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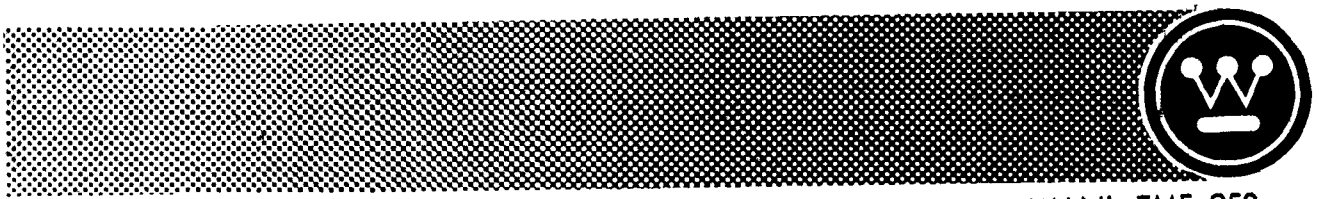

V/ANL-TME-958

UNCLASSIFIED

INTERIM REPORT

ON

FISSION PRODUCT DIFFUSION CODE (FIPDIF)

(Title Unclassified)

Astronuclear Laboratory

Westinghouse Electric Corporation

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INTERIM REPORT

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AEC RESEARCH AND DEVELOPMENT REPORT

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I. INTRODUCTION

Basic to any study required to define the hazards involved in the use of a NERVA engine for space flight applications is a thorough understanding of the diffusion of radioactive fission products generated in the fuel during engine operation, so that a realistic prediction can be made of the source strength of radioactive debris that could be deposited on the earth's surface creating a serious biological hazard. The loss of fission products from the core must be predicted for any combination of the following conditions:

a. Normal startup - operation - shutdown

b. Accidental loss of coolant

c. Nuclear excursion

An experimental fission product diffusion program was initiated at WANL several years ago to measure the diffusion rates of representative fission products as a function of time, temperature, environment, and fuel characteristics.

The results [1] of the experimental program to date have shown that the 273 isotopes comprising the fission product inventory can be reduced to 20 isotopes for the purpose of defining the diffusion rates of all the important isotopes. These twenty isotopes are further reduced by assigning them to one of seven groups (see Appendix I) for which experimental diffusion rates have been measured.

In order to predict the magnitude of the fission product inventory of an operated NERVA engine under all conditions of interest, a comprehensive computer program is being developed. This program includes the effects of diffusion of the various fission products. This report describes the work performed to date in developing the computer program known as FIPDIF. In addition, three appendices are included to describe the supporting work used in developing this code.

2.0 PROGRAM DESCRIPTION

2.1 GENERAL

FIPDIF is a program, written in Fortran II, for calculation of the fission product release and the fission product inventory remaining in a multi-section NERVA reactor core. In its present form it can be used to simulate a reactor startup - run - shutdown profile consisting of as many as forty time intervals. These time intervals may be of any desired length. During each time interval, a power level and temperature is specified for each core section. As many as ten core sections may be used. At the conclusion of any or all of the specified time intervals, the following data may be printed out.

a. Remaining fission product inventory in each core section and/or total core inventory of each isotope.

b. Curies of each isotope which have diffused from each section and/or total curies of each isotope which have diffused from the core.

2.2 CALCULATIONS PERFORMED BY FIPDIF

The two basic equations solved by FIPDIF are:

$$\frac{d}{dt} N(NS,NCH,NI) = P(NS,NTC) \times \gamma(NCH,NI)$$

$$-R(NS,NCH,NI) \times N(NS,NCH,NI)$$

$$+ \sum_{NJ=2}^{NI-1} BR(NCH,NI,NJ) \times \lambda(NCH,NJ) \times N(NS,NCH,NJ) \quad \ldots 2.2.1$$

where:

$N(NS,NCH,NI)$ = number of atoms of isotope NI, of decay chain NCH, in core section NS.

$P(NS,NTC)$ = power (fission/second) in core section NS during time interval NTC.

$\gamma(NCH,NI)$ = fission yield of isotope NI.

$R(NS,NCH,NI) = \lambda(NCH,NI) + D(NS,NCH,NI)$

where:

$\lambda(NCH,NI)$ = decay constant (sec^{-1}) of isotope NI

$D(NS,NCH,NI)$ = rate constant for diffusion of the isotope from the core section.*

$BR(NCH,NI,NJ)$ = branching ratio for production of isotope NI by decay of isotope NJ in decay chain NCH.

---

* This term is a function of the temperature of the core section (see Appendix I) and is determined experimentally.

$$\frac{d}{dt} L(NS,NCH,NI) = D(NS,NCH,NI) \times N(NS,NCH,NI) \quad \ldots . 2.2.2$$

where:

L(NS,NCH,NI) = number of atoms of the isotope which have diffused from the core section.

Equation 2.2.1 is changed, for ease of programming, to:

$$\frac{d}{dt} N(NS,NCH,NI) = \sum_{NJ=1}^{NI-1} BR(NCH,NI,NJ) \times \lambda(NCH,NJ) \times N(NS,NCH,NJ) \quad \ldots . 2.2.3$$

where:

$\lambda(NCH,1) = \sigma\phi_{U^{235}}$ (an affective value of the product of the fission cross section of and the neutron flux.)*

$BR(NCH,NI,1) = \gamma(NCH,NI) \times G(NCH,NI)$**

This equation is solved for N(NS,NCH,NI) in terms of its initial concentration and the initial concentrations of the isotopes which precede it in the decay chain. The isotope number densities which are calculated to be present in any given core section at the end of a time interval, during which the temperature and power level are constant in the section, are used as initial conditions for calculations made during the succeeding time interval. Appropriate values of R are calculated for each isotope corresponding to the temperature in the core section and the appropriate diffusion category for the isotope.

Solution of the second equation, for loss of the isotope from the core section by diffusion, is also obtained in terms of the concentrations of the isotopes at the beginning of the time interval. In the case of a series of time intervals during which different temperatures and power levels exist in a given core section, the losses during the individual time intervals are summed to obtain total losses to the time of interest.

---

* This is calculated from the input power level and weight of U^{235} in each core section.

** G(NCH,NI) is used to account for the faster diffusion of the fraction of some elements which recoil into the pyrocoat (see Appendix I).

2.3 INPUT REQUIRED BY FIPDIF

The first data card* contains three indicators, each of which is written at the end of a four-column field. The meaning of these indicators is explained in Appendix II.

The second card contains five numbers, each of which is written at the end of a four-column field. NTOUT, the number of times output is desired, must be less than or equal to NTCALC, the number of time intervals to be used in representing a profile. The remaining three numbers listed on card 2 are adequately explained in Appendix II.

Card group number three consists of one card for each of the diffusion categories. Each card contains:

a. Infinite-temperature diffusion constant

b. Activation energy divided by the universal gas constant

c. Yield multiplier

These three numbers are written with decimal points (E format), in fields of ten columns.

It should be noted that, in order to simulate the diffusion characteristics of some rapdily-diffusing elements, it is necessary to represent them as two separate elements which have different diffusion parameters. (The possible causes for this phenomena are discussed in Appendix I). In cases where this condition exists, two diffusion categories must be provided for these elements and appropriate yield multipliers** must be assigned to each group (see Appendix I).

Card group number four consists of a list of the number of isotopes in the decay chains for which calculations are to be performed. The number of isotopes in a chain is computed by adding one to the number of radioactive isotopes in the chain. (The one is added because U^{235} is regarded as the first isotope of each chain, decaying with a decay

---

* A listing of data cards and formats used is given in Appendix II.

** When establishing decay chains which involve these elements, two isotopes must be listed to represent any isotope of an element which diffuses in this manner. The appropriate yield multiplier must then be applied as a multiplier for branching ratios of parents of these isotopes.

constant $\sigma\phi$ to form other members of the chain). As an example, if the first decay chain is A→B→C where C is stable, the number to be written in the fourth column of the first card is (3). Twenty numbers are punched on each card, corresponding to twenty decay chains. Each number is punched at the end of a four-column field. Enough cards are included to supply data on the decay chains of interest (no more than four cards will be used as calculations may be performed for a maximum of eighty decay chains).

Card group number five consists of indicators, one for each decay chain, that determine which of two options will be used in performing the diffusion calculations. The first option, which is called by placing a (1) in the appropriate column is slightly faster than the second option but is only useful for simple chains (such as the 144 chain). The second option is applicable for any chain. Unless computer time is at a great premium, it is recommended that this option, which is called by placing a (2) in the appropriate column, be used for all chains. Card group number five will consist of as many cards and numbers as does card group number four. Again, the numbers are punched, twenty to a card, at the ends of fields which are four columns wide.

Card group number six consists of one card sub-group for each nuclide considered. Each sub-group will consist of one card containing data pertaining to the isotope such as its decay constant, and one card which provides, for each parent of the isotope, the identification number* (in the chain) and the branching ratio for production of the isotope by decay of the parent (if the isotope has no parents, the second card is not included). The arrangement of data on these cards is discussed in Appendix II.

Card group number seven contains a list of the times at which output is desired. Eight numbers, with decimal points, are entered per card. These numbers are listed in fields ten columns wide. A maximum of forty output times may be requested and each must correspond to one of the calculation times listed in card group number eight.

Card group number eight consists of a list of times at the end of time intervals during which temperature and power level (fissions/second) are to be specified in each core section. The numbers are arranged in the same format as those in card group number seven. There must be as many or more of these times as are listed in card group number seven.

---

* Although U^{235} is not listed specifically as a parent of each isotope, it is regarded as such and the first isotope of each decay chain such as LA-144, is assigned the number (2).

Card group number nine consists of a series of card sub-groups. There is one sub-group, listing power and temperature as a function of time, for each core section. Each sub-group contains as many pairs of numbers as there are times listed in card group number eight. Each pair of numbers consists of a section power level (fissions/second) and a temperature ($^{\circ}$K) corresponding to the core section during the time interval. These data pairs are listed sequentially, four to a card. Each power level and temperature is punched with an E10.0 format in fields of ten column width.

Card group number ten contains a list of pairs of data, one for each core section. The first piece of data in a pair is the volume of the section (cm^3). The second is the weight of U^{235} in the section (grams). These data pairs are entered four to a card. The volumes and weights are punched with an E10.0 format.

Card group number eleven is not included unless there are initial concentrations of fission products at the start of a problem*. In the event that it is desired to input initial concentration of fission products, the following cards must be prepared for each core section:

> For each chain, a group of cards (one or two) must be prepared which list the number of curies of each member of the chain (beginning with the second member) which are present in the section. These numbers are punched, eight to a card, with an E 10.0 format.

Card group number twelve consists of one card which may be used to describe the computer run.

---

* If an initial fission product concentration does exist, due to an earlier reactor run, it is simpler to include a simulation of the former run and the ensuing shutdown period together with the reactor run to be simulated.

