

A ONE-DIMENSIONAL FUEL
BURNUP MODEL OF A PWR

by

Douglas Lee Gilliatt

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Nuclear Science and Engineering

APPROVED:

R. J. Onega, Chairman

T. F. Parkinson

H. A. Kurstedt

December, 1982
Blacksburg, Virginia

ACKNOWLEDGEMENTS

I wish to sincerely thank my teacher and friend Ronald J. Omega who was never too busy to help.

I also wish to thank John D. Teachman and Roy Harper for their help with my computer programming.

Last, but not least, I would like to thank my wife and family for their support and understanding.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
LIST OF FIGURES	iv
LIST OF TABLES	vi
CHAPTER 1. INTRODUCTION	
1.1 Introduction	1
1.2 Methodology for Approaching Fuel Burnup Problem	2
1.3 Scope of Problem	4
CHAPTER 2. MATHEMATICAL MODEL USED	
2.1 Introduction	6
2.2 Parameterization of the Flux	9
2.3 Neutron Diffusion Calculations	10
2.3.1 Solution Techniques	
2.4 Isotopic Concentrations	26
CHAPTER 3. RESULTS	
3.1 Computer Program	39
3.2 Flux Approximation	43
3.3 Isotopic Concentrations	51
3.3.1 Relative Accuracy between MAY19 and FUELBURN2	75
CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS	79
REFERENCES	82
APPENDIX. COMPIATION AND EXECUTION OF MAY19 PROGRAM	83
VITA	115

LIST OF FIGURES

	Page
2.1 CONSTANT PROPERTY REGIONS OF THE REACTOR CORE.	7
3.1 FLOW CHART OF COMPUTER PROGRAM MAY 19.	41
3.2 FLUX SHAPE AT 0 HOURS.	44
3.3 FLUX SHAPE AT 226.0 DAYS	45
3.4 FLUX SHAPE AT 466.0 DAYS	46
3.5 AVERAGE CORE FLUX 0-24 HOURS	48
3.6 AVERAGE CORE FLUX 2-16 DAYS.	49
3.7 AVERAGE CORE FLUX 46-466 DAYS.	50
3.8 AVERAGE CORE U-235 CONCENTRATION 0-466 DAYS.	52
3.9 AVERAGE CORE Pu-239 CONCENTRATION 46-466 DAYS.	53
3.10 AVERAGE CORE FISSILE ISOTOPE (U-235 AND Pu-139) CONCENTRATION 0-466 DAYS	54
3.11 AVERAGE CORE LBP ISOTOPE (B-10) CONCENTRATION 0-466 DAYS	55
3.12 AVERAGE CORE U-238 CONCENTRATION 0-466 DAYS.	56
3.13 REGION 2 U-238 CONCENTRATION	58
3.14 AVERAGE CORE I-135 CONCENTRATION 0-24 HOURS.	59
3.15 AVERAGE CORE I-135 CONCENTRATION 2-16 DAYS	60
3.16 AVERAGE CORE I-135 CONCENTRATION 46-466 DAYS	61
3.17 AVERAGE CORE Xe-135 CONCENTRATION 0-24 HOURS	62
3.18 AVERAGE CORE Xe-135 CONCENTRATION 2-16 DAYS.	63
3.19 AVERAGE CORE Xe-135 CONCENTRATION 46-466 DAYS.	64

LIST OF FIGURES (CONTINUED)

	PAGE
3.20 AVERAGE CORE Sm-149 CONCENTRATION 0-24 HOURS. . .	66
3.21 AVERAGE CORE Sm-149 CONCENTRATION 2-16 DAYS . . .	67
3.22 AVERAGE CORE Sm-149 CONCENTRATION 46-466 DAYS . .	68
3.23 AVERAGE CORE Pm-149 CONCENTRATION 0-24 HOURS. . .	69
3.24 AVERAGE CORE Pm-149 CONCENTRATION 2-16 DAYS . . .	70
3.25 AVERAGE CORE Pm-149 CONCENTRATION 46-466 DAYS . .	71
3.26 SOLUBLE BORON CONCENTRATION 0-24 HOURS.	72
3.27 SOLUBLE BORON CONCENTRATION 2-16 DAYS	73
3.28 SOLUBLE BORON CONCENTRATION 46-466 DAYS	74

