define

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

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

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

and

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

where the matrix operators D(C) and Z(C) for C = At 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

$$\Omega_{0}^{T}(A) = \exp\left[\int_{0}^{T} A(s) ds\right] = \exp(A_{T}).$$
(15)

The solution to Eq. (8) is given by

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

where

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

As is readily proved, 7 both the matrix A and e^{At} are non-negative.

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

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

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

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

$$Defining the matrix operator D(C) by^{4}$$

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

or

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

Eq. (19) becomes

$$\underline{X}(\tau) = \underline{X}(0) + \tau A D(A\tau) \underline{X}(0) + \tau D(A\tau)\underline{s}$$
(22)
$$= \underline{X}(0) + \tau D(A\tau) [\underline{A} \underline{X}(0) + \underline{s}],$$

which is Eq. (13).

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

$$\underline{Y}(\tau) = B \{ A^{-1} (e^{A\tau} - I) \underline{X}(0) + [-A^{-1}\tau - A^{-1}A^{-1} (e^{A\tau} - I)] \underline{s} \}$$

$$= B \{ \tau D(A\tau) \underline{X}(0) + \tau^{2} [-C^{-1} + C^{-1} D(C)] \underline{s} \}$$

$$= B \{ \tau D(A\tau) \underline{X}(0) + \tau^{2} Z(A\tau) \underline{s} \},$$
(23)

where we have defined

$$CZ(C) = D(C) - I$$
⁽²⁴⁾

for C = A τ 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

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

$$T(C) = C^{-1}(D(C) - I) = \bigotimes_{n=0}^{\infty} C^{n}$$
(25)

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

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

where p is determined by

$$||\mathsf{H}|| < \frac{1}{2} \tag{28}$$

or^{4,6}
$$p > \ln \left(\sum_{ij}^{\prime} |C_{ij}|^2 \right) / (2 \ln 2).$$
 (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).

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

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

M is determined 4 such that the excluded terms have an error less than some ε , or

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

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

$$Z(2^{p + 1}H) = \frac{1}{2}Z(2^{p}H) + \frac{1}{4}\left[D(2^{p}H)\right]^{2}.$$
 (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 <u>not</u> printed. <u>B. INPC</u>

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 τ) 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

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

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 by ⁸

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

 \overline{L} = leakage rate = 1.157 x 10⁻⁸s⁻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	14	NSKIP	NSKIP = 0: Unabridged output NSKIP = 1: Abbreviated terminal output				
	2	14	MATRIX	MATRIX = 0: Do not print A matrix MATRIX = 1: Print A matrix				
1	7.	A7	HANMAT(I, 1)	Alphanumeric nuclide name				
	2	F4	HANMAT(I, 2)	Nuclide ID No., negative if nuclide not retained by filter				
1	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 assoicated 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 C	ARD MUST FOLLOW	THE LAST PAIR OF CARDS 1 AND 2				
	1	14	INT	Number of time intervals				
	2	14	ITP	PRINTING FREQUENCY ITP = 1: Print every interval ITP = 2: Print every second interval ITP = N: Print every Nth interval				
3	3	14	IAC	Input units of initial concentration and source terms IAC = 0: Atoms and atoms/s IAC = 1: Curies and curies/s if radio- active, grams if stable				
]	4	E 12.5	TEND(INT + 1)	Time at end of problem in hours				
	1	E 12.5	CONTIC(1)	Initial concentration (atoms) of nuclide l in the containment building				
4	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				
	ı	E 12.5	TEND(N)	Beginning time in hours of the Nth time step				
5	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				
	1	E 12.5	SOURCE(1,N)	Source term (atoms/s) for nuclide 1 in Nth time step				
6	2	E 12.5	SOURCE(2,N)	Source term (atoms/s) for nuclid≘ 2 in Nth time step				
	:	:	:	•				
	Ī	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							

TABLEII

BASIC DATA FOR LEAF Tests 1 and 2

NUCLIDE	DECAY CONSTANT (s ⁻¹)	CONTAINMENT BUILDING CONCENTRATION	SOURCE (atoms/s)			
		At $T = 0$ (atoms)	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.

$$\frac{dN}{dt} = AN + S, \qquad (37)$$

where

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

and

$$\underline{R}(\tau) = \bar{L} \int_{0}^{\tau} dt' \underline{N}(t')$$
(39)

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with

$\begin{bmatrix} R_1 \end{bmatrix}$		1.157 x 10 ⁻⁸	0	0	0	0	0	
R ₂	_	0	1.157 x 10-8	0	0	0	o	
$R = R_3 $,	L =	0	0	1.157 x 10 ⁻⁸	0	0	0	(40)
0		0	0	0	0	0	0 '	(40)
0			0	0	0	0	0	
		L	•	•	v	v	°.	

and the A matrix given by

$A = \begin{bmatrix} -4.384 \times 10^{-2} \\ 4.359 \times 10^{-2} \\ 0 \\ 2.500 \times 10^{-4} \\ 0 \\ 0 \end{bmatrix}$	0 -6.8772 x 10 ⁻⁵ -6.8760 x 10 ⁻⁵ 0 0 0	0 0 -9.02712 x 10 0 2.5 x 10 ⁻⁴	$\begin{array}{c} & 0 \\ 4 & 4.359 \times 10^{-2} \\ & 0 & \cdot \\ -4.359 \times 10^{-2} \\ & 0 \\ 0 \\ \end{array}$	0 0 -6.876 ± 10 6.876 ± 10	$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 5 \\ -6.527 \times 10^{-4} \end{bmatrix}$	•	(41)
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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 by 8



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 chain[&] 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 Rb is stable and the listing is marked with an * indicating that the inventory is given in atoms and grams, <u>not</u> atoms and curies.

Test Problem 1 88 CHAIN - ZERO SOURCE

(All results in atoms)

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

3

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TABLE	IV-
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	Test Problem 2						
88	CHAIN - NON ZE	RO					
SOURCES							

- (A	1	1	r	es	u	11	ts	1	n	а	to	ms)
		_	_			_				_				

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

TABLE V

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

SJ «U	08 (N	ANE=15	APPAA	C = A	100	T	, C	L'=U	, u	4=980	4R4	U1, PF	=22,F	°L=50,∏	=305))	
34	681N	C(1001)		- 01		.	7 \										
SA	ESREI	(ES=0)		ISP	>=0	HT.	37 \										
SCI	LOSE	R (FS=J	DBIN)				•										
\$0	PERM	(FS=MAI	CL IN2	, O A	۰C =	ZD	ο,	FSI	= 28	SI)							
\$ M	AČRU	(MDF = 4)	ACL182	2,0)ĂC	=Z	DØ)									
\$PI	ното	R(FS=LI	EAF)														
\$U	PDATI	E(F,P=1	LÉAF)														
\$R	UN(I:	=COMPII	LE)														
SFI	060(: M_	SETA=1)														
*C	OMPI	LE, LEAP	F														
SFI	м.																
	0	1			_			_									
AS	85	1	0	0	3.	419	5	Ē	01	85.0							
SE	65	2	-1	0	1.	"	<i>(</i>	E =	201	85.0							
SF	85M	1	0	•	2	64	a	۶.	. ń 2	85 0							
BR	85	4	ž	ž	4.	62	5	E -	03	85.0							
KR	85M	-5	4	õ	4	29	8	Ē-	05	85.0							
ĸR	85	+6	+5	0	2.	04	7	È-	09	85.0							
•	212																
RB	85	7	+5	6	0.	0				85.0							
•	788																
	11	1 0	60.0														
•	•		2 6		F -		•	15	.7	F=08							
1	••	F+18	1 5		E-	1.8	2	. 0		F+18	2.	5	E+18	3.0	F+18	3.5	E+18
4	.0	E+18				••		••		2.10	- •	2		5.0	2.10	202	2.10
Ż	.0		2.5		E -	04	1	.15	57	£-08							
1	.0	E+18	1.5		E+	18	ŝ	.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	•15	57	E-08				_	_		
1	•0	E+18	1.5		E+	18	2	• 0		E+18	2.	5	E+19	3.0	E+18	3.5	E+1d
4	•0	2+18	7 E		c _	•		10		6-08							
1	.0	F+18	1.5		E-	18	2			E=08	2.	5	F+18	3.0	F+18	3.5	F+18
4	.0	E+18	••-			••	÷-	••				-	2.10	5.0		202	2110
8	.0		2.5		E+	04	1	. 15	57	E-08							
1	.0	E+18	1.5		E+	18	S	•0		E+18	5.	5	E+18	3.0	E+18	3.5	E+18
4	•0	E+18															
2	4.0		2.5		E-	04	1	•15	57	E-08	-	-					
1	•0	E+18	1.5		£+	18	2	• 0		2+18	2.	5	E+18	5.0	E+18	2.2	2+18
7	• •	C+10	25		۶.		•	19	. 7	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	
3	6.0		2.5		E٩	•04	1	.15	57	E-08							
1	•0	E+18	1.5		E+	18	2	• 0		E+18	5.	5	E+18	3.0	E+18	3.5	E+18
4	•0	E+18			_	•											
4	5.0		2.5		Ε-	04	. 1	•19	57	E-08		Ľ		¬ 4			
4	•0	E+10 F+10	2*2		E+	16	د	•0		5+19	٤.	3	C+18	C .U	6419	1.0	C+19
	• • 8 . ^	L+10	2.5		F -	04	1	. 1 9	57	F=08							
4	20	E+1A	3.5		Ē.	18	3	.0		E+18	2.	5	E+18	2.0	E+18	1.0	E+18
i	.0	E+18										-					
5	4.0		2.5		ŧ-	04	1	.15	57	E 08							
4	• 0	E+18	3.5		E+	18	3	•0		E+18	2.	5	£+18	5.0	E+18	1.0	E+18
1	•0	E+18															
2E	J.																