2.4 OUTPUT OBTAINED FROM FIPDIF

There are four options which may be used to obtain output from FIPDIF*. The type of output desired is indicated by placing a number (1, 2, 3, or 4) in the twelfth column of the first card. Selection of option (1) will cause the fission product inventories to be printed as a function of core section as well as totals for the core. If option (2) is selected, only the total core inventories are printed. Selection of option (3) causes the curies of each isotope which have diffused from each section of the core to be printed, plus the total number of curies of each isotope which have diffused from the core. In addition, the data requested in option (1) is printed. If option (4) is selected, the total number of curies which remain in the core (as per option (2)) and the total number which diffused are printed.

If option (1) or (2) is specified, calculations of the quantities of the isotopes which diffuse will not be performed**. Options (3) or (4) involve the use of a scratch tape and greatly increase the computer time required. They should not be requested unless the additional data provided is needed.

---

* See Appendix II.

** Calculated core inventories will however, appropriately reflect the diffusion.

APPENDIX I

1.0 EXPERIMENTAL DETERMINATION OF DIFFUSION RATES

Experiments have shown that the diffusion of fission products within NERVA fuel will occur at temperatures above 1500°C, with the diffusion rate increasing sharply at temperatures above 2300°C.[1] The fuel temperatures expected in the NERVA reactor at normal operating power will exceed 1500°C in the lower end of the core and will reach approximately 2200°C at the exit end of the core.[2] At these temperatures, the diffusion of fission products affords a mechanism whereby the fission products can be released from the core, thus reducing the fission product inventory. Analytical studies have shown that considerably higher temperatures will be reached from decay heat after shutdown with loss of coolant. Under these conditions, a substantial loss of fission products could occur. In order to calculate these losses, the fission product diffusion rates must be experimentally measured.

The diffusion of elements through a composite medium is an involved physico-chemical process, the rate of which cannot be predicted from a theoretical basis. Only by experimental means may diffusion rates be evaluated. Therefore, in order to determine the extent to which isotopes diffuse from a NERVA core, it is necessary to determine the diffusion rate of each of 273 isotopes comprising the fission product inventory. This appears a formidable task, however, two facts reduce the complexity of the problem considerably:

1. The diffusion rates of all isotopes of an element may be considered to be equal, and

2. After 2 to 30 minutes power operation, 92% of the total activity in the fuel at shutdown is due to 20 elements comprising 142 isotopes. Each of these elements contributes 0.7% or more to the total activity.

A listing of these elements and their relative per cent activity are given in Table I, for a 10 minute power operation. Although the relative percentages of individual isotopes vary with decay time, it had been shown by analysis using an existing fission product inventory code, FPIP, that the sum total of activity from these 20 elements comprises 92% of the total activity for infinite decay times.

Thus the problem of experimentally evaluating fission product diffusion reduces to measuring diffusion rates of 20 elements. At present, the diffusion rates of eleven of the elements have been measured. Isotopes used to study these elements are: Sr^{89}, Y^{91}, Zr^{95}, Mo^{99}, Ru^{103}, Te^{129}, I^{131}, Cs^{137}, Ba^{140}, La^{140}, and $Ce^{141-144}$. It is planned

that eventually all 20 elements will be examined.

1.1 EXPERIMENTAL PROCEDURE

In the experimental program the diffusion rates, of the elements mentioned above, are measured as a function of time and temperature. Fuel samples 0.25" in diameter and 0.25" long with a 0.097" diameter hole along the axis are cut from NERVA B-4 fuel elements. These samples are irradiated at temperatures less than 900°C to a total of $\sim 10^{17}$ nvt. Following irradiation, the samples are subjected to thermal anneal experiments to measure the fractional release of fission products as a function of time. The irradiated samples are heated in a vacuum of 10^{-4} torr at temperatures ranging from 1500°C to 2700°C for time intervals up to 30 minutes. A description of the experiments and apparatus used for the post-irradiation tests is given in Reference 1.

Following the post-irradiation heating, the specimens are dissolved and analyzed radiochemically to determine the fractional release of the various fission products.

1.2 ANALYSIS OF DIFFUSION RATE DATA

In this study, it was found that the fractional release of all nuclides could be described empirically by two simple equations. The first equation is:

$$1 - f = f_o e^{-Dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.2.1$$

where:

$1 - f$ = fraction retained

f_o = fraction of diffusing species initially present = 1

D = apparent diffusion constant

Equation 1.2.1 adequately described the release rate of the elements Ce, Y, I, Te, and Cs. The apparent diffusion constant, D, obtained in this manner has the dimension of reciprocal time units and is thus a rate constant.

The second equation is:

$$1 - f = Ge^{-D_1 t} + (1 - G)e^{-D_2 t} \quad \ldots\ldots\ldots\ldots 1.2.2$$

where:

(1 - f) = fraction of nuclide retained

The values of D_2 and (1 - G) are evaluated graphically from the experimentally obtained curves of log (1 - f) vs. time. D_1 and D_2 are apparent diffusion constants. D_1 and G are calculated by substitution in the above equation.

Equation 1.2.2 was found to apply to elements which had relatively fast diffusion rates, and whose release fraction as a function of time was characterized by an initial burst of activity. The initial burst has been attributed to nuclides deposited in the fuel beads by a recoil process during irradiation at a temperature below the threshold for diffusional release. During a post-irradiation thermal anneal at a temperature above the diffusion threshold, the fission product release can be thought of as originating from two sources: fission products from the UC_2 beads and fission products deposited outside the beads. The relative proportion of the release from these two sources is a function of the thermal anneal temperature. Samples which are irradiated at a temperature above the diffusion threshold temperature should release from the pyro-graphite coating on the bead that fraction of the nuclides deposited there by recoil as they are deposited. What one would anticipate during normal reactor operation is that a fraction of the nuclides which can escape the fuel beads by recoil will be released by the fuel at a rate D_1 and the remaining fission nuclide which remain in the UC_2 bead will escape the fuel at a rate D_2. The diffusion rates D_1 and D_2 can be determined from thermal anneal measurements on cold irradiated fuel. A value of the fraction of nuclides which escape the UC_2 bead by recoil may be calculated by consideration of the recoil path length of fission products in UC_2, and the diameter of the UC_2 fuel beads.

The fraction G of the inventory of a fission nuclide which escapes from a spherical fuel particle by recoil during fission is related to the recoil path length, Ra, and the radius of the sphere by the equation 1.4.6:

$$G = \frac{3}{16}\frac{(R-r)^4}{RaR^3} + \frac{1}{2}\frac{(R-r)^3}{R^3} - \frac{3}{8}\frac{(R^2 - Ra^2)}{(RaR^3)}(R - r)^2$$

which is derived in Section 1.4.

The recoil path length of a fission product in UC_2 is 11.2 microns as shown in Section 1.5. Using this recoil range of 11.2 microns and a nominal bead radius of 118

microns, the fraction of fission nuclides which will escape the UC_2 sphere is 0.138. Since the UC_2 beads in the fuel used in this study are comprised of a range of sizes from 32.5 to 85 microns in radius, an average recoil release over the range of radii must be calculated. This calculation outlined in Section 1.6 gives an average value of release by recoil of 0.145. The fraction of fission products released from NERVA fuel according to equation 2 is now given as:

$$(1 - f) = .145\, e^{-D_1 t} + .855 e^{-D_2 t} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1.2.3$$

This recoil deposition applies to all fission product nuclides; however, for those nuclides whose diffusion rates are slow, the burst effect was not observed. This lack of an initial burst effect is probably due to the slow diffusion rate of these nuclides in the graphite matrix surrounding the fuel beads.

The rate constant, D, was found to increase with temperature according to the Arhennius equation:

$$D = Do\ e^{-E/RT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2.4$$

where:

E = the activation energy in K-cals

R = the gas constant

T = the temperature in degrees Kelvin

This relationship held over the range 1500 to 2200°C. Values of D obtained from samples which had been heated at 2200°C for 20 minutes or longer or at 2300°C did not adhere to the Arhennius equation. Subsequent photomicrographs of these samples showed degradation of the pyrocoat and dispersion of the UC_2 bead into the graphite lattice. This dispersion of UC_2, resulting in small crystallities, permits more rapid diffusion of fission products and corresponding increases in the rate constants. Such alteration of the character of the fuel limits the applicability of the diffusion constants to reactor conditions where temperatures of 2200°C are not maintained for more than 15 minutes.

1.3 CLASSIFICATION OF NUCLIDES

Table 1 gives the relative contribution of various fission products to the radioactivity of fuel ten minutes after thermal fission of U^{235}. The elements have been arranged into groups given in Table 2 according to their experimentally determined diffusion rates.

At present, diffusion rate data is available for only 11 of the 20 elements. The remaining elements have been placed in the various categories according to diffusion data obtained by Bryant[4]. It should be noted that the fuel used by Bryant for diffusion studies consisted of 10 micron diameter uncoated UC_2 crystallites dispersed homogeneously throughout a graphite lattice. These smaller uncoated particles would give greater nuclide release fractions than the corresponding release fractions from beaded fuel, however, Bryant's original element classification has been retained for those elements which were not analyzed for in this present study. These elements will be re-classified as diffusion data from beaded fuel becomes available.

For each diffusion group, values of Do and E/R are given. Those elements which require two exponential terms (equation 1.2.2) to describe their diffusional behavior have been separated into two classifications encompassing diffusion groups 1 through 4 (see Table II). Elements with the suffix O refer to that fraction of the nuclide atoms that constitute the burst release. Accordingly, these groups have been assigned .145 contribution factors as previously described. Elements which have been classified according to their diffusion rates from beaded fuel are denoted by asterisks. The elements without asterisks have been classified according to Bryant's data. Those elements included in group seven have zero values of Do and E/R since these elements were not released from NERVA fuel under the range of time and temperature conditions to which the fuel samples were subjected and which are expected during normal operation.

