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USER'S MANUAL
FOR THE SOURCE TERM PROGRAM (STP-1)
FOR COMPUTING THE DISTRIBUTION OF
CORROSION AND FISSION PRODUCTS IN LMFBR's

AEC Research and Development Report

Atomics International
North American Rockwell

P.O. Box 309
Canoga Park, California 91304

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**USER'S MANUAL
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FOR COMPUTING THE DISTRIBUTION OF
CORROSION AND FISSION PRODUCTS IN LMFBR's**

By
G. B. ZWETZIG

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ABSTRACT

A manual for use of the Source Term Computer Program (STP-1) is presented. This program, written for the IBM 360, calculates the generation and transport of fission products and activated structural materials in a Liquid Metal-Cooled Fast Breeder Reactor (LMFBR) for user-selected cladding failure rates and core corrosion rates. The program also calculates ^{24}Na and ^{22}Na specific activities in the coolant, and radiation levels in the vicinity of the primary loop. A subroutine for plotting selected quantities is also included. The manual describes the equations used in the calculations, and presents the input data and output for a sample problem.

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I. INTRODUCTION

The Source Term Program (STP-1) is a FORTRAN H computer program for calculating the distribution of fission products and activated structural materials in the primary loop and cover gas spaces of a Liquid Metal-Cooled Fast Breeder Reactor (LMFBR) as a function of power history. Provisions are included for calculating the ^{22}Na and ^{24}Na activities which are present, the fission product inventories in the fuel (with and without fission product escape), and the residual radiation levels associated with sections of the primary loop.

The code is presently dimensioned to accommodate fission product chains containing up to 30 elements and a total of 80 members. To provide proper representation of chemical behavior, all chains yielding significant quantities of isotopes of an element of interest must be included. The code is dimensioned to keep track of up to 10 gaseous or volatile fission products which can enter the cover gas spaces.

Four mechanisms are provided to account for fission product escape from the fuel to the cladding gas gap or plenum: (1) recoil, (2) knockout of surface fuel by recoil atoms, (3) diffusion, and (4) direct release from high-temperature regions of the fuel (typically, 1600°C or above). The mechanisms to be utilized in a given problem are selected by the user.

Fission products reach the coolant either by escape from defective cladding or by fissioning of fuel present in the coolant. The rate of failure of cladding and the fuel inventory in the coolant are specified as functions of time by the user. Two cladding failure rates are provided: (1) for "pinhole" type failures, which would only permit release of gaseous and volatile elements, and (2) for gross failures, which would permit "washout" of nonvolatile elements.

The code is readily applied to problems involving changes in reactor power and reactor shutdown over the period of interest. This is accomplished by performing the computations for a series of time blocks. Within each time block, the reactor power, system temperatures, and flow rates remain constant. The conditions at the end of a time block serve as the input conditions for the next time block. Cladding defect rate constants, plutonium release rate constants, and other input factors can also be varied for each time block.

The structural material activation products (corrosion products) considered are ^{51}Cr , ^{54}Mn , ^{56}Fe , ^{58}Co , and ^{60}Co . These are assumed to be produced by two means: (1) activation of core structural material and cladding, with subsequent corrosion into the coolant stream, and (2) corrosion of primary loop wall materials into the coolant stream, followed by activation as these materials pass through the core. The corrosion rate in the core is dependent on core coolant temperature, with the necessary constants supplied by the user. The corrosion rate in the primary loop is determined by the element solubility potential in each primary loop region.

The LMFBR system model consists of a core region, up to five deposition regions, and up to two cover gas regions. A typical representation is shown in Figure 1. Each deposition region shown in Figure 1 is assigned a characteristic coolant temperature, and a coolant flow rate for each time block. In the present example, the flow rate would be identical in Deposition Regions 1 through 4. A much smaller rate would be appropriate for Region 5 (Cold Trap). Each of the

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Figure 1. Representation of a "Typical" LMFBR for STP-1 Analysis

two cover gas regions would be characterized by a pressure, a volume, and an adjoining coolant temperature for each time block. In STP-1, it is assumed that the concentration of each isotope and element is uniform throughout the primary loop at any given time.

An option is included in the code which permits calculation of all quantities, calculation of corrosion product activities only, or calculation of fission product quantities only.

II. BASIC EQUATIONS

A. GENERAL

A semi-analytical integration technique is employed in STP-1. This technique assumes that the time behavior of the various quantities of interest can be suitably described by a differential equation of form

$$\frac{dX}{dt} = \sum_i^i A_i - \left(\sum_j^j B_j \right) X \quad , \quad \dots(1)$$

where $\sum_i^i A_i$ and $\sum_j^j B_j$ are assumed constant over the integration time step. The code development task is to develop the equations for A_i and B_j for the various quantities of interest, and assure (through the selection of appropriate time steps) that the requirement of approximate constancy of $\sum_i^i A_i$ and $\sum_j^j B_j$ is met. If this is done, and $\sum_i^i A_i \equiv A$ and $\sum_j^j B_j \equiv B$, the quantities of interest will be properly calculated by the solution to Equation 1.

$$X = \frac{A}{B} [1 - \exp(-B \Delta t)] + X_0 \exp(-B \Delta t) \quad , \quad \dots(2)$$

where X_0 is the previous value of X , and Δt is the value of the time step.

The following sections describe how the quantities A_i and B_j are developed for the various quantities of interest.

In this discussion, the quantities A , B , N , and C will be used with double indices [e.g., $N(Z, M)$ or $A(I, 3)$]. N will represent an atomic inventory in either a specific region or in the coolant, and C will represent an atomic concentration in the coolant (atoms/cm³). The first index for these quantities will indicate either an element (denoted by Z) or an isotope (denoted by I). The second index identifies the region of interest. The specific index assignments employed in STP-1 are as shown in the following listing.

FISSION PRODUCTS

<u>Region Designation</u>	<u>Quantity</u>
1	Inventory or concentration in coolant
2	Inventory in fuel without fission product escape
3	Inventory in fuel with fission product escape
4	Inventory in fuel cladding gas gap and plenum
5 to ND+4	Inventory of adsorbed deposits in Deposition Regions 1 to ND
ND+5 to 2ND+4	Inventory of precipitated deposits in Deposition Regions 1 to ND
2ND+5 to 2ND+4+NV	Inventory of atoms in Cover Gas Regions 1 to NV

CORROSION PRODUCTS

<u>Region Designation</u>	<u>Quantity</u>
1	Concentration in coolant
2 to ND+1	Inventory of precipitated deposits in Deposition Regions 1 to ND

In the discussions which follow, the general region designation, M, is employed for regions other than 1 to 4 for fission products and other than 1 for corrosion products.

B. FISSON PRODUCTS

1. Fission Product Generation in Fuel

Two quantities are calculated relative to the fission product inventory in the fuel: one inventory (identified by the index 2) represents the inventory of isotope I, neglecting fission product escape from the fuel; the other (identified by the index 3) represents the inventory of I when escape is accounted for.

Note: ND = Number of deposition regions
 NV = Number of cover gas regions

The rate of change of the inventory of I, neglecting escape is

$$\frac{dN(I, 2)}{dt} = RY(I) - \lambda(I)N(I, 2) + \lambda(I - 1)N(I - 1, 2) \quad , \quad \dots(3)$$

where

R = fission rate (sec^{-1})

$\lambda(I)$ = radioactive decay constant of isotope I (sec^{-1})

$N(I, 2)$ = inventory of I in all fuel, neglecting escape (atoms)

$I - 1$ = index denoting precursor in fission product chain

$Y(I)$ = fission yield of isotope I.

In defining fission product chains, an index, IM, is utilized in the code logic. $IM(I) = 0$ identifies the first member of a chain, and is used to signal that there is no contribution from precursor decay. The values of A and B for $N(I, 2)$ therefore are:

$$IM(I) = 0 \quad A(I, 2) = RY(I) \quad \dots(4a)$$

$$IM(I) \neq 0 \quad A(I, 2) = RY(I) + \lambda(I - 1)N(I - 1, 2) \quad \dots(4b)$$

$$B(I, 2) = \lambda(I) \quad \dots(5)$$

Four mechanisms for fission product escape are provided in STP-1: (1) diffusion, (2) recoil, (3) knockout, and (4) direct release.

The diffusion mechanism assumes that the rate of escape of I is proportional to the total quantity of I present in the fuel. Thus,

$$\left. \frac{\partial N(I, 3)}{\partial t} \right|_{\text{diff}} = -\epsilon(Z)N(I, 3) \quad , \quad \dots(6)$$

where $\epsilon(Z)$ = effective escape constant by diffusion for element Z, of which I is an isotope.

For recoil, the number of fission fragments of isotope, I, escaping from the total surface of the fuel per unit time is

$$\left. \frac{\partial N(I, 3)}{\partial t} \right|_{\text{recoil}} = - \frac{RY(I)A_f R_{ff}}{4V_f}, \quad \dots(7)$$

where:

A_f = total surface area of fuel (cm^2)

R_{ff} = mean range of fission fragments (cm)

V_f = total fuel volume (cm^3)

There is evidence⁽¹⁾ that an important mechanism for fission product escape is the knockout or local vaporization of fuel near the fuel body surface by the passage of a recoil fission fragment. This, in turn, leads to the release of the fission products contained in the affected fuel. The affected region is estimated to be $\sim 10\text{\AA}$ thick, and the number of fuel molecules ejected is estimated to be ~ 2000 per fission fragment escaping from the fuel. Since the total rate of escape of recoil atoms is $RA_f R_{ff}/2V_f$ (total fission yield = 200%), the rate of loss of atoms of I by knockout is:

$$\left. \frac{\partial N(I, 3)}{\partial t} \right|_{\text{ko}} = - \frac{0.5RA_f R_{ff} N_{\text{ko}} M_f N(I, 3)}{2V_f^2 \rho_f A_o}, \quad \dots(8)$$

where:

N_{ko} = number of fuel molecules ejected from surface per recoil atom

M_f = molecular weight of fuel

ρ_f = density of fuel material (g/cm^3)

A_o = Avogadro's number.

The factor of 0.5 in the numerator on the right side of Equation 8 is included to account for the fact that approximately one-half of the inventory of I in this thin outer layer would have already escaped by recoil. It is assumed that the other 50% of the atoms in this region that recoiled into the fuel have been replaced by nonescaping recoil atoms from within the fuel.

It should be noted that the studies⁽²⁾ which indicate the importance of the knockout mechanism also indicate that the rate of loss by this means appears to decrease with time. Since STP-1 does not provide for this variation, the user may account for this by judicious selection of the input value for N_{ko} .

During irradiation, grain growth (recrystallization) occurs in UO_2 at temperatures above $\sim 1600^\circ C$, and essentially all the fission gas trapped in defects is then released because the defects migrate to a free surface.⁽³⁾ Equation 9 is utilized in STP-1 to represent this behavior of gaseous and volatile fission product elements.

$$\left. \frac{\partial N(I, 3)}{\partial t} \right|_{\text{direct}} = -F_{\text{dir}} RY(I) \quad , \quad \dots (9)$$

where F_{dir} = fraction of fuel at or above the recrystallization temperature of the fuel material.

In order to identify those elements that are gaseous or volatile, an index, $IV(Z)$, is utilized. When $IV(Z) = 0$, the element is defined as not gaseous and nonvolatile, and Equation 9 is not employed.

Summarizing the preceding, the values of A and B for $N(I, 3)$ are as follows:

$$A(I, 3) = RY(I) \left(1 - \frac{A_f R_{ff}}{V_f} - F_{\text{dir}} \right) + \lambda(I - 1) N(I - 1, 3) \quad , \quad \dots (10)^*$$

$$B(I, 3) = \lambda(I) + \epsilon(Z) + \frac{R A_f R_{ff} N_{ko} M_f}{4 V_f^2 \rho_f A_o} \quad , \quad \dots (11)$$

where, for isotopes of nongaseous or nonvolatile elements, $F_{\text{dir}} = 0$.

2. Fission Product Release to Cladding Gas Gap and Plenum

The fission product inventory in the cladding gas and fuel element plenum is denoted by the index, 4. The basic processes adding atoms of isotope, I, to this region are the same as those which cause a loss of I from the fuel, thus:

*For $IM(I) = 0$, last term equals zero.

$$\left. \frac{\partial N(I,4)}{\partial t} \right|_{\text{diff}} = \epsilon(Z)N(I,3) \quad , \quad \dots(12)$$

$$\left. \frac{\partial N(I,4)}{\partial t} \right|_{\text{recoil}} = \frac{RY(I)A_f R_{ff}}{4V_f} \quad , \quad \dots(13)$$

$$\left. \frac{\partial N(I,4)}{\partial t} \right|_{\text{ko}} = \frac{RA_f R_{ff} N_{\text{ko}} M_f N(I,3)}{4V_f^2 \rho_f A_o} \quad , \quad \dots(14)$$

$$\left. \frac{\partial N(I,4)}{\partial t} \right|_{\text{dir}} = F_{\text{dir}} RY(I) \quad . \quad \dots(15)$$

In addition, there is a contribution due to decay of precursors already in the gas gap [for $IM(I) \neq 0$],

$$\left. \frac{\partial N(I,4)}{\partial t} \right|_{\text{pre}} = \lambda(I - 1)N(I - 1,4) \quad . \quad \dots(16)$$

Loss of isotope, I, from the cladding gas gap and plenum will occur by radioactive decay, by escape from fuel to coolant through already defective cladding, and by new cladding failures which permit loss of a fraction of the stored inventory. The loss by radioactive decay is given by

$$\left. \frac{\partial N(I,4)}{\partial t} \right|_{\text{decay}} = -\lambda(I)N(I,4) \quad . \quad \dots(17)$$

If the fraction of cladding which is failed is $FC(t)$, the loss from already defected cladding is accounted for by multiplying Equations 12 through 15 by the factor $[1 - FC(t)]$.

The rate of loss of isotope I from the stored inventory in the cladding due to new cladding failures (failures which occur during the integration time interval) is given by

$$\left. \frac{\partial N(I,4)}{\partial t} \right|_{dFC} = -\frac{dFC(t)}{dt} N(I,4) , \quad \dots(18)$$

where $dFC(t)/dt$ is the instantaneous cladding fractional rate.

Because $N(I,3)$ is calculated before $N(I,4)$, it is possible to improve calculational accuracy by using the average value of $N(I,3)$ over the integration time interval. This is done by linear averaging, so that

$$\bar{N}(I,3) = \frac{N(I,3)_t + N(I,3)_{t-\Delta t}}{2} . \quad \dots(19)$$

Using the preceding equations, the values of A and B for $N(I,4)$ are as follows:

$$\begin{aligned} A(I,4) = & [1 - FC(t)] \left\{ RY(I) \left(F_{dir} + \frac{A_f R_{ff}}{4V_f} \right) \right. \\ & + \left. \left[\frac{RA_f R_{ff} N_{ko} M_f}{4V_f^2 \rho_f A_o} + \epsilon(Z) \right] \bar{N}(I,3) \right\} \\ & + \lambda(I - 1)N(I - 1,4) , \quad \dots(20)^* \end{aligned}$$

$$B(I,4) = \lambda(I) + \frac{dFC(t)}{dt} . \quad \dots(21)$$

If the value of F_{dir} is increased to a value higher than any previously attained, in going from one time block to the next, this would cause additional release of some of the volatile or gaseous atoms previously trapped in the fuel body. STP-1 accounts for this by increasing the inventory of the gaseous or volatile atoms in the cladding gas gap and decreasing the inventory in the fuel (Region 3) by an amount $[F_{dir}(\text{new}) - F_{dir}(\text{old})]N(I,3)$.

3. Cladding Fractional Failure Rate

Although not indicated in the preceding section, STP-1 provides two cladding fractional failure functions denoted by the index, IFC. The index, $IFC = 1$,

*For $IM(I) = 0$, last term equals zero.

refers to gross cladding failures which would permit "washout" of nonvolatile fission products by the coolant. The index, $IFC = 2$, refers to minor or "pin-hole" type failures which would permit escape of gaseous and highly volatile elements. Each isotope is assigned a value, by the user, for the value of $IFC(I)$ (either 1 or 2) which determines which fractional failure function is applied to that isotope.

Input constants, $FC1$ to $FC5$, are also supplied by the user for each cladding fractional failure function.

$FC1$ is the fraction of the total cladding failed at the beginning of the problem, and $FC2$ is the cladding fractional failure rate at the beginning of the problem. These four quantities [$FC1(1)$, $FC2(1)$, $FC1(2)$, and $FC2(2)$] need be supplied only once for a given problem. The balance of the quantities, $FC3$ to $FC5$, must be supplied for each time block, and are used as follows within each time block:

$$\frac{dFC(IFC,t)}{dt} = FC3(IFC) + FC4(IFC) \exp [FC5(IFC)BLTIME] , \quad \dots(22)$$

where:

$$\frac{dFC(IFC,t)}{dt} = \text{fractional cladding failure rate}$$

$BLTIME$ = time measured from the beginning of the time block (sec).

It will be noted that Equation 22 provides the option of having an exponentially increasing or decreasing cladding fractional failure rate, a linear rate, or both.

The fraction of the total cladding failed at the end of each time step is given by

$$FC(IFC,t + \Delta t) = FC(IFC,t) + \frac{dFC(IFC,t)}{dt} \Delta t , \quad \dots(23)$$

where Δt = integration time step (sec).

4. Release from Defected Cladding to Coolant

The rate of release of fission products into the coolant is identically equal to the rate of loss from the cladding gas gap and plenum, as previously described. The rate at which atoms of I enter the coolant (defined as Region 1) from the cladding gas gap and plenum is therefore:

$$\begin{aligned}
\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{fuel}} = & FC(IFC,t) \left\{ RY(I) \left(F_{\text{dir}} + \frac{A_f R_{ff}}{4V_f} \right) \right. \\
& + \left[\frac{RA_f R_{ff} N_{ko} M_f \bar{N}(I,3)}{4V_f^2 \rho_f A_o} + \epsilon(Z) \right] \bar{N}(I,3) \left. \right\} \\
& + \frac{dFC(IFC,t)}{dt} \bar{N}(I,4) \quad , \quad \dots(24)
\end{aligned}$$

where

$$\bar{N}(I,4) = \frac{N(I,4)_t + N(I,4)_{t-\Delta t}}{2} \quad \dots(25)$$

Since the coolant may also receive atoms of I from surface deposits, cover gas regions, and from fission of fissile material in the coolant, the contribution to the coolant from Equation 24 is only one of the terms used in computing A(I,1). The following sections describe the contributions from these other sources.