TABLE VI

DECAY CHAINS AND NUCLIDE RELATED DATA

		PARE	INT	DECAY	
NUCLIDE	ŢD	1	2	CONSTANT	ATOMIC MASS
AS 85	1	0	0	3.41500D=01	8.50000D+01
SE 85	2	-1	Q	1.77700D-02	8,400000+01
SE 85m	3	0	0	3.64800D=02	8_50000D+01
88 85	4	2	3	4_02<00p=03	8 ¢0000 _{D+} 01
KR 85M	4 5	4	0	4 29#00D=05	8 \$00000+01
KR 85	-6	-5	0	204700D-09	8,500000+01
RB 85	7	-5	6	0	8, <00000+01

BRANCHING RATIO

FROM	TQ	RATIO
1	2	.8000
5	6	•2120
5	7	•7880

TABLE VII

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

TTHE STEP DATA

TIME PERIOD IN HOURS

	0.0- 2.0	2.0. 4.ā	4.0- 6.0	6.0- 8 <u>.</u> 0	8.0- 24.0	24.0- 30.0	30,0- 36.0
FILTRATION REMOVAL RATE	2.5000ñD+04	2,5000ñD+04	2.500000-04	2.500000-04	2.50000D+04	2,50000D-04	2.50000D=ñ4
LEAKAGE REMOVAL RATE	1.1570ñD-08	1.157njD=08	1.157000-08	1.157000-98	1.157000.08	1.157000-08	1.157000-08
SOURCE TERMS AS A5 SE 85 SE 85M BR 85 KR A5 KR A5 KR 85 R8 85	1.00000000 1.500000018 2.000000018 3.500000018 3.500000018 3.500000018 4.000000018	1.000n0D.1A 1.500ññD.1A 2.000n7D.1A 2.500n7D.1A 3.000n7D.1A 3.500n7D.1A 4.00000D.1A	1.00000n+18 1.5nn0n+18 2.0n010+18 2.5nn00+18 3.01010+18 3.55000n+18 4.000001+18	1.000000-18 1.500000-18 2.500000-18 2.500000-18 3.00000+18 3.500000-18 4.000000-18	1.000000.18 1.50000.18 2.00000.18 3.50000.18 3.00000.18 3.500000.18 3.500000.18	1.,00000+18 1.500000+18 2.00000+18 2.500000+18 3.00000+18 3.500000+18 4.000000+18	1.000000. 1.500nn0. 2.000000. 3.500000. 3.000000. 3.50000. 18. 4.000000. 18. 1.500000. 18. 1.500000. 18. 1.500000. 18. 1.500000. 18. 1.500000. 18. 1.500000. 18. 1.500000. 18. 1.500000. 18. 1.50000. 18. 1.50000. 18. 1.50000. 18. 1.50000. 18. 1.50000. 18. 1.50000. 18. 1.50000. 18. 1.50000. 18. 1.50000. 18. 1.5000. 18. 1.5000. 18. 1.5000. 18. 1.5000. 18. 1.5000. 18. 18. 19. 19. 18. 19. 18. 19. 18. 19. 19. 19. 19. 19. 19. 19. 19

	36.0- 42.0	42.0- 48.ô	48.0- 54.0	54.0- 60 <u>.</u> 0
FILTRATION REMOVAL RATE	2.50000D-04	2.500niD-04	2.500000404	2.500000-04
LEAKAGE REMOVAL RATE	1.157000-08	1.157000-08	1.157000-08	1.157000-09
SOURCE TERMS				
AS 85	1.000000+18	4.000nnD.1A	4.000007+18	4.000000+10
56 85	1.500000+18	3.50001D+18	3.500007+18	3.400000+18
SF ASH	21000000918	3.000n0D+18	3.000000+18	3.00000+18
80 45	2.500000+18	2.500n1D+1A	2.500000+18	2.500000+18
KO 854	3 00000018	2 00000D-1A	2,00000n+18	2,00000D+48
KR (10 M	3 500000018	1.000000.18	1.00000n.18	1.000000+48
50 AS	4 000000-18	1.000000.16	1.00000n+18	1.000000+18
88 85	4.000000.18	1,000nnp.1A	1,00000n+18	1,000000+18

TABLE VIII

THE A MATRIX PRINTED BY QUADRANTS

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QUADRANT 1
                                             ٥.
                                                           0.
                                                                                         0.
 0.
                0.
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                                            4_02500D-03
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                                                           9+11176D=06
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                              0.
  QUADRANT 2
                                            ٥.
-3.41750D-01 0.
                                                           0.
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                                                                          0.
                              0.
 2•73200D-01 -1•80200D-02
                                                                                         0.
                                             0.
                                                           0.
                                                                          0.
                              0.
                                                                                         0.
 0.
               0+
                             -3.67300D-02
                                             0.
                                                           0.
                                                                          0.
               1.77700D-02
                             3.648000-02 -4.275010-03
                                                                                         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.
                                                           3.38682D-05 2.04700D-09 -2.50012D-04
                                            0.
 0.
               0.
                              0.
  QUADRANT 3
 2.50000D-04
                                             0
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               2.50000D-04
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                              2.50000D-04
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                                             2.50000D-04
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  QUADRANT A
-3.41500D-01 0.
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2.73200D-01 -1.77700D-02
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                             -3,64800D-02
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               0•
               1.77700D-02 3.64800D-02 -4.02500D-03
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                                             0.
                                                          -4.29800D-05
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               0•
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                                                           0.
                                                                         -2.04700D-09
                                                           3.38682D-05 2.04700D-09 -0.
                                             0.
               0•
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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		CLIDE	CONTAINME	CONTAINMENT INVENTORY		FILTER INVENTORY		TED RELEASE
			ATOMS	CURTESTOM	ATOMS	CURJESIGM	ATOMS	CUNIESIGM
	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.	U.	0	0	0.
	ΚŔ	85	_ 0	0	0	0	0	0.
4	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 I	FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURTES.GM	ATOMS	CUPTESOGM	ATOMS	CURIESIGM	
AS 85	2.926120+18	2.700730+07	2.142110.15	1.977110+04	2,43658D+14	2.248900+03	
SE 85	1,276030+20	6.128410+07	1.82814D+18	8.780020+05	1.05464D+16	5.065140+03	
SE 85M	5,44514D+19	5.368610+07	3.73159D+17	3,679150+05	4,51887D+15	4.455360+03	
88 85 Kr 85m	1.579860+21 5.929230+22	1•71863D+08 6•88752D+07	1.09581D+20	1.192060+07	1.26839D+17 2.52747D+18	1.3/9810+04	
KR 85	2,718920+22	1.50422D+03	0.	0.	1,10485D+18	6.112500-02	
+ RB 85	1.77564D+22	2.506090+00	1=84415D+22	2.60278D+00	8,53471D+17	1.204570-04	