TABLE I

Per cent contribution of fission elements to total activity after ten minutes NERVA operation:

Element	%	Element	%
Rb	10.01	La	3.77
Nb	7.94	I	3.40
Sr	7.90	Sb	3.32
Y	7.89	Ce	3.21
Zr	6.70	Mo	3.10
Cs	6.57	Te	2.61
Kr	6.57	Se	2.19
Ba	5.10	Sn	1.25
Br	5.14	As	0.72
Xe	4.81	Ru	0.70
			92.90

TABLE II

Classification of Elements for FIPDIF in Type II Fuel

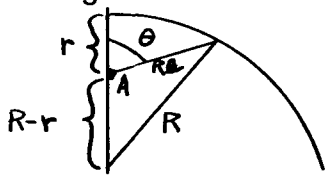
Diffusion Group	f	Do	E/R	Element
1	0.855	3.977×10^{2}	3.32×10^{4}	Sr* Sn Sb Br
2	0.145	8.70	1.55×10^{4}	Sr*-0 Sn-0
3	0.855	1.80×10^{-3}	6.00×10^{3}	Ba*
4	0.145	9.17×10^{-3}	2.50×10^{3}	Ba*-0
5	1	1.215	3.22×10^{4}	Ce* Y* La* Kr Xe
6	1	5.383×10^{10}	8.72×10^{4}	I* Cs* Te* Se Rb As
7	1	0	0	Mo* Zr* Ru* Nb

* Nuclides analyzed for were:

Sr^{89}, Ba^{140}, Ce^{144}, Y^{91}, La^{140}, I^{131}, Te^{129}, Cs^{137}, Mo^{99}, Zr^{95}, Ru^{103}

1.4 SPHERICAL MODEL FOR CALCULATION OF ESCAPE OF FISSION FRAGMENTS

Consider a fission fragment of recoil path length, Ra, originating at Point A a distance r from the surface of a spherical fuel bead of radius, R. If a line equal to Ra is drawn from Point A to the surface, the angle subtended between Ra and a radius through Point A is θ.



When the particle originates within recoil distance of the surface, the probability of release of the particle from the sphere is:

$$P = \int_0^{\theta} 2\pi \sin\theta \, d\theta / 4\pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.4.1$$

Integrating equation 1.4.1 and rearranging we get:

$$P = \frac{1 - \cos\theta}{2}$$

The volume of the spherical shell containing fission fragments within recoil distance of the surface is:

$$dv = 4\pi (R-r)^2 \, d\,(R-r) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.4.2$$

a relationship between the angle θ and (R-r) is given by:

$$-\cos\theta = \frac{Ra^2 + (R-r)^2 - R^2}{2(R-r)\,Ra}$$

thus $$P = \frac{1}{2}\left[1 + \frac{Ra + (R-r) - R}{2(R-r)\,Ra}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1.4.3$$

Combining equations 1.4.2 and 1.4.3 we get:

$$Pdv = \frac{\pi}{Ra}\left[(R-r)^3 + 2\,Ra(R-r)^2 - (R^2 - Ra)\,(R - r)\right] d(R - r) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1.4.4$$

Integrating equation 1.4.4 between the limits (R - Ra) to R gives:

$$\frac{\pi}{Ra}\left[\frac{(R - r)^4}{4} + \frac{2}{3}Ra(R - r)^3 - \frac{1}{2}(R^2 - Ra^2)\,(R - Ra)^2\right] \quad 1.4.5$$

The fractional release G is now obtained by dividing equation 1.4.5 by an expression for the volume of a sphere which gives:

$$G = \frac{3}{16}\frac{(R-r)^4}{RaR^3} + \frac{1}{2}\frac{(R-r)^3}{R^3} - \frac{3}{8}\frac{R^2 - Ra^2}{RaR^3}(R-r)^2 \quad \ldots\ldots 1.4.6$$

1.5 CALCULATION OF THE RANGE OF A FISSION FRAGMENT IN UC_2

During the fission process, the kinetic energy imparted to a fission fragment is 167 mev.

If two particles result, the kinetic energy apportioned between them is given by:

$$E = \frac{1}{2} M_1 V_1^2 + \frac{1}{2} M_2 V_2^2 \quad \ldots\ldots 1.5.1$$

where M_1 = mass of 1st fragment

V_1 = velocity of 1st fragment

M_2 = mass of second fragment

V_2 = velocity of second fragment

for Sr^{89} $M_1 = 89$

$M_2 = 235 - 89 = 146$

from conservation of momentum

$$M_1 V_1 = M_2 V_2 \quad \ldots\ldots 1.5.2$$

Expressing E in ergs and masses in gms a value of V_1 may be obtained by substitution into equation 1.5.1.

$$V_1 = 1.50 \times 10^9 \text{ cm/sec}$$

The corresponding energy of an alpha particle traveling at this velocity from the expression for kinetic energy, $E = \frac{1}{2} MV^2$, is 4.691 Mev.

The range in air of a 4.691 Mev alpha particle is 3.90 mg/cm^2.

The range of this α particle in uranium and in graphite may be determined by the empirical expression[4]:

$$\frac{R_Z}{Ra} = 0.90 + 0.0275\ Z + (0.06 - 0.0086\ Z) \text{ Log } E/M \quad \ldots\ldots \quad 1.5.3$$

where:

R_Z = the range in material with atomic number Z

Ra = the range in air

M = mass number of particle = 4 for an alpha particle

E = energy in Mev

The range of an alpha particle in uranium and in graphite were found to be 13.14 and 3.90 mg/cm^2 respectively.

The range of an alpha particle in UC_2 may be calculated by the Bragg relationship[4]:

$$\frac{1}{R_{UC_2}} = \frac{W_1}{R_U} + \frac{W_2}{R_C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.5.4$$

where:

R_{UC_2} = range in UC_2

R_U = range in uranium

R_C = range in carbon

W_1 = weight fraction uranium

W_2 = weight fraction carbon

The range of 4.69 Mev alpha particle in UC_2 is thus 10.78 mg/cm^2.

Dividing by the density of UC_2 and converting centimeters to microns the range is:

$10.781/1.128 = 9.56\mu$

The range of a fission fragment, R_f, may now be determined by the relationship[5]:

$$\frac{R_f}{R_\alpha} = 7 \left(\frac{A}{Z^{2/3}}\right) \left(\frac{e^2}{\hbar v}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots 1.5.5$$

where:

A = mass number of fission fragment

Z = atomic number of fission fragment

e = charge on the electron

$\hbar$ = Plank's constant/2π

v = velocity of fragment

R_α = range of alpha particle with velocity, v

Substituting the appropriate values for Sr^{89} in equation 1.5.5, the range in UC_2 or the recoil path length is found to be: 11.24μ.

1.6 PROBABILITY OF ESCAPE OF A FISSION FRAGMENT FROM A SPHERICAL FUEL BEAD

The probability of escape of a fission fragment from a spherical fuel bead is given by equation 10, Section 1.4, which may be represented as:

$$G = \frac{\int_{R-Ra}^{R} f(R-r)\, d(R-r)}{4/3\, \pi R^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.6.1$$

where R is the radius of the fuel bead and Ra is the fission fragment recoil distance. Any random fuel batch contains fuel beads with radii that vary from 32.5 to 85 microns. Since the recoil distance of fission fragments is 11.2 microns, a substantial loss of fission fragments would occur from the smaller diameter beads while the loss from the largest diameter beads becomes negligible. Calculation of the release of fission fragments from the mean bead diameter would be in error, since the contribution from the smaller diameter beads is proportionally greater than the retention of the larger diameter beads. What is needed then is a calculation of the recoil release from beads of various radii within the range 32.5 to 85

microns and corresponding weighting factors for each of these radii to account for their relative abundance in a fuel sample.

Quality control analysis of UC_2 fuel beads shows a typical distribution to be[6]:

Radius (microns)	w/o
32.5 - 35	2
35 - 50	48
50 - 82.5	48
82.5 - 85	2

These results are typical of a Gaussian distribution; consequently, a Gaussian distribution was chosen to determine weighting factors to apply to the various radii.

The probability, P, of having beads of radius m is given by:

$$p = \frac{1}{\sqrt{2\pi M}} e^{-\left(\frac{M-m}{2M}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.6.2$$

where M is the mean bead radius.

Using equation 1.6.2 weighting factors were determined for 14 bead radii equally spaced about the mean bead diameter. The total recoil fractional release was now determined by taking the sum of the products of the recoil fractional release calculated for each radii according to equation 1.6.2 and the corresponding weighting factor.

hence:

$$G_{(total)} = \sum_{R=32.5}^{R=85} \left\{ R - Ra \int^{R} \frac{f(R-r)\,d(R-r)}{4/3\,\pi R^3} \right\} \left\{ \frac{1}{(2\pi M)^{\frac{1}{2}}} \right\} e^{\frac{-(M-R)^2}{2M}} \quad \ldots\ldots\ldots\ldots \quad 1.6.3$$

$$G = .145$$

APPENDIX II

FIPDIF INPUT

Card	Column		Data	Format
1	1- 4	INDT = 1:	Read nuclear data from cards.	I4
		INDT = 2:	Read nuclear data from tape (Library tape has not yet been constructed).	
	5- 8	INIC = 1:	Initial fission product concentrations are zero.	
		INIC = 2:	Initial fission product concentrations are to be read from cards.	
	9-12	INDOUT = 1:	Fission product inventories are to be printed out by section. Totals for the core are also printed out.	
		INDOUT = 2:	Total core inventory is printed.	
		INDOUT = 3:	Core inventories plus curies of isotopes which have diffused are printed. Total inventories and curies diffused are also printed.	
		INDOUT = 4:	Total inventories and curies diffused are printed.	
2	1- 4	NTOUT:	Number of times output is desired. $\leq$ 40	I4
	5- 8	NOSEC:	Number of core sections. $\leq$ 10	I4
	9-12	NOGRP.	Number of diffusion categories. $\leq$ 20	I4
	13-16	NOCHAN:	Number of decay chains. $\leq$ 80	I4
	17-20	NTCALC:	Number of time intervals during which different power levels and temperatures exist. $\leq$ 40	I4

Card	Column		Data	Format
	50-52	IDI (1, 2).	Diffusion group for isotope (1, 2).	I3
	53-55	NPAR:	Number of direct parents of isotope (1, 2). Do not include U^{235} as a parent.	I3
6-II	1- 9	NAME (1, 3).	Name of third isotope of first decay chain.	A6, A3
		Etc.		
6-II-A	1- 5		Identification number of first parent of isotope (1, 3).	I5
	6-15		Branching ratio for decay of first parent in formation of isotope (1, 3).	E10.0
	16-20		Identification number of second parent (1, 3).*	I5
	21-25		Etc.	
7-I	1-10	TOUT (1)	First time (other than zero time) at which output is desired. (See page 6)	E10.0
	11-20	TOUT (2)	Second time at which output is desired.	
		Etc.		
8-I	1-10	TCALC (1	End of first time interval during which power and temperature are to be specified.	E10.0
	11-20	TCALC (2):	End of second time interval during which power and temperature are to be specified.	E10.0
		Etc.		

*Note: Isotopes in a chain should be assigned identification numbers, within the chain, such that no isotope has a parent with a higher identification number.