5. Adsorbed Deposits

The equation employed in STP-1 for adsorption of fission product atoms on surfaces assumes that the atoms of isotope, I, in the coolant are striking the surface at a rate of C(I,1)AGA(M) collisions/cm²-sec, where C(I,1) is the concentration of I in the coolant, and AGA(M) has the dimensions of velocity (cm/sec) and applies to Deposition Region M. The probability of striking an unoccupied adsorption site is proportional to the number of unoccupied sites per cm² in the region Q(M), times the area per site, f/Δ(M), where f is the fraction or multiple of the total surface area available for adsorption sites, and Δ(M) is the number of sites per cm² in Region M. The number of atoms of I lost from the coolant by adsorption in Region M per unit time is thus given by

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{ads}} = -C(I,1)AGA(M) \frac{f}{\Delta(M)} Q(M) \text{AREA}(M) \quad , \quad \dots(26a)$$

where:

N(I,1) = total inventory of I in coolant

AREA(M) = total surface area in Region M

Concurrent with the preceding, a fraction of the atoms of I adsorbed in Region M will statistically receive sufficient energy to be desorbed. If we denote this fraction by $EQL(Z,M)$, where Z is the element of which I is an isotope, and where $EQL(Z,M) = AKA(Z) \exp [BKA(Z)/T(M)]$, the rate at which atoms of I are adsorbed will be given by

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{des}} = EQL(Z,M)N(I,M) , \quad \dots(26b)$$

where $N(I,M)$ = total atoms of I adsorbed in Region M.

The net rate of adsorption/desorption is then given by

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{ads}} = -C(I,1)AGA(M) \frac{f}{\Delta(M)} Q(M)AREA(M) + EQL(Z,M)N(I,M) . \quad \dots(27)$$

Solution of Equation 27 requires the value of $Q(M)$. This is computed at each time step, based on the assumption that $Q(M)$ does not differ significantly from its equilibrium value, which may be shown to be given by

$$Q(M)_{\text{eq}} = \frac{[\Delta(M)]^2}{\Delta(M) + fAGA(M) \left\{ N(23,1)/EQLNA(M) \sum_I N(I,1)/[EQL(Z,M) + \lambda(I)] \right\}} , \quad \dots(28)$$

where:

$N(23,1)$ = concentration of ^{23}Na in coolant (atoms/cm³)

$EQLNA(M)$ = statistical removal fraction for Na in Region M (sec⁻¹).

It will be noted that Equation 28 includes the coolant (^{23}Na) as one of the participants in the adsorption process.

Because of the large amount of energy involved in radioactive decay, relative to the magnitude of chemical binding and physical adsorption energies, and because radioactive decay usually produces a change in elemental identity, and hence chemical properties, it is assumed in STP-1 that all adsorbed atoms which undergo radioactive decay re-enter the coolant immediately thereafter. This provides an additional source of atoms of I in the coolant, due to the decay of adsorbed atoms of the precursor of I. Specifically,

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{ads, pre}} = \lambda(I-1)N(I-1,M) \quad \dots (29)$$

Based on the preceding, the partial values of A and B for the coolant, related to adsorption/desorption in Region M, are

$$A(I,1)_{\text{ads}} = \text{EQL}(Z,M)N(I,M) + \lambda(I-1)N(I-1,M) \quad , \quad \dots (30a)^*$$

$$B(I,1)_{\text{ads}} = \text{AGA}(M) \frac{f}{\Delta(M)} Q(M) \text{AREA}(M) \quad . \quad \dots (30b)$$

Similarly, the value of A and B for adsorbed deposits in Region M are

$$A(I,M) = C(I,1) \text{AGA}(M) \frac{f}{\Delta(M)} A(M) \text{AREA}(M) \quad , \quad \dots (31a)$$

$$B(I,M) = \text{EQL}(Z,M) + \lambda(I) \quad . \quad \dots (31b)$$

6. Precipitated Deposits

As stated earlier, STP-1 assumes the concentration of all isotopes and elements is homogeneous throughout the primary loop. The coolant, however, has different average temperatures in the various deposition regions of the loop. If the concentration of an element, other than a noble gas, reaches a point where it exceeds its solubility in one or more of these regions, precipitation is assumed to occur in that region.

STP-1 employs a "black box" model to treat this process. If the flow rate through a Region M is $\text{FM}(M) \text{ cm}^3/\text{sec}$, and the concentration of Element Z in the coolant is $C(Z,1) \text{ atoms/cm}^3$, then, according to this model, the number of atoms entering the region per unit time is $\text{FM}(M)C(Z,1)$. If the concentration, $C(Z,1)$, exceeds the solubility[†] of Element Z in Region M, $\sigma(Z,M)$, and, if precipitation were 100% efficient in a single pass, the rate at which atoms would leave Region M would be $\text{FM}(M)\sigma(Z,M)$. The net loss of atoms of Z from the coolant, by precipitation in Region M, would then be $\text{FM}(M) [C(Z,1) - \sigma(Z,M)]$.

*If $\text{IM}(I) = 0$, last term = 0.

†Solubility is for the prevalent chemical form of Z, either as an element or a compound, and concentration is similarly expressed.

Because of the large flow rates present in most regions of an LMFBFR, it is unlikely that 100% precipitation would occur in a single pass. Accordingly, a precipitation efficiency, $AGP(M)^*$, is assigned to each region. The rate of loss of atoms of Z from the coolant by precipitation is then given by

$$\left. \frac{\partial N(Z,1)}{\partial t} \right|_{\text{precip}} = -AGP(M)FM(M) [C(Z,1) - \sigma(Z,M)] \quad \dots (32)$$

Tending to counter precipitation will be removal of the precipitate, either by erosion or by dissolution of those atoms or molecules receiving sufficient energy statistically to break their bonds to a precipitate particle or clump. This process will operate independently of whether or not precipitation is occurring, so long as precipitate remains on the surface. Letting $AEX(M)$ denote the re-entry rate constant for precipitated deposits in Region M, and $N(Z,M)$ denote the total inventory of Z precipitated in this region, the overall transfer rate for Element Z in Region M due to precipitation is given by

$$\left. \frac{\partial N(Z,1)}{\partial t} \right|_{\text{precip}} = -AGP(M)FM(M) [C(Z,1) - \sigma(Z,M)] + AEX(M)N(Z,M) \quad \dots (33)$$

In applying Equation 33 to individual isotopes of Element Z, it is necessary also to consider decay of the radioactive species in the precipitate. As in the case of adsorption, STP-1 assumes that, upon decaying, the daughters immediately leave the precipitate and enter the coolant. It is also necessary to consider the direction of transfer of precipitate atoms. If, as assumed, $C(Z,1) > \sigma(Z,M)$, precipitation will occur. At a later time, however, the concentration may be reduced, by operation of some other process or by an increase in the coolant temperature. In this case, dissolution of the precipitate will commence, and will continue until $C(Z,1)$ is equal to $\sigma(Z,M)$, or until all of the precipitate has dissolved.

For the case of $C(Z,1) > \sigma(Z,M)$, the rate of loss of atoms of Isotope I from the coolant by precipitation will be equal to the rate of loss of atoms of Element Z, $\dagger AGP(M) = AP(M) \exp [BP(M)/T(M)]$, where $AP(M)$ and $BP(M)$ are input constants, and $T(M)$ is the coolant temperature in Region M.

weighted by the isotopic fraction of I in the coolant [i.e., $C(I,1)/C(Z,1)$]. The rate at which I will enter the coolant from existing deposits, either by erosion-dissolution when $C(Z,1) < \sigma(Z,1)$, will equal the elemental rate weighted by the isotopic fraction of I in the precipitate.

Including radioactive decay, the isotopic equations for the precipitation process are as follows:

Case 1: $C(Z,1) > \sigma(Z,M)$

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{prec}} = -AGP(M)FM(M) [C(Z,1) - \sigma(Z,M)] \frac{C(I,1)}{C(Z,1)} + AEX(M)N(I,M) + \lambda(I-1)N(I-1,M) \quad \dots(34a)$$

Case 2: $C(Z,1) < \sigma(Z,M)$

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{prec}} = -AGP(M)FM(M) [C(Z,1) - \sigma(Z,1)] \frac{N(I,M)}{N(Z,M)} + AEX(M)N(I,M) + \lambda(I-1)N(I-1,M) \quad \dots(34b)$$

From the preceding, the partial values of A and B for the coolant due to precipitation in Region M are

Case 1:

$$A(I,1)_{\text{prec},M} = AEX(M)N(I,M) + \lambda(I-1)N(I-1,M) \quad , \quad \dots(35a)^*$$

$$B(I,1)_{\text{prec},M} = AGP(M)FM(M) [C(Z,1) - \sigma(Z,M)]/C(Z,1) \quad \dots(35b)$$

*Last term equals zero for $IM(I) = 0$.

Case 2:

$$A(I,1)_{\text{prec},M} = \{AEX(M) - AGP(M)FM(M) [C(Z,1) - \sigma(Z,M)]/N(Z,M)\} N(I,M) \\ + \lambda(I-1)N(I-1,M) , \quad \dots(36a)^*$$

$$B(I,1)_{\text{prec},M} = 0 . \quad \dots(36b)$$

The values of A and B for the precipitated surface deposits are:

Case 1:

$$A(I,M) = AGP(M)FM(M) [C(Z,1) - \sigma(Z,M)] \frac{C(I,1)}{C(Z,M)} , \quad \dots(37a)$$

$$B(I,M) = AEX(M) + \lambda(I) . \quad \dots(37b)$$

Case 2:

$$A(I,M) = 0 , \quad \dots(38a)$$

$$B(I,M) = AEX(M) + \lambda(I) - AGP(M)FM(M) [C(Z,1) - \sigma(Z,M)] / N(Z,M) . \quad \dots(38b)$$

A process map is provided in the computer output to indicate the status of precipitation or dissolution in each region. The symbols are as follows:

<u>Symbol</u>	<u>Process</u>
1	Adsorption only
2	Precipitation
3	Dissolution of precipitate

*Last term equals zero for $IM(I) = 0$.

7. Cover Gas

The equations governing the transport of atoms of gaseous and volatile elements [elements for which the vaporization index, $IV(I) \neq 0$] into cover gas regions assume a knowledge of the equilibrium distribution coefficient, k_D , for these elements. The equations are developed in the following manner:

The distribution coefficient is defined as

$$k_D = \frac{Y_2}{X_2} = \frac{\text{mole fraction of element Z in vapor}}{\text{mole fraction of element Z in liquid}} \quad \dots(39)$$

Assuming X_2 is small,

$$X_2 = \frac{\text{moles of Z per cm}^3 \text{ of sodium}}{\text{moles of sodium per cm}^3} \quad \dots(40)$$

Assuming the cover gas region has a constant pressure, temperature, and volume during a time block (with the pressure maintained constant by suitable controllers), the total number of moles of gas and vapor in the cover gas region will remain constant. Denoting this number of moles by M_{tot} ,

$$Y_2 = \frac{\text{moles of Z in cover gas region}}{M_{\text{tot}}} \quad \dots(41)$$

Combining Equations 39, 40, and 41, the number of moles of Z in the cover gas region at equilibrium, $M(Z)_{\text{eq}}$ is given by

$$M(Z)_{\text{eq}} = k_D \frac{\text{moles of Z per cm}^3 \text{ of sodium}}{\text{moles of sodium per cm}^3} M_{\text{tot}} \quad \dots(42)$$

Noting that $M_{\text{tot}} = PV/RT$, and transforming to an atomic basis,

$$N(Z)_{eq} = k_D \frac{C(Z,1)_{eq}}{\rho(T)/22.99} \frac{PV}{RT} , \quad \dots(43)$$

where:

$N(Z)_{eq}$ = number of atoms of Z in cover gas space at equilibrium

$C(Z,1)_{eq}$ = concentration of Z in coolant at equilibrium

$\rho(T)$ = density of sodium at temperature T

T = absolute temperature of sodium adjoining cover gas space

P = pressure in cover gas space

R = gas constant

V = volume of cover gas space

22.99 = atomic weight of sodium.

As applied in STP-1, k_D is represented in the form

$$k_D(Z,M) = AVAP(Z) \exp [BVAP(Z)/T_{vap}] , \quad \dots(44)$$

where T_{vap} is the coolant temperature adjoining the vaporization region.

Also, for simplicity,

$$AKL(Z,M) \equiv \frac{k_D(Z,M)22.99}{\rho(T_{vap})} \frac{P(M)V(M)}{RT_{vap}} , \quad \dots(45)$$

where the index, M, specifies the cover gas space, M. Using Equation 45, Equation 43 can be rewritten

$$N(Z,M)_{eq} = AKL(Z,M)C(Z,1)_{eq} . \quad \dots(46)$$

Based on the preceding, the vaporization process is described in STP-1 as follows:

The rate of vaporization of atoms of Element Z into Cover Gas Region M is proportional to the concentration of Z in the coolant, $C(Z,1)$, the interface area, A, a surface striking or diffusion velocity in the liquid, U_l , and an escape probability, P_e . Similarly, the rate of reentry of atoms of Z from the cover gas into the coolant will be proportional to its concentration in Region M, $C(Z,M)$, the interface area, A, a velocity-related term, U_v , and a reentry or capture probability P_c . The net rate of transfer of atoms of Z is then given by the difference in these two rates:

$$\left. \frac{dN(Z,M)}{dt} \right|_{\text{vap}} = U_l P_e A C(Z,1) - U_v P_c A N(Z,M) / V(M) \quad , \quad \dots (47)$$

where:

$N(Z,M)$ = inventory of Element Z in Cover Gas Region M (atoms)

$V(M)$ = volume of Cover Gas Region M (cm^3).

At equilibrium, the cover gas inventory will be given by

$$N(Z,M)_{\text{eq}} = \frac{U_l P_e V(M)}{U_v P_c} C(Z,1)_{\text{eq}} \quad . \quad \dots (48)$$

Comparing Equation 48 with Equation 46, it is seen that the ratio, $[U_l P_e V(M) / U_v P_c]$, is equal to the quantity $AKL(Z,M)$. It can be shown that, in the absence of radioactive decay processes, the reciprocal of the time constant for the rate of change of the cover gas inventory, $N(Z,M)$, is equal to $C_v P_c A / V(M)$. If this quantity is denoted by $\alpha(M)$, Equation 47 may be rewritten

$$\left. \frac{dN(Z,M)}{dt} \right|_{\text{vap}} = \alpha(M) [AKL(Z,M) C(Z,1)_{\text{eq}} - N(Z,M)] \quad . \quad \dots (47a)$$

Substituting Equation 46 in Equation 47a, one obtains

$$\left. \frac{dN(Z,M)}{dt} \right|_{\text{vap}} = \alpha(M) [N(Z,M)_{\text{eq}} - N(Z,M)] \quad \dots(47b)$$

The value of $N(Z,M)_{\text{eq}}$ will change with changing system conditions; but, for a given condition, is given by

$$N(Z,M)_{\text{eq}} = \frac{VC \cdot C(Z,1) + \sum^J N(Z,J)}{VC + \sum^J AKL(Z,J)} \quad \dots(48)$$

where the summations are made over the total number of cover gas regions.

The treatment of isotopes of the vaporizing elements is based on the appropriate elemental transfer rate, as described previously, weighted by their relative abundance in either the coolant or cover gas region (depending on the direction of flow).

The treatment of radioactive decay depends on the nature of the daughter isotope. If the daughter is a vaporizing species [$IV(I) \neq 0$], it is assumed to remain in the cover gas; if it is not [$IV(I) = 0$], it is assumed to immediately reenter the coolant. The equations for the rate of transfer of isotopes of vaporizing elements are as follows:

For $N(Z,M)_{\text{eq}} > N(Z,M)$,

$$\begin{aligned} \frac{dN(I,M)}{dt} = & \alpha(M) [N(Z,M)_{\text{eq}} - N(Z,M)] \frac{C(I,1)}{C(Z,1)} \\ & - \lambda(I)N(I,M) + \lambda(I-1)N(I-1,M) \quad \dots(49a) \end{aligned}$$

For $N(Z,M)_{\text{eq}} < N(Z,M)$,

$$\begin{aligned} \frac{dN(I,M)}{dt} = & \alpha(M) [N(Z,M)_{\text{eq}} - N(Z,M)] \frac{N(I,M)}{N(Z,M)} \\ & - \lambda(I)N(I,M) + \lambda(I-1)N(I-1,M) \quad \dots(49b) \end{aligned}$$

*Except for short periods following step changes in system conditions.

The corresponding values of A and B for the cover gas are:

For $N(Z,M)_{eq} > N(Z,M)$,

$$A(I,M) = \alpha(M) [N(Z,M)_{eq} - N(Z,M)] \frac{C(I,1)}{C(Z,1)} + \lambda(I - 1)N(I - 1,M)^* , \dots (50a)$$

$$B(I,M) = \lambda(I) . \dots (50b)$$

For $N(Z,M)_{eq} < N(Z,M)$,

$$A(I,M) = \lambda(I - 1)N(I - 1,M)^{\dagger} , \dots (51a)$$

$$B(I,M) = -\alpha(M) [N(Z,M)_{eq} - N(Z,M)] \frac{1}{N(Z,M)} + \lambda(I) . \dots (51b)$$

The partial values of A and B for the coolant are:

Vaporizing Species:

$$A(I,1) = -[N(I,M)_{new} - N(I,M)_{old}]/DEL T , \dots (52a)$$

$$B(I,1) = 0 , \dots (52b)$$

where the subscripts "new" and "old" designate the newly computed and the previous values of the cover gas inventory of isotope I, and DELT is the length of the integration time step.