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FISSION PRODUCT INVENTORY AT 4.00 HOURS

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

NU	CLIDE	CONTAINMENT INVENTORY		FILTER I	FILTER INVENTORY		n RELEASE
		ATOMS	CURTES.GM	ATOMS	CUPTESIGM	ATOMS	CURIES+GM
AS	85	2,92612D+18	2.701730+07	2.142110+15	1.97711D+04	4.87415D+14	4.49871D+03
SE	85	1,276n3D+20	6.12841n.07	1.82814D+18	8.780020+05	2,117630+16	1.017040+04
SĽ	85M	5,44514D+19	5.368610.07	3.73159D+17	3.67915D+05	9,05488D+15	8.927630+03
ВĶ	85	1,57986D+21	1.718630+08	1.09581D+20	1.192060+07	2,58448D+17	2.811490+04
KK	85M	1.041920+23	1.210310+08	0.	0	9.43324D+18	1.095790+04
KR	85	5,78235D+22	3,199050,03	0.	0	4,62540D+18	2.558970_01
• R8	85	2.63/96D+22	3.723140+00	5.883200+22	8.30339D+00	2.72274D+18	3.842810-04

FISSION PRODUCT TRIVENTORY AT 6.00 HOURS

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

NUCLIDE	CONTAINMENT	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
	ATOMS	CURIES+GM	ATOMS	CURIESIGM	ATOMS	CURIES+GM	
AS 85	2.026120+18	2.700730+07	2,142110+15	1,97711D+j4	7.317720+14	6.748520+03	
SE 85	1.27603D+20	6+128410+07	1 928140+18	8.78004D+05	3.18n62D+16	1.52756D+04	
SE 85M	5 4514D+19	5.36861D+07	3 731590+17	3.679150.05	1_35009D+16	1,33999D+04	
8 ^R 85	1.579860+21	1.718630+08	1.095810+20	1.19200D+07	3,90,56D+17	4.243170+04	
KR 85M	1.171380+23	1.503030+08	0.	0.	1,95558D+19	2.271650+04	
KR 85	9 198A1D+22	5.133A60+03	0	0.	1.084870+19	5.979870-01	
♦ RB 85	3, 19810D+22	4-513710+00	1,116600+23	1,575950+11	5,16765D+18	7.293480-04	

20

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	CHRIES.GM	ATOMS	CURIES	ATOMS	CURIES+GM
AS	85	2.026120+18	2.700730+07	2,142110+15	1,97711D+04	9.749290+14	8.99834D+03
SE	85	1.276.30+20	6.128410+07	1.828140+18	8.78004D+05	4.24361D+16	2.038080+04
SE	85M	5.4514D+19	5.368610.07	3 731590.17	3.679150.05	1.812690+16	1.787220.04
BR	85	1 €7986D+21	1.718630.08	1 095A10.20	1 19200D+07	5 21,64D+17	5.67486D+04
ΚŔ	85M	1.613140+23	1.873860+08	0	0	3.20188D+19	3.72170D+04
KR	85	1.260880+23	6+971320+03	0.	0.	1,98361D+19	1.09742D+00
* R8	85	3.597130+22	5 • 176890+00	1.730100+23	2.44181D+ <u>01</u>	8.00489D+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	CURIESIGM	ATOMS	CURIES+GM
AS	85	2.92612D+18	2.700730+07	2,142110+15	1.97711D.n4	2.92499D+15	2.69968D+04
SE	85	1. 276030+20	6+128410+07	1.828140+18	8.78004D+05	1.274750+17	6.12225D+04
SE	85 <u>m</u>	5,44514D+19	5.368610.07	3 731590+17	3,679150+05	5 44151D+16	5,36503D+04
BR	85	1 \$7986D+21	1.71863n.08	1,09581n.20	1,1920°D+07	1 57453D+18	1,712830+05
KR	85M	2.523500+23	2.592870+08	0	0.	1.67=27D+20	1.94603D+05
KR	85	4.34092D+23	2.401589+04	0.	0.	2.04864D+20	1+133390+01
• RB	85	4.596410+22	6+497540+00	7,900250+23	1.11502D+02	3.65424D+19	5.160320-03

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FISSION PRODUCT INVENTORY AT 30.00 HOURS

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

NUCLIDE		CONTAINMENT	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
		ATOMS	CUPIES.GM	ATOMS	CUPIESIGM	ATOMS	CURIES+GM	
AS	85	2.926120+18	2.710730+07	2,142110+15	1.97711D+04	3.65626D+15	3.374630.04	
SE	85	1.27603D+20	6.128410+07	1.828140+18	8.7002D+05	1.59-65D+17	7.653810.04	
SE	85M	5.445140+19	5-358610+07	3.731590+17	3 679150+05	6.80-31D+16	6.70671D+04	
BH	85	1 57986D+21	1.71863n+08	1,09581n+20	1,1920°D+07	1 96035D+18	2.14234D.05	
κŔ	85M	2.357380+23	2.622220.08	0.	0.	2.23=83D+20	2.597180+15	
KR	85	5. 536920+23	3.063270+04	0	0.	3.28280D+20	1.81619D+01	
* RB	85	4 452140+22	6.565910+00	1 03997n+24	1 46779D+n2	4 81298D+19	6.79292D-03	

FISSTON PRODUCT INVENTORY AT 36.00 HOURS

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

NU	CLIDE	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
		ATOMS	CURIES.GM	ATOMS	CURIESIGM	ATOMS	CURIES+GM
AS	85	2.92612D+18	2.700730+07	2.14211D+15	1.97711D+04	4-38753D+15	4.04957D+04
SE	85	1.376n30+20	6.12841n+07	1.829140+18	8.78004D+05	1.91254D+17	9.18538D+04
SE	85M	5_44514D+19	5.36861n+07	3,73159n+17	3 67915D+05	8 16 12D+16	8.048390+04
BR	85	1.57986D+21	1.718430+08	1.09581n+20	1,19200D+07	2.364180+18	2.57184D+05
KR	85M	2. 570770+23	2+637770+08	0.	0.	2.80190D+20	3.25475D+05
KR	85	6.73692D+23	3.727160+04	0	0	4.81645D+20	2,664670+01
# RB	85	4 A7413D+22	6.506950+00	1,291870+24	1.823310.02	5 97 877D+ 19	8.43828D-03

FISSTON 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.GN	ATOMS	CURIES+GM
AS SE BR KR R R R R	85 85 85 85 85 85 85 85 85	2.026120+18 1.276030+20 5.445140+19 1.579860+21 2.276040+23 7.038280+23 4.682890+22	2.700730+07 6.128419+07 5.358510+07 1.718530+08 2.643920+08 4.391800+04 6.609300+00	2.142110+15 1.828140+18 3.731590+17 1.095810+20 0. 0. 1.544540+24	1.97711D+ñ4 8.78004D+ñ5 3.67915D+ñ5 1.19206D+07 0. 8. 2.17993D+ñ2	5.11880D+15 2.23144D+17 9.52392D+16 2.75900D+18 3.37015D+20 6.6519D+20 7.14815D+19	4.72451D+04 1.071690+05 9.39007D+04 3.00135D+05 3.91484D+05 3.679170+01 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	CONTAINMENT INVENTORY		FILTER INVENTORY		INTEGRATED RELEASE	
		ATOMS	CURIES.GM	ATOMS	CURIES+GM	ATOMS	CURIES+GM	
A	S 85	1.170450+19	1.080290+08	8.54842n+15	7.90842D+ñ4	8.04359D+15	7.42402D.04	
S	E 85	3 716790+20	1.795060+08	5 36076n+18	2 5746 D+04	3_15 _{870D+17}	1.517030.05	
S	E 85M	8.167710+19	8.052920+07	5 597390.17	5.51872D+n5	1,15643D+17	1.140170.05	
8	R 85	2. #26730+21	3. A75030+08	2.043140+20	2.2226UD+17	3.46132D+18	3.765360+05	
к	R 85M	2,990750+23	3.357950+08	0.	0.	4.025810+20	4.67647D.05	
K	R 85	8.46819D+23	4.795420+04	0.	0.	8.722720+20	4.825790+01	
# R	B 85	4 20756D+22	5,938440+00	1,762850+24	2,48804D+02	8,15847D+19	1,151470-02	