LIST OF TABLES

	Page
2-1 NOMENCLATURE.	12
3-1 SAMPLE REACTOR CORE PHYSICAL DATA	40
3-2 COMPARISON OF ISOTOPIC CONCENTRATIONS AT THE END OF 450 DAYS COMPUTED BY MAY19, FUELURN2 AND THE PROGRAM BASED ON MODEL _a	41

CHAPTER 1

INTRODUCTION

1.1 Introduction

Virtually all the commercial light water nuclear reactors in use in the United States today are fueled with uranium dioxide slightly enriched in U-235. The uranium dioxide is in the form of pellets which are inserted into long, thin metal (usually zirconium alloy) tubes. The resulting assembly is called a fuel rod. Several of these fuel rods are then arranged in the form of a lattice to form a fuel assembly. (The Westinghouse 17 x 17 fuel assembly lattice has 264 fuel rods whereas the General Electric 8 x 8 fuel assembly lattice has 62 or 63 fuel rods [7].) These fuel assemblies are then loaded into a pressure vessel and arranged in a matrix to form a reactor core. The enrichment in U-235 will vary from fuel assembly to fuel assembly and in some cases will vary from fuel rod to fuel rod within a fuel assembly.

Usually once a year a commercial light water reactor is refueled. When a reactor is refueled not all the fuel assemblies are replaced. Only some of the fuel assemblies are replaced and the rest are shuffled around in the core along with the new assemblies which replaced the old. The pattern of fuel shuffling and the level of enrichment of the fresh fuel must be determined by the utility nuclear engineer. In making

these determinations, the engineer must ensure that the refueled core will produce the rated power of the core, will cost as little as possible and will meet all the required safety parameters over its operating life.

1.2 Methodology for Attacking Fuel Burnup Problem

A nuclear engineer is assisted in the management of core fuel by a large number of fuel burnup or core depletion computer codes. These computer codes calculate the concentrations of various isotopes in the core at any time in the core life. The more complex codes can calculate the isotopic distributions in two and three dimensions. The simpler codes will compute the isotopic concentrations for a one-dimensional model or for a zero-dimensional model [7].

The existing core-depletion codes can be divided into two categories -- those developed and used by industry and those developed by universities and national laboratories. Several of the depletion codes developed and used by industry are included in the Leahs In-Core Fuel Management System and the Fuel Management System (FMS) developed by Scandpower [9]. Two of the simpler depletion codes developed by a university are the Pennsylvania State University codes MUGDET and MORAD [7].

Many of the codes developed by industry are not generally available to the public. However, in at least one case, a university made

arrangements for its nuclear engineering students to have indirect access to a utility's computer codes and hardware as part of a nuclear engineering course [3].

Most of the existing core depletion codes are based on equivalent diffusion theory parameters. The approach in determining equivalent diffusion theory parameters is to divide the neutron energy spectrum into several groups, e.g., thermal neutrons, epithermal neutrons and fast neutrons. Then equivalent cross sections are determined for each energy group duplicating the actual reaction rates which occur within that energy group. The reaction rates in a reactor fuel assembly vary with position in the fuel assembly and the energy range being considered. At any given point in the fuel assembly and for any given isotope at that point, the cross sections of that isotope will be a function of the energy of the neutrons impinging upon the isotope.

Also, the number of neutrons of a specific energy which impinge upon the isotope will be a function of the neutron energy spectrum and the neutron flux at that point. Thus, to compute the reaction rates at a specific point for a specific isotope one must know how the isotopic cross sections vary with energy, the neutron energy spectrum and the neutron flux at that point. It is easy to see why the determination of equivalent cross sections for a reactor core is one of the most difficult reactor physics problems to solve. In spite of the difficulty in solving this problem, there are many computer codes, such as LEOPARD [7] and VIM [1], which calculate the equivalent cross sections of a core.