Nonvaporizing Species:

$$A(I,1) = \lambda(I - 1)N(I - 1,M) , \dots (52c)$$

$$B(I,1) = 0 . \dots (52d)$$

*Last term equals zero for $IM(I) = 0$

†Equals zero for $IM(I) = 0$

8. Fission Product Generation in the Coolant

STP-1 includes provisions for generation of fission products directly in the coolant by means of fission of fissile material homogeneously distributed throughout the coolant. In addition, it provides means for time variation of the amount of fissile material in the coolant.

The rate at which fissile material enters the coolant during each time block is given by

$$\frac{dFP}{dt} = FP3 + FP4 \exp (FP5BLTIME) , \quad \dots(53)$$

where FP3, FP4, and FP5 are input constants, and BLTIME is time (in seconds), measured from the beginning of the time block. The weight of fissile material (in grams) in the coolant, FP, is then computed at each time step

$$FP = FP + \frac{dFP}{dt} DELT , \quad \dots(54)$$

where DELT is the length of the integration time step.

Provision is also made for an initial fissile inventory in the coolant, FP1.

The rate at which atoms of Isotope I are generated in the coolant is given by

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{fiss}} = \frac{FP 6.023 \times 10^{23}}{239VC} \sigma_f \phi V_o Y(I) , \quad \dots(55)$$

where:

FP = coolant fissile inventory (grams)

VC = total coolant volume (cm³)

σ_f = spectrum-weighted fission cross section (cm²)

ϕ = average neutron flux in core (cm⁻² sec⁻¹)

V_o = core coolant volume (cm³)

Y(I) = direct fission yield of Isotope I

239 = molecular weight of fissile species (Pu assumed).

The partial value of A(I,1) due to fissile material in the coolant is identical with the right-hand side of Equation 55.

9. Coolant Concentration

The concentration of Isotope I in the coolant is obtained by summing the partial A(I,l)'s and B(I,l)'s developed in the preceding sections, over the various regions and processes, dividing each of the sums by the total coolant volume, and accounting for radioactive decay. The new concentration, C(I,l), is then computed from the preceding and the coolant concentration at the beginning of the time interval. Thus,

$$A(I,l) = \frac{1}{VC} \sum_{\text{process}} \sum_{\text{region}} A(I,l)_{\text{partial}} , \quad \dots(56)$$

$$B(I,l) = \lambda(I) + \frac{1}{VC} \sum_{\text{process}} \sum_{\text{region}} B(I,l)_{\text{partial}} , \quad \dots(57)$$

$$C(I,l)_{\text{new}} = \frac{A(I,l)}{B(I,l)} \left\{ 1 - \exp [-B(I,l)DELT] \right\} + C(I,l)_{\text{old}} \exp [-B(I,l)DELT] . \quad \dots(58)$$

It should be noted that the reason for dividing all quantities except $\lambda(I)$ by the total coolant volume, VC, is due to the fact that the computation is for coolant concentration, while the partial A(I,l) and B(I,l) values were developed on a total atomic inventory basis.

C. ACTIVATED STRUCTURAL MATERIALS (Corrosion Products)

1. Products Considered

STP-1 computes the generation and transport of the following radioisotopes: 27.8d ^{51}Cr , 300d ^{54}Mn , 45.1d ^{59}Fe , 72d ^{58}Co , and 5.3y ^{60}Co . The reactions used to compute these activities are as follows:

27.8 ^{51}Cr : $^{50}\text{Cr}(n,\gamma)$, $^{54}\text{Fe}(n,\alpha)$, $^{52}\text{Cr}(n,2n)$

300d ^{54}Mn : $^{54}\text{Fe}(n,p)$, $^{55}\text{Mn}(n,2n)$

45.1d ^{59}Fe : $^{58}\text{Fe}(n,\gamma)$

72d ^{58}Co : $^{58}\text{Ni}(n,p)$, $^{59}\text{Co}(n,2n)$

5.3y ^{60}Co : $^{59}\text{Co}(n,\gamma)$, $^{60}\text{Ni}(n,p)$.

2. Generation of Corrosion Products

a. Introduction

Corrosion products are generated by two mechanisms in an LMFBR: (1) structural material in the vicinity of the reactor core is activated, and enters the coolant by corrosion, and (2) structural material throughout the primary loop enters the coolant by corrosion, and is subsequently activated as it passes through the core. STP-1 treats both of these sources of corrosion products.

In the corrosion product computation, 16 isotopes are considered; 13 of these are the 5 radioactive species of interest and their 8 parents, as listed in the preceding section (Section II-C-1). The remaining three isotopes do not participate in the nuclear reactions, but represent the balance of the Cr, Fe, and Ni present in the structure and coolant, and must therefore be included to properly treat chemical behavior. Table 1 identifies the 16 isotopes used in the calculations, their index, I, their atomic and mass numbers, and their element identification index, IZC(I).

b. Contribution From the Core Structure

The contribution of radioactive species from the core structure is calculated by the following procedure:

(1) Calculation of Atom Densities, ADEN(I), in Core Structure for Stable Isotopes

$$ADEN(I) = RHO(Z) 6.023 \times 10^{23} \text{SUFZA}(I)/W(Z) \quad , \quad \dots(59)$$

where:

$RHO(Z)$ = density of Element Z in core structure (g/cm^3)

$\text{SUFZA}(I)$ = isotopic abundance of Isotope I of Element Z

$W(Z)$ = atomic weight of Element Z

Equation 59 is performed for isotopes, $I = 1$ to 11.

The user of STP-1 need only specify the values of $RHO(Z)$, as the values of $\text{SUFZA}(I)$ and $W(Z)$ are included in STP-1. The values of $RHO(Z)$ should be specified according to the convention:

TABLE 1
ISOTOPES USED IN CORROSION PRODUCT CALCULATIONS

I	Z	A	IZC(I)	Chemical Designation
1	24	50	1	^{50}Cr
2	24	52	1	^{52}Cr
3	26	54	3	^{54}Fe
4	26	58	3	^{58}Fe
5	25	55	2	^{55}Mn
6	28	58	5	^{58}Ni
7	28	60	5	^{60}Ni
8	27	59	4	^{59}Co
9	24	535	1	Nonparticipating stable Cr
10	26	565	3	Nonparticipating stable Fe
11	28	625	5	Nonparticipating stable Ni
12	24	51	1	^{51}Cr
13	25	54	2	^{54}Mn
14	26	59	3	^{59}Fe
15	27	58	4	^{58}Co
16	27	60	4	^{60}Co

RHO (1) Cr

RHO (2) Mn

RHO (3) Fe

RHO (4) Ni

RHO (5) Co

(2) Calculation of Macroscopic Cross Section

As indicated earlier, several of the radioactive species of interest may be produced by more than one reaction. Accordingly, a total macroscopic cross section, SIGMA(I), is calculated which sums the macroscopic cross sections of the contributing reactions.

For ^{51}Cr ,

$$\text{SIGMA}(12) = \text{ADEN}(1)\text{S10}(1) + \text{ADEN}(2)\text{S10}(2) + \text{ADEN}(3)\text{S10}(3) \quad \dots(60a)$$

For ^{54}Mn ,

$$\text{SIGMA}(13) = \text{ADEN}(3)\text{S10}(4) + \text{ADEN}(5)\text{S10}(5) \quad \dots(60b)$$

For ^{59}Fe ,

$$\text{SIGMA}(14) = \text{ADEN}(4)\text{S10}(6) \quad \dots(60c)$$

For ^{58}Co ,

$$\text{SIGMA}(15) = \text{ADEN}(6)\text{S10}(7) + \text{ADEN}(8)\text{S10}(8) \quad \dots(60d)$$

For ^{60}Co ,

$$\text{SIGMA}(16) = \text{ADEN}(8)\text{S10}(9) + \text{ADEN}(7)\text{S10}(10) \quad \dots(60e)$$

S10(1) through S10(10) are spectrum-weighted microscopic cross sections, to be supplied by the user according to the following convention:

<u>Cross Section</u>	<u>Reaction</u>	<u>Cross Section</u>	<u>Reaction</u>
S10(1)	$^{50}\text{Cr}(n,\gamma)$	S10(6)	$^{58}\text{Fe}(n,\gamma)$
S10(2)	$^{52}\text{Cr}(n,2n)$	S10(7)	$^{58}\text{Ni}(n,p)$
S10(3)	$^{54}\text{Fe}(n,\alpha)$	S10(8)	$^{59}\text{Co}(n,2n)$
S10(4)	$^{54}\text{Fe}(n,p)$	S10(9)	$^{59}\text{Co}(n,\gamma)$
S10(5)	$^{55}\text{Mn}(n,2n)$	S10(10)	$^{60}\text{Ni}(n,p)$

(3) Calculation of Radioactive Isotope Atom Densities in Core Structure

The atom densities of the radioactive species ($I = 12$ to 16) in the core structure are calculated for each time step as follows:

$$\text{ADEN}(I)_t = \frac{\text{SIGMA}(I)\phi}{\lambda(I)} \left\{ 1 - \exp[-\lambda(I)\Delta t] \right\} + \text{ADEN}(I)_{t-\Delta t} \exp[-\lambda(I)\Delta t] , \quad \dots(61)$$

where

ϕ = average flux in core region

$\lambda(I)$ = radioactive decay constant

Δt = integration time step.

Only a reference value of ϕ (in conjunction with a reference value of reactor power) need be supplied. The value of ϕ is automatically adjusted, relative to the reference flux in each time block, to correspond to the power level specified for the time block. The values of $\lambda(I)$ are built into STP-1.

(4) Calculation of Rate of Entry Into Coolant

Having obtained the atom densities (ADEN) of the various isotopes in the core structure, the rate of entry of Isotope I into the coolant (Region 1) is calculated from

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{corr}} = \text{ADEN}(I) \text{RC}(Z) \text{ACORE} , \quad \dots(62)$$

where:

$\text{RC}(Z)$ = average corrosion rate of Element Z over core (cm/sec)

ACORE = core surface area for corrosion (cm^2)

Both RC(Z) and ACORE must be supplied as input to the program. Specification of RC(Z) requires three quantities: ACOR(Z), BCOR(Z), and TCORE. RC(Z) is then computed as follows:

$$RC(Z) = ACOR(Z) \exp [BCOR(Z)/TCORE] \quad \dots(63)$$

ACOR(Z) and BCOR(Z) need only be provided in the initial input data. TCORE is typically the mean coolant temperature in the core (°C), and must be specified for each time block (unless flow rates and temperatures are unchanged from the preceding time block). In specifying ACOR(Z) and BCOR(Z), it is necessary to observe the same convention described earlier for RHO(Z). It is possible to specify different corrosion rates for each element.

c. Contribution From the Loop Structure

The rate of transfer of stable isotopes from the walls of Primary Loop Region M to the coolant is calculated as follows:

$$\left. \frac{\partial N(I,1)}{\partial t} \right|_{\text{corr},M} = -AKC(M)FM(M) [CNZC(Z) - SOLBC(Z,M)] SZS(Z)SUFZA(I) \quad , \quad \dots(64)$$

where:

AKC(M) = corrosion efficiency in Region M

FM(M) = volumetric flow rate in Region M (cm³/sec)

CNZC(Z) = coolant concentration of Corrosion Product Element Z (atoms/cm³)

SOLBC(Z,M) = solubility of Corrosion Product Z in coolant in Region M (atoms/cm³)

SZS(Z) = volume fraction of Element Z in walls of primary loop

SUFZA(I) = isotopic abundance of Corrosion Product Parent Isotope I in walls.

It can be seen that the driving potential for this transfer is the difference between the coolant concentration of Element Z and its solubility in Region M. The rate is also proportional to the isotopic composition of the walls of the

primary loop, as reflected in the product, SZS(Z)SUFZA(I), the flow rate, FM(M), and the precipitation efficiency.

Equation 64 is only employed in those regions where the concentration of Z is less than its solubility in the coolant in that region, and where there are no precipitated deposits of Element Z in the region. It will be noted that Equation 64 provides a solubility-based model for corrosion in the primary loop.

d. Activation of Elements in Coolant

Equation 62 gives the rate of entry of atoms from the core structure into the coolant. Some of these atoms are the radioactive species of interest, while others are stable but subject to activation as they subsequently pass through the core. Equation 64 provides another source of stable isotopes from the walls of the primary loop. These two sources are combined, and the concentration of each stable isotope in the coolant is computed as described in Section II-C-5. These coolant concentrations are then used to compute the rate of generation of the radioactive species of interest in the coolant as follows:

For ^{51}Cr :

$$\left. \frac{\partial N(12,1)}{\partial t} \right|_{\text{cool}} = V_o \phi [C(1,1)S10(1) + C(2,1)S10(2) + C(3,1)S10(3)] \quad \dots (65a)$$

For ^{54}Mn :

$$\left. \frac{\partial N(13,1)}{\partial t} \right|_{\text{cool}} = V_o \phi [C(3,1)S10(4) + C(5,1)S10(5)] \quad \dots (65b)$$

For ^{50}Fe :

$$\left. \frac{\partial N(14,1)}{\partial t} \right|_{\text{cool}} = V_o \phi C(4,1)S10(6) \quad \dots (65c)$$

For ^{58}Co :

$$\left. \frac{\partial N(15,1)}{\partial t} \right|_{\text{cool}} = V_o \phi [C(6,1)S10(7) + C(8,1)S10(8)] \quad \dots (65d)$$

For ^{60}Co :

$$\left. \frac{\partial N(16,1)}{\partial t} \right|_{\text{cool}} = V_o \phi [C(8,1)S10(9) + C(7,1)S10(10)] \quad \dots(65e)$$

where:

$C(I,1)$ = concentration of Isotope I in the coolant (atoms/cm³)

ϕ = average flux in core volume (cm⁻² sec⁻¹).

3. Precipitated Deposits

The equations employed for precipitation of corrosion products are essentially the same as those described for fission products, except that the contribution to the coolant inventory of radioactive corrosion product decay is neglected (See Section II-B-7).

4. Adsorbed Deposits

The process of adsorption of corrosion products is not treated in STP-1, because the high concentrations of stainless steel constituent atoms in the coolant will make precipitation the dominant deposition process.

5. Coolant Concentration of Corrosion Products

The computation of the coolant concentrations of the radioactive and stable isotopes of the core and primary loop structural materials is similar to that performed for fission products. The only differences are that there are no transport processes for adsorbed or vaporized atoms, or contributions from parent radioactive decay.

The partial values of $A(I,1)$ and $B(I,1)$ are obtained from Equations 62, 64, 65a to 65e, and from precipitation equations similar to those developed for fission products (Equations 35a, 35b, 36a, and 36b). These values are then summed, as in Equations 59 and 60 (where radioactive decay is accounted for), and the new coolant concentration for each isotope is calculated per Equation 61.

D. ELEMENT SUMMATION

Because, on a practical level, it is elemental (rather than isotopic) concentration that determines physico-chemical behavior, it is necessary that the individual concentrations and/or inventories of the constituent isotopes of an

element be summed to obtain the overall elemental concentration or inventory at the conclusion of each time step. This operation is performed by assigning an element identification index to each isotope in the isotope list: IZZ(I) for fission products, and IZC(I) for corrosion products. The value of IZZ(I) must be provided by the user, in accordance with the isotope list used in his problem (See sample problem, Section VI). The values of IZC(I) are built into STP-1, and are given in Table 1.

An additional index, IV(I), is also required for fission products. If IV(I) = 0, this identifies isotopes belonging to elements that do not vaporize. If the element does vaporize, the value of IV(I) identifies the element to which that isotope belongs.

Using these indices, the concentrations or regional inventories of elements are readily obtained by summing the values for the individual isotopes having the same IZZ(I) or IZC(I) index; or, in cover gas spaces, by summing those having the same IV(I) index.

E. SODIUM ACTIVITIES

The specific activities of ^{24}Na and ^{22}Na in the coolant are calculated by STP-1 at each time step as follows:

The rate of production and decay of ^{24}Na per cubic centimeter is given by

$$\frac{dC(24)}{dt} = C(23)\sigma(n,\gamma)\varphi \frac{V_o}{VC} - \lambda(24)C(24) \quad , \quad \dots(66a)$$

where:

$C(24)$ = concentration of ^{24}Na in coolant (atoms/cm³)

$C(23)$ = concentration of ^{23}Na in coolant (atoms/cm³)

$\sigma(n,\gamma)$ = spectrum-weighted microscopic cross section for ^{24}Na (cm²)

φ = average neutron flux in core (cm⁻² sec⁻¹)

$\lambda(24)$ = radioactive decay constant of ^{24}Na (sec⁻¹)

V_o = core coolant volume (cm³)

VC = total coolant volume (cm³)

In a similar manner, the rate of production and decay of ^{22}Na per cubic centimeter is given by

$$\frac{dC(22)}{dt} = C(23)\sigma(n,2n)\phi \frac{V_0}{VC} - \lambda(22)C(22) \quad , \quad \dots(67a)$$

where $\sigma(n,2n)$ is the spectrum-weighted microscopic cross section for the reaction, $^{23}\text{Na}(n,2n)^{22}\text{Na}$. Equations 66a and 67a have the following analytic solutions, which are computed by STP-1 for each time step:

$$C(24)_t = \frac{C(23)\sigma(n,\gamma)\phi V_0}{\lambda(24)VC} \{1 - \exp[-\lambda(24)\Delta t]\} + C(24)_{t-\Delta t} \exp[-\lambda(24)\Delta t] \quad , \quad \dots(66b)$$

$$C(22)_t = \frac{C(23)\sigma(n,2n)\phi V_0}{\lambda(22)VC} \{1 - \exp[-\lambda(22)\Delta t]\} + C(22)_{t-\Delta t} \exp[-\lambda(22)\Delta t] \quad . \quad \dots(67b)$$

The quantity printed by STP-1 is the specific activity, in units of $\mu\text{Ci}/\text{cm}^3$.

F. RADIATION DOSE RATE CALCULATIONS

Radiation dose rate calculations are performed by STP-1 for each deposition region, based on the simplifying assumption that each region can be represented by a line source. The model used for the calculations is shown in Figure 2. The calculations are based on the approximate point-source relationship:

$$D = \frac{6 \sum_i C(i)E(i)}{R^2} \quad , \quad \dots(68)$$

where:

D = dose rate (R/hr)

$C(i)$ = curies of Isotope, i , at source (Ci)

$E(i)$ = gamma energy evolved per disintegration (Mev)

R = distance from point-source to position of interest (ft).