Card	Column		Data	Format
9-I-A	1-10	P (1, 1):	Power in first core section during first time interval.	E10.0
	11-20	TEMP (1, 1):	Temperature (^{o}K) in first core section during first time interval.	E10.0
	21-30	P (1, 2):	Power in first core section during second time step.	E10.0
		Etc.		
9-I-B	1-10	P (1, 5):	Power in first core section during fifth time interval.	E10.0
		Etc.		
9-II-A	1-10	P(2, 1):	Power in second core section during first time interval.	E10.0
		Etc.		
10-I	1-10	VSEC (1):	Volume of first core section (cm^3)	E10.0
	11-20	WTU25 (1):	Weight of U^{235} in first core section (grams)	E10.0
	21-30	VSEC (2):	Volume of second core section (cm^3)	E10.0
		Etc.		
	OMIT CARD GROUP ELEVEN IF INIC = 1			
11			See page 7 .	
12	1-80		Description of problem being run.	20A4

APPENDIX III

FORTRAN LISTING OF FIPDIF CODE

The fortran listing of the program consists of a main program and three sub-[redacted]tines. The main program is used to read input data and perform preliminary calculations. The sub-routine MAIN calculates residual inventory and curies of activity diffused. MAIN calls EXINT which performs the multiple integrations required for the inventory and diffusion calculations. The sub-routine FIPOUT prints out the desired information at the times requested.

```
      COMMON INDT,INIC,INDOUT,INFOUT,NOSEC,NOGRP,NOCHAN,NTCALC,NTOUT,NT,
     1DO,EQ,F,NISOT,BR,NAME,NAMEND,DECON,YIELD,EBETA,EGAM,IDI ,NPAR,
     2TOUT,TCALC,P,TEMP,V,WTU25,  C,A,EXIN,E,R,T ,NTO ,VSEC ,BB,CC ,
     3 EXSUB,EXIND,TDCUR ,INDDEC
       EQUIVALENCE(BR,E),(C,TDCUR)
      DIMENSION DO(20),EQ(20),F(20),NISOT(80),BR(80,10,10),NAME(80,10) ,
     1NAMEND(80,10),DECON(80,10),YIELD(80,10),EBETA(80,10),EGAM(80,10),
     2IDI(80,10),IDPAR(10),B(10),TOUT(40),TCALC(40),
     3 P(15,40),TEMP(15,40),VSEC(15),WTU25(15),C(10,80,10),A(10),
     4 UR25N(15),TERM(20),E(80,10,10),R(80,10) ,DIFC(20),DESC(20)
     5,BB(12,12),CC(12,12),INDDEC(80),TDCUR(10,80,10)
  666 REWIND 12
      RIPT 5,1,INDT,INIC,INDOUT                                    NON-STANDARD
      INFOUT =1
      RIPT 5,1,NTOUT,NOSEC,NOGRP,NOCHAN,NTCALC                     NON-STANDARD
      GO TO (2,3),INDT
    3  CONTINUE
      GO TO 9
    2 DO 7 NG=1,NOGRP
    7 RIPT 5,8,DO(NG),EQ(NG),F(NG)                                 NON-STANDARD
      RIPT 5,1,(NISOT(NCH),NCH=1,NOCHAN)                           NON-STANDARD
      RIPT 5,1,(INDDEC(NCH),NCH=1,NOCHAN)                          NON-STANDARD
      DO 4 NCH=1,NOCHAN
      NIS=NISOT(NCH)
      BR(NCH,1,1)=0.
      DO 4 NI=2,NIS
      RIPT 5,6,NAME(NCH,NI),NAMEND(NCH,NI),DECON(NCH,NI),YIELD(NCH,NI),  NON-STANDARD
     2EBETA(NCH,NI),EGAM(NCH,NI),IDI (NCH,NI),NPAR                 NON-STANDARD
      BR(NCH,1,NI)=0.
      ID=IDI (NCH,NI)
      BR(NCH,NI,1)=YIELD(NCH,NI)*F(ID)
      DO 32 NN=2,NIS
   32 BR(NCH,NI,NN)=0.
      NP=NPAR
      IF(NP-1) 60,61,61
   60 GO TO 4
   61 RIPT 5,50,((IDPAR(N),B(N)),N=1,NP)                           NON-STANDARD
      DO 5 N=1,NP
      NN=IDPAR(N)
    5 BR(NCH,NI,NN)=B(N)
    4 CONTINUE
    9 RIPT 5,8,(TOUT(NT),NT=1,NTOUT)                               NON-STANDARD
      RIPT 5,8,(TCALC(NT),NT=1,NTCALC)                             NON-STANDARD
```

```
      COMMON INDT,INIC,INDOUT,INP[redacted]HAN,NT[redacted]UT,NT,      9/18/64
      DO 10 NS=1,NOSEC
   10 RIPT 5,8,((P(NS,NT),TEMP(NS,NT)',NT=1,NTCALC)                    NON-STANDARD
      RIPT 5,8,((VSEC(NS),WTU25(NS)),NS=1,NOSEC)                       NON-STANDARD
      GO TO (20,21),INIC
   20 DO 30 NS=1,NOSEC
      DO 30 NCH=1,NOCHAN
      DO 30 NI=2,NIS
   30 C(NS,NCH,NI)=0.
      GO TO 40
   21 DO 22 NS=1,NOSEC
      DO 22 NCH=1,NOCHAN
   22 RIPT 5,8,(C(NS,NCH,NI),NI=2,NIS)                                 NON-STANDARD
      DO 222 NS=1,NOSEC
      DO 222 NCH=1,NOCHAN
      NIS=NISOT(NCH)
      DO 222 NI=2,NIS
  222 C(NS,NCH,NI)=C(NS,NCH,NI)*3.7*10.**10/(DECON(NCH,NI)*.6025)
   50 FORMAT(5(I5,E10.0))
    8 FORMAT(8E10.0)
    6 FORMAT(A6,A3,4E10.0,2I3)
    1 FORMAT(20I4)
   40 CALL MAIN
      GO TO 666
      END
```

[redacted] STORAGE NOT USED BY [redacted]RAM

DEC	OCT	DEC	OCT
640	01200	8316	20174

STORAGE LOCATIONS FOR VARIABLES APPEARING IN COMMON STATEMENTS

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
A	9514	22452	BB	8686	20756	BR	32561	77461	CC	8542	20536
C	24561	57761	DECON	14811	34733	DO	16551	40247	EBETA	13211	31633
EGAM	12411	30173	EQ	16531	40223	E	32561	77461	EXIND	8397	20315
EXIN	9504	22440	EXSUB	8398	20316	F	16511	40177	IDI	11611	26533
INDDEC	8396	20314	INDOUT	16559	40257	INDT	16561	40261	INFOUT	16558	40256
INIC	16560	40260	NAMEND	15611	36373	NAME	16411	40033	NISOT	16491	40153
NOCHAN	16555	40253	NOGRP	16556	40254	NOSEC	16557	40255	NPAR	10811	25073
NTCALC	16554	40252	NTO	8702	20776	NTOUT	16553	40251	NT	16552	40250
P	10730	24752	R	9503	22437	TCALC	10770	25022	TDCUR	24561	57761
TEMP	10130	23622	TOUT	10810	25072	T	8703	20777	V	9530	22472
VSEC	8701	20775	WTU25	9529	22471	YIELD	14011	33273			

STORAGE LOCATIONS FOR VARIABLES APPEARING IN DIMENSION AND EQUIVALENCE STATEMENTS

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
B	629	01165	DESC	564	01064	DIFC	584	01110	IDPAR	639	01177
TERM	604	01134	UR25N	619	01153						

STORAGE LOCATIONS FOR VARIABLES NOT APPEARING IN COMMON, DIMENSION, OR EQUIVALENCE STATEMENT

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
ID	544	01040	NCH	543	01037	NI	542	01036	NIS	541	01035
NN	540	01034	NP	539	01033	NS	538	01032			

SYMBOLS AND LOCATIONS FOR SOURCE PROGRAM FORMAT STATEMENTS

	EFN	LOC		EFN	LOC		EFN	LOC		EFN	LOC
8)1	1	00777	8)6	6	01002	8)8	8	01004	8)11	50	01007

LOCATIONS FOR OTHER SYMBOLS NOT APPEARING IN SOURCE PROGRAM

[redacted]

COMMON IND',INIC,INDOUT,INFOUT,NOSEC,NOGRP,NOCHAN,NTCALC,NTOUT,NT, 9/18/64

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
1)	520	01010	2)	492	00754	3)	501	00765	4)	32767	77777
6)	505	00771	A)201	473	00731	C GO	524	01014	C)G2	525	01015
C)G3	526	01016	C)G7	527	01017	C)100	528	01020	C)1G0	529	01021
C)1G1	530	01022	C)1G2	531	01023	C)1G3	532	01024	C)1G4	533	01025
C)201	534	01026	C.202	535	01027	C.203	536	01030	C)204	537	01031
D)10F	204	00314	D)10K	236	00354	D)11G	406	00626	D)11H	413	00635
D)111	438	00666	D)311	437	00665	D)40B	151	00227	D)40C	189	00275
D)60B	150	00226	D)711	436	00664	E)E	202	00312			

LOCATIONS OF NAMES IN TRANSFER VECTOR

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
EXP(2	4	00004	MAIN	5	00005	(FPT)	0	00000	(RTN)	3	00003
(RWT)	1	00001	(TSH)	2	00002						

ENTRY POINTS TO SUBROUTINES NOT OUTPUT FROM LIBRARY

EXP(2 MAIN (FPT) (RTN) (RWT) (TSH)

EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL

EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC
666	9	00017	3	16	00062	2	18	00063	7	19	00066
32	41	00276	60	44	00313	61	45	00315	5	55	00347
4	56	00355	9	57	00407	10	68	00450	20	85	00505
30	88	00536	21	90	00551	22	92	00602	222	101	00667
40	102	00725									