The calculation of equivalent cross sections is often accomplished with neutron transport theory [8]. In order to understand one of the typical core depletion codes, it is necessary to understand relatively complex neutron transport calculations. For a senior or first year graduate nuclear engineering student, this is frequently beyond his abilities. For them, using a typical core depletion code can be somewhat like using a black box which generates numbers. If there was a readily available core depletion code based only on one-group diffusion theory, then a nuclear engineering student could use the code with a complete understanding of what he was doing. However, since a depletion code based only on one-group diffusion theory would be too crude and inaccurate for most engineering purposes, there are none readily available.

1.3 Scope of Problem

The objective of this thesis is to fill this gap. That is, the intention of this thesis is to develop a computer code based only on a one-group diffusion theory and utilizing simple thermal cross sections (adjusted for the temperature of the reactor), which will deplete a core in one dimension and show (in one dimension) how the shape and magnitude of the flux change over core life. Although some accuracy will have to be sacrificed due to using thermal cross sections and only one energy group, the intention is to have sufficient accuracy for a student to

still gain insight and understanding in how a core depletes and how the flux is coupled to the core isotopic concentrations.

CHAPTER 2

MATHEMATICAL MODEL USED

2.1 Introduction

The model used to determine the fuel burnup is based upon a typical pressurized water reactor with three concentric regions of different fuel enrichment as shown in Figure 2.1. One-group diffusion theory is used. Only the radial dimension in a cylindrical coordinate system is considered. The reactor is assumed to be critical and to be at a constant power, temperature and pressure. The fuel is uranium dioxide pellets enriched in uranium 235. The density of the fuel pellets is assumed to be 92.5% of the theoretical density. The lumped burnable poison is in the form of clad rods which are inserted into the fuel assemblies.

Geometrically, the model core is assumed to be very tall so that the flux will be essentially constant in the vertical direction. The flux is assumed not to vary azimuthally and thus becomes a function of the radial dimension only.

After the isotopic concentrations are computed, the flux is determined by applying the constraints of constant core power and core criticality. The flux is assumed to be constant for a short period of time (24 hours or less) and the isotopic concentrations at the end of