The calculations also assume an effective attenuation thickness, t , due to pipe walls or IHX walls and tubes, and a mean radiation absorption coefficient, μ .

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Figure 2. Model for Radiation Dose Rate Calculations

When Equation 68 is applied to Figure 2, the dose at O is given by

$$D(O) = \frac{6B(M) \sum_i C(I,M) E(I,M)}{L(M)R(M)} \int_0^{\tan^{-1} L(M)/R(M)} \exp(-\mu t / \cos \theta) d\theta, \dots (69)$$

where the index M identifies the deposition region of interest, B(M) is the radiation buildup factor, and L(M) the length of the deposition region (ft). The integral in Equation 69 is a geometric kernel, GEOM(M), and is solved numerically by integrating over the angle, θ , in ten steps. It will be noted that the integration is performed only within one quadrant, corresponding to the arrangement shown in Figure 2. This places the point, O, at one end of the deposition region, and is done to facilitate determination of the combined dose rate due to two adjoining regions (the two dose rates simply are added). If the dose rate near the midpoint of a region is required, the user may simply insert the half-length of the region for L(M). This reduced value of L(M) in the denominator of Equation 69 will automatically provide for the dose contribution from both quadrants.

Because STP-1 combines the multiple loops of an LMFBR in the process of computing isotopic transport and deposition, the resulting deposits represent those present in all loops. Since the dose rate of interest will normally apply to only one loop, the user must supply the quantity, $\text{FRAC}(M)$, which specifies the fraction of the total deposits that are present in Region M for the purpose of calculating dose rate. For example, for a three-loop system, the value of $\text{FRAC}(M)$ for a primary loop region typically would be 0.333.

The user must also supply a quantity, $\text{VNA}(M)$, which indicates the volume of sodium (cm^3) to be assumed to be present in the deposition region for the purpose of computing dose rate.

The attenuation product, μt , must be supplied for each region as $\text{ATT}(M)$.

The buildup factor is approximated as $1.5 \text{ ATT}(M)$, for $\text{ATT}(M) > 1$. For $\text{ATT}(M) < 1$, $B(M) = 1.0$.

The gamma energy per disintegration must be supplied by the user for the fission products of interest. The gamma energies for the corrosion products are built into STP-1 as follows:

^{51}Cr 0.0288 Mev/dis

^{54}Mn 0.835 Mev/dis

^{59}Fe 1.16 Mev/dis

^{58}Co 0.981 Mev/dis

^{60}Co 2.5 Mev/dis

III. CRT PLOTS

A subroutine has been included in STP-1 to provide CRT plots of the time behavior of selected isotopes and radiation levels in various reactor regions when the code is used in the North American Rockwell computing system. The subroutine will accommodate the following:

Up to 25 fission product isotopes, in up to 11 regions, as follows:

Region 1 – Specific activity in coolant ($\mu\text{Ci}/\text{cm}^3$)

Region 2 – Total activity in fuel without fission product escape (Ci)

Region 3 – Total activity in fuel with fission product escape (Ci)

Region 4 – Total activity in cladding gas gap and plenum (Ci)

Regions 5 to 9 – Specific activity of combined adsorbed and precipitated deposits ($\mu\text{Ci}/\text{cm}^2$) in Deposition Regions 1 to 5.

Regions 10 to 11 – Total activity in Cover Gas Regions 1 and 2 (μCi).

Up to 5 corrosion product isotopes, in up to 6 regions, as follows:

Region 1 – Specific activity in coolant ($\mu\text{Ci}/\text{cm}^3$)

Regions 2 to 6 – Specific activity of precipitated deposits ($\mu\text{Ci}/\text{cm}^2$) in Deposition Regions 1 to 5.

Radiation levels, in up to 5 deposition regions.

The data to be plotted is stored at the time of each output edit. Since the maximum number of stored points for each quantity to be plotted is 100, the number of output edits should be limited to this number (See sample problem, Section VI).

The following general input quantities are required:

NFP – Total number of fission product curves to be plotted (e. g., for 3 fission products, each plotted in 3 regions, NFP = 9).
Maximum value = 275.

NCP – Total number of corrosion product curves to be plotted.
Maximum value = 30.

NRD — Number regions for which radiation levels will be plotted.
Maximum value = 5.

NCURV — Total number of curves to be plotted (Note: up to 5 curves
may be plotted per frame).

In addition, the following quantities are required for each curve:

NUMFR — Frame number on which data is to be plotted

IORD — 0 = linear ordinate
 1 = logarithmic ordinate

IQUANT — Positive integer indicates number of isotope on fission
product list

— Negative integer indicates corrosion product:

-12	^{51}Cr
-13	^{54}Mn
-14	^{59}Fe
-15	^{58}Co
-16	^{60}Co

Zero indicates radiation level

IREG — Region number, as indicated previously

1 to 11 for fission products

1 to 6 for corrosion products

1 to 5 for radiation levels

It should be noted that all curves selected for plotting on a given frame must specify the same value of IORD(I), and must also have the same units. CRT plotting specifications must be made in the following order: (1) fission products, (2) corrosion products, and (3) radiation levels.

IV. INITIAL CONDITIONS

Upon filling a loop with sodium, the constituent elements of the loop walls will immediately begin to dissolve into the sodium. In an isothermal system, this dissolution will continue until the concentration of each element reaches its solubility limit under the prevailing temperature conditions. In a nonisothermal system, an equilibrium concentration will be attained which is dependent on the mass transfer characteristics of the system. In either case, a concentration of Fe, Cr, Ni, etc., is present in the sodium in the parts per million range at the beginning of reactor operation. Similarly, the sodium, as supplied, contains numerous other impurities in the parts per million range. Since the presence of these stable isotopes may have an important effect on the chemical behavior of their sister radioactive isotopes, STP-1 includes provisions for the user to set the initial concentrations of the fission and corrosion product isotopes (stable and radioactive) being studied. Normally, of course, initial concentrations will only be assigned to the stable isotopes.

Based on the initial concentrations of fission product isotopes supplied by the user, STP-1 computes initial adsorbed surface inventories and cover gas inventories for those elements that vaporize.

Calculation of initial adsorbed inventories requires first the calculation of the fraction of adsorption sites in each region, M , which are unoccupied under equilibrium conditions, $[Q(M)/\Delta(M)]_{eq}$. This is obtained from Equation 28 as follows:

$$\frac{\Delta(M)}{\Delta(M) + fAGA(M) \left\{ N(23,1)/EQLNA + \sum_i N(I,1)/[EQL(Z,M) + \lambda(I)] \right\}} \quad \dots(70a)$$

The initial adsorbed surface inventories are then calculated from

$$N(I,M)_{ads,init} = \frac{Q(M)}{\Delta(M)} AREA(M) C(I,1) AGA(M) / [EQL(Z,M) + \lambda(I)] \quad \dots(70b)$$

The initial cover gas inventory for each isotope of a vaporizing element is calculated from

$$N(I,M)_{\text{vap,init}} = AKL(Z,M)C(I,1) \quad , \quad \dots(71)$$

where $AKL(Z,M)$ = equilibrium distribution factor for Element Z in Region M (cm^3).

V. VARIABLE TIME STEP

STP-1 begins the calculation with an initial integration time step, TMIN (sec), supplied by the user. After completion of each time step, the average rate of change of the concentration of each element over the time step is computed. This slope, S2, is then used in combination with the slope obtained for the preceding time step (S1) to obtain the predicted slope ($S3_p$) for the next time step, as follows:

$$S3_p = (\beta + 1)S2 - \beta S1, \quad \dots (72)$$

where

$$\beta = \frac{\Delta_3 + \Delta_2}{\Delta_1 + \Delta_2}, \quad \dots (73)$$

and Δ_1 is the length of integration time step corresponding to S1, etc. Using the predicted and the most recently calculated slopes, the average concentration of each element over the next time step, $\overline{C3}$, is computed from

$$\begin{aligned} \overline{C3} = C2 + 0.5 \frac{S3_p (\Delta_3)^2 + S2 \Delta_3 \Delta_2}{\Delta_3 + \Delta_2} \\ + 0.25 \frac{(S3_p - S2)(\Delta_3)^2}{\Delta_3 + \Delta_2}. \quad \dots (74) \end{aligned}$$

This average concentration is then used to calculate the concentration, $C3_c$, at end of the time step. At the end of the time step, the predicted concentration, $C3_p$, is also calculated for each element as follows:

$$C3_p = C2 + S3_p \Delta_3. \quad \dots (75)$$

The fractional difference between the predicted concentration, $C3_p$, and the calculated value, $C3_c$, is then computed and compared with the convergence

parameter, EPS3. If the fractional difference,

$$\left| \frac{C3_c - C3_p}{C2} \right| > EPS3 ,$$

a new value of $S3_p$ is computed by taking the linear average of the predicted slope, $S3_p$, and the calculated slope, $S3_c$, which is obtained from $C3_c$, as follows:

$$S3_p \text{ (new)} = 0.5 [S3_p \text{ (old)} + S3_c] \quad \dots (76)$$

Having obtained a new value of $S3_p$ for all elements not meeting the preceding convergence criterion, the computation is repeated and the convergence test is re-applied. This procedure is repeated until the convergence criterion is met by all elements.

A second convergence criterion is also applied. The convergence parameter in this case is EPS2 (= 0.4 EPS3). When

$$\left| \frac{C3_c - C3_p}{C2} \right| < EPS2$$

for all isotopes, the time step is doubled.

The convergence parameter, EPS3, is a variable with a minimum value equal to EPS1. EPS3 is specified to insure that the predicted and computed slopes do not differ by more than $\pm 5\%$. This is accomplished by specifying

$$EPS3 = \frac{0.5 \Delta_3 S2}{C2} \quad \dots (77)$$

To limit computational time when S2 becomes small, a lower limit on EPS3, equal to EPS1, is employed.

The time step is truncated during the calculation, to provide output edits at the specified times and to prevent overshoot of concentration beyond its solubility value in any region in a single time step.

TABLE 2
DESCRIPTION OF LMFBR

Nominal Power (Mwt)	2000
Nominal Average Flux ($\text{cm}^{-2}\text{-sec}^{-1}$)	5×10^{15}
Number of Fuel Subassemblies	256
Number of Fuel Pins Per Subassembly	217
Height of Active Core [in. (cm)]	50 (127)
Height of Upper Blanket [in. (cm)]	12 (30.5)
Fuel OD [in. (cm)]	0.23 (0.584)
Fuel Cladding OD [in. (cm)]	0.25 (0.635)
Fuel Density (g/cm^3)	10
Number of Primary Loops	3
Surface Area of Hot Leg (Total for 3 loops) [ft^2 (cm^2)]	10,470 (9.74×10^6)
Surface Area of IHX (Total for 3 loops) [ft^2 (cm^2)]	184,500 (1.716×10^8)
Surface Area of Cold Leg (Total for 3 loops) [ft^2 (cm^2)]	5,640 (5.74×10^6)
Surface Area of Cold Trap (Total for 2 units) [ft^2 (cm^2)]	5,610 (5.225×10^6)
Number of Cover Gas Regions	1
Volume of Cover Gas Region [ft^3 (cm^3)]	352 (1×10^7)
Primary Loop Sodium Loading [ft^3 (cm^3)]	3×10^4 (8.51×10^8)
Sodium Volume in Core [ft^3 (cm^3)]	92.3 (2.62×10^6)
Core Corrosion Area (Fuel pins plus subassembly wrappers) [ft^2 (cm^2)]	1.88×10^4 (1.75×10^7)

VI. SAMPLE PROBLEM

A. DESIRED INFORMATION

For the purpose of this example, a problem of limited scope will be specified. On this basis, it is desired to study the transport behavior of the important corrosion products and the following fission product isotopes: ^{131}I , ^{133}Xe , ^{135}Xe , ^{137}Cs , and $^{140}\text{Ba-La}$.

B. DESCRIPTION OF SYSTEM

It is desired to study the behavior of the preceding isotopes in the system described in Table 2. The primary loop will be divided into five regions, as follows:

- Region 1 — Combined hot leg (3 loops)
- Region 2 — Combined inlet (hot) half of IHX's (3 units)
- Region 3 — Combined outlet (cold) half of IHX's (3 units)
- Region 4 — Combined cold leg (3 loops)
- Region 5 — Combined cold traps (2 units).

The desired operating conditions are given in Table 3.

The overall core corrosion rate will be assumed to be 1 mil/year for a core average temperature of 910°F, and 1×10^{-3} mil/year for a core average temperature of 500°F. This variation may be expressed for each element as

$$RC(Z) = 2.11 \times 10^{-7} \exp(-3844/T) \text{ cm/sec} ,$$

where T is core average temperature, in °C. It will also be assumed that the value of RC for Cr is twice the value for other elements, i. e.

$$RC(\text{Cr}) = 4.22 \times 10^{-7} \exp(-3844/T) .$$

It will be assumed that 0.01% of the cladding contains pinhole defects at the beginning of the problem, and that additional pinhole defects are generated at the rate of 1%/year during the first 200 days, and at the rate of 0.5%/year during the second 200 days. In addition, it will be assumed that 0.1% of the cladding

TABLE 3
OPERATING CONDITIONS FOR SAMPLE PROBLEM

	Time Block		
	1	2	3
Duration (days)	200	200	100
Power (Mwt)	2000	1000	0
Reactor Outlet Temperature, T_o (°F)	1060	1060	500
Reactor Inlet Temperature, T_i (°F)	760	760	500
Primary Coolant Flow (cm ³ /sec)	1.51×10^8	7.55×10^7	7.55×10^6
Cold Trap Coolant Flow (cm ³ /sec)	1.58×10^5	1.58×10^5	1.58×10^5
Temperatures (°F)			
Region 1	1060	1060	500
Region 2	985	985	500
Region 3	835	835	500
Region 4	760	760	500
Region 5	302	302	302
Core Average	910	910	500
Cover Gas Space	1060	1060	500
Cover Gas Pressure (atm)	1.0	1.0	1.0

develops massive failures at the beginning of the second 200-day operating period. For this purpose, the exponential form of the cladding fractional failure rate function will be employed, with a time constant of 1 hr.

C. ORGANIZATION OF FISSION PRODUCT CHAINS

The fission product chains containing the isotopes of direct interest are shown on the preceding page.

For solution by STP-1, these chains are simplified by deleting short half-life isotopes near the beginning of a chain, splitting branched chains into two parallel chains, and neglecting minor branches. The simplifications adopted for this sample problem are as follows:

Chain 1 (6.8% of Mass 131 yield)

Chain 2 (93.2% of Mass 131 yield)

Chain 3 (72% of Mass 133 yield)

Chain 4 (28% of Mass 133 yield)

Chain 5 (100% of Mass 135 yield)

Chain 6 (96% of Mass 137 yield)

Chain 7 (100% of Mass 140 yield)

Examination of Chains 1 through 7 reveals that the following seven elements are included: Te, I, Xe, Cs, Ba, La, and Ce. In order to realistically represent the chemical behavior of these elements, it is necessary to include the fission contribution of stable isotopes of these elements, and include the concentration of stable isotopes of these elements present as impurities in the coolant. The fission contribution of stable isotopes is provided by adding composite "dummy" one-member chains which sum the contribution of one or more chains terminating in stable isotopes of the preceding elements. Based on Reference 4, the following composite "dummy" chains were selected:

Chain 8 Stable Te¹³⁰

Chain 9 Stable I¹²⁷

Chain 10 Stable Xe¹³²

Chain 11 Stable Ba¹³⁸

Chain 12 Stable La¹³⁹

Chain 13 Stable Ce¹⁴⁸

While a specific mass number has been assigned to each of the preceding stable isotopes, the contribution of stable isotopes would, as indicated previously usually come from several mass chains. In the present case, the makeup of Chains 8 through 13 is as follows. The fission yield⁽⁵⁾ contribution of each Mass Chain is indicated in parentheses. (Note: A "dummy" chain is not required for Cs, since its only stable isotope (Cs^{133}) terminates Chains 3 and 4 above).