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 I	NVENTORY	INTEGRATE	D RELEASE
	ATOMS	CURIES	ATOMS	CUPIES.GM	ATOMS	CURIES+GM
AS 85 SE 85 SE 85M BR 85 KR 85 KR 85	1.170450+19 3.716790+20 8.167710+19 2.26730+21 3.140100+23 9.478750+23	1.040290+08 1.785060+08 8.052920+07 3.075030+08 3.647610+08 5.244050+04	8.568420+15 5.36076n+18 5.59739n+17 2.043140+20 0. 0.	7.90842D+ñ4 2.57464D+ñ4 5.51874D+ñ5 2.22264D+ñ7 0. 0. 2.82621D+ñ2	1.09487D+16 4.08757D+17 1.36655D+17 4.16776D+18 4.78415D+20 1.09493D+21 9.26736D+19	1.01238D+05 1.96314D+05 1.341430+05 4.53384D+05 5.55738D+05 6.07975D+01 1.30797D-02

FISSTON PRODUCT INVENTORY AT 60.00 HOURS

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

NU	CLIDE	CONTAINMENT	INVENTORY	FĪLŤ¤R I	NVENTORY	INTEGRATE	n RELEASE
		ATOMS	CURIES.GM	ATOMS	CURTESIGM	AŤOMS	CURIESIGM
AS SE BR KR RB	85 85 85 85 85 85 85 85	1.17045D+19 3.71679D+20 8.16771D+19 2.62673D+21 3.23862D+23 1.63210D+24 4.76996D+22	1. ñ8029n+08 1. 785060+08 8. n52920+07 3. n7503n+08 3. 762050+08 5. 710040+04 6. 732190+00	8,5x842n+15 5,36076n+18 5,59739n+17 7,04314n+20 0, 0, 2,25634n+24	7.90842D+ñ4 2.57461D+ñ4 5.51872D+n5 2.22260D+n7 0. 0. 3.18454D+ñ2	1.38938D+16 5.01444D+17 1.56467D+17 4.87419D+18 5.58309D+20 1.34630D+21 1.04424D+20	1.28236D+05 2.40925D+05 1.54268D+05 5.30233D+05 6.485440+05 7.448310+01 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.

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REFERENCE

- "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, "¹³¹ I 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).
- 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, <u>The Theory of Matrices</u>, (Chelsea Publishing Company, New York, 1960), pp. 125ff, 185ff.
- E. Bodewig, <u>Matrix Calculus</u>, (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.
- 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^pH) AND Z(2^pH) RECURSION RELATIONS

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

$$D(2^{r}H)$$
: Define

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

$$C = 2^{p}H.$$
 (A-2)

Clearly if
$$p = 0$$

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

If
$$p = 1$$

$$D(C) = D(2H) = (2H)^{-1} (e^{2H} - I)$$

= $H^{-1} (e^{H} - I) (\frac{e^{H} + I}{2})$
= $D(H) [I + \frac{1}{2} HD(H)].$ (A-4)

By induction we may write

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

$$D(2^{n + 1}H) = (2^{n + 1}H)^{-1}(e^{2^{n + 1}H} - I)$$

= $(2^{n}H)^{-1}(e^{2^{n}H} - I)\frac{1}{2}(e^{2^{n}H} + I)$
= $D(2^{n}H)\left[I + \frac{1}{2}(2^{n}H)D(2^{n}H)\right].$ (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^pH): Define .

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

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

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

$$2^{P}H Z(2^{P}H) + I = D(2^{P}H)$$
(A-9)

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

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

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

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

$$H' = H - \varepsilon I, \quad \varepsilon << 1$$
 (A-12)

and

|H'| ≠ 0, (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

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

P I	ROGRAM LEAF (INP+OUT)	LEAF	2
		LEAF	3
LE	EAF - A COMPUTER PROGRAM TU CALCULATE FISSION PRODUCT RELEASE	LEAF	4
FF	ROM A REACTOR CONTAINMENT BUILDING FOR ARBITHARY RADIOACTIVE	LEAF	5
CI	ECAY CHAINS	LEAF	6
		LEAF	7
6,	Y CLARENCE E. LEE	LEAF	8
-	COURTNEY E. APPERSON. JR.	LEAF	9
	JOHN E- FOLFY	LEAF	10
		LEAF	11
P	FACTOR JECHNOLOGY DIVISION		12
			12
L.	OS ALAMOS SCIENTIFIC LABORATORI		13
	OVERBER 1970		14
T 1-	TO TO THE FIGURE VERSION OF FEAST IT WAS OPEARED ON	LEAF	15
11	IS IS THE EIGHTH VERSION OF LEAF. IT WAS CREATED ON	LEAF	10
11	NOVERBER 1975. THE CHANGES INCORPORATED IN VERSION	LEAF	17
ET	GHI REMOVE A DIMENSION ERROR.	LEAF	18
		LEAF	19
INPL	T INSTRUCTIONS FOR THE CODE FOLLOW	LEAF	20
		LEAF	21
CARC	WORD SYMBOL FORMAT INFORMATION	LEAF	22
0	PRINT UPTION	LEAF	23
	Î NSKIP I4 0/} LINE PRINTER/TERMINAL	LEAF	24
	2 MATRIX I4 0/1 PRINT A MATRIX NO/YES	LEAF	25
1	NUCLIDE BASIC DATA - ONE CARD PER NUCLIDE	LEAF	26
-	1 HANMAT(I+1) A7 NUCLIDE NAME	LEAF	27
	2 HANMAT(1+2) F4 ID NUMBER (NEGATIVE IF NOT	LEAF	28
	DETAINED BY FILTED	LEAF	20
	3 HANMATITADI E4 DECAY DADENTI		27
	A HANMAT (1.4) F4 DECAT PARENT 2		20
			31
	6 ANMATCH 17 FIZ-3 NUCLEAR DESAT CONSTANT	LEAF	32
2	BRANCHING PATTO - ONE CADU DED BRANCH ASTER CARD ONE		و د
2	FOR FACH NEGATIVE DECAY DADENT		34
	POR LACH NEGATIVE DECAT PARENT	LEAF	35
	A DRV(10K) ELC-5 BRANCHING RATIU	LEAF	36
DLAN	A CARD AFTER LAST SET OF CARDS ONE AND TWO	LEAF	37
•		LEAF	38
3	NUMBER OF TIME STEPS	LEAF	39
	I INI IA NUMBER OF TIME INTERVALS	LEAF	40
	Z ITP IA PRINT FREQUENCY	LEAF	41
	3 IAC I4 UNITS OF CONTIC AND SOURCE	LEAF	42
	O - ATOMS ANC ATOMS/SFC	LEAF	43
	1 - CURIES OF GRAMS AND	LEAF	44
	CURIES/SEC OR GRAMS/SEC	LEAF	45
	▲ TEND(INT+1) E12±5 MAXIMUM TIME IN HOURS	LEAF	46
4	INITIAL VALUE OF ALL NUCLIDE CONCENTRATIONS IN CONTAINMENT	LEAF	47
	1 CONTIC(1) E12.5 INITIAL CONCENTRATION OF NUCLIDE	LEAF	48
	Z CONTIC(2) E12.5 INITIAL CONCENTRATION OF NUCLIDE	LEAF	49
	N CONTIC(N) E12.5 INITIAL CONCENTRATION OF NUCLIDE	LEAF	50
5	TIME STEP DATA - INT CARDS	LEAF	51
	1 TEND (N) E12.5 BEGINNING OF NTH TIME STEP	LEAF	52
	IN HOURS	LEAF	53
	2 LAMDAV (N) E12+5 CLEAN UP RATE DURING INTERVAL	LEAF	54
	3 LAMDAL (N) E12.5 LEAKAGE RATE DURING INTERVAL	LEAF	50
6	TIME STEP SOURCE DATA - CARDS FIVE AND SIX ARE ENTERED AS A SET	LEAF	55
	1 SOURCE (1+INT) F12+5 SOURCE TERM FOR NUCLIDE A		
	2 SOURCE (2+INT) F12 5 SOURCE TERM FOR MOLLIDE 1		⊃/ =^
	N SOURCE (NAINT) F12-5 - SOURCE TERM FOR NUCLIDE 2		58
	SUCCEDENTIAL LIES SUCCE LERM OR NUCLIDE N		59
PPOG			60
1100		LLAF	61