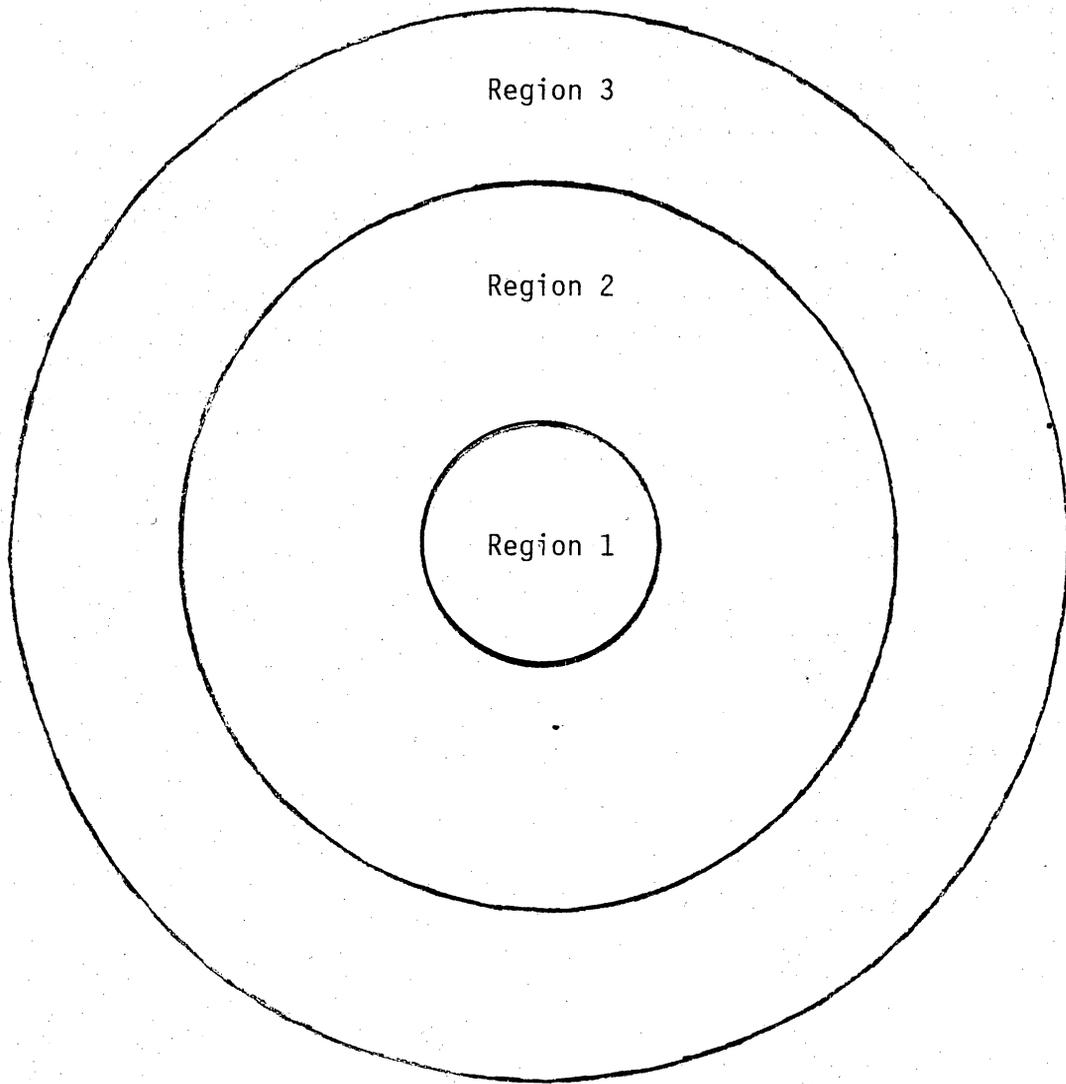


FIGURE 2.1
CONSTANT PROPERTY REGIONS OF THE REACTOR CORE
(NOT TO SCALE)

the period of constant flux are compared. The new isotopic concentrations are then used to calculate a new flux and this process is repeated until the end of core life at 466 days. 466 days was chosen because the sample core used later on to test the model has a core life of 466 days.

Because a reactor core is composed of rectangular fuel assemblies, the regions of the core do not have smoothly curved borders. Assigning radii to these regions is therefore somewhat misleading without a diagram. To correct this difficulty, equivalent radii are calculated. This is done by first determining the area of each region by multiplying the number of fuel assemblies in each region times the area of a fuel assembly. Once the area of each region is calculated, the equivalent radii are determined as shown below. The first radius R1 is calculated using the relation

$$R1 = \left(\frac{\text{AREA OF REGION 1}}{\pi} \right)^{\frac{1}{2}} \quad (2.1.1)$$

and the end of the second zone is

$$R2 = \left(\frac{\text{AREA OF REGION 1} + \text{AREA OF REGION 2}}{\pi} \right)^{\frac{1}{2}} \quad (2.1.2)$$

and finally the core radius is

$$R3 = \left(\frac{\text{TOTAL AREA OF CORE}}{\pi} \right)^{\frac{1}{2}} \quad (2.1.3)$$

Each of the three regions of fuel enrichment are homogenized and treated as separate and distinct elements. This homogenization process is begun by first computing the volume fractions of all the basic core materials in each region. Then the isotopic concentrations and macroscopic cross sections are calculated for each region from the volume fractions and material densities.

2.2 Parameterization of the Flux

The flux is approximated by the equation

$$\phi(r,t) = A_0(t) \cos B_1 r + A_1(t) \sin B_2 r \quad (2.2.1)$$

where r is the distance from the core center, t is time, and A_0 and A_1 are time varying coefficients to be determined. The arguments contain the parameters

$$B_1 = \frac{\pi}{2R_3}$$

and

$$B_2 = \frac{\pi}{R_3} .$$

This flux approximation (Eq. 2.2.1) was chosen because it constrains the flux to go to zero at R_3 and because it is capable of generating a wide range of flux shapes including a flux which is flat over the inner half of the core.