Te - Chain 8: Mass Numbers 128 (0.0071), 130 (0.02341)

I - Chain 9: Mass Number 127 (0.0043)

Xe - Chain 10: Mass Numbers 129 (0.012), 132 (0.0455), 134 (0.06449),
136 (0.06887)

Ba - Chain 11: Mass Number 138 (0.061)

La - Chain 12: Mass Number 139 (0.053)

Ce - Chain 13: Mass Number 142 (0.054)

From the preceding, Fission Product Element, Vaporizing Element, and Isotope lists can be prepared, and appropriate indices assigned. The total number of FP elements, NZ, equals 7. The FP element list, therefore, will have this number of entries. Letting $\text{NZZ}(\text{J})$ equal the atomic number of Element J, the FP element list would be as follows:

<u>J</u>	<u>NZZ(J)</u>	<u>Element Symbol</u>
1	52	Te
2	53	I
3	54	Xe
4	55	Cs
5	56	Ba
6	57	La
7	58	Ce

Of the preceding elements, only I, Xe, and Cs are likely to be present in the cover gas spaces. Vaporization of I will, however, be marginal, since it would exist in sodium in the form of the relatively nonvolatile NaI. Thus, the

TABLE 4
FP ISOTOPE LIST WITH INDICES AND DECAY
AND YIELD CONSTANTS

I	Symbol	Radioactive Decay Constant (sec ⁻¹)	Fission Yield	IM(I)	IZ(I)	IA(I)	IZZ(I)	IV(I)	IFC(I)
1	^{131m} Te	6.69 x 10 ⁻⁶	0.00227	0	52	-131	1	0	2
2	¹³¹ I	9.95 x 10 ⁻⁷	0.000044	1	53	131	2	1	2
3	¹³¹ Xe	0.0	0.0	1	54	131	3	2	2
4	¹³¹ Te	4.62 x 10 ⁻⁴	0.0311	0	52	131	1	0	2
5	¹³¹ I	9.95 x 10 ⁻⁷	0.000596	1	53	131	2	1	2
6	¹³¹ Xe	0.0	0.0	1	54	131	3	2	2
7	^{133m} Te	2.31 x 10 ⁻⁴	0.0334	0	52	-133	1	0	2
8	¹³³ I	9.26 x 10 ⁻⁶	0.00746	1	53	133	2	1	2
9	¹³³ Xe	1.52 x 10 ⁻⁶	0.0002	1	54	133	3	2	2
10	¹³³ Cs	0.0	0.0	1	55	133	4	3	2
11	¹³³ Te	9.28 x 10 ⁻⁴	0.0130	0	52	133	1	0	2
12	¹³³ I	9.26 x 10 ⁻⁶	0.00290	1	53	133	2	1	2
13	¹³³ Xe	1.52 x 10 ⁻⁶	0.00008	1	54	133	3	2	2
14	¹³³ Cs	0.0	0.0	1	55	133	4	3	2
15	¹³⁵ I	2.87 x 10 ⁻⁵	0.06298	0	53	135	2	1	2
16	¹³⁵ Xe	2.10 x 10 ⁻⁵	0.00545	1	54	135	3	2	2
17	¹³⁵ Cs	1.04 x 10 ⁻¹⁴	0.00007	1	55	135	4	3	2
18	¹³⁵ Ba	0.0	0.0	1	56	135	5	0	1
19	¹³⁷ Cs	7.37 x 10 ⁻¹⁰	0.0657	0	55	137	4	3	2
20	^{137m} Ba	4.44 x 10 ⁻³	0.00003	1	56	-137	5	0	1
21	¹³⁷ Ba	0.0	0.0	1	56	137	5	0	1
22	¹⁴⁰ Cs	1.09 x 10 ⁻²	0.04431	0	55	140	4	3	2
23	¹⁴⁰ Ba	6.27 x 10 ⁻⁷	0.00656	1	56	140	5	0	1
24	¹⁴⁰ La	4.79 x 10 ⁻⁶	0.00012	1	57	140	6	0	1
25	¹⁴⁰ Ce	0.0	0.0	1	58	140	7	0	1
26	¹³⁰ Te	0.0	0.03051	0	52	130	1	0	2
27	¹²⁷ I	0.0	0.0043	0	53	127	2	1	2
28	¹³² Xe	0.0	0.1909	0	54	132	3	2	2
29	¹³⁸ Ba	0.0	0.061	0	56	138	5	0	1
30	¹³⁹ La	0.0	0.053	0	57	139	6	0	1
31	¹⁴² Ce	0.0	0.054	0	58	142	7	0	1

number of vaporizing FP elements, NZV, would be 3. Letting NZZV(K) equal the atomic number of Vaporizing Element K, the FP vaporizing element list would be as follows:

<u>K</u>	<u>NZZV(K)</u>	<u>Element Symbol</u>
1	53	I
2	54	Xe
3	55	Cs

The following indices are required for the FP isotope list:

- IM(I): IM(I) = 0 identifies first member of a FP chain
IM(I) = 1 signifies isotope is not first member of the chain
- IZ(I): atomic number of isotope
- IA(I): mass number of isotope (negative integer denotes metastable state)
- IZZ(I): number of element of which isotope is a member (value of J for element from FP element list)
- IV(I): IV(I) = 0 isotope does not vaporize
IV(I) > 0 number of vaporizing element of which isotope is a member (value of K for element from FP vaporizing element list)
- IFC(I): IFC(I) = 1 signifies isotope release to coolant is controlled by major failure cladding defect function
IFC(I) = 2 isotope release controlled by minor failure cladding defect function

Table 4 summarizes the values of the above indices for the FP isotope list and also presents radioactive decay and yield constants.

D. INPUT DATA

Input data sheets for the preceding sample problem are shown in the following Fortran sheets. Explanatory notes, and references to previous sections of this manual, are given in the numbered paragraphs that follow the Fortran sheets.

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 1 of 29	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 13 25 37 49 61	STP - 1 - SAMPL PROBLEM	Title		
1 13 25 37 49 61	3 1 7 3 5 1 0	NISO - Length of FP isotope list NZ - Length of FP element list NZV - Length of FP vaporizing element list ND - Number of deposition regions NV - Number of cover gas regions NOPTCL - Calculation option		
1 13 25 37 49 61	5 2 5 3 5 4 5 5 5 6 5 7 5 8	NZZ(I), I = 1, NZ Atomic numbers of FP elements on element list		
1 13 25 37 49 61	5 3 5 4 5 5	NZZV(I) I = 1, NZV Atomic number of FP elements in vaporizing element list		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 2 of 29	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 13 25 37 49 61	0 0 2 2 7 6 6 9 - 0 6 1 6 7 0 5 2 - 1 3 1 1 0 2	Y(I) - Fission yield I = 1 ALAM(I) - Radioactive decay constant (sec ⁻¹) ENER(I) - Gamma energy per disintegration (Mev) IM(I) IZ(I) IA(I) IZZ(I) (V(I) IFC(I)		
1 13 25 37 49 61	0 0 0 0 4 4 9 9 5 - 0 7 3 8 7 1 5 3 1 3 1 2 1 2	I = 2		
1 13 25 37 49 61	0 0 0 0 0 0 1 5 4 1 3 1 3 2 2	I = 3		
1 13 25 37 49 61	0 3 1 1 4 6 2 - 0 4 2 1 3 0 5 2 1 3 1 1 0 2	I = 4		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 3 of 29		JOB NO.	
NUMBER				IDENTIFICATION		DESCRIPTION \ DO NOT KEY PUNCH			
1	0 0 5 9 6					I = 5			
13	9 9 5 - 0 7								
25	3 8 7								
37	1 5 3								
49	1 3 1 2			73	80				
61	1 2			9 0					
1	0 0					I = 6			
13	0 0								
25	0 0								
37	1 5 4								
49	1 3 1 3			73	80				
61	2 2			1 0 0					
1	0 3 3 4					I = 7			
13	2 3 1 - 0 4								
25	2 0 9 5								
37	0 5 2								
49	- 1 3 3 1			73	80				
61	0 2			1 1 0					
1	0 0 7 4 6					I = 8			
13	9 2 6 - 0 6								
25	5 3								
37	1 5 3								
49	1 3 3 2			73	80				
61	1 2			1 2 0					

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 4 of 29		JOB NO.	
NUMBER				IDENTIFICATION		DESCRIPTION DO NOT KEY PUNCH			
1	0	0	0	2					I = 9
13	1	5	2	- 0 6					
25	0	8	1						
37	1		5	4					
49	1	3	3	3	73	80			
61	2		2			1	3	0	
1	0	0							I = 10
13	0	0							
25	0	0							
37	1		5	-5					
49	1	3	3	4	73	80			
61	3		2			1	4	0	
1	0	1	3						I = 11
13	9	2	8	- 0 4					
25	1	8	5						
37	0		5	2					
49	1	3	3	1	73	80			
61	0		2			1	5	0	
1	0	0	2	9					I = 12
13	9	2	6	- 0 6					
25	5	3							
37	1		5	3					
49	1	3	3	2	73	80			
61	1		2			1	6	0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 5 of 29		JOB NO.	
NUMBER				IDENTIFICATION		DESCRIPTION DO NOT KEY PUNCH			
1	0 0 0 0 8					I = 13			
13	1 5 2 - 0 6								
25	0 8 1								
37	1 5 4								
49	1 3 3 3			73	80				
61	2 2					1 7 0			
1	0 0					I = 14			
13	0 0								
25	0 0								
37	1 5 5								
49	1 3 3 4			73	80				
61	3 2					1 8 0			
1	0 6 2 9 8					I = 15			
13	2 8 7 - 0 5								
25	1 7 7 4								
37	0 - 5 3								
49	1 3 5 2			73	80				
61	1 2					1 9 0			
1	0 0 5 4 5					I = 16			
13	2 - 0 5								
25	2 6 1								
37	1 5 4								
49	1 3 5 3			73	80				
61	2 2					2 0 0			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER	DATE	PAGE 6 of 29	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH		
1	0 0 0 0 7		I = 17		
13	1 0 4 - 1 4				
25	0 0				
37	1 5 5				
49	1 3 5 4	73 80			
61	3 2	2 1 0			
1	0 0		I = 18		
13	0 0				
25	0 0				
37	1 5 6				
49	1 3 5 5	73 80			
61	0 1	2 2 0			
1	0 6 5 7		I = 19		
13	7 3 7 - 1 0				
25	6 1 8				
37	0 5 5				
49	1 3 7 4	73 80			
61	3 2	2 3 0			
1	0 0 0 0 3		I = 20		
13	4 4 4 - 0 3				
25	6 1 8				
37	1 5 6				
49	- 1 3 7 5	73 80			
61	0 1	2 4 0			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 7 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	0 . 0		I = 21
13	0 . 0		
25	0 . 0		
37	1 5 6		
49	1 3 7 5	73 80	
61	0 1	2 5 0	
1	0 4 4 3 1		I = 22
13	1 . 0 9 - 0 2		
25	3 . 1 5		
37	0 5 5		
49	1 4 0 4	73 80	
61	3 2	2 6 0	
1	0 0 6 5 6		I = 23
13	6 . 2 7 - 0 7		
25	2 4 9		
37	1 5 6		
49	1 4 0 5	73 80	
61	0 1	2 7 0	
1	0 0 0 1 2		I = 24
13	4 . 7 9 - 0 6		
25	2 . 2 2		
37	1 5 7		
49	1 4 0 6	73 80	
61	0 1	2 8 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 8 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	0 . 0		I = 25
13	0 . 0		
25	0 . 0		
37	1 5 8		
49	1 4 0 7	73 80	
61	0 1	2 9 0	
1	0 3 0 5 1		I = 26
13	0 . 0		
25	0 . 0		
37	0 5 2		
49	1 3 0 1	73 80	
61	0 2	3 0 0	
1	0 0 4 3		I = 27
13	0 . 0		
25	0 . 0		
37	0 5 3		
49	1 2 7 1 2	73 80	
61	1 2	3 1 0	
1	0 1 9 0 9		I = 28
13	0 . 0		
25	0 . 0		
37	0 5 4		
49	1 3 2 3	73 80	
61	2 2	3 2 0	

FORTRAN FIXED IO DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 9 of 29	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	0 6 1		I = 29	
13	0 0			
25	0 0			
37	0 5 6			
49	1 3 8 5			
61	0 1	3 3 0		
1	0 5 3		I = 30	
13	0 0			
25	0 0			
37	0 5 7			
49	1 3 9 6			
61	0 1	3 4 0		
1	0 5 4		I = 31	
13	0 0			
25	0 0			
37	0 5 8			
49	1 4 2 7			
61	0 1	3 5 0		
1	0 0		FC1(1) - Initial fraction cladding failed - major	
13	0 0		FC2(1) - Initial fractional cladding failure rate - major	
25	0 0 0 1		FC1(2) - Initial fraction cladding failed - minor	
37	0 0		FC2(2) - Initial fractional cladding failure rate - minor	
49	0 0		FP1 - Initial weight of Pu in coolant (g)	
61	1 0	3 6 0	FAD - See Section II-B-5	

FORTRAN FIXED IO DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 10 of 29	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1	1 2 9 4 + 0 7	AREAF - Total fuel surface area (cm ²)		
13	1 8 9 4 + 0 6	VOLF - Total fuel volume (cm ³)		
25	7 0 - 0 4	RFF - Mean fission fragment range (cm)		
37	2 0 0 0	FKO - Number fuel molecules ejected per recoil atom		
49	1 0	FR4O - Fuel density (g/cm ³)		
61	2 7 0	FMW - Fuel molecular weight		
1	1 7 8 - 0 7	AKA(1) Te		
13	2 8 8	BKA(1) (°C)		
25	1 7 8 - 0 7	AKA(2) I		
37	2 8 8	BKA(2) (°C)		
49	1 7 8 - 0 7	AKA(3) Xe		
61	2 8 8	BKA(3) (°C)		
1	4 7 3 - 0 7	AKA(4) Cs		
13	3 2 8	BKA(4) (°C)		
25	2 6 1 - 0 9	AKA(5) Ba		
37	3 2 0 0	BKA(5) (°C)		
49	2 4 - 0 7	AKA(6) La		
61	4 3 8	BKA(6) (°C)		
1	2 4 - 0 7	AKA(7) Ce		
13	4 3 8	BKA(7) (°C)		
25				
37				
49				
61		4 0 0		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 11 of 29	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 5 . 2 3 + 2 1		AS(1) (atoms/cm ³)	Te	
13 - 6 4 0		BS(1) (°C)		
25 1 . 3 0 5 + 2 0		AS(2)	I	
37 - 2 6 7 2 .		BS(2)		
49 7 . 5 8 + 1 5	73 80	AS(3)	Xe	
61 3 6 6 .	4 1 0	BS(3)		
1 7 . 8 4 + 2 1		AS(4)	Cs	
13 0 . 0		BS(4)		
25 6 . 4 8 + 1 5		AS(5)	Ba	
37 - 2 8 8 .		BS(5)		
49 6 . 4 8 + 1 5	73 80	AS(6)	La	
61 - 2 8 8 .	4 2 0	BS(6)		
1 6 . 4 8 + 1 5		AS(7)	Ce	
13 - 2 8 8 .		BS(7)		
25				
37				
49	73 80			
61	4 3 0			
1 1 . 1 5 8 - 0 5		ALPVA(1) (sec ⁻¹)		
13 0 . 0		BLPVA(1) (°C)		
25				
37				
49	73 80			
61	4 4 0			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 12 of 29	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 . 0 1		EQLNA(1)		
13 . 0 1		EQLNA(2)		
25 . 0 1		EQLNA(3)		
37 . 0 1		EQLNA(4)		
49 . 0 1	73 80	EQLNA(5)		
61	4 5 0			
1 1 . 0 + 0 7		VVAP(1) - Cover gas volume (cm ³)		
13				
25				
37				
49	73 80			
61	4 6 0			
1 0 . 3 7		AVAP(1)	NaI	
13 - 1 5 0 .		BVAP(1) (°C)	See notes	
25 1 . 4 8 + 0 8		AVAP(2)	Xe	
37 - 2 7 1 8 .		BVAP(2) (°C)		
49 0 . 1 5	73 80	AVAP(3)	Cs	
61 5 0 3 0 .	4 7 0	BVAP(3) (°C)		
1 1 . 5 1 6		RHO(1) (g/cm ³)	Density of Cr in cladding	
13 . 1 6		RHO(2) (g/cm ³)	Density of Mn in cladding	
25 5 . 4 6 6		RHO(3) (g/cm ³)	Density of Fe in cladding	
37 . 0 0 4		RHO(4) (g/cm ³)	Density of Co in cladding	
49 . 7 5 8	73 80	RHO(5) (g/cm ³)	Density of Ni in cladding	
61	4 8 0	See Section II-C-2-b.		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 13 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	4 - 2 2 - 0 7		ACOR(1) (cm/sec)	Cr
13	3 8 4 4		BCOR(1) (°C)	Core corrosion constants
25	2 - 1 1 - 0 7		ACOR(2)	Mn
37	3 8 4 4		BCOR(2)	See notes
49	2 - 1 1 - 0 7	73 80	ACOR(3)	Fe
61	3 8 4 4	4 9 0	BCOR(3)	
1	2 - 1 1 - 0 7		ACOR(4)	Co
13	3 8 4 4		BCOR(4)	
25	2 - 1 1 - 0 7		ACOR(5)	Ni
37	3 8 4 4		BCOR(5)	
49		73 80		
61		5 0 0		
1	2 - 0 + 1 9		ASC(1) (atoms/cm ³)	Cr
13	3 - 5 3 2 + 0 3		BSC(1) (°C)	Solubility constants
25	2 - 1 + 1 8		ASC(2)	Mn
37	2 - 1 3 7 + 0 3		BSC(2)	See notes
49	4 - 7 + 1 7	73 80	ASC(3)	Fe
61	1 - 1 4 3 + 0 3	5 1 0	BSC(3)	
1	6 - 3 + 1 9		ASC(4)	Co
13	4 - 6 2 4 + 0 3		BSC(4)	
25	2 - 4 + 2 0		ASC(5)	Ni
37	4 - 7 2 5 + 0 3		BSC(5)	
49		73 80		
61		5 2 0		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 14 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	2 1		SZS(1) Cr	Elemental volume fractions
13	0 2 1		SZS(2) Mn	in primary loop walls
25	6 9 5		SZS(3) Fe	See Section II-C-2-c
37	4 - 5 - 0 4		SZS(4) Cu	
49	0 8 5	73 80	SZS(5) Ni	
61		5 3 0		
1	2 - 6 6 - 0 2		S10(1) (barns)	See notes
13	1 - 8 5 - 0 5		S10(2)	
25	6 - 6 4 - 0 4		S10(3)	
37	1 - 0 2 - 0 2		S10(4)	
49	3 - 0 5 - 0 5	73 80	S10(5)	
61	1 - 6 8 - 0 2	5 4 0	S10(6)	
1	1 - 6 5 - 0 2		S10(7)	
13	2 - 9 5 - 0 5		S10(8)	
25	1 - 3 6 - 0 1		S10(9)	
37	4 - 3 2 - 0 3		S10(10)	
49		73 80		
61		5 5 0		
1	2 - 1 8 - 0 2		AN23 - Sodium number density in coolant (atoms/cm ³) x 10 ⁻²⁴	
13	1 - 9 9 - 0 3		SIGNG - Cross section for ²³ Na(n,γ) ²⁴ Na (barns)	
25	8 - 4 4 - 0 9		ALAM22 - Decay constant for ²² Na (sec ⁻¹)	
37	3 - 3 6 - 0 6		SIG2N - Cross section for ²³ Na(n,2n) ²² Na (barns)	
49	1 - 2 8 3 - 0 5	73 80	ALAM22 - Decay constant for ²⁴ Na (sec ⁻¹)	
61		5 6 0		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 15 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	. 0 0 0 1		EPS1 - Convergence criterion
13	1 . 0		TMIN - Minimum time step (sec)
25			
37			See Section V
49		73	80
61		5 7 0	
1	5 . 0 + 1 5		FLUC - Reference neutron flux (cm ⁻² sec ⁻¹)
13	2 . 5 + 0 3		PWRC - Reference power (Mwt)
25	1 . 7 5 + 0 7		ACORE - Core corrosion area (cm ²)
37	2 . 6 2 + 0 6		VO - Core coolant volume (cm ³)
49	8 . 5 1 + 0 8	73	80
61	1 . 8 6 6 5	5 8 0	SIG49F - Tramp fuel fission cross section (barns)
1	9 . 7 4 + 0 6		AREA(1) - Total surface area, Region 1 (cm ²)
13	1 . 5 7 + 1 5		DELL(1) - Adsorption sites/cm ² , Region 1 (cm ⁻²)
25	8 . 5 8 + 0 7		AREA(2)
37	1 . 5 7 + 1 5		DELL(2)
49	8 . 5 8 + 0 7	73	80
61	1 . 5 7 + 1 5	5 9 0	DELL(3)
1	5 . 2 4 + 0 6		AREA(4)
13	1 . 5 7 + 1 5		DELL(4)
25	5 . 2 2 5 + 0 6		AREA(5)
37	1 . 5 7 + 1 5		DELL(5)
49		73	80
61		6 0 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 16 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1 . 0 - 0 5		AX(1) (sec ⁻¹)
13	1 1 5 4 .		BX(1) (°C)
25	1 . 0 - 0 5		AX(2) Precipitate re-entry rate constants
37	1 1 5 4 .		BX(2)
49	1 . 0 - 0 5	73	80
61	1 1 5 4 .	6 1 0	BX(3)
1	1 . 0 - 0 5		AX(4)
13	1 1 5 4 .		BX(4)
25	1 . 0 - 0 5		AX(5)
37	1 1 5 4 .		BX(5)
49		73	80
61		6 2 0	
1	1 . 8 2 - 0 6		AP(1)
13	0 . 0		BP(1) (°C)
25	1 0 0 .		AA(1) (sec ⁻¹) See notes
37	0 . 0		BA(1) (°C)
49	1 . 8 2 - 0 8	73	80
61	0 . 0	6 3 0	ACC(1) BCC(1) (°C)
1	1 . 3 7 - 0 4		AP(2)
13	0 . 0		BP(2)
25	1 0 0 .		AA(2)
37	0 . 0		BA(2)
49	1 . 3 7 - 0 6	73	80
61	0 . 0	6 4 0	ACC(2) BCC(2)