С		LEAF	62
С	INPA	LEAF	63
С	INPC	LEAF	64
č	NAKEA	LFAF	65
č	SOLVER	LEAF	66
ž			47
Š			67
C		LEAF	.68
С	PAPER OR TERM	LEAF	69
С		LEAF	70
С		LEAF	71
C	NN#20 NUMBER OF NUCLIDES TIMES TWO	LEAF	72
č			73
č			73
C	NIT#25 NUMBER OF TIME INTERVALS PLOS (NE	LEAP	14
С	NBR=10 NUMBER OF BRANCHING RATIOS	LEAF	75
С		LEAF	76
	IMPLICIT DOUBLE (A=G.P~Z)	PARAM1	2
	PADAMETER (NNT=10) . (NN=2+NNT) . (NTT=25) . (NRR=10) . (NNP=NNT+1)	PARAMI	
		DADAM1	د ۸
	COMPUN / DASISI/ IVIDRUNSKIP	PARAMI	
	LOUBLE LAMDY & LAMDL	PARAMI	_5
	COUBLE LAMUAV (NIT) +LAMDAL (NIT)	LEAF	78
	CIMENSION A(NN+NN)+SOURCE(NNT+NIT)+CONTIC(NN)+XNTOT(NN)+	LEAF	79
	1 XOUT (NNT+6+NIT) +XIENV(NN) +TEND(NIT) +ANMAT(NNF+2) +BRV(NBP) +	LEAF	80
	2 B(NN+NN) +D(NN+NN) +E(NN+NN) +B((NN+NN) +CSOURC(NN) +HANMAT(NNP+A) -	LEAF	ค้า
			01
~	2 VENATO NAV	LEAP	02
C		LEAF	83
С	*** READ LEAF INPUT DATA	LEAF	84
С	*** NSKIP GREATER THAN ZERO - DU NOT PRINT INPUT DATA AND USE	LEAF	85
С	*** TERMINAL OUTPUT FORMAT	LEAF	86
	FEAD 90, NSKIP,MATR1X	LEAF	87
	CALL TNPA (ANMAT + HANMAT + BRV)	LEAF	88
		LEAF	80
			07
		LEAP	90
		LEAF	91
	XIENV(IK)=0.0D0	LEAF	92
	×ENVIC(IK)≠0.0D0	LEAF	93
	CSOURC(IK)=0-0D0	LEAF	94
	CONTIC(IK) = 0 - 6D0	LEAF	05
	IV CONTINUE	LEAP	90
	CALL INFCCINIFCONFIC FENDELAMUAV (LAMUAL SUURCE HANMA] (IP ANMA)	LEAF	97
		LEAF	98
	XOUT(J+1+1)=CONTIC(J)	LEAF	99
	XOUT(J+3+1)=0+000	LEAF	100
	XOUT(J+5+1)=0+0D0	LEAF	101
	20 CONTINUE	LEAF	102
			102
			103
	11NCD4(1END(1)+1)+(END(1))+3600+000	LEAF	104
	10 30 10 = 101	LEAF	105
	CSOURC(IN)≠SOURCE(IN+IT)	LEAF	106
	30 CONTINUE	LEAF	107
		LEAF	108
	AMDI = AMDAI (TT)		100
			109
		LEAP	110
	IF (MATRIX-EU-1) CALL PRMAT(A,IT)	LEAF	111
	CALL SULVER (A+B+D+E+TINCD)	LEAF	112
	CALL FSOLVE(BL,B,D,E,CONTIC,CSOURC,XNTOT,XIENV,TINCD,XENVIC)	LEAF	113
	CO 40 J=1,I	LEAF	114
	XOUT(J+1+T+1) = XNTOT(J)	LFAF	116
	$X_{0}UT(.1+3+T+1) = X_{0}TOT(.1+1)$		111
		LEAP	110
	2001101010111111001001	LEAF	117
	40 CUNTINUE	LEAF	118
	50 CONTINUE	LEAF	119
	INT=INT+)	LEAF	120
	CALL PREP (XOUT.ANMAT.INT)		121
	 Marcola Acceleration and Acceleration and Acceleration 	LL Pr	

		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, ILP, TENO)	LEAF	125
	80	CONTINUE	LEAF	126
С			LEAF	127
	90	FORMAT(214)	LEAF	128
		END	LEAF	129
		SUBROUȚINE INPA(ANMAT, HANMAI, BRV)	LEAF	130
С	444	INPA READS AND PRINTS THE NUCLEAR DATA	LEAF	131
		IMPLICIT DOUBLE (A+G,P+Z)	PARAM2	2
		PARAMETER (NNT=10) + (NN=2*NN1) + (NIT=25) + (NBR=101 + (NNP=NNT+1)	PARAM2	3
		COMMON /BASISI/ I.IBR.NSKIP	PARAM2	4
		LIMENSION ANMAT (NNP .2) . HANMAT (NNP .4) . BRV (NBR) . HBRP (3. NBR)	LEAF	133
			LEAF	134
			LEAF	135
~			LEAF	136
C	10	FEAD NUCLEAR DATA SEAD 1100 (HANMATIT, D. L. L. AN . (ANMATIT, K) KE1020		137
	10	TE (HANMAT(T.)) EO HIN GO TÚ 70		130
		TO DO 103.4		139
		TE (ARS(HANMAT(TAL)) +1) 20.20.30		140
	20	CONTINUE		142
			LEAF	143
	30	PRINT 120. I	LEAF	144
		CALL EXIT	LEAF	145
С	***	TEST FOR BHANCHING RATIOS	LEAF	146
	40	CO 60 J=3+4	LEAF	147
		IF (HANMAT(I+J)+0+0) 50+60+00	LEAF	148
	50	READ 130, BRV(IBR)	LEAF	I49
		$FBRP(1 \bullet IBR) = ABS(HANMAT(I \bullet J))$	LEAF	150
		+BRP(2+16R)=I	LEAF	151
		FURP (3) 10R) = URV (10R)	LEAF	152
			LEAF	153
	90		LEAF	154
				155
	70			157
		IBR=1	LEAF	158
		IF (NSKIP_EQ.1) GO TO 100	LEAF	159
С	***	PRINT DECAY DATA	LEAF	160
		PRINT 140	LEAF	161
		PRINT 150	LEAF	162
		PRINT 16C	LEAF	163
		PRINT 150	LEAF	164
		PRINT 170	LEAF	165
		LCNT=13	LEAF	166
			LEAF	167
		PRINT 180. (MANMAT(J.J.J.).JJ=1.4).(ANMAT(J.J.J.).JJ=1.2)	LEAF	168
		LCNI=LUNI+I	LEAF	169
	90	IF (LUNI+GE+60) PRINT 140	LEAF	170
	00		LEAF	171
		$\frac{1}{1} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^$	LEAF	172
c	888	COINT POANCHING PATING	LEAF	173
C		$\frac{1}{100} = \frac{1}{100} = \frac{1}$		174
		PRINT 150		175
		PRINT 190	LEAF	177
		CO 90 J=1.IBR	I F AF	179
		PRINT 200+ HBRP(1+J)+HBRP(2+J)+HBRP(3+J)	IFAF	170
	90	CONTINUE	LEAF	180
	100	CONTINUE	LEAF	181
		FETURN	LEAF	182