SYMBOL TABLE PRECEDES PROGRAM CARD IN BINARY DECK

```
      SUBROUTINE EXINT(NA)
      COMMON INDT,INIC,INDOUT,INFOUT,NOSEC,NOGRP,NOCHAN,NTCALC,NTOUT,NT,
     1DO,EQ,F,NISOT,BR,NAME,NAMEND,DECON,YIELD,EBETA,EGAM,IDI ,NPAR,
     2TOUT,TCALC,P,TEMP,V,WTU25,  C,A,EXIN,E,R,T ,NTO ,VSEC ,BB,CC ,
     3 EXSUB,EXIND,TDCUR ,INDDEC
       EQUIVALENCE(BR,E),(C,TDCUR)
      DIMENSION DO(20),EQ(20),F(20),NISOT(80),BR(80,10,10),NAME(80,10) ,
     1NAMEND(80,10),DECON(80,10),YIELD(80,10),EBETA(80,10),EGAM(80,10),
     2IDI(80,10),IDPAR(10),B(10),TOUT(40),TCALC(40),
     3 P(15,40),TEMP(15,40),VSEC(15),WTU25(15),C(10,80,10),A(10),
     4 UR25N(15),TERM(20),E(80,10,10),R(80,10) ,DIFC(20),DESC(20)
     5,BB(12,12),CC(12,12),INDDEC(80),TDCUR(10,80,10)
      NAT=NA
      INDD=1
      IF(NAT-1) 2,2,3
    2 EXIN=(EXPF((A(1)-EXSUB)*T)-EXPF(-EXSUB*T))/A(1)
      EXIND=(EXPF((A(1)-EXSUB)*T)-EXPF(-EXSUB*T))/(A(1))**2 -(T/A(1))*
     1 EXPF(-EXSUB*T)
      GO TO 4
    3 CC(1,1)=1.0/A(1)
      CC(1,2)=-CC(1,1)
      BB(1,1)=A(1)
      BB(1,2)=0.
      DO 10 N=2,NAT
      NP1=N+1
      NM1=N-1
      SUMC=0.
      DO 11 M=1,N
      BB(N,M)=BB(NM1,M)+A(N)
      CC(N,M)=CC(NM1,M)/BB(N,M)
   11 SUMC=SUMC+CC(N,M)
      CC(N,NP1)=-SUMC
      BB(N,NP1)=0.
   10 NO=N
   31 EXIN=0.
      NP1=NO+1
      DO 12 M=1,NP1
   12 EXIN=EXIN+CC(NO,M)*EXPF((BB(NO,M)-EXSUB)*T)
      GO TO (4,4,5,5),INDOUT
    5 EXIND=0.
      DO 6 M=1,NO
    6 EXIND=EXIND+(CC(NO,M)/BB(NO,M))*(EXPF((BB(NO,M)-EXSUB)*T)-EXPF(-
     1EXSUB*T))
```

[redacted]

Card	Column		Data	Format
3-I	1-10	DO (1):	Diffusion constant for first diffusion group.	E10.0
	11-20	EQ (1):	Activation energy for first group - divided by the gas constant.	E10.0
	21-30	F (1):	Yield multiplier for first group. (This is used in the event that two categories are required to represent diffusion of one isotope.)	E10.0
3-II	1-10	DO (2):	Diffusion constant for second diffusion group.	E10.0
		Etc.		
4-I	1- 4	NISOT (1):	Number of isotopes in first chain. $\leq$ 10 (See page 5)	I4
4-II	1- 4	NISOT (21):	Number of isotopes in twenty-first chain. $\leq$10 (See page 5)	I4
		Etc.		
5-I	1- 4	INDDEC (1):	(See page 5)	I4
5-II	1- 4	INDDEC (21)		I4
		Etc.		
6-I	1- 9	NAME (1, 2):	Name of second isotope of first decay chain. (The first member of each chain is U^{235}.)	A6, A3
	10-19	DECON (1, 2):	Decay constant of this isotope.	E10.0
	20-29	YIELD (1, 2):	Fission yield.	E10.0
	30-39	EBETA (1, 2):	One third of end point beta energy (Mev).	E10.0
	40-49	EGAM (1, 2):	Decay gamma energy (Mev).	E10.0

```
      SUBROUTINE EXINT(NA)
      [redacted]
      EXIND=EXIND+CC(NO,NP1)*T*EXPF(-EXSUB*T)
    4 RETURN
      END
```


[redacted]

STORAGE NOT USED BY PROGRAM

DEC	OCT	DEC	OCT
390	00606	8316	20174

STORAGE LOCATIONS FOR VARIABLES APPEARING IN COMMON STATEMENTS

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
A	9514	22452	BB	8686	20756	BR	32561	77461	CC	8542	20536
C	24561	57761	DECON	14811	34733	DO	16551	40247	EBETA	13211	31633
EGAM	12411	30173	EQ	16531	40223	E	32561	77461	EXIND	8397	20315
EXIN	9504	22440	EXSUB	8398	20316	F	16511	40177	IDI	11611	26533
INDDEC	8396	20314	INDOUT	16559	40257	INDT	16561	40261	INFOUT	16558	40256
INIC	16560	40260	NAMEND	15611	36373	NAME	16411	40033	NISOT	16491	40153
NOCHAN	16555	40253	NOGRP	16556	40254	NOSEC	16557	40255	NPAR	10811	25073
NTCALC	16554	40252	NTO	8702	20776	NTOUT	16553	40251	NT	16552	40250
P	10730	24752	R	9503	22437	TCALC	10770	25022	TOCUR	24561	57761
TEMP	10130	23622	TOUT	10810	25072	T	8703	20777	V	9530	22472
VSEC	8701	20775	WTU25	9529	22471	YIELD	14011	33273			

STORAGE LOCATIONS FOR VARIABLES APPEARING IN DIMENSION AND EQUIVALENCE STATEMENTS

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
B	379	00573	DESC	314	00472	DIFC	334	00516	IDPAR	389	00605
TERM	354	00542	UR25N	369	00561						

STORAGE LOCATIONS FOR VARIABLES NOT APPEARING IN COMMON, DIMENSION, OR EQUIVALENCE STATEMEI

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
INDD	294	00446	NAT	293	00445	NM1	292	00444	NO	291	00443
NP1	290	00442	N	289	00441	SUMC	288	00440			

LOCATIONS FOR OTHER SYMBOLS NOT APPEARING IN SOURCE PROGRAM

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
1)	275	00423	2)	264	00410	3)	267	00413	6)	269	00415
A)103	238	00356	A)105	251	00373	C)G1	281	00431	C)G2	282	00432
C)101	283	00433	C)102	284	00434	C)103	285	00435	C)105	286	00436
C)200	287	00437	D)10C	233	00351	D)204	121	00171	D)604	120	00170
D)704	119	00167	E)2	71	00107						

[redacted]

LOCATIONS OF NAMES IN TRANSFER VECTOR

	DEC	OCT	DEC	OCT	DEC	OCT	DEC	OCT
EXP	0	00000						

ENTRY POINTS TO SUBROUTINES NOT OUTPUT FROM LIBRARY

EXP

EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATI

EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC
2	9	00025	3	12	00110	11	23	00201	10	26	00216
31	27	00231	12	30	00244	5	32	00273	6	34	00301
4	36	00352									

SYMBOL TABLE PRECEDES PROGRAM CARD IN BINARY DECK

[redacted]

```
      SUBROUTINE FIPOUT
      COMMON INDT,INIC,INDOUT,INFOUT,NOSEC,NOGRP,NOCHAN,NTCALC,NTOUT,NT,
     1DO,EQ,F,NISOT,BR,NAME,NAMEND,DECON,YIELD,EBETA,EGAM,IDI ,NPAR,
     2TOUT,TCALC,P,TEMP,V,WTU25,  C,A,EXIN,E,R,T ,NTO ,VSEC ,BB,CC ,
     3 EXSUB,EXIND,TDCUR ,INDDEC
      DIMENSION DO(20),EQ(20),F(20),NISOT(80),BR(80,10,10),NAME(80,10) ,
     1NAMEND(80,10),DECON(80,10),YIELD(80,10),EBETA(80,10),EGAM(80,10),
     2IDI(80,10),IDPAR(10),B(10),TOUT(40),TCALC(40),
     3 P(15,40),TEMP(15,40),VSEC(15),WTU25(15),C(10,80,10),A(10),
     4 UR25N(15),TERM(20),E(80,10,10),R(80,10) ,DIFC(20),DESC(20)
     5,BB(12,12),CC(12,12),INDDEC(80),TDCUR(10,80,10)
       EQUIVALENCE(BR,E),(C,TDCUR)
      IF(INFOUT-1) 10,10,11
   10 RIPT 5,1,DESC                                          NON-STANDARD
    1 FORMAT (20A4)
      WOT 6,2,DESC                                           NON-STANDARD
    2 FORMAT(1H1,15X,///////////////////////,20A4)
      WOT 6,3                                                NON-STANDARD
    3  FORMAT(1H1/////,40X,25H INITIAL CONDITIONS          )
      GO TO (4,5),INIC
    4 WOT 6,6                                                NON-STANDARD
      GO TO 100
    6  FORMAT(1HO/////,35X,55H ALL INITIAL FISSION PRODUCT DENSITIES ARE
     1 ZERO          )
   11 WOT 6,30,TOUT(NTO)                                     NON-STANDARD
   30  FORMAT(1H1//////////////////////////,30X,29H TIME AFTER START OF PR
     1OBLEM ,2X,E10.4,7HSECONDS  )
      GO TO (5,96,5,96),INDOUT
    5 DO 7 NS=1,NOSEC
      WOT 6,8,NS,(TEMP(NS,1))                                NON-STANDARD
    8 FORMAT (1HO//,35X, 8H SECTION ,I2,3X, 2H (,E9.4,14H DEG. KELVIN ))
   60 WOT 6,50                                               NON-STANDARD
   50 FORMAT (1HO,10X,8HISOTOPE,8X,6HCURIES)
      DO 7 NCH=1,NOCHAN
      WOT 6,12                                               NON-STANDARD
   12 FORMAT(1HO)
      NIS=NISOT(NCH)
      WOT 6,13                                               NON-STANDARD
   13 FORMAT (1H )
   95 DO 14 NI=2,NIS
      CU=(C(NS,NCH,NI)/(3.7*(10.**10)))*(DECON(NCH,NI)*.6025 )
   14 WOT 6,15,NAME(NCH,NI),NAMEND(NCH,NI),CU                NON-STANDARD
   15 FORMAT '1H ,10X,A6,A3,5X,E10.4)
```

```
  7 CONTINUE
 96 WOT 6,33                                                          NON-STA
 33 FORMAT(1H1/////,32X,34H TOTAL INVENTORY - ALL SECTIONS          )
    WOT 6,34                                                          NON-STA
 34 FORMAT(1H ///)
    WOT 6,50                                                          NON-STA
    DO 77 NCH=1,NOCHAN
    NIS=NISOT(NCH)
    DO 77 NI=2,NIS
    SUM=0.
    DO 78 NS=1,NOSEC
 78 SUM=SUM+(C(NS,NCH,NI)/(3.7*(10.**10)))*DECON(NCH,NI)*.6025
 77 WOT 6,15,NAME(NCH,NI),NAMEND(NCH,NI),SUM                          NON-STA
    IF(NTO-NTOUT) 100,111,111
111 GO TO (100,100,101,101 ),INDOUT
101 WOT 6,999                                                         NON-STA
999 FORMAT (1H135X,/////////////////////////,17H CURIES RELEASED    )
    DO 44 NS=1,NOSEC
    DO 44 NCH=1,NOCHAN
    NIS=NISOT(NCH)
    DO 44 NI=1,NIS
 44 TDCUR(NS,NCH,NI)=0.
    REWIND 12
    NTC=0
    DO 36 NTT=1,NTOUT
    WOT 6,30,TOUT(NTT)                                                NON-STA
    NTCP1=NTC+1
    DO 35 NTC=NTCP1,NTCALC
    DO 37 NS=1,NOSEC
    DO 37 NCH=1,NOCHAN
    NIS=NISOT(NCH)
    DO 37 N=1,NIS
    NI=NIS-N+1
    READ TAPE 12,DCUR
 37 TDCUR(NS,NCH,NI)=TDCUR(NS,NCH,NI)+(DCUR/(3.7*10.**10)) *DECON(NCH,
   1NI)*.6025
    IF (TCALC(NTC)-TOUT(NTT)) 35,69,69
 69 GO TO (63,63,39,63),INDOUT
 39 DO 93 NS=1,NOSEC
    WOT 6,8,NS,(TEMP(NS,NTT))                                         NON-STA
    WOT 6,50                                                          NON-STA
    DO 93 NCH=1,NOCHAN
    WOT 6,12                                                          NON-STA
```

```
      WOT 6,13                                                          NON-STANDARD
      NIS=NISOT(NCH)
      DO 93 NI=2,NIS
   93 WOT 6,15,NAME(NCH,NI),NAMEND(NCH,NI),TDCUR(NS,NCH,NI)             NON-STANDARD
   63 WOT 6,38                                                          NON-STANDARD
   38 FORMAT(1H1/////,32X,36H TOTAL DIFFUSION - ALL SECTIONS          )
      WOT 6,34                                                          NON-STANDARD
      WOT 6,50                                                          NON-STANDARD
      DO 22 NCH=1,NOCHAN
      NIS=NISOT(NCH)
      DO 22 NI=2,NIS
      SUM=0.
      DO 89 NS=1,NOSEC
   89 SUM=SUM+TDCUR(NS,NCH,NI)
      WOT 6,15,NAME(NCH,NI),NAMEND(NCH,NI),SUM                          NON-STANDARD
   22 CONTINUE
      GO TO 36
   35 CONTINUE
   36 CONTINUE
  100 RETURN
      END
```