2.3 Neutron Diffusion Calculations

In order to determine the parameters A_0 and A_1 , the core is constrained to be critical and to have a constant thermal power output.

The core multiplication factor is the neutron production rate divided by the neutron destruction rate or

$$K = \frac{\int_{v_1} M_1 \phi dV + \int_{v_2} M_2 \phi dV + \int_{v_3} M_3 \phi dV}{\int_{v_1} L_1 \phi dV + \int_{v_2} L_2 \phi dV + \int_{v_3} L_3 \phi dV}, \quad (2.3.1)$$

where " v_1 " designates that the integral is over the first region of the core, " v_2 " designates that the integral is over the second region of the core, " v_3 " designates that the integral is over the third region of the core, " K " is the effective multiplication factor of the core.

The neutron destruction operators are defined by

$$\begin{aligned} L_1 = & -\nabla \cdot D \nabla + N_{11} (\sigma_{a1}) + N_{21} (\sigma_{a2}) + N_{31} (\sigma_{a3}) \\ & + P_{11} (\sigma_{a4}) + P_{21} (\sigma_{a5}) + P_{31} (\sigma_{a6}) + P_{41} (\sigma_{a7}) \\ & + O_{11} (\sigma_{a8}) + BOR_1 (\sigma_{a9}) + STRUCT (1), \end{aligned}$$

$$\begin{aligned} L_2 = & -\nabla \cdot D \nabla + N_{12} (\sigma_{a1}) + N_{22} (\sigma_{a2}) + N_{32} (\sigma_{a3}) \\ & + P_{12} (\sigma_{a4}) + P_{22} (\sigma_{a5}) + P_{32} (\sigma_{a6}) + P_{42} (\sigma_{a7}) \\ & + O_{12} (\sigma_{a8}) + BOR_2 (\sigma_{a9}) + STRUCT (2) \end{aligned}$$

and

$$\begin{aligned}
 L3 = & - \nabla \cdot D \nabla + N13 (\sigma a1) + N23 (\sigma a2) + N33 (\sigma a3) \\
 & + P13 (\sigma a4) + P23 (\sigma a5) + P33 (\sigma a6) + P43 (\sigma a7) \\
 & + O13 (\sigma a8) + BOR3 (\sigma a9) + STRUCT (3).
 \end{aligned}$$

The neutron production operators are defined by

$$M1 = \hat{v}1 (N11) \sigma f1 + \hat{v}2 (N21) \sigma f2,$$

$$M2 = \hat{v}1 (N12) \sigma f1 + \hat{v}2 (N22) \sigma f2$$

and

$$M3 = \hat{v}1 (N13) \sigma f1 + \hat{v}2 (N23) \sigma f2.$$

The symbols used in the above equations and in some of the equations which follow are explained in Table 2-1. (The vertical leakage term is not included in equation 2.3.1 because it is small compared to the other terms.)

Since the height of the core can be factored out of all the integrals in equation 2.3.1, it cancels out and the numerator of equation 2.3.1 can be written as

TABLE 2-1
NOMENCLATURE

Symbol	Unit	Meaning
D	cm	The diffusion coefficient of the core
N1i	atoms/cm ³	U-235 concentration in region "i"
N2i	atoms/cm ³	Pu-239 concentration in region "i"
N3i	atoms/cm ³	U-238 concentration in region "i"
P1i	atoms/cm ³	Xe-135 concentration in region "i"
P2i	atoms/cm ³	I-135 concentration in region "i"
P3i	atoms/cm ³	Sm-149 concentration in region "i"
P4i	atoms/cm ³	Pm-149 concentration in region "i"
O1i	atoms/cm ³	Lumped burnable poison isotope concentration in region "i"
BOR1	atoms/cm ³	The soluble boron concentration in region 1
BOR2	atoms/cm ³	The soluble boron concentration in region 2
BOR3	atoms/cm ³	The soluble boron concentration in region 3
STRUCT(1)	cm ⁻¹	Total macroscopic cross section of the materials in region 1 which are assumed to be unaffected by the flux
STRUCT(2)	cm ⁻¹	Total macroscopic cross section of the materials in region 2 which are assumed to be unaffected by the flux
STRUCT(3)	cm ⁻¹	Total macroscopic cross section of the materials in region 3 which are assumed to be unaffected by the flux
λ_X	sec ⁻¹	Decay constant of Xe-135
λ_{Pm}	sec ⁻¹	Decay constant of Pm-149