С			LEAF	183
	110	FORMAT (A7,3F4,2D12,5)	LEAF	184
	120	FORMAT (1H0.4X.+THERE IS AN ERROR IN NUCLIDE +.13)	LEAF	185
	130	FORMAT (60)2-5)	LEAF	186
	140	FORMAT (1H1)	LFAF	187
	150		LEAF	188
	160	FORMAT (5) X- & DECAY CHAINS AND NUCLIDE DELATED DATAS)	LEAF	189
	170		LEAF	190
	1,0		LEAF	191
	100	ECONAT (64, 67, 14, 14, 24, 24, 24, 14, 24, 10, 12, 5, 14, 10, 12, 5)		102
	100	$ \begin{bmatrix} c \\ c$		192
	140	FORMAL (CIA+ORANCHING RATIOS##/#36A+FROM=#35##*10##3A,*RATIO##//	LEAF	173
	200	FURMAI (3/A)F444A+F443A+F7+7)	LEAF	194
			LEAF	195
		SUBROUTINE INPC (INT, CONTIC, LEND, LAMDAV, LAMDAL, SOURCE, HANMAT, ITP, AN	LEAF	196
_	1		LEAF	197
С	***	INPC READS THE CASE DATA	LEAF	198
		IMPLICIT DOUBLE (A-G,P-Z)	PARAM2	2
		PARAMETER (NNT±I3),(NN=2*NN <u>1</u>),(NIT±25),(NBR=10),(NNP=NNT+I)	PARAMZ	3
		COMMON /HASISI/ I.IHR.NSKIP	PARAM2	4
		COUBLE PRECISION LAMDAV(NIT),LAMDAL(NIT)	LEAF	200
		CIMENSION SOURCE(NNT+NIT)+ HANMAT(NNP+4)+ CONTIC(NN)+ TEND(NIT)	LEAF	201
		CIMENSION HTEND(8) ANMAT(NNP+2)	LEAF	202
С	***	FEAD BASIC TIME DATA	LEAF	203
		READ 120. INT.ITP.IAC.HTIME	LEAF	204
		INT1 = INT + 1	LEAF	205
		TEND(INT)=HTIME	LEAF	206
С	***	FEAD INITIAL CONCENTRATION OF CONTAINMENT	LEAF	207
		FEAD $130 \cdot (CONTIC(J) \cdot J = 1 \cdot 1)$	LEAF	208
С	***	READ TIME STEP DATA	LEAF	209
		CO 10 J=1.INT	LEAF	210
		FEAD 130. TEND(J).LAMDAV(J).LAMDAL(J)	LEAF	211
		FEAD $130 \cdot (SOURCE(M \cdot J) \cdot M = 1 \cdot I)$	LEAF	212
	10	CONTINUE	LEAF	213
С	***	CONVERT CONTIC AND SOURCE TU ATOMS AND ATOMS/SEC	LEAF	214
		IF (IAC_{EU+0}) GO TO 60	LEAF	215
		CO 50 M=I•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=3.70+10/ANMAT(M.1)	LEAF	220
	40	CONTINUE	LEAF	221
		CONTIC(M)=CONTIC(M)*CF	LFAF	222
		C0 50 J=1.INT	LFAF	223
		SOURCE (M+J)=SOURCE (M+J) *CF	LEAF	224
	50	CONTINUE	LEAF	224
	60	CONTINUE	LEAF	226
С	***	PRINT INPUT DATA	LEAF	227
-		IF (NSKIP-FQ-1) GO TO 110	LEAF	229
		ERINT 140	LEAF	220
		PRINT 160	LEAF	230
		ERINT 170	LEAF	231
		PRINT 180	LEAF	232
				232
				234
				234
				233
				230
				230
				235
				235
			LEAP	240
				241
			LEAF	242
		CO YU Sale	LEAF	243

		K-1 TAI2-3-4 1	LEAF	244
				245
			LEAP	245
	70	CONTINUE	LEAF	240
			LEAF	247
		PRINT 200, $(HTEND(J), J=1, LM)$	LEAF	248
		PRINT 210, $(HTEND(J), J=2, L)$	LEAF	249
		FRINT 220, (LAMDAV(J),J=LIN1,LIN2)	LEAF	250
		FRINT 230. (LAMDAL(J).J=LIN1.LIN2)	LEAF	251
		FRINT 240	LEAF	252
			LEAF	253
			LEAF	254
	90	EXITE 200 HANNATOLAITATOOARGE(OLADAO-LINITATIRE)		254
	00			200
			LEAF	200
			LEAF	257
		LIN2=MIND(LIN2,INT)	LEAF	258
		LIN29=L1N2+1	LEAF	259
		PRINT 150	LEAF	260
		LNCT=LNCT+NLN+3	LEAF	261
			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
		FETURN	LEAF	268
С			LEAF	269
-	120	FORMAT (314+E12-5)	LEAF	270
	130	FORMAT (6012-5)	LEAF	271
	140	FORMAT (1H1)	LEAF	272
	150		LEAF	273
	160			274
	100			275
	1/0	FORMAT (CZASWIINE SIEP DALA" \$77		215
	100	FORMAT (39A WITHE PERIOD IN HUCRS (/)	LEAF	210
	190			211
	200	FORMAT (1H++21X+7(0X+F6+1))		218
	510	FORMAT (1H++2/X+/(8X+F6+1))	LEAF	279
	220	FORMAT (7.5X. + ILIRATION REMOVAL RATE + 7(2* 1PD12.5))	LEAF	280
	230	FORMAT (7-5X++LEARAGE PEMOVAL RATE ++7(2X+1PD12,5))	LEAF	591
	240	FORMAT (7,5X,*SOURCE TERMS*)	LEAF	282
	250	FORMAT (/X+A7+14X+7(2X+1PU)2+5))	LEAF	283
		END	LEAF	284
_		SUBROUTINE_MAKEA(ANMAT+HANMAT+BRV+A+BL+LAMDV+LAMDL)	LEAF	285
С	***	PAKEA CONSTRUCTS THE MAIN SOLUTION MATRIX	LEAF	286
		IMPLICIT DOUBLE(A-G.P-Z)	PARAM1	2
		FARAMETER (NNT=I) + (NN=2*NN1) + (NIT=25) + (NBR=10) + (NNP=NNT+1)	PAPAM1	3
		COMMON /BASIS1/ I.IBR.NSKIP	PAPAM1	4
		COUBLE LAMDV+LAMDL	PARAM1	5
		CIMENSION ANMAT(NNP+2)+BRV(NBR)+A(NN+NN)+BB(NNT+NNT)+BL(NN+NN)	LEAF	288
		CIMENSION HANMAT(NNP•4)	LEAF	289
		I2=I*2	LEAF	290
		IP=I+1	LEAF	291
		CO 10 IK=1+I2	LEAF	292
		DO 10 JK=1+12	LEAF	293
		A(IK - JK) = 0.000	LEAF	294
		(1K, JK) = 0.000	LEAF	295
	10	CONTINUE	LEAF	294
	10			207
				200
				200
	20			279
	20			300
			LEAF	201
				302
		nn en evelet	LLAP	303

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		CO 50 IDX=3.4	LEAF	304
С	***	IDENTIFY SOURCE TERMS	LEAF	305
-		IF (ABS(HANMAT(IK,IDX)).NE.JK) GO TO 50	LEAF	306
		IF (HANMAT(IK+IDX)) 30+30+40	LEAF	307
	30	EB(IK,JK)=BRV(IBR)*ANMAT(JK,1)	LEAF	308
		IBR=IBR+1	LEAF	309
		GO TO Se	LEAF	310
	40	$\tilde{\mathbf{E}}_{\mathbf{B}}(\mathbf{I}_{\mathbf{K}},\mathbf{J}_{\mathbf{K}}) = \mathbf{ANMAT}(\mathbf{J}_{\mathbf{K}},1)$	LEAF	311
	50	CONTINUE	LEAF	312
	50	$A(TK \bullet JK) = BB(TK \bullet JK)$	LEAF	313
	60	CONTINUE	LEAF	314
		BH(IK, IK) = ANMAT(IK, 1)	LEAF	315
		A(TK = TK) = = BB(TK = TK) = I AMDI	LEAF	316
		IF (HANMAT(IK + 2) - GT - 0 - 0) A (IK + IK) = A (IK + IK) = LAMDV	LEAF	317
	70		LEAF	318
	10		LEAF	319
			LEAF	320
		JI = J + ANMAT (JK + 2) - GT - 0 - 0) A (JK + -JK) = J AMDV	LEAF	321
	90		LEAF	322
	94		LEAF	323
			LEAF	324
			LEAF	325
			LEAF	326
				327
			LEAF	328
		U = [+J]	LEAF	329
	~ ^	1F (MANMA)(1846// 304304100	LEAF	330
	90		LEAF	331
	100		LEAF	332
	110		LEAF	333
	120		LEAF	334
	120		LEAF	335
	120		LEAF	336
	130		LEAF	337
			LEAF	338
	140		LEAF	339
	140		LEAF	340
			LEAF	341
			LEAF	342
~		SOLRODINE SOLVER (AVBAUTATING)	LEAF	343
C	***		DADAM2	2,2
		IMPLICII DUUDLE (A=0, P=2)	PADAM2	
		PARAMETER (NNT=10) • (NN-2WNNT) • (NT=23) • (ND-10) • (NNT=10) • (NNT=10)	PARANE PARANE	5
			IEAE	345
		EIMENSION A(INNINN) & B(INNINN) & C(INNINNI) & C(INNINNI) & C(INNINNI)		346
		LIMENSION FUNNINI GUNNINI		340
				347
				340
				350
				350
				352
	• • •			352
	10			353
	20			354
		P=(0)(0)(30)(2)(2)(2)(2)(2)(2)(2)(2)(2)(2)(2)(2)(2)		355
	~ ~	TL (N) 2012014()		250
	0 د			221
		GO 10 20	LEAF	358
	40		LEAF	359
	50		LLAF	300
		I=IINCU/(2.000**NP)	LEAF	361
		CALL SUALAR(A+T+C)	LEAF	302
		CO 70 J=1,12	LEAF	363
		SI+1=LC 03 03	LEAF	364