[redacted]

[redacted]

STORAGE NOT USED BY PROGRAM

DEC	OCT	DEC	OCT
960	01700	8316	20174

STORAGE LOCATIONS FOR VARIABLES APPEARING IN COMMON STATEMENTS

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
A	9514	22452	BB	8686	20756	BR	32561	77461	CC	8542	20536
C	24561	57761	DECON	14811	34733	DO	16551	40247	EBETA	13211	31633
EGAM	12411	30173	EQ	16531	40223	E	32561	77461	EXIND	8397	20315
EXIN	9504	22440	EXSUB	8398	20316	F	16511	40177	IDI	11611	26533
INODEC	8396	20314	INDOUT	16559	40257	INDT	16561	40261	INFOUT	16558	40256
INIC	16560	40260	NAMEND	15611	36373	NAME	16411	40033	NISOT	16491	40153
NOCHAN	16555	40253	NOGRP	16556	40254	NOSEC	16557	40255	NPAR	10811	25073
NTCALC	16554	40252	NTO	8702	20776	NTOUT	16553	40251	NT	16552	40250
P	10730	24752	R	9503	22437	TCALC	10770	25022	TDCUR	24561	57761
TEMP	10130	23622	TOUT	10810	25072	T	8703	20777	V	9530	22472
VSEC	8701	20775	WTU25	9529	22471	YIELD	14011	33273			

STORAGE LOCATIONS FOR VARIABLES APPEARING IN DIMENSION AND EQUIVALENCE STATEMENTS

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
B	949	01665	DESC	884	01564	DIFC	904	01610	IDPAR	959	01677
TERM	924	01634	UR25N	939	01653						

STORAGE LOCATIONS FOR VARIABLES NOT APPEARING IN COMMON, DIMENSION, OR EQUIVALENCE STATE

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
CU	864	01540	DCUR	863	01537	NCH	862	01536	NI	861	01535
NIS	860	01534	N	859	01533	NS	858	01532	NTCP1	857	01531
NTC	856	01530	SUM	855	01527						

SYMBOLS AND LOCATIONS FOR SOURCE PROGRAM FORMAT STATEMENTS

	EFN	LOC		EFN	LOC		EFN	LOC		EFN	LOC
8)1	1	01501	8)2	2	01477	8)3	3	01470	8)6	6	01460
8)8	8	01424	8)C	12	01404	8)D	13	01403	8)F	15	01402
8)U	30	01443	8)11	33	01375	8)12	34	01363	8)16	38	01347
8)1I	50	01412	8)V7	999	01361						

[redacted]

LOCATIONS FOR OTHER SYMBOLS NOT APPEARING IN SOURCE PROGRAM

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
1)	834	01502	2)	715	01313	3)	724	01324	6)	728	01330
A)101	683	01253	A)1G0	696	01270	C)G0	838	01506	C)G1	839	01507
C)G2	840	01510	C)G3	841	01511	C)G4	842	01512	C)G5	843	01513
C)100	844	01514	C)101	845	01515	C)102	846	01516	C)1G0	847	01517
C)200	848	01520	C)202	849	01521	C)204	850	01522	C)206	851	01523
C)207	852	01524	C)208	853	01525	C)20A	854	01526	D)107	143	00217
D)10L	316	00474	D)10S	393	00611	D)116	546	01042	D)214	494	00756
D)215	513	01001	D)21A	581	01105	D)21J	670	01236	D)307	142	00216
D)314	493	00755	D)316	545	01041	D)31A	580	01104	D)406	106	00152
D)40D	233	00351	D)40I	292	00444	D)412	481	00741	D)41C	625	01161
D)41L	678	01246	D)50D	232	00350	D)51C	624	01160	D)707	141	00215
D)716	544	01040									

LOCATIONS OF NAMES IN TRANSFER VECTOR

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
EXP(2	6	00006	(FIL)	5	00005	(RLR)	9	00011	(RTN)	2	00002
(RWT)	7	00007	(SLI)	1	00001	(SLO)	4	00004	(STH)	3	00003
(TSB)	8	00010	(TSH)	0	00000						

ENTRY POINTS TO SUBROUTINES NOT OUTPUT FROM LIBRARY

EXP(2 (FIL) (RLR) (RTN) (RWT) (SLI) (SLO) (STH)
(TSB) (TSH)

EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATIONS

EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN
10	21	00035	4	27	00067	11	29	00076	5	32	00114	
60	39	00136	95	44	00171	14	46	00242	7	48	00264	
96	49	00276	78	57	00357	77	58	00405	111	61	00445	
101	62	00452	44	67	00513	37	82	00664	69	84	00742	
39	85	00747	93	98	01043	63	100	01106	89	108	01167	
22	111	01214	35	113	01233	36	114	01237	100	115	01247	

[redacted]

SYMBOL TABLE PRECEDES PROGRAM CARD IN BINARY DECK

[redacted]

```
      SUBROUTINE MAIN
      COMMON INDT,INIC,INDOUT,INFOUT,NOSEC,NOGRP,NOCHAN,NTCALC,NTOUT,NT,
     1DO,EQ,F,NISOT,BR,NAME,NAMEND,DECON,YIELD,EBETA,EGAM,IDI ,NPAR,
     2TOUT,TCALC,P,TEMP,V,WTU25,  C,A,EXIN,E,R,T ,NTO ,VSEC ,BB,CC ,
     3 EXSUB,EXIND,TDCUR ,INDDEC
      DIMENSION DO(20),EQ(20),F(20),NISOT(80),BR(80,10,10),NAME(80,10) ,
     1NAMEND(80,10),DECON(80,10),YIELD(80,10),EBETA(80,10),EGAM(80,10),
     2IDI(80,10),IDPAR(10),B(10),TOUT(40),TCALC(40),
     3 P(15,40),TEMP(15,40),VSEC(15),WTU25(15),C(10,80,10),A(10),
     4 UR25N(15),TERM(20),E(80,10,10),R(80,10) ,DIFC(20),DESC(20)
     5,BB(12,12),CC(12,12),INDDEC(80),TDCUR(10,80,10)
        EQUIVALENCE(BR,E),(C,TDCUR)
      IF(INFOUT-1) 200,200,201
  200 CALL FIPOUT
      INFOUT=2
  201 DO 1 NS=1,NOSEC
      UR25N(NS)=(WTU25(NS)/235.)*10.**24
      DO 1 NCH=1,NOCHAN
    1 C(NS,NCH,1)=UR25N(NS)
      DO 6 NCH=1,NOCHAN
      NIS=NISOT(NCH)
      DO 6 NI=1,NIS
      DO 6 NP=2,NIS
    6 E(NCH,NI,NP)=BR(NCH,NI,NP)*DECON(NCH,NP)
      NTC=0
      DO 2 NTO= 1,NTOUT
      NTCP1=NTC+1
      DO  66 NTC=NTCP1,NTCALC
      NTO=NTO
      IF (NTC-1) 1000,1000,1001
 1000 T=TCALC(NTC)
      GO TO 1002
 1001 NTCM1=NTC-1
      T=TCALC(NTC)-TCALC(NTCM1)
 1002 DO 20 NS=1,NOSEC
      SIGPHI=P(NS,NTC)/(C(NS,1,1)*.6025  )
      DO 10 NCH=1,NOCHAN
      DECON(NCH,1)=SIGPHI
   10 R(NCH,1)=SIGPHI
      DO 3 NG=1,NOGRP
    3 DIFC(NG)=DO(NG)*EXPF(-EQ(NG)/TEMP(NS,NTC))
      DO 20 NCH=1,NOCHAN
      NIS=NISOT(NCH)
```

[redacted]

```
      DO 5 NI=2,NIS
      ID=IDI (NCH,NI)
    5 R(NCH,NI)=DECON(NCH,NI)+DIFC(ID)
      E(NCH,1,1)=0.
      DO 111 NI=2,NIS
      ID=IDI(NCH,NI)
  111 E(NCH,NI,1)=YIELD(NCH,NI)*F(ID)*DECON(NCH,1)
      DO 20 N=1,NIS
      NI=NIS-N+1
      EXSUB=R(NCH,NI)
      DD=R(NCH,NI)-DECON(NCH,NI)
      NTERM=NI-1
      IF(NTERM) 2001,2001,2006
 2001 STERM=0.
      STERMD=0.
        GO TO (20,20,21,21),INDOUT
 2006 INDD=INDDEC(NCH)
      STERM=0.
      STERMD=0.
      GO TO (2000,2222),INDD
 2222 CONTINUE
      DO 959 J=1,NTERM
      TERM=0.
      TERMD=0.
      IMJ=NI-J
      CMULT=C(NS,NCH,IMJ)
      IND1=NIS-(N+J-1)                                        3
      IND1P1=IND1+1
      JP1=IND1P1+J-1
      DO 808 L2=IND1P1,JP1
      L2=L2
      IF(E(NCH,L2,IND1)) 808,808,996
  996 INDTRM=1
      A(INDTRM)=R(NCH,L2)-R(NCH,IND1)
      COEF=E(NCH,L2,IND1)
      IF( L2 -NI) 995,818,818
  818 CALL EXINT(INDTRM)
      TERM=TERM+COEF*EXIN*CMULT
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      INDTRM=INDTRM-1
      GO TO 808
  995 COEF1=COEF
      L2P1=L2+1
```