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 17 of 29		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION DO NOT KEY PUNCH					
1	1 . 3 7 - 0 4			AP(3)					
13	0 . 0			BP(3)					
25	1 0 0 .			AA(3)					
37	0 . 0			BA(3)					
49	1 . 3 7 - 0 6	73	80	ACC(3)					
61	0 . 0	6 5 0		BCC(3)					
1	5 . 3 2 - 0 7			AP(4)					
13	0 . 0			BP(4)					
25	1 0 0 .			AA(4)					
37	0 . 0			BA(4)					
49	5 . 3 2 - 0 9	73	80	ACC(4)					
61	0 . 0	6 6 0		BCC(4)					
1	0 . 9			AP(5)					
13	0 . 0			BP(5)					
25	1 0 0 .			AA(5)					
37	0 . 0			BA(5)					
49	1 . 0 - 0 5	73	80	ACC(5)					
61	0 . 0	6 7 0		BCC(5)					
1	5 0 .			EL(1) (ft)					
13	2 .			DIST(1) (ft)					
25	. 7 5 5			ATT(1)					
37	. 3 3 3			FRAC(1)					
49	0 . 0	73	80	VNA(1) (cm ³)					
61		6 8 0							

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE		PAGE 18 of 29		JOB NO.	
NUMBER		IDENTIFICATION		DESCRIPTION DO NOT KEY PUNCH					
1	2 5 .			EL(2)					
13	4 . 7 5			DIST(2)					
25	4 . 1 9			ATT(2)					
37	. 3 3 3			FRAC(2)					
49	0 . 0			73		80		VNA(2)	
61				6 9 0					
1	2 5 .			EL(3)					
13	4 . 7 5			DIST(3)					
25	4 . 1 9			ATT(3)					
37	. 3 3 3			FRAC(3)					
49	0 . 0			73		80		VNA(3)	
61				7 0 0					
1	5 0 .			EL(4)					
13	1 . 7 5			DIST(4)					
25	. 6 7 8			ATT(4)					
37	. 3 3 3			FRAC(4)					
49	0 . 0			73		80		VNA(4)	
61				7 1 0					
1	1 0 .			EL(5)					
13	2 .			DIST(5)					
25	1 . 1 9			ATT(5)					
37	. 5			FRAC(5)					
49	0 . 0			73		80		VNA(5)	
61				7 2 0					

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 19 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	2 5		NCURV
13	1 0		NFP
25	1 0		NCP
37	5		NRD
49		73 80	
61		7 3 0	
1	1 1 8 6		CRT data - See notes
13	1 1 8 7		
25	1 1 8 8		
37	2 1 1 5 6		
49	2 1 1 5 7	73 80	
61	2 1 1 5 8	7 4 0	
1	3 1 2 3 7		
13	3 1 2 3 8		
25	4 1 2 4 7		
37	4 1 2 4 8		
49	5 1 - 1 3 2	73 80	
61	5 1 - 1 3 3	7 5 0	
1	5 1 - 1 3 4		
13	5 1 - 1 3 5		
25	5 1 - 1 3 6		
37	6 1 - 1 6 2		
49	6 1 - 1 6 3	73 80	
61	6 1 - 1 6 4	7 6 0	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 20 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	6 1 - 1 6 5		
13	6 1 - 1 6 6		
25	7 1 0 1		
37	7 1 0 2		
49	7 1 0 3	73 80	
61	7 1 0 4	7 7 0	
1	7 1 0 5		
13			
25			
37			
49		73 80	
61		7 8 0	
1			
13			
25			
37			
49		73 80	
61			
1			
13			
25			
37			
49		73 80	
61			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 21 of 29	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH	
1	7		IPR1 - Number of initial concentrations for FP isotopes	
13	1 1		IPR2 - Number of initial concentrations for CP isotopes	
25				
37				
49		73	80	
61		2 0 1 0		
1	1 4		IN(I) I = 1,7 ¹³³ Cs FP isotope number	
13	2 . 0 4 + 1 6		VALUE(I) I = 1,7 (atoms/cm ³) Initial concentration	
25	2 6		2 ¹³⁰ Te	
37	4 . 2 5 + 1 5		2	
49	2 7	73	80	3 ¹²⁷ I
61	3 . 6 1 + 1 5	2 0 2 0 3		
1	2 8		4 ¹³² Xe	
13	4 . 1 3 + 1 1		4	
25	2 9		5 ¹³⁸ Ba	
37	3 . 5 4 + 1 3		5	
49	3 0	73	80	6 ¹³⁹ La
61	3 . 3 3 + 1 3	2 0 3 0 6		
1	3 1		7 ¹⁴² Ce	
13	3 . 1 5 + 1 3		7	
25				
37				
49		73	80	
61		2 0 4 0		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE	PAGE 22 of 29	JOB NO.	
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH				
1	1		IN(I) I = 1,11	⁵⁰ Cr			
13	1 - 2 8 8 + 1 4		VALUE(I) I = 1,11 (atoms/cm ³)				
25	2		2	⁵² Cr			
37	2 - 7 0 5 + 1 5		2				
49	9	73	80	3	Stable Cr		
61	3 - 8 6 + 1 4	2 0 5 0		3			
1	3		4	⁵⁴ Fe			
13	1 - 6 1 + 1 5		4				
25	4		5	⁵⁸ Fe			
37	. 9 1 8 + 1 4		5				
49	1 0	73	80	6	Stable Fe		
61	2 - 6 1 + 1 6	2 0 6 0		6			
1	5		7	⁵⁵ Mn			
13	1 - 0 6 + 1 6		7				
25	6		8	⁵⁸ Ni			
37	1 - 3 7 + 1 5		8				
49	7	73	80	9	⁶⁰ Ni		
61	5 - 3 + 1 4	2 0 7 0		9			
1	1 1		10	Stable Ni			
13	1 - 1 9 + 1 4		10				
25	8		11	⁵⁹ Co			
37	6 - 8 1 + 1 4		11				
49		73	80				
61		2 0 8 0					

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 23 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1				
13				
25				
37				
49				
61				
1	2 0 0 0		POWER (Mwt)	From Table 3
13	2 0 0		DUR (days)	
25	1 0		TED (days)	
37		1	IQ	
49				
61			First time block	
1		3 0 0 0		
13	0 0		FC3(1)	Cladding fractional failure rate constants
25	0 0		FC4(1)	Major failures
37	0 0		FC5(1) (sec ⁻¹)	
49	3 1 7 1 - 1 0		FC3(2)	
61	0 0		FC4(2)	"Pinhole" failures
1	0 0		FC5(2) (sec ⁻¹)	
13	0 0		FP3 (g/sec)	
25	0 0		FP4 (g/sec)	Pu release rate constants
37	0 0		FP5 (sec ⁻¹)	
49	0 0 5		FF Fdir	Section II-B-1
61				
		3 0 2 0		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 24 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH
1	4 8 7 8		TCORE	Coolant temperature in core (°C)
13	5 7 1 1		T(1)	Coolant temperature in Region 1 (°C)
25	5 2 9 4		T(2)	Coolant temperature in Region 2 (°C)
37	4 4 6 1		T(3)	Coolant temperature in Region 3 (°C)
49	4 0 4 4		T(4)	Coolant temperature in Region 4 (°C)
61	1 5 0		T(5)	Coolant temperature in Region 5 (°C)
1	1 5 1 + 0 8		FM(1)	Coolant flow rate, Region 1 (cm ³ /sec)
13	1 5 1 + 0 8		FM(2)	Coolant flow rate, Region 2 (cm ³ /sec)
25	1 5 1 + 0 8		FM(3)	Coolant flow rate, Region 3 (cm ³ /sec)
37	1 5 1 + 0 8		FM(4)	Coolant flow rate, Region 4 (cm ³ /sec)
49	1 5 8 + 0 5		FM(5)	Coolant flow rate, Region 5 (cm ³ /sec)
61				
1		3 0 4 0		
13	5 7 1 1		TVAP(1)	Coolant temperature at Cover Gas Region 1 (°C)
25	1 0		PVAP(1)	Cover gas pressure, Region 1 (atm)
37				
49				
61				
1		3 0 5 0		
13	0 0		EPS(1)	Element diffusion loss rate Te
25	0 0		EPS(2)	constant in fuel (sec ⁻¹) I
37	0 0		EPS(3)	Xe
49	0 0		EPS(4)	Cs
61	0 0		EPS(5)	Ba
			EPS(6)	La
		3 0 6 0		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 25 of 29	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 0 0 0		EPS(7)	Ca	
13				
25				
37				
49	73		80	
61		3 0 7 0		
1 1 0 0 0		POWER	Time Block 2 data	
13 2 0 0		DUR		
25 1 0		TED		
37	1	IQ		
49	73		80	
61		4 0 0 0		
1 0 0 0		FC3(1)		
13 2 7 8		FC4(1)	- 0 7	
25 2 7 8		FC5(1)	- 0 4	
37 1 5 8 5		FC3(2)	- 1 0	
49 0 0	73	FC4(2)	80	
61 0 0		4 0 1 0	FC5(2)	
1 0 0 0		FP3		
13 0 0		FP4		
25 0 0		FP5		
37 0 0 1		FF		
49	73		80	
61		4 0 2 0		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.	PROGRAMMER	DATE	PAGE 26 of 29	JOB NO.
NUMBER	IDENTIFICATION	DESCRIPTION	DO NOT KEY PUNCH	
1 4 8 7 8		TCORE		
13 5 7 1 1		T(1)		
25 5 2 9 4		T(2)		
37 1 1 6 1		T(3)		
49 4 0 4 4	73	T(4)	80	
61 1 5 0 0		4 0 3 0	T(5)	
1 7 5 5		FM(1)	+ 0 7	
13 7 5 5		FM(2)	+ 0 7	
25 7 5 5		FM(3)	+ 0 7	
37 7 5 5		FM(4)	+ 0 7	
49 1 5 8	73	FM(5)	80	
61		4 0 4 0		
1 5 7 1 1		TVAP(I)		
13 1 0		PVAP(I)		
25				
37				
49	73		80	
61		4 0 5 0		
1 0 0 0		EPS(1)		
13 0 0 0		EPS(2)		
25 0 0 0		EPS(3)		
37 0 0 0		EPS(4)		
49 0 0 0	73	EPS(5)	80	
61 0 0 0		4 0 6 0	EPS(6)	

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER	DATE	PAGE 27 of 29	JOB NO.
NUMBER		IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH		
1	0 . 0	73 80	EPS(7)		
13					
25					
37					
49					
61		4 0 7 0			
1	0 . 0	73 80	POWER Time Block 3 data		
13	1 0 0 .		DUR		
25	1 0 .		TED		
37			IQ		
49					
61		5 0 0 0			
1	0 . 0	73 80	FC3(1)		
13	0 . 0		FC4(1)		
25	0 . 0		FC5(1)		
37	0 . 0		FC3(2)		
49	0 . 0		FC4(2)		
61	0 . 0	5 0 1 0	FC5(2)		
1	0 . 0	73 80	FP3		
13	0 . 0		FP4		
25	0 . 0		FP5		
37	0 . 0		FF		
49					
61		5 0 2 0			

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO.		PROGRAMMER		DATE	PAGE 28 of 29	JOB NO.
NUMBER		IDENTIFICATION		DESCRIPTION DO NOT KEY PUNCH		
1	2 6 0 .	73	80	TCORE		
13	2 6 0 .			T(1)		
25	2 6 0 .			T(2)		
37	2 6 0 .			T(3)		
49	2 6 0 .			T(4)		
61	2 6 0 .	5 0 3 0		T(5)		
1	7 . 5 5 + 0 6	73	80	FM(1)		
13	7 . 5 5 + 0 6			FM(2)		
25	7 . 5 5 + 0 6			FM(3)		
37	7 . 5 5 + 0 6			FM(4)		
49	1 . 5 8 + 0 5			FM(5)		
61		5 0 4 0				
1	2 6 0 .	73	80	TVAP(1)		
13	1 . 0			PVAP(1)		
25						
37						
49						
61		5 0 5 0				
1	0 . 0	73	80	EPS(1)		
13	0 . 0			EPS(2)		
25	0 . 0			EPS(3)		
37	0 . 0			EPS(4)		
49	0 . 0			EPS(5)		
61	0 . 0	5 0 6 0		EPS(6)		

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 29 of 29 JOB NO. _____

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	0 - 0		EPS(7)
13			
25			
37			
49			
61		5 0 7 0	
1	/ *		END OF DATA
13			
25			
37			
49			
61		9 0 0 0 0 0 0 0	
1			
13			
25			
37			
49			
61			
1			
13			
25			
37			
49			
61			

1. Title. Format (18A4). Maximum of 72 alpha-numeric characters.

2. NISO, NZ, NZV, ND, NV, NOPTCL. Format (6112). See data sheet and Section IV-C. NOPTCL defines the type of calculation to be performed, as follows:

<u>NOPTCL</u>	<u>Action</u>
0	Perform complete calculation
1	Omit corrosion product calculations
2	Omit fission product calculations

Depending on the option selected, some of the following data may not be required. That which must be omitted for NOPTCL = 1 will be identified by a single asterisk preceding the paragraph number. That which must be omitted for NOPTCL = 2 will be identified by two asterisks preceding the paragraph number. Where no asterisks are present, data must be supplied for any value of NOPTCL.

** 3. [NZZ(I), I=1, NZ]. Format (24I3). See data sheet.

** 4. [NZZV(I), I=1, NZV]. Format (24I3). See data sheet.

** 5. [Y(I), ALAM(I), ENER(I), IM(I), IZ(I), IA(I), IZZ(I), IV(I), IFC(I), I=1, NISO]. Format (3E12.5, 6I6).

See Sections II-F and VI-C, and Table 4. ENER(I) is total gamma energy per disintegration (Mev).

** 6. [FC1(I), FC2(I), I=1, 2], FP1, FAD. Format (6E12.5).

See Sections II-B-3, II-B-5, II-B-8 and data sheet. FAD is f of Section II-B-5.

** 7. AREAF, VOLF, RFF, FKO, FRHO, FMW. Format (6E12.5).

See data sheet and Section II-B-1.

** 8. [AKA(I), BKA(I), I=NZ]. Format (6E12.5). AKA(I) and BKA(I) are used to compute the desorption constant, EQL(Z, M), as follows (See Section II-B-5):

$$EQL(Z, M) = AKA(Z) \exp [BKA(Z)/T(M)] ,$$

where $T(M)$ is the coolant temperature in Region M. The constants for Cs and Ba are experimental values, obtained at Atomics International.⁽⁶⁾ The rest of the values are assumed.

** 9. [AS(I),BS(I),I=1,NZ]. Format (6E12.5). AS(I) and BS(I) are used to compute fission product solubility, SOLB(Z, M), as follows:

$$\text{SOLB}(Z, M) = \text{AS}(Z) \exp [\text{BS}(Z)/T(M)] ,$$

where $T(M)$ is the coolant temperature in Region M. The solubility, of course, must be for the chemical form of the fission product in sodium. In the present case, Te and Cs are assumed to be in elemental form; I is present as NaI; and Ba, La, and Ce are present as the oxides, BaO, La_2O_3 , and CeO_2 . The solubility of NaI is derived from Reference 7, Xe from Reference 8, and Te from Reference 9. Cs is assumed to be miscible with Na in all proportions. Because of the absence of published values for the other elements and compounds, solubilities were estimated from the limited data available, or were assumed. The assumption for the oxides was a solubility of 0.1 ppm at 100°C and 1 ppm at 500°C. (NOTE: Since solubilities are only required for calculating precipitation, and since the noble gases are excluded from this mechanism, any values could be used for Xe.)

** 10. [ALPVA(I),BLPVA(I),I=1,NV]. Format (6E12.5). These quantities make up the vaporization rate constant for Cover Gas Region M as follows:

$$\text{ALFA}(M) = \text{ALPVA}(M) \exp [\text{BLPVA}(M)/\text{TVAP}(M)]$$

The value selected allows the cover gas to reach its equilibrium value with a time constant of 24 hr. See Section II-B-7.