		B(J•JJ)=0•0D0	LEAF	365
	60	CONTINUE	LEAF	366
		B(J+J)=1+900	LEAF	367
	70	CONTINUE	LEAF	368
С	***	CALCULATE U(H) AND Z(H)	LEAF	369
		CO 90 J=1.M	LFAF	370
		FM = 1 + 0 D 0 / (M + 2 + 0 D 0 + J)	LEAF	371
		CALL SCALAR (B+FM+D)	LEAF	372
		CALL MULTI(C+D+F)		373
			LEAF	374
		F(. . ,. J) = F(. . ,. J) + 1 - 0D0	LEAF	375
	80		LEAF	376
		CALL FQUAL (F+B)	LEAF	377
	90	CONTINUE	LEAF	378
	•••	S=1-0.00		370
		C0 120 J=1 • NP		380
			LEAF	381
		5=5+2,000	LEAF	382
		CALL SCALAH (C+Q+F)	LEAF	382
		CALL MULTI(F+B+F)	LEAF	384
			LEAS	304
				384
	100			300
	100			301
				200
				207
C	***			370
Ŭ				271
		$CALL MULTI(G \cdot F \cdot F)$		202
		CALL = SCALAR(F + 0.25D0 + G)		373
		CALL SCALAB (D. 5.50DO.F)		305
			LEAF	304
				307
	112	[1, 1] = [1, 1] = [1, 1] + [1, 1] + [1, 1]		27/
С				300
-	120	CONTINUE		600
		CALL SCALAR (A+TINCD+F)		400
		CALL MULTI(F+B+E)	LEAF	402
		[0, 130, J] = 1 + 12	LEAF	402
	130	$F(J_{1}) = F(J_{1}) = F(J_{1}) = J_{0}$		403
С	444	$T + A \neq D(A)$	LEAG	405
		FFTURN		405
		END	LEAF	400
		SUBBOUTINE ESOLVE (BLABADAEAGONTICACSOURCAYNTOTAXIENVATALODAYENVACA		400
С		FSOLVE CALCULATES THE FINAL CONCENTRATIONS AND INTEGRALS		400
		IMPLICIT DOUBLE (A-G+P+Z)		407
		PARAMETER (NNT=10) (NN=2*NNI) (NTT=25) (NRH=10) (NNP=NNT=1)	DADANO	2
		COMMON /BASISI/ I+IBR+NSKIP	DADAMO	נ ג
		CIMENSION B(NN+NN) + BL(NN+NN) + D(NN+NN) + F(NN+NN) + F(NN+NN) + X(NN)		4 611
		1. Y(NN) - XENVIC(NN)		412
		CIMENSION CONTIC(NN) + CSOURC(NN) + XNTOT(NN) + XIENV(NN)	LEAF	412
		I2=I+2	LEAF	415
С	***	CALCULATE CONTAINMENT AND FALTER INVENTORY	LEAF	415
		CALL MVMUL (E+CONTIC+X)	LEAF	416
		CALL SCALAR (0,TINCD,F)	LEAF	417
		CALL MVMUL (F,CSOURC,Y)	LEAF	418
		CALL VADD (X+Y+XNTOT)	LEAF	410
C	***	CALCULATE INTEGRATED RELFASE	LEAF	420
		TINCUZ=TINCD+TINCD	LEAF	421
		CALL SCALAH (B+TINCD+F)	LEAF	423
		CALL MVMUL (F, CONTIC, XIENV)	LEAF	422
		CALL SCALAR (D.TINCD2.F)	LEAF	423
		CALL MYMUL (F.CSDURC.Y)		724
				763

			1 5 1 5	424
				420
			LEAP	421
		CALL VADD (T XENVIC XIENV)	LEAF	428
		CO 10 J=1,12	LEAF	429
		CONTIC(J)=XTOT(J)	LEAF	430
		XENVIC(J)=XIENV(J)	LEAF	431
	10	CONTINUE	LEAF	432
		RETURN	LEAF	633
		END		434
		END CHUDOULTING DDED (YOUT ANNAT INT)		734
_		SUBROUTINE PREPTADULANMALAINT	LEAP	435
Ç	* + 0	PREP CONVERTS DENSITIES TO CURIES OR GRAMS	LEAF	436
		IMPLICIT DOUBLE(A-G,P-Z)	PAPAM2	2
		PARAMETER (NNT=10) + (NN=2+NN1) + (NIT=25) + (NBK=10) + (NNP=NNT+1)	PARAM2	3
		COMMON /BASISI/ I.IBR.NSKIP	PARAM2	Ā
		CIMENSION XOUT (NNT + 6 + NIT) + ANMAT (NND + 2)	LEAF	430
				430
			LEAP	439
		CD 40 JJ=1+I	LEAF	440
		IF (ANMAT(JJ+I) ER.0.0) GO 10 20	LEAF	441
		CURIES=ANMAT(JJ+1)/3-70+10	LEAF	442
		CO 10 JX=1+5+2	LEAF	443
		$XOUT(JJ \cdot JX + 1 \cdot J) = XOUT(JJ \cdot JX \cdot J) + CURTES$	LEAF	444
	10		LEAF	445
	1.0			443
	~~		LEAP	440
	20	GRA 15=ANMAT (JJ+2)/6+02250+23	LEAF	447
		CO 30 JX=1+5+2	LEAF	448
		×011(JJ+JX+1+J)=×0UT(JJ+JX+J)+GRAMS	LEAF	449
	30	CONTINUE	LEAF	450
	40	CONTINUE	LEAF	451
	50	CONTINUE		452
	50			452
				433
			LEAP	434
_		SUBROUTINE PAPER (XOUT, ANMAT, ANMAT, INT, ITP TEND)	LEAF	455
С	***	PAPER PRINIS THE RESULTS OF LEAF	LEAF	456
		IMPLICIT DUUBLE(A-G•P-Z)	PARAM2	2
		PARAMETER (NNT=10) • (NN=2+NNT) • (NIT=25) • (NBR=10) • (NNP=NNT+1)	PARAM2	3
		COMMON /HASISI/ I.TAR.NSKIP	PADAM2	
		TIMENSION XOUT (NNT & ANTT) - HANMAT (NND-6) - TEND (NTT) - ANMAT (NND-2)	IEAE	~ = 0
		DO NOT LINE TO		458
			LEAF	457
		PIIME=/END(J)	LEAF	460
		PRINT 40	LEAF	461
		PRINT 50+ HTIME	LEAF	462
		FRINT 60	LEAF	463
		FRINT 70	LEAF	464
		PDINT 85		404
				405
				400
			LEAF	467
		- COT - COT - CANMA (COT + 1) + (AUU - (COT + 0) + 0) + 0) = 1 + 0)	LLAF	468
		CO TO 20	LEAF	469
	10	PRINT 100, HANMAT(JK,1), (XOUT(JK,JT,J), JT=1+6)	LEAF	470
	20	CONTINUE	LEAE	471
	30	CONTINUE		472
		EFTION		470
c			LEAF	413
Ċ			LEAF	414
	40		LEAF	475
	50	FORMAL (4/X+*FISSION PRODUCL INVENTORY AT *+F7.2+* HOURS*+/)	LEAF	476
	60	FORMAT_ (294,80HSTABLE NUCLIVE INVENTORIES ARE GIVEN IN GRAMS AND A	LEAF	477
]	FE NOTED BY A + IN THE MARGIN (//)	LEAF	478
	70	FORMAT (20X+ *NUCLIDE*,9X++CUNTAINMENT INVENTORY*+10X-*FT TED TAVEN	LEAF	470
	- 1	TORY++11X+#INTEGRATED RELEASE++/)	LEAE	480
	່ອດ່			400
	00	FORMET CONSTRUCTION TO LEVER STORY TO LEVERS	LEAP	481
	30	FURMAI (2004A/+4445(3.44)PUI6(54)A(PUI2(5))	LEAF	482
	100	FURMAI (18A+109+1A+A/+4A+3(3X+1PU]2+5+1X+1PU]2+5))	LEAF	483
		LNU	LEAF	484