[redacted]

```
      DO 807 L3=L2P1,JP1
      L3=L3
      COEF = COEF1
      IF(E(NCH,L3,L2)) 807,807,994
  994 INDTRM=INDTRM+1
      A(INDTRM)=R(NCH,L3)-R(NCH,L2)
      COEF=COEF*E(NCH,L3,L2)
      IF (L3-NI)  993,817,817
  817 CALL EXINT(INDTRM)
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      TERM=TERM+COEF*EXIN*CMULT
      INDTRM=INDTRM-1
      GO TO 807
  993 COEF2=COEF
      L3P1=L3+1
      DO 806 L4=L3P1,JP1
      COEF =COEF2
      IF(E(NCH,L4,L3)) 806,806,992
  992 INDTRM=INDTRM+1
      A(INDTRM)=R(NCH,L4)-R(NCH,L3)
      COEF=COEF*E(NCH,L4,L3)
      IF(L4-NI) 991,816,816
  816 CALL EXINT(INDTRM)
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      TERM=TERM+COEF*EXIN*CMULT
      INDTRM=INDTRM-1
      GO TO 806
  991 COEF3=COEF
      L4P1=L4+1
      DO 805 L5=L4P1,JP1
      COEF =COEF3
      IF(E(NCH,L5,L4))  805,805 ,990
  990 INDTRM=INDTRM+1
      A(INDTRM)=R(NCH,L5)-R(NCH,L4)
      COEF=COEF*E(NCH,L5,L4)
      IF(L5-NI) 989,815,815
  815 CALL EXINT(INDTRM)
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      TERM=TERM+COEF*EXIN*CMULT
      INDTRM=INDTRM-1
      GO TO 805
  989 COEF4=COEF
      L5P1=L5+1
```

[redacted]

```
      DO 804 L6=L5P1,JP1
      COEF =COEF4
      IF(E(NCH,L6,L5)) 804,804,988
  988 INDTRM=INDTRM+1
      A(INDTRM)=R(NCH,L6)-R(NCH,L5)
      COEF = COEF*E(NCH,L6,L5)
      IF(L6-NI) 987,814,814
  814 CALL EXINT(INDTRM)
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      TERM=TERM+COEF*EXIN*CMULT
      INDTRM=INDTRM-1
      GO TO 804
  987 COEF5=COEF
      L6P1=L6+1
      DO 803 L7=L6P1,JP1
      COEF = COEF5
      IF(E(NCH,L7,L6)) 803,803,986
  986 INDTRM=INDTRM+1
      A(INDTRM)=R(NCH,L7)-R(NCH,L6)
      COEF=COEF*E(NCH,L7,L6)
      IF(L7-NI) 985,813,813
  813 CALL EXINT(INDTRM)
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      TERM=TERM+COEF*EXIN*CMULT
      INDTRM=INDTRM-1
      GO TO 803
  985 COEF6=COEF
      L7P1=L7+1
      DO 802 L8=L7P1,JP1
      COEF =COEF6
      IF(E(NCH,L8,L7)) 802,802,984
  984 INDTRM=INDTRM+1
      A(INDTRM)=R(NCH,L8)-R(NCH,L7)
      COEF=COEF*E(NCH,L8,L7)
      IF(L8-NI) 983,812,812
  812 CALL EXINT(INDTRM)
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      TERM=TERM+COEF*EXIN*CMULT
      INDTRM=INDTRM-1
      GO TO 802
  983 COEF7=COEF
      L8P1=L8+1
      DO 801 L9=1,L8P1
```

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```
      COEF =COEF7
      IF(E(NCH,L9,L8)) 801,801,982
  982 INDTRM=INDTRM+1
      A(INDTRM)=R(NCH,L9)-R(NCH,L8)
      COEF=COEF*E(NCH,L9,L8)
      IF(L9-NI) 981,811,811
  811 CALL EXINT(INDTRM)
      TERM=TERM+COEF*EXIN*CMULT
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      INDTRM=INDTRM-1
      GO TO 801
  981 COEF8=COEF
      L9P1=L9+1
      DO 800 L10=L9P1,JP1
      COEF =COEF8
      IF(E(NCH,L10,L9)) 800,800,980
  980 INDTRM=INDTRM+1
      A(INDTRM)=R(NCH,L10)-R(NCH,L9)
      COEF=COEF*E(NCH,L10,L9)
      IF(L10-NI) 979,810,810
  810 CALL EXINT(INDTRM)
      TERM=TERM+COEF*EXIN*CMULT
      TERMD=TERMD+DD*COEF*EXIND*CMULT
      INDTRM=INDTRM-1
      GO TO 800
  979 WOT 6,960                                              NON-STANDARD
  960 FORMAT (33H ALLOWED CHAIN LENGTH EXCEEDED     )
  800 CONTINUE
      INDTRM=INDTRM-1
  801 CONTINUE
      INDTRM=INDTRM-1
  802 CONTINUE
      INDTRM=INDTRM-1
  803 CONTINUE
      INDTRM=INDTRM-1
  804 CONTINUE
      INDTRM=INDTRM-1
  805 CONTINUE
      INDTRM=INDTRM-1
  806 CONTINUE
      INDTRM=INDTRM-1
  807 CONTINUE
      INDTRM=INDTRM-1
```

```
  808 CONTINUE
      STERMD=STERMD+TERMD
  959 STERM=STERM+TERM
      GO TO (20,20,21,21),INDOUT
 2000 DO 8 J=1,NTERM
      STEND=0.
      STJUMP=0.
      IND1=NI-J
      IND2=IND1+1
      COEF1=1.0
      COEF =1.0
      DO 9 M=1,J
      COEF1=E(NCH,IND2,IND1)
      COEF=COEF*COEF1  *10.**3
      A(M)=R(NCH,IND2)-R(NCH,IND1)
      IND1=IND1+1
       MEX=M
    9 IND2=IND2+1
      CALL EXINT(J)
      STLND=(COEF*EXIND/(10.**(3*MEX)))*DD
  666 STLINE=(COEF*EXIN) /(10.**(3*MEX))
      IF(J-1) 11,11,12
   12 IND1=NIS-(N+J-1)
      COEF=E(NCH,NI,IND1)
      A(1)=R(NCH,NI)-R(NCH,IND1)
      CALL EXINT(1)
      STEND=COEF*EXIN
      STENDD=COEF*EXIND*DD
      IF(J-2) 11,11,13
   13 JL1=J-1
      IND1 =NIS-(N+J-1)
      IND2 =NIS-(N+J-1)
      DO 14 L=1,JL1
      IND2=IND2+1
      COEF1=E(NCH,IND2,IND1)
      COEF2=E(NCH,NI,IND2)
      COEF=COEF1*COEF2
      A(1)=R(NCH,IND2)-R(NCH,IND1)
      A(2)=R(NCH,NI)-R(NCH,IND2)
      CALL EXINT(2)
      TJUMP=COEF*EXIN
      TJUMPD=COEF*EXIND*DD
      STJMPD=STJMPD+TJUMPD
```