** 11. [EQLNA(M),M=1,ND]. Format (6E12.5). Surface adsorption rate for sodium. See Section II-B-5. Assumed values indicate low affinity for adsorption.

** 12. [VVAP(I),I=1,NV]. Format (6E12.5). See data sheet.

** 13. [AVAP(I),BVAP(I),I=1,NZV]. Format (6E12.5). The quantities define the vapor equilibrium constants for the vaporizing elements as follows (See Section II-B-8):

$$AKL(Z,M) = AVAP(Z) \exp [BVAP(Z)/T(M)]$$

The values for NaI and Cs are taken from Reference 10. The values for Xe are estimated from solubility data, Reference 8.

- * 14. [RHO(I), I=1,5]. Format (6E12.5). See data sheet.
- * 15. [ACOR(I), BCOR(I), I=1,5]. Format (6E12.5). ACOR(I) and BCOR(I) are core corrosion rate constants. See Sections II-C-2-b and VI-B.
- * 16. [ASC(I), BSC(I), I=1,5]. Format (6E12.5). ASC(I) and BSC(I) are used to compute the temperature dependent solubility of Cr, Mn, Fe, Co, and Ni as follows:

$$SOLBC(Z,M) = ASC(Z) \exp [BSC(Z)/T(M)]$$

where T(M) is coolant temperature in Region I. Values for Mn are assumed.

- * 17. [SZS(I), I=1,5]. Format (6E12.5). See data sheet.
- * 18. [S10(I), I=1,10]. Format (6E12.5). Spectrum-weighted microscopic cross sections for activation of structural materials, based on typical LMFBR neutron spectrum. See Section II-C-2-b.
- 19. AN23, SIGNG, ALAM22, SIG2N, ALAM24. Format (6E12.5). See data sheet.
- 20. EPS1, TMIN, ITMIN. Format (2E12.5, I12). See data sheet.
- 21. FLUC, PWRC, ACORE, VO, VC, SIG49F. Format (6E12.5). See data sheet and Sections II-B-8 and II-C-2-b.
- 22. [AREA(I), DELL(I), I=1, ND]. Format (6E12.5). See data sheet. Value of DELL(I) is assumed to be equal to number of iron atoms in an atomic monolayer of 1-cm² area.
- 23. [AX(I), BX(I), I=1, ND]. Format (6E12.5). AX(I) and BX(I) are used to compute the precipitate re-entry rate in Region I, according to

$$AEX(I) = AX(I) \exp [BX(I)/T(I)]$$

See Section II-B-6. Values are assumed.

24. [AP(I), BP(I), AA(I), BA(I), ACC(I), BCC(I), I=1, ND]. Format (6E12.5). Each of these pairs of quantities is used to define a transfer constant. For example, AP(I) and BP(I) define the precipitation/dissolution efficiency, AGP(I) (See Sections II-B-6 and II-C-3) as follows:

$$AGP(I) = AP(I) \exp [BP(I)/T(I)] ,$$

where T(I) is the coolant temperature in Region I. In a similar manner, AA(I) and BA(I) define the adsorption velocity constant, AGA(I) (Section II-B-5), and ACC(I) and BCC(I) define the corrosion efficiency, AKC(I) (Section II-C-2-c).

The definitive evaluation of these constants is beyond the scope of this report. The values used in this example reflect their dependence on surface area [except AGA(I)], surface-to-volume ratio, and Reynolds Number within each region. These relative values were then adjusted in magnitude to provide physically reasonable time constants.

The capability for temperature dependence was provided to permit variation with operating conditions if desired. In addition, an automatic flow rate variation is provided for AGP(I) and AKC(I) (See Sections II-B-6, II-C-2-c and II-C-5).

25. [EL(I), DIST(I), ATT(I), FRAC(I), VNA(I), I=1, ND]. Format (6E12.5). See Section II-F. EL(M)=L(M) and DIST(M)=R(M), as described in Section II-F.

26. NCURV, NFP, NCP, NRD. Format (6I12). CRT output dimensions. See Section III.

27. [NUMFR(I), IORD(I), IQUNT(I), IREG(I), I=1, NCURV]. Format (24I3). CRT data. See Section III. The data sheets specify the following:

<u>Frame No.</u>	<u>Ordinate Scale</u>	<u>Isotope</u>	<u>Region</u>
1	Log	^{133}I	Hot half of IHX
1	Log	^{133}I	Cold half of IHX
1	Log	^{133}I	Cold leg
2	Log	^{135}I	Hot half of IHX
2	Log	^{135}I	Cold half of IHX
2	Log	^{135}I	Cold leg
3	Log	^{140}Ba	Cold half of IHX
3	Log	^{140}Ba	Cold leg
4	Log	^{140}La	Cold half of IHX
4	Log	^{140}La	Cold leg
5	Log	^{54}Mn	Hot leg
5	Log	^{54}Mn	Hot half of IHX
5	Log	^{54}Mn	Cold half of IHX
5	Log	^{54}Mn	Cold leg
5	Log	^{54}Mn	Cold trap
6	Log	^{60}Co	Hot leg
6	Log	^{60}Co	Hot half of IHX
6	Log	^{60}Co	Cold half of IHX
6	Log	^{60}Co	Cold leg
6	Log	^{60}Co	Cold trap
7	Log	Radiation	Hot leg
7	Log	Radiation	Hot half of IHX
7	Log	Radiation	Cold half of IHX
7	Log	Radiation	Cold leg
7	Log	Radiation	Cold trap

NOTE: Plotting specifications must be supplied in the indicated order [i. e., (1) fission products, (2) corrosion products, (3) radiation dose rates].

28. IPR1,IPR2. Format (2I12). See data sheet.

29. [IN(I),VALUE(I),I=1,IPR1 and I=1,IPR2]. Format (3(I12,E12.5)).

The first seven pairs of values pertain to stable fission product isotopes. IN(I) is the number of the isotope on the Fission Product Isotope List (Table 4), and VALUE(I) is the initial concentration of that isotope in the coolant. The values entered correspond to impurity levels of 5 wppm for Cs, 1 wppm for Te and NaI, 0.1 wppb for Xe, and 0.01 wppm for BaO, La_2O_3 , and CeO_2 .

The following 11 pairs of values pertain to the 11 stable corrosion product isotopes. The concentrations correspond to elemental solubilities at the initial cold-leg temperature (760°F), adjusted for relative isotopic abundance within each element.

30. POWER,DUR,TED,IQ. Format (3E12.5,I12). POWER is the reactor thermal power in megawatts. DUR is the duration of the time block in days. TED is the number of days between output edits. Data points for CRT plots are stored only at the time of each output edit, so that this number should be chosen carefully. There cannot be more than 100 edits per problem; however, too few edits will provide a sparse mesh for data plotting. Thirty to fifty edits will provide reasonable results for most problems. It should be noted that an output edit will occur at the end of each time block, regardless of the value of TED.

IQ is an index that indicates whether the following quantities need be read in for this time block:

TCORE

T(I),I=1,ND

FM(I),I=1,ND

TVAP(I),PVAP(I),I=1,NV

EPS(I),I=1,NZ

If IQ=1, some or all of these quantities must be read in, depending on the value of NOPTCL. If IQ=0, these quantities are unchanged, and need not be read in. The definitions of these quantities are given in Paragraphs 33 through 36, which follow.

** 31. [FC3(I),FC4(I),FC5(I),I=1,2]. Format (6E12.5). Cladding fractional failure rates. See Sections II-B-3 and VI-b.

** 32. [FP3,FP4,FP5,FF. Format (6E12.5). FP3,FP4, and FP5 are the fissile material release rate constants described in Section II-B-8. FF is the fraction of the fuel above recrystallization temperature, denoted by F_{dir} in Section II-B-1.

33. TCORE,[T(I),I=1,ND]. Format (6E12.5). See data sheet and Table 3.

34. [FM(I),I=1,ND]. Format (6E12.5). See data sheet and Table 3.

** 35. [TVAP(I),PVAP(I),I=1,NV]. Format (6E12.5). See data sheet and Table 3.

** 36. [EPS(I),I=1,NZ]. Format (6E12.5). See data sheet and Section II-B-1. Loss by diffusion mechanism is assumed negligible.

37. Subsequent Time Block Data Cards 4000 to 4070 and 5000 to 5070 present the same input data as cards 3000 to 3070, except that the data are for Time Blocks 2 and 3, respectively. A /* card follows the last data card.

E. OUTPUT DATA

Figure 3 presents the basic input data edit for the sample problem. Figure 4 shows the edit for Time Block 1 input data. Figure 5 presents the output edit at the end of the first time block. Figures 6 through 12 are the CRT output for the sample problem.

STP-1 SAMPLE PROBLEM
 EPS1 = 0.0001 NOPTCL = 0 MIN. TIME STEP = 1.00000E 00 SEC.
 NOPTCL CODE: 0-COMplete CALCULATION; 1- FISS. PROD. ONLY; 2- CORR. PROD. ONLY

TOTAL NO. FP CHAIN LOCATIONS = 31 TOTAL NO. ELEMENTS IN FP CHAINS = 7

NO. OF FP ELEMENTS THAT VAPORIZE OR HAVE VOLATILE PARENTS = 3

NO. OF DEPOSITION REGIONS = 5 NO. OF COVER GAS SPACES = 1

ATOMIC NO. ID. I = 1 2 3 4 5 6 7

NZZ(I) = 52 53 54 55 56 57 58

FISSION PRODUCT CHAINS

CHAIN 1 A = 131						
Z	YIELD	LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
52	0.22700E-02	0.66900E-05	0.16700E 01	1	0	YES
53	0.44000E-04	0.99500E-06	0.38700E 00	2	1	YES
54	0.0	0.0	0.0	3	2	YES
CHAIN 2 A = 131						
Z	YIELD	LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
52	0.31100E-01	0.46200E-03	0.21300E 00	1	0	YES
53	0.59600E-02	0.99500E-06	0.38700E 00	2	1	YES
54	0.0	0.0	0.0	3	2	YES
CHAIN 3 A = 133						
Z	YIELD	LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
52	0.33400E-01	0.23100E-03	0.20950E 01	1	0	YES

Figure 3. Basic Input Data Edit for Sample Problem
 (Sheet 1 of 7)

53	0.74600E-02	0.92600E-05	0.53000E 00	2	1	YES
54	0.20000E-03	0.15200E-05	0.81000E-01	3	2	YES
55	0.0	0.0	0.0	4	3	YES
Z	CHAIN 4 YIELD	A = 133 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
52	0.13000E-01	0.92800E-03	0.18500E 01	1	0	YES
53	0.29000E-02	0.92600E-05	0.53000E 00	2	1	YES
54	0.80000E-04	0.15200E-05	0.81000E-01	3	2	YES
55	0.0	0.0	0.0	4	3	YES
Z	CHAIN 5 YIELD	A = 135 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
53	0.62980E-01	0.28700E-04	0.17740E 01	2	1	YES
54	0.54500E-02	0.21000E-04	0.26100E 00	3	2	YES
55	0.70000E-04	0.10400E-13	0.0	4	3	YES
56	0.0	0.0	0.0	5	0	NO
Z	CHAIN 6 YIELD	A = 137 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
55	0.65700E-01	0.73700E-09	0.61800E 00	4	3	YES
56	0.30000E-04	0.44400E-02	0.61800E 00	5	0	NO
56	0.0	0.0	0.0	5	0	NO
Z	CHAIN 7 YIELD	A = 140 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
55	0.44310E-01	0.10900E-01	0.31500E 01	4	3	YES
56	0.65600E-02	0.62700E-06	0.24900E 00	5	0	NO
57	0.12000E-03	0.47900E-05	0.22200E 01	6	0	NO
58	0.0	0.0	0.0	7	0	NO
Z	CHAIN 8 YIELD	A = 130 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
52	0.30510E-01	0.0	0.0	1	0	YES
Z	CHAIN 9 YIELD	A = 127 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS

Figure 3. Basic Input Data Edit for Sample Problem
(Sheet 2 of 7)

53	0.43000E-02	0.0	0.0	2	1	YES
Z	CHAIN 10 YIELD	A = 132 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
54	0.19090E 00	0.0	0.0	3	2	YES
Z	CHAIN 11 YIELD	A = 138 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
56	0.61000E-01	0.0	0.0	5	0	NO
Z	CHAIN 12 YIELD	A = 139 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
57	0.53000E-01	0.0	0.0	6	0	NO
Z	CHAIN 13 YIELD	A = 142 LAMBDA	GAMMA ENERGY	AT. NO. ID.	VAP. ID.	GAS
58	0.54000E-01	0.0	0.0	7	0	NO

REFERENCE POWER = 0.20000E 04 MWt REFERENCE FLUX = 0.50000E 16

CORE SURFACE AREA = 0.17500E 08 SQ CM CORE COOLANT VOLUME = 0.26200E 07 CC

TOTAL COOLANT VOLUME = 0.85100E 09 CC TRAMP FUEL CROSS SECTION = 0.18665E 01 BARNS

TOTAL FUEL SURFACE AREA = 1.2940E 07 SQ CM TOTAL FUEL VOLUME = 1.8940E 06 CC

FISSION FRAGMENT RANGE = 7.0000E-04 CM KNOCKOUT MOLECULES PER RECOIL ATOM = 2000.00

FUEL DENSITY = 10.00 G/CC FUEL MOL. WGT = 270.00

INITIAL FRACTION DEFECTIVE CLADDING - NON. VOL. = 0.0 VOL. = 1.00000E-04

INITIAL FRACTIONAL RATE OF CLAD FAILURE - NON. VOL. = 0.0 VOL. = 0.0

INITIAL MASS OF PLUTONIUM IN COOLANT = 0.0 GRAMS

FRACTION OF SURFACE AVAILABLE FOR ADSORPTION = 1.00000E 00

Figure 3. Basic Input Data Edit for Sample Problem
(Sheet 3 of 7)

REGION DEPENDENT DATA						
REGION NO.		1	2	3	4	5
AREA (SQ CM)		0.97400E 07	0.85800E 08	0.85800E 03	0.52400E 07	0.52250E 07
ADS SITES		0.15700E 16	0.15700E 16	0.15700E 16	0.15700E 16	0.15700E 16
FP PRECIP.	A	0.18200E-05	0.13700E-03	0.13700E-03	0.53200E-06	0.90000E 00
EFFIC.	B	0.0	0.0	0.0	0.0	0.0
FP ADSORP.	A	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03	0.10000E 03
RATE CONST.	B	0.0	0.0	0.0	0.0	0.0
AT EXCH RATE	A	0.10000E-04	0.10000E-04	0.10000E-04	0.10000E-04	0.10000E-04
CONST.	B	-0.11510E 04	-0.11510E 04	-0.11510E 04	-0.11510E 04	-0.11510E 04
CP CORROSION	A	0.18200E-07	0.13700E-05	0.13700E-05	0.53200E-08	0.10000E-04
EFFIC.	B	0.0	0.0	0.0	0.0	0.0
NA DEP RATE		0.10000E-01	0.10000E-01	0.10000E-01	0.10000E-01	0.10000E-01

VAPORIZATION REGION DATA		
REGION NO.		1
VOLUME CC		0.10000E 08
VAP RATE	A	0.11580E-04
CONST	B	0.0

Figure 3. Basic Input Data Edit for Sample Problem
(Sheet 4 of 7)

ELEMENT DEPENDENT DATA

FISSION PRODUCT ELEMENTS

		EQUILIB. ADSORPTION CONSTS		SOLUBILITY CONSTANTS		DISTRIBUTION COEFFICIENTS	
I	Z	A	B	A	B	A	B
1	52	0.17800E-06	-0.28800E 03	0.52300E 22	-0.64000E 03		
2	53	0.17800E-06	-0.28800E 03	0.13050E 21	-0.26720E 04		
3	54	0.17800E-06	-0.28800E 03	0.75800E 16	0.36600E 03		
4	55	0.47300E-06	-0.32800E 01	0.78400E 22	0.0		
5	56	0.26100E-08	-0.32000E 04	0.64800E 16	-0.29800E 03		
6	57	0.24000E-06	-0.43800E 03	0.64800E 16	-0.28800E 03		
7	58	0.24000E-06	-0.43800E 03	0.64800E 16	-0.28800E 03		
1	53					0.45700E-02	0.42400E 04
2	54					0.14800E 09	-0.27180E 04
3	55					0.56200E 01	0.22700E 04

STRUCTURAL ELEMENTS

	CORROSION RATE CONSTANTS		SOLUBILITY CONSTANTS		DENSITY IN	VOL FRACTION
	A	B	A	B	CORE (AT/CC)	IN WALLS
CR	0.42200E-06	-0.38440E 04	0.20000E 20	-0.35320E 04	0.17566E-01	0.21000E 00
MN	0.21100E-06	-0.38440E 04	0.21000E 19	-0.21370E 04	0.17546E-02	0.21000E-01
FE	0.21100E-06	-0.38440E 04	0.47000E 18	-0.11430E 04	0.58967E-01	0.69500E 00
CO	0.21100E-06	-0.38440E 04	0.63000E 20	-0.46240E 04	0.40892E-04	0.45000E-03
NI	0.21100E-06	-0.38440E 04	0.24000E 21	-0.47250E 04	0.77784E-02	0.85000E-01

CORROSION PRODUCT CROSS SECTIONS (BARN*1.0E24)

CR-50 (N,G)	CR-52 (N,2N)	FE-54 (N,A)	FE-54 (N,P)	MN-55 (N,A)
2.66000E-02	1.85000E-05	6.64000E-04	1.02000E-02	3.05000E-05
FE-58 (N,G)	NI-58 (N,P)	CO-59 (N,2N)	CO-59 (N,G)	NI-60 (N,P)
1.68000E-02	1.65000E-02	2.95000E-05	1.36000E-01	4.32000E-03

COOLANT ACTIVATION DATA

Figure 3. Basic Input Data Edit for Sample Problem
(Sheet 5 of 7)

SODIUM 23 ATOM DENSITY = 0.21800E-01 AT/CC
 SODIUM 24 PRODUCTION CROSS SECTION = 0.19900E-02 BARNS LAMBDA-24 = 0.12830E-04 SEC**-1
 SODIUM 22 PRODUCTION CROSS SECTION = 0.33600E-05 BARNS LAMBDA-22 = 0.84400E-08 SEC**-1

INPUT DATA FOR CRT DISPLAY :
 NO. OF FISSION PRODUCT CURVES = 10
 NO. OF CORROSION PRODUCT CURVES = 10
 NO. OF RADIATION DOSE RATE CURVES = 5
 TOTAL NO. OF CURVES = 25

NUMFR	IORD	IQUANT	I REG	NUMFR	IORD	IQUANT	I REG	NUMFR	IORD	IQUANT	I REG	NUMFR	IORD	IQUANT	I REG
1	1	8	6	1	1	8	7	1	1	8	8	2	1	15	6
2	1	15	7	2	1	15	8	3	1	23	7	3	1	23	8
4	1	24	7	4	1	24	8	5	1	-13	2	5	1	-13	3
5	1	-13	4	5	1	-13	5	5	1	-13	6	6	1	-16	2
6	1	-16	3	6	1	-16	4	6	1	-16	5	6	1	-16	6
7	1	0	1	7	1	0	2	7	1	0	3	7	1	0	4
7	1	0	5												

INITIALIZATION HAS BEEN PERFORMED.