TABLE 2-1 (Con't)

Symbol	Unit	Meaning
λ_I	sec ⁻¹	Decay constant of I-135
γ_{Pm1}	atoms/fission	Yield of Pm-149 atoms per U-235 fission
γ_{Pm2}	atoms/fission	Yield of Pm-149 atoms per Pu-239 fission
γ_{I1}	atoms/fission	Yield of I-135 atoms per U-235 fission
γ_{I2}	atoms/fission	Yield of I-135 atoms per Pu-239 fission
γ_{X1}	atoms/fission	Yield of Xe-135 atoms per U-235 fission
γ_{X2}	atoms/fission	Yield of Xe-135 atoms per Pu-239 fission
σ_{a1}	cm ²	Microscopic absorption cross section of U-235
σ_{a2}	cm ²	Microscopic absorption cross section of Pu-239
σ_{a3}	cm ²	Microscopic absorption cross section of U-238
σ_{a4}	cm ²	Microscopic absorption cross section of Xe-135
σ_{a5}	cm ²	Microscopic absorption cross section of I-135
σ_{a6}	cm ²	Microscopic absorption cross section of Sm-149
σ_{a7}	cm ²	Microscopic absorption cross section of Pm-149
σ_{f1}	cm ²	Microscopic fission cross section of U-235
σ_{f2}	cm ²	Microscopic fission cross section of Pu-239
σ_{a8}	cm ²	Microscopic absorption cross section of the lumped burnable poison isotope

TABLE 2-1 (Con't)

Symbol	Unit	Meaning
σ_a^9	cm^2	Microscopic absorption cross section of the soluble boron
ϕ	$\frac{\text{neutrons}}{\text{cm}^2\text{-sec}}$	Neutron flux
A_0	dimensionless	First coefficient of the flux approximation
A_1	dimensionless	Second coefficient of the flux approximation
$\hat{\nu}_1$	$\frac{\text{neutrons}}{\text{fission}}$	Neutrons emitted per fission of U-235
$\hat{\nu}_2$	$\frac{\text{neutrons}}{\text{fission}}$	Neutrons emitted per fission of Pu-239

$$2\pi \int_0^{R1} M1\phi r dr + 2\pi \int_{R1}^{R2} M2\phi r dr + 2\pi \int_{R2}^{R3} M3\phi r dr.$$

Substituting the flux approximation from equation 2.2.1 into the above expression the numerator of equation 2.3.1 becomes

$$2\pi \int_0^{R1} M1\phi r dr + 2\pi \int_{R1}^{R2} M2\phi r dr + 2\pi \int_{R2}^{R3} M3\phi r dr$$

$$= 2\pi M1 \int_0^{R1} (A\cos B_1 r + A\sin B_2 r) r dr$$

$$+ 2\pi M2 \int_{R1}^{R2} (A\cos B_1 r + A\sin B_2 r) r dr$$

$$+ 2\pi M3 \int_{R2}^{R3} (A\cos B_1 r + A\sin B_2 r) r dr. \quad (2.3.2)$$

By using the information

$$\int x \sin ax dx = \frac{\sin ax}{a^2} - \frac{x \cos ax}{a}$$

and

$$\int x \cos ax dx = \frac{\cos ax}{a^2} + \frac{x \sin ax}{a},$$

the integrals in equation 2.3.2 can be evaluated. Equation 2.3.2 yields

$$\begin{aligned} & 2\pi M1 \int_0^{R1} (A \cos B_1 r + A \sin B_2 r) r dr \\ & + 2\pi M2 \int_{R1}^{R2} (A \cos B_1 r + A \sin B_2 r) r dr \\ & + 2\pi M3 \int_{R2}^{R3} (A \cos B_1 r + A \sin B_2 r) r dr \\ & = 2\pi M1 (C_{01} A_0 + C_{11} A_1) \\ & + 2\pi M2 (C_{02} A_0 + C_{12} A_1) \\ & + 2\pi M3 (C_{03} A_0 + C_{13} A_1), \end{aligned} \tag{2.3.3}$$