```
 14 STJUMP=STJUMP+TJUMP
    IF(NIS-3) 222,222,223
222 SKIP=0.
    GO TO 11
223 IF(J-3) 222,222,224
224 JM3=J-3
    SKIP=0.
    INDSUB=2
    DO 225 K=1,JM3
    IND1=NIS-(N+J-1)
    IND2=IND1+INDSUB
    MUP=J-INDSUB+1
    COEF=1.0
228 DO 226 M=1,MUP
    COEFM=E(NCH,IND2,IND1)
    COEF=COEF*COEFM
    A(M)=R(NCH,IND2)-R(NCH,IND1)
     IND1=IND2
226 IND2=IND2+1
    CALL EXINT(MUP)
    SKPTRM=COEF*EXIN
    SKTMD=COEF*EXIND*DD
    INDSUB=INDSUB+1
    SKIPD=SKIPD+SKPTMD
225 SKIP=SKIP+SKPTRM
 11 IMJ=NI-J
    CMULT=C(NS,NCH,IMJ)
    STERMD=STERMD+CMULT*(STLND+STENDD+STJMPD+SKIPD)
  8 STERM=STERM+CMULT*(STLINE+STEND+STJUMP+SKIP)
    GO TO (20,20,21,21),INDOUT
 21 A(1)=-R(NCH,NI)
    CALL EXINT(1)
    DCUR=STERMD+DD*C(NS,NCH,NI)* (EXPF(-R(NCH,NI)*T)-1.0)/(-R(NCH,NI))
    WRITE TAPE 12,DCUR
 20 C(NS,NCH,NI)=STERM+C(NS,NCH,NI)*EXPF(-R(NCH,NI)*T )
    IF(TCALC(NTC)-TOUT(NTO)) 66,4000,4000
 66 CONTINUE
4000 CALL FIPOUT
  2 CONTINUE
    RETURN
    END
```


[redacted]

STORAGE NOT USED BY PROGRAM

DEC	OCT	DEC	OCT
2355	04463	8316	20174

STORAGE LOCATIONS FOR VARIABLES APPEARING IN COMMON STATEMENTS

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
A	9514	22452	BB	8686	20756	BR	32561	77461	CC	8542	20536
C	24561	57761	DECON	14811	34733	DO	16551	40247	EBETA	13211	31633
EGAM	12411	30173	EQ	16531	40223	E	32561	77461	EXIND	8397	20315
EXIN	9504	22440	EXSUB	8398	20316	F	16511	40177	IDI	11611	26533
INDDEC	8396	20314	INDOUT	16559	40257	INDT	16561	40261	INFOUT	16558	40256
INIC	16560	40260	NAMEND	15611	36373	NAME	16411	40033	NISOT	16491	40153
NOCHAN	16555	40253	NOGRP	16556	40254	NOSEC	16557	40255	NPAR	10811	25073
NTCALC	16554	40252	NTO	8702	20776	NTOUT	16553	40251	NT	16552	40250
P	10730	24752	R	9503	22437	TCALC	10770	25022	TDCUR	24561	57761
TEMP	10130	23622	TOUT	10810	25072	T	8703	20777	V	9530	22472
VSEC	8701	20775	WTU25	9529	22471	YIELD	14011	33273			

STORAGE LOCATIONS FOR VARIABLES APPEARING IN DIMENSION AND EQUIVALENCE STATEMENTS

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
B	2344	04450	DESC	2279	04347	DIFC	2299	04373	IDPAR	2354	04462
TERM	2319	04417	UR25N	2334	04436						

STORAGE LOCATIONS FOR VARIABLES NOT APPEARING IN COMMON, DIMENSION, OR EQUIVALENCE STATEME

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
CMULT	2259	04323	COEF1	2258	04322	COEF2	2257	04321	COEF3	2256	04320
COEF4	2255	04317	COEF5	2254	04316	COEF6	2253	04315	COEF7	2252	04314
COEF8	2251	04313	COEFM	2250	04312	COEF	2249	04311	DCUR	2248	04310
DD	2247	04307	ID	2246	04306	IMJ	2245	04305	IND1P1	2244	04304
IND1	2243	04303	IND2	2242	04302	INDD	2241	04301	INDSUB	2240	04300
INDTRM	2239	04277	JL1	2238	04276	JM3	2237	04275	JP1	2236	04274
J	2235	04273	L10	2234	04272	L2P1	2233	04271	L2	2232	04270
L3P1	2231	04267	L3	2230	04266	L4P1	2229	04265	L4	2228	04264
L5P1	2227	04263	L5	2226	04262	L6P1	2225	04261	L6	2224	04260
L7P1	2223	04257	L7	2222	04256	L8P1	2221	04255	L8	2220	04254
L9P1	2219	04253	L9	2218	04252	MEX	2217	04251	M	2216	04250
MUP	2215	04247	NCH	2214	04246	NI	2213	04245	NIS	2212	04244
N	2211	04243	NS	2210	04242	[redacted] NTCM1	2209	04241	NTCP1	2208	04240
NTC	2207	04237	NTERM	2206	04236	SIGPHI [redacted]		35	SKIPD	2204	04234

SKIP	2203	04233	SKPTMD	2202	04232	SKPTRM	2201	04231	SKTMD	2200	04230
STENDD	2199	04227	STEND	2198	04226	STERMD	2197	04225	STERM	2196	04224
STJMPD	2195	04223	STJUMP	2194	04222	STLINE	2193	04221	STLND	2192	04220
TERMD	2191	04217	TJUMPD	2190	04216	TJUMP	2189	04215			

SYMBOLS AND LOCATIONS FOR SOURCE PROGRAM FORMAT STATEMENTS

	EFN	LOC		EFN	LOC		EFN	LOC		EFN	LOC
8)U0	960	04112									

LOCATIONS FOR OTHER SYMBOLS NOT APPEARING IN SOURCE PROGRAM

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
1)	2123	04113	2)	2094	04056	3)	2105	04071	6)	2110	04076
A)105	1973	03665	A)10E	1986	03702	A)1G5	1999	03717	A)1GF	2018	03742
A)1GG	2037	03765	A)1GH	2056	04010	A)1GI	2075	04033	A)20J	1960	03650
C)G1	2127	04117	C)G2	2128	04120	C)G3	2129	04121	C)G5	2130	04122
C)G6	2131	04123	C)G7	2132	04124	C)G8	2133	04125	C)G9	2134	04126
C)GB	2135	04127	C)100	2136	04130	C)101	2137	04131	C)102	2138	04132
C)103	2139	04133	C)104	2140	04134	C)105	2141	04135	C)106	2142	04136
C)107	2143	04137	C)108	2144	04140	C)109	2145	04141	C)10A	2146	04142
C)10B	2147	04143	C)10C	2148	04144	C)10D	2149	04145	C)10E	2150	04146
C)1G1	2151	04147	C)1G2	2152	04150	C)1G3	2153	04151	C)1G4	2154	04152
C)1G5	2155	04153	C)1G6	2156	04154	C)1G7	2157	04155	C)1G8	2158	04156
C)1G9	2159	04157	C)1GA	2160	04160	C)1GB	2161	04161	C)1GC	2162	04162
C)1GD	2163	04163	C)1GE	2164	04164	C)1GF	2165	04165	C)1GG	2166	04166
C)1GH	2167	04167	C)1GI	2168	04170	C)200	2169	04171	C)201	2170	04172
C)202	2171	04173	C)203	2172	04174	C)204	2173	04175	C)205	2174	04176
C)206	2175	04177	C)207	2176	04200	C)208	2177	04201	C)209	2178	04202
C)20A	2179	04203	C)20B	2180	04204	C)20C	2181	04205	C)20D	2182	04206
C)20E	2183	04207	C)20F	2184	04210	C)20G	2185	04211	C)20H	2186	04212
C)20I	2187	04213	C)20J	2188	04214	D)10I	195	00303	D)10S	381	00575
D)121	1215	02277	D)12P	1408	02600	D)133	1683	03223	D)208	85	00125
D)200	329	00511	D)20U	418	00642	D)211	503	00767	D)215	593	01121
D)219	687	01257	D)222	1222	02306	D)227	1288	02410	D)237	1784	03370
D)300	328	00510	D)311	502	00766	D)315	592	01120	D)319	686	01256
D)321	1214	02276	D)327	1287	02407	D)409	96	00140	D)40Q	357	00545
D)40T	408	00630	D)41D	779	01413	D)41H	869	01545	D)41L	959	01677
D)41P	1049	02031	D)429	1301	02425	D)42B	1314	02442	D)42D	1327	02457
D)42F	1340	02474	D)42H	1353	02511	D)42J	1366	02526	D)42L	1379	02543
D)42Q	1449	02651	D)439	1825	03441	D)43A	1864	03510	D)43G	1946	03632
D)509	95	00137	D)51D	778	01412	D)51H	868	01544	D)51L	958	01676
D)51P	1048	02030	D)52Q	144[redacted]		D)53G	194[redacted]	03631	D)60T	407	00627

[redacted]

D)629	1300	02424	D)62B	1313	02441	D)62D	1326	02456	D)62F	1339	02473
D)62H	1352	02510	D)62J	1365	02525	D)62L	1378	02542	D)639	1824	03440
D)63A	1863	03507	D)721	1213	02275	D)727	1286	02406	D)729	1299	02423
D)72B	1312	02440	D)72D	1325	02455	D)72F	1338	02472	D)72H	1351	02507
D)72J	1364	02524	D)72L	1377	02541	D)739	1823	03437	D)73A	1862	03506
E)12	510	00776	E)14	553	01051	E)16	602	01132	E)18	647	01207
E)1A	694	01266	E)1C	739	01343	E)1E	786	01422	E)1G	829	01475
E)1I	876	01554	E)1K	919	01627	E)1M	966	01706	E)1O	1009	01761
E)1Q	1056	02040	E)1U	1129	02151	E)20	1174	02226	E)24	1264	02360

LOCATIONS OF NAMES IN TRANSFER VECTOR

	DEC	OCT		DEC	OCT		DEC	OCT		DEC	OCT
EXINT	3	00003	EXP	2	00002	EXP(2	1	00001	FIPOUT	0	00000
(FIL)	5	00005	(STB)	6	00006	(STH)	4	00004	(WLR)	7	00007

ENTRY POINTS TO SUBROUTINES NOT OUTPUT FROM LIBRARY

EXINT EXP EXP(2 FIPOUT (FIL) (STB) (STH) (WLR)

EXTERNAL FORMULA NUMBERS WITH CORRESPONDING INTERNAL FORMULA NUMBERS AND OCTAL LOCATION

EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EFN	IFN	LOC	EF
200	8	00027	201	10	00034	1	13	00064	6	18	00141	
1000	25	00226	1001	27	00231	1002	29	00241	10	33	00317	
3	35	00326	5	40	00516	111	44	00552	2001	51	00631	
2006	54	00643	2222	58	00656	996	70	01000	818	74	01016	
995	79	01053	994	85	01134	817	89	01154	993	94	01211	
992	99	01270	816	103	01310	991	108	01345	990	113	01424	
815	117	01444	989	122	01477	988	127	01556	814	131	01576	
987	136	01631	986	141	01710	813	145	01730	985	150	01763	
984	155	02043	812	159	02064	983	164	02115	982	169	02153	
811	173	02173	981	178	02230	980	183	02307	810	187	02327	
979	192	02362	800	193	02370	801	195	02411	802	197	02426	
803	199	02443	804	201	02460	805	203	02475	806	205	02512	
807	207	02527	808	209	02544	959	211	02554	2000	213	02572	
9	226	02707	666	229	02751	12	231	02774	13	238	03043	
14	252	03164	222	254	03177	223	256	03202	224	257	03207	

[redacted]

228	265	03267	226	270	03317	225	276	03361
8	280	03413	21	282	03442	20	287	03511
4000	290	03633	2	291	03640			

11	277	03371
66	289	03623

SYMBOL TABLE PRECEDES PROGRAM CARD IN BINARY DECK

[redacted]

BEGIN LOAD TIME 16.048

ENTRY POINTS TO SUBROUTINES REQUESTED FROM LIBRARY,

(FPT)	(RWT)	(TSHM)	(RTN)	EXP(2	EXP	(SLI)	(STHM)	(SLC
(TSB)	(RLR)	(STB)	(WLR)					

SUBROUTINE ENTRY POINTS AND STARTING LOCATIONS UPPER PROGRAM 16252 LOWER COMMON 20174

	ENTRY	START		ENTRY	START		ENTRY	START		ENTRY	START
MAIN-P	00152	00144	EXINT	01351	01344	FIPOUT	02170	02152	MAIN	04066	04052
EXP(2	10540	10535	EXP	10617	10614	ANYER	11364	10713	SBRER	11362	
OVFLW	11355		UNFLW	11360		BRCDE	11342		EPMDE	11333	
(SVN)	10720		(SIX)	10717		(FPT)	10721		ERROR	11050	
ERTRP	11374		ERSIN	11366		(TSHM)	11424	11414	(TSH)	11424	
(BLOK)	12104	11465	(STHD)	11501		(STHM)	11476		(STH)	11476	
(WLR)	12207	12156	(STB)	12165		(RLR)	12277	12240	(TSB)	12247	
(RWT)	12317	12314	(SLO)	12325	12325	(SLI)	12342	12342	(WTC)	12430	12357
(WER)	12371		(RDC)	12507	12456	(RER)	12465		(RTN)	13354	12523
(FIL)	13343		(IOH)	13504		(EXB)	14505	14430	(IOB)	14432	
(TCO)	15224	15115	(TEF)	15223		(RCH)	15222		(ETT)	15221	
(REW)	15220		(WEF)	15217		(BSR)	15216		(WRS)	15215	
(RDS)	15214		(IOS)	15120		STCH)	15236		(TCN)	15235	
(LCH)	15234		(CHR)	15233		(RUN)	15232		(BSF)	15231	
(SDL)	15230		(SDH)	15227		(BTT)	15226		(TRC)	15225	
(IOU)	15262	15257	(FT)	15306	15300	(EXEM)	15307		(EXE)	15307	
(TES)	16235	16235	EXIT	16240	16236						

EXECUTION TIME 16.051

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2. Reactor Analysis Department, WANL. "Reactor Analysis of NRX-A Thermal and Fluid Flow Analysis, Vol. III." WANL-TNR-128, September, 1963.

3. E. Bryant and J. E. Sattizahn. "RIFT Safety Review." Los Alamos Report RFS-135, 1963.

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