INITIAL NON-ZERO COOLANT CONCENTRATIONS HAVE BEEN PRESCRIBED

Z	A	CONCENTRATION (ATOMS/CM**3)
55	133	C.204000D 17
52	130	C.425000D 16
53	127	C.361000D 16
54	132	C.413000D 12
56	138	C.354000D 14
57	139	C.333000D 14
58	142	C.315000D 14
24	50	C.128800E 15
24	52	C.270500E 16
26	54	C.161000E 16
26	58	C.918000E 14

Figure 3. Basic Input Data Edit for Sample Problem
 (Sheet 6 of 7)

25	55	C.106000E 17
28	58	0.137000E 16
28	60	0.530000E 15
27	59	C.681000E 15
24	535	C.386000E 15
26	565	C.261000E 17
28	625	0.119000E 15

Figure 3. Basic Input Data Edit for Sample Problem
(Sheet 7 of 7)

OPERATING DATA

TIME BLOCK 1

POWER = 1999.99951 MW
DURATION OF TIME BLOCK = 200.00000 DAYS INTERVAL BETWEEN EDITS = 10.00000 DAYS

FRACTION OF FUEL PERMITTING DIRECT RELEASE OF FISSION PRODUCTS = 5.00000E-02

CLADDING FAILURE RATE CONSTANTS - NON. VOL.: 0.0 0.0 0.0
VOL.: 3.17100E-10 0.0 0.0

COOLANT TEMPERATURE IN CORE = 487.79980 DEG C
REGION DEPENDENT TEMPERATURE AND FLOW RATES

REGION	1	2	3	4	5
TEMP (DEG C)	571.09985	525.39990	446.09985	404.39990	150.00000
FLOW (CC/SEC)	0.15100E 09	0.15100E 09	0.15100E 09	0.15100E 09	0.15800E 06

VAPORIZATION REGION 1

COOLANT TEMP (DEG C) 0.57110E 02
GAS PRESS. (ATM.) 1.00000

RATE CONSTANT 0.11580E-04

COMPUTED SOLUBILITIES BY ELEMENT AND REGION

FISSION PRODUCT ELEMENTS

I	Z	REG1	REG2	REG3	REG4	REG5	EPS
1	52	0.17053E 22	0.15613E 22	0.12458E 22	0.10745E 22	0.73369E 20	0.0
2	53	0.12125E 19	0.83874E 18	0.32683E 18	0.17623E 18	0.23954E 13	0.0
3	54	0.14388E 17	0.15133E 17	0.17218E 17	0.18738E 17	0.86966E 17	0.0
4	55	0.78400E 22	0.78400E 22	0.78400E 22	0.78400E 22	0.78400E 22	0.0

Figure 4. Edit for Time Block 1 Input Data
(Sheet 1 of 2)

5	56	0.39135E 16	0.37611E 16	0.33978E 16	0.31790E 16	0.95001E 15	0.0
6	57	0.39135E 16	0.37611E 16	0.33978E 16	0.31790E 16	0.95001E 15	0.0
7	58	0.39135E 16	0.37611E 16	0.33978E 16	0.31790E 16	0.95001E 15	0.0

COMPUTED SOLUBILITIES BY ELEMENT AND REGION

STRUCTURAL ELEMENTS

ELEM	REG1	REG2	REG3	REG4	REG5
CR	0.41220E 17	0.25325E 17	0.72862E 16	0.32206E 16	0.11881E 10
MN	0.49789E 17	0.37079E 17	0.17449E 17	0.10647E 17	0.13645E 13
FE	0.63519E 17	0.54254E 17	0.36253E 17	0.27836E 17	0.23055E 15
CO	0.19187E 17	0.10140E 17	0.19848E 16	0.68158E 15	0.25792E 07
NI	0.61245E 17	0.31919E 17	0.60291E 16	0.20227E 16	0.50111E 07

Figure 4. Edit for Time Block 1 Input Data
(Sheet 2 of 2)

*** PROGRAM OUTPUT ***

TIME = 200.00 DAYS TIME INTERVAL = 1.39259E-01 DAYS

NOTES: 1. NEGATIVE MASS NO. (A) DENOTES METASTABLE STATE
2. NEGATIVE ACTIVITY VALUE DENOTES STABLE ISOTOPE WITH ACTIVITY VALUE REPLACED BY NUMBER OF STABLE ATOMS IN THE SAME VOLUME, AREA OR REGION

PROCESS MAP

CODE - 1 = CORROSION/ADSORPTION, 2 = PRECIPITATION, 3 = DISSOLUTION

FISSION PRODUCTS

	REGION				
Z	(1)	(2)	(3)	(4)	(5)
52	1	1	1	1	1
53	1	1	1	1	2
54	1	1	1	1	1
55	1	1	1	1	1
56	1	1	1	1	1
57	1	1	1	1	1
58	1	1	1	1	1

CORROSION PRODUCTS

	REGION				
Z	(1)	(2)	(3)	(4)	(5)
24	1	1	1	1	2
25	1	1	1	1	2
26	1	1	1	1	2
27	1	1	1	1	2
28	1	1	1	1	2

FISSION PRODUCT ACTIVITIES

Figure 5. Output Data at End of First Time Block
(Sheet 1 of 5)

Z	A	COOLANT (UCI/CC)	FUEL-TOTAL (CI)	FUEL (CI)	GAS GAP (CI)
52	-131	4.2847E-02	3.8038E 06	3.7972E 06	6.5032E 03
53	131	1.8276E-02	3.8774E 06	3.8535E 06	2.2771E 04
54	131	-2.9564E 10	-2.3125E 24	-2.2345E 24	-7.7402E 22
52	131	4.1079E-01	5.2113E 07	5.2051E 07	6.2354E 04
53	131	6.0421E-01	6.2098E 07	6.1308E 07	7.8580E 05
54	131	-5.4227E 11	-3.7373E 25	-3.5865E 25	-1.4969E 24
52	-133	4.4399E-01	5.5568E 07	5.5900E 07	6.7387E 04
53	133	2.5861E 00	6.8468E 07	6.7734E 07	7.2932E 05
54	133	5.6870E 00	6.9801E 07	6.7894E 07	9.0224E 05
55	133	-8.8104E 12	-4.2003E 25	-4.0273E 25	-1.7200E 24
52	133	1.7116E-01	2.1784E 07	2.1758E 07	2.5982E 04
53	133	1.0046E 00	2.6643E 07	2.6358E 07	2.8331E 05
54	133	2.2111E 00	2.6777E 07	2.6424E 07	3.5079E 05
55	133	-2.0404E 16	-1.6353E 25	-1.5680E 25	-6.6948E 23
53	135	2.7761E 01	1.0553E 08	1.0012E 08	5.3849E 06
54	135	3.8633E 01	1.1467E 08	1.0877E 08	5.8679E 06
55	135	1.0313E-05	2.0529E 01	1.8893E 01	1.6230E 00
56	135	-2.0352E 06	-6.5274E 18	-5.9472E 18	-5.7755E 17
55	137	7.2296E-01	1.3929E 06	1.2824E 06	1.0988E 05
56	-137	7.2183E-01	1.4422E 06	1.3317E 06	1.0984E 05
56	137	-1.4162E 11	-4.7768E 23	-4.3719E 23	-4.0368E 22
55	140	2.4901E 01	7.4245E 07	7.0448E 07	3.7801E 06
56	140	2.2633E 01	8.5238E 07	8.0971E 07	4.2480E 06
57	140	2.2326E 01	8.5439E 07	8.1112E 07	4.3079E 06
58	140	-6.5807E 12	-4.8900E 25	-4.5200E 25	-3.6954E 24
52	130	-4.2563E 15	-3.2685E 25	-3.1670E 25	-1.0035E 24
53	127	-2.4427E 12	-4.6062E 24	-4.2403E 24	-3.6363E 23
54	132	-4.9699E 12	-2.0452E 26	-1.8827E 26	-1.6145E 25
56	138	-3.5365E 13	-6.5338E 25	-6.3322E 25	-2.0172E 24
57	139	-3.3272E 13	-5.6775E 25	-5.5016E 25	-1.7527E 24
58	142	-3.1472E 13	-5.7833E 25	-5.6055E 25	-1.7858E 24

SURFACE DEPOSITS (UCI/SQ CM)

Z	A	REGION				
		(1)	(2)	(3)	(4)	(5)
52	-131	1.6474E-06	1.2263E-06	4.9123E-07	2.4942E-07	3.9650E-13
53	131	4.1652E-06	3.1102E-06	1.2549E-06	6.4002E-07	2.2517E 01

Figure 5. Output Data at End of First Time Block
(Sheet 2 of 5)

54	131	-2.7644E 07	-2.0843E 07	-8.6112E 06	-4.4563E 06	-8.7454E 00
52	131	2.3417E-07	1.7421E-07	6.9682E-08	3.5351E-08	5.5699E-14
53	131	1.3770E-04	1.0282E-04	4.1487E-05	2.1159E-05	7.4440E 02
54	131	-5.2537E 08	-3.9635E 08	-1.6397E 08	-8.4926E 07	-1.6844E 02
52	-133	5.0605E-07	3.7648E-07	1.5059E-07	7.6398E-08	1.2039E-13
53	133	7.2327E-05	5.3832E-05	2.1555E-05	1.0942E-05	3.6119E 02
54	133	8.6488E-04	6.5597E-04	2.6555E-04	1.3520E-04	2.2107E-10
55	133	-3.4642E 09	-2.5782E 09	-1.0322E 09	-5.2393E 08	-8.3319E 02
52	133	4.8579E-08	3.6141E-08	1.4456E-08	7.3336E-09	1.1554E-14
53	133	2.8096E-05	2.0911E-05	8.3730E-06	4.2504E-06	1.4031E 02
54	133	3.4405E-04	2.5660E-04	1.0325E-04	5.2568E-05	8.5956E-11
55	133	-1.1446E 13	-8.5201E 12	-3.4125E 12	-1.7326E 12	-2.7676E 06
53	135	2.5345E-04	1.8859E-04	7.5456E-05	3.8288E-05	1.2566E 03
54	135	4.8106E-04	3.5796E-04	1.4324E-04	7.2690E-05	1.1485E-10
55	135	4.3720E-09	3.2540E-09	1.3028E-09	6.6132E-10	1.0525E-15
56	135	-2.2496E 03	-1.6738E 03	-6.6970E 02	-3.3977E 02	-5.3532E-04
55	137	3.0784E-04	2.2913E-04	9.1736E-05	4.6566E-05	7.4114E-11
56	-137	4.2771E-08	3.1820E-08	1.2727E-08	6.4566E-09	1.0172E-14
56	137	-1.5331E 08	-1.1407E 08	-4.5640E 07	-2.3155E 07	-3.6482E 01
55	140	6.0174E-07	4.4767E-07	1.7906E-07	9.0838E-08	1.4311E-13
56	140	8.5713E-03	6.3773E-03	2.5511E-03	1.2942E-03	2.0390E-09
57	140	1.1852E-03	8.8288E-04	3.5421E-04	1.8001E-04	2.8757E-10
58	140	-6.2578E 09	-4.7520E 09	-1.9947E 09	-1.0413E 09	-2.0991E 03
52	130	-1.0434E 13	-8.0791E 12	-3.5785E 12	-1.9418E 12	-1.0240E 07
53	127	-1.3820E 12	-1.1516E 12	-6.0725E 11	-3.6551E 11	-6.7217E 17
54	132	-5.5579E 09	-4.2134E 09	-1.7665E 09	-9.2359E 08	-2.4534E 03
56	138	-9.6659E 14	-1.1198E 15	-1.3885E 15	-1.4772E 15	-1.5682E 15
57	139	-7.8770E 10	-6.2270E 10	-2.9086E 10	-1.6330E 10	-1.6175E 05
58	142	-7.4510E 10	-5.8902E 10	-2.7513E 10	-1.5446E 10	-1.5300E 05

CCVER GAS (UC1)

REGION		
Z	A	(1)
53	131	9.2727E-03
54	131	-4.0832E 20
53	131	3.0655E-01
54	131	-7.9212E 21
53	133	1.2858E-01
54	133	8.6117E 09

Figure 5. Output Data at End of First Time Block
(Sheet 3 of 5)

55	133	-1.9296E 21						
53	133	4.9948E-02						
54	133	3.3483E 09						
55	135	-3.9353E 21						
53	135	4.1578E-01						
54	135	4.3283E 09						
55	135	3.0537E 02						
55	137	5.1482E-06						
55	140	0.0						
53	127	-7.1092E 15						
54	132	-9.6473E 22						
FISSION PRODUCT ELEMENT INVENTORIES								
Z	COOLANT (AT/CC)		SURFACE DEPOSITS (ATOMS)					
			(1)	(2)	(3)	(4)	(5)	
52		4.2563E 15	1.0163E 20	6.9318E 20	3.0704E 20	1.0175E 19	5.3505E 13	
53		2.5159E 12	1.3461E 19	9.8808E 19	5.2102E 19	1.9153E 18	3.5122E 24	
54		5.8020E 12	5.9820E 16	3.9927E 17	1.6716E 17	5.3326E 15	1.3785E 10	
55		2.0486E 16	1.1182E 20	7.3322E 20	2.9367E 20	9.1062E 18	1.4504E 13	
56		3.6842E 13	5.4146E 21	9.6079E 22	1.1913E 23	7.7403E 21	8.1938E 21	
57		3.3444E 13	7.6731E 17	5.3434E 18	2.4958E 18	8.5574E 16	8.4513E 11	
58		3.8053E 13	7.8668E 17	5.4615E 18	2.5318E 18	8.6396E 16	8.1040E 11	
Z	COVER GAS (ATOMS)							
53		7.1092E 15						
54		1.0510E 23						
55		5.9513E 21						
FRACTION OF AVAILABLE SITES UNOCCUPIED								
			2.6366E-12	1.9615E-12	7.8457E-13	3.9302E-13	6.2704E-19	
CORROSION PRODUCT ACTIVITIES								
Z	A	COOLANT (UCI/CC)	SURFACE DEPOSITS (UCI/SQ CM)					
			(1)	(2)	(3)	(4)	(5)	
24	50	-1.6525E 13	0.0	0.0	0.0	0.0	-7.2106E 18	

Figure 5. Output Data at End of First Time Block
(Sheet 4 of 5)

24	52	-3.2115E 14	0.0	0.0	0.0	0.0	-1.4018E 20
26	54	-5.5561E 13	0.0	0.0	0.0	0.0	-1.8609E 19
26	58	-3.1504E 12	0.0	0.0	0.0	0.0	-1.0554E 18
25	55	-2.2132E 13	0.0	0.0	0.0	0.0	-1.0864E 19
28	56	-5.9547E 13	0.0	0.0	0.0	0.0	-2.6146E 19
28	60	-2.3010E 13	0.0	0.0	0.0	0.0	-1.0104E 19
27	59	-4.6415E 11	0.0	0.0	0.0	0.0	-3.1930E 17
24	535	-4.5743E 13	0.0	0.0	0.0	0.0	-1.9970E 19
26	565	-3.9595E 14	0.0	0.0	0.0	0.0	-3.0011E 20
28	625	-5.1669E 12	0.0	0.0	0.0	0.0	-2.2685E 18
24	51	5.0622E-02	0.0	0.0	0.0	0.0	5.4290E 03
25	54	1.8978E-02	0.0	0.0	0.0	0.0	3.7252E 03
26	59	5.5663E-03	0.0	0.0	0.0	0.0	5.3724E 02
27	58	1.0127E-01	0.0	0.0	0.0	0.0	1.6166E 04
27	60	1.3678E-03	0.0	0.0	0.0	0.0	3.0533E 02

CORROSION PRODUCT INVENTORIES

Z	COOLANT (AT/CC)	(1)	(2)	(3)	(4)	(5)
24	3.8343D 14	0.0	0.0	0.0	0.0	8.7447E 26
25	2.2158D 13	0.0	0.0	0.0	0.0	5.6790E 25
26	9.5467D 14	0.0	0.0	0.0	0.0	1.6708E 27
27	5.1013D 11	0.0	0.0	0.0	0.0	1.7107E 24
28	8.7724D 13	0.0	0.0	0.0	0.0	2.0126E 26

SODIUM ACTIVITIES (UCI/CC)

SODIUM-24 = 1.8049E 04

SODIUM-22 = 4.1356E 00

REGION	(1)	(2)	(3)	(4)	(5)
DOSE RATE (R/HR)	0.00	0.00	0.00	0.00	8414.11

FRACTION OF CLADDING FAILED (NON-VOL.) = 0.0

(VOL.) = 5.5784E-03

PLUTONIUM IN COOLANT = 0.0 GRAMS

Figure 5. Output Data at End of First Time Block
(Sheet 5 of 5)

Figure 6. ^{133}I (Chain 3) Deposition

Figure 7. ^{135}I Deposition

Figure 8. ^{140}Ba Deposition

Figure 9. ^{140}La Deposition

Figure 10. ^{54}Mn Deposition

Figure 11. ^{60}Co Deposition

Figure 12. Radiation Dose Rates

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