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		SUBROUTINE TERM(XOUT+HANMAT+INT+ITP+TEND)	LEAF	485
С	***	TERM CREATES TI 700 OUTPUT FORMAT	LEAF	486
		IMPLICIT DOUBLE (A-G+P+Z)	PARAMZ	2
		PARAMETER (NNT=10) + (NN=2+NN+) + (NIT=25) + (NBR=10) + (NNP=NNT+1)	PARAM2	3
		COMMON (BASISI / I. IBB-NSKIP	PARAM2	Ā
		CIMENSION XOUT (NNT+6+NIT) + HANMAT (NNP+4) + TEND (NIT)	LEAF	484
				400
				407
			LEAP	490
		PRINI JOO HIIME	LEAF	491
		PRINI 40	LEAF	492
		CO 10 JK=1+I	LEAF	493
		FRINT 50+ HANMAT(JK+1)+(XOU <u>I</u> (JK+JT+J)+JT≠1+5+2)	LEAF	494
	10	CONTINUE	LEAF	495
	20	CONTINUE	LEAF	496
		FETURN	LEAF	497
С			LEAF	498
	30	FORMAT (//+2X++FISSION PRODUCT INVENTORY A1++F7+2++ HOURS IN ATOMS	LEAF	499
		14•/)	LFAF	500
	40	FORMAT (2X++NUCLIDE++3X++CONTAINMENT INVENIORY++3X++FILTER INVENTO	LEAF	501
		18Y6 3X CHINIFGRATED DELEASES /	LEAF	502
	50	$\frac{1}{1} = \sqrt{3} \sqrt{3} = \frac{1}{1} \sqrt{3} \sqrt{3} \sqrt{3} \sqrt{3} \sqrt{3} \sqrt{3} \sqrt{3} 3$		502
	20			503
			LEAF	504
~			LEAF	505
C	***	PRMAI FRINIS INC A MAIRIX	LEAF	506
			PARAM2	2
		$PARAMETER (NN N = I_0) \bullet (NN = 2 \bullet NN_1) \bullet (N I T \neq 2 D) \bullet (NB R = I_0) \bullet (NN P = NN T + I)$	PARAMZ	3
		COMMON /BASISI/ I+IBR+NSKIP	PARAM2	4
		CIMENSION 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
		CO 10 J=1,I	LEAF	514
	10	PRINT 70+(A(J+JJ)+JJ=IP+I2)	LEAF	515
		N=N+1	LEAF	516
		ERINT 60.N	LEAF	517
			LEAF	519
	20			510
				520
			LEAF	520
				521
	20		LEAF	522
	30		LEAF	523
			LEAF	524
		FRINI DUN	LEAF	525
	4.0		LEAF	526
	40		LLAF	527
_		FETURN	LEAF	528
С			LEAF	529
	50	FORMAT(1H1+5X+#A MATRIX PRINTED BY QUADRANTS FOR TIME INTERVAL#.	LEAF	530
		1 13./)	LEAF	531
	60	FORMAT(/+5×++QUADRANT++I3+/)	LEAF	532
	70	FORMAT(2X,12(1X,1PDI0.3))	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	220
		FARAMETER (NNT=10) • (NN=2*NN1) • (NIT=25) • (NBR=10) • (NNP=NNT=1)	PARAM2	2
		COMMON ZRASISIZ IATRANSKIP	DADAMO	د
			LEAF	238
			LLAP	539
			LEAF	540
		CD ID 22-1415	LEAF	541

		(J, J) ≠S⇒A(J, J)	LEAF	542
	10	CONTINUE	LEAF	543
	20	CONTINUE	LEAF	544
			LEAF	545
		END	LEAF	546
			LEAF	547
c		AND TA MULTAR TRESTWO MATRICES IN DOUBLE		549
C		MPLICIT DUBLE (A-G-P-Z)		240
		$\frac{1}{2} \left[\frac{1}{2} \left$	DADAMO	2
		FARAMELER (NK)=1977 (NK)=2*NK1/ (NI)=2277 (NBO-1077 (NK)=NK)*[/		د ۸
			LEAE	== -
		CIMENSION A (MAANNYA B (MAANNYA C (MAANNYA	LEAF	220
				221
				222
			LEAP	223
		AM=0.000	LEAF	554
		CO 10 J=1+I2	LEAF	555
	10	$AM = AM + A(K_{\bullet}J) + B(J_{\bullet}KK)$	LEAF	556
	20	C (K KK) = AM	LEAF	557
		PETURN	LEAF	558
		END	LEAF	559
		SUBROUTINE EQUAL(A+B)	LEAF	560
C	244	EQUAL SETS A MATRIX EQUAL TO A MATRIX IN DOUBLE	LEAF	561
		IMPLICIT DOUBLE(A=G,P=2)	PARAM2	2
		PARAMETER (NNT=1;) • (NN=2*NN1) • (NIT=25) • (NBH=10) • (NNP=NNT+1)	PARAM2	3
		COMMON /BASISI/ I.IBR.NSKIP	PAPAM2	4
		CIMENSION A(NN+NN)+ 8(NN+NN)	LEAF	563
		I2=1*2	LEAF	564
		CO 20 K=1.12	LEAF	565
		CO 10 KK=1•I2	LEAF	566
		£(K•KK)=A(K•KK)	LEAF	567
	10	CONTINUE	LEAF	568
	20	CONTINUE	LEAF	569
		FETURN	LEAF	570
		END	LEAF	571
		SUBROUTINE MVMUL(A+B+C)	LEAF	572
С	***	NVHUL DOES PRODUCT OF MATHIX AND VECTOR	LEAF	573
		IMPLICIT DOUBLE(A-G,P-Z)	PARAM2	2
		PARAMETER (NNT=1)) + (NN=2+NN1) + (NIT=25) + (NBR=10) + (NNP=NNT+1)	PARAM2	3
		COMMON /BASIS1/ I.IBR.NSKIP	PARAM2	4
		CIMENSION A(NN,NN), B(NN), C(NN)	LEAF	575
		I2=I+2	LEAF	576
		CO 50 KI=1+I5	LEAF	577
		AM=0.0DU	LEAF	578
		CO 10 KJ=1+I2	LEAF	579
	10	AM=AM+A(KI+KJ)+B(KJ)	LEAF	580
	20	С(КІ)=АМ	LEAF	581
		RETURN	LEAF	582
		END	LEAF	583
		SUBROUTINE VADD(A+B+C)	LEAF	584
С	***	VADD DUES VECTOR ADDITION	LEAF	585
		IMPLICIT DOUBLE(A-G.P+Z)	PARAM2	2
		PARAMETER (NNT=13) • (NN=2*NN1) • (NIT=25) • (NBR=10) • (NNP=NNT+1)	PARAM2	3
		COMMON /BASIS1/ I.IBR.NSKIP	PARAN2	4
		CIMENSION A(NN), B(NN), C(NN)	LEAF	587
		IS=I*S	LEAF	588
		CO 10 KI=1+I2	LEAF	589
		C(KI) = A(KI) + B(KI)	LEAF	590
	10	CONTINUE	LEAF	59ï
		RETURN	LEAF	592
		END	LEAF	593

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