where

$$C_{01} = \left[\frac{\cos B_1 r}{B_1^2} + \frac{r \sin B_1 r}{B_1} \right]_0^{R1},$$

$$C_{02} = \left[\frac{\cos B_1 r}{B_1^2} + \frac{r \sin B_1 r}{B_1} \right]_{R1}^{R2},$$

$$C_{03} = \left[\frac{\cos B_1 r}{B_1^2} + \frac{r \sin B_1 r}{B_1} \right]_{R2}^{R3},$$

$$C_{11} = \left[\frac{\sin B_2 r}{B_2^2} - \frac{r \cos B_2 r}{B_2} \right]_0^{R1},$$

$$C_{12} = \left[\frac{\sin B_2 r}{B_2^2} - \frac{r \cos B_2 r}{B_2} \right]_{R1}^{R2}$$

and

$$C_{13} = \left[\frac{\sin B_2 r}{B_2^2} - \frac{r \cos B_2 r}{B_2} \right]_{R2}^{R3}$$

In the denominator or neutron destruction term of equation 2.3.I,
the neutron leakage term

$$(-\nabla \cdot D \nabla \phi)$$

can be taken out of all three integrals to create a fourth integral

$$\int_V (-\nabla \cdot D \nabla \phi) dV$$

or

$$2\pi \int_0^R (-\nabla \cdot D\nabla\phi) r dr .$$

The expansion of the integrand is straight forward and is shown below.

$$-\nabla \cdot D\nabla\phi = -\nabla \cdot (-DA_0 B_1 \sin B_1 r + DA_1 B_2 \cos B_2 r) \hat{r} \quad (2.3.4)$$

$$-\nabla \cdot D\nabla\phi = -\frac{1}{r} \frac{\partial}{\partial r} r(-DA_0 B_1 \sin B_1 r + DA_1 B_2 \cos B_2 r) \quad (2.3.5)$$

$$\begin{aligned} -\nabla \cdot D\nabla\phi &= \frac{DA_0 B_1}{r} \sin B_1 r - \frac{DA_1 B_2}{r} \cos B_2 r \\ &+ DA_0 B_1^2 \cos B_1 r + DA_1 B_2^2 \sin B_2 r. \end{aligned} \quad (2.3.6)$$

Substituting the integrand back into the neutron leakage integral yields the equation

$$\begin{aligned} 2\pi \int_0^R (-\nabla \cdot D\nabla\phi) r dr &= 2\pi DA_0 \int_0^R B_1 \sin(B_1 r) dr \\ &- 2\pi DA_1 \int_0^R B_2 \cos(B_2 r) dr + 2\pi DA_0 \int_0^R B_1^2 r \cos(B_1 r) dr \\ &+ 2\pi DA_1 \int_0^R B_2^2 r \sin(B_2 r) dr \end{aligned} \quad (2.3.7)$$

After evaluation of the integrals on the right hand side of equation 2.3.7, the results are

$$\begin{aligned}
 2\pi \int_0^{R3} (-\nabla \cdot D\nabla\phi) r dr &= -2\pi DA_0 \cos B_1 r \Big|_0^{R3} \\
 &\quad - 2\pi DA_1 \sin B_2 r \Big|_0^{R3} \\
 &\quad + 2\pi DA_0 [\cos B_1 r + r B_1 \sin B_1 r] \Big|_0^{R3} \\
 &\quad + 2\pi DA_1 [\sin B_2 r - r B_2 \cos B_2 r] \Big|_0^{R3} \quad (2.3.8)
 \end{aligned}$$

or evaluating the integrals further,

$$\begin{aligned}
 2\pi \int_0^{R3} (-\nabla \cdot D\nabla\phi) r dr &= 2\pi DA_0 + 0 + 2\pi DA_0 \left(\frac{\pi}{2} - 1\right) + 2\pi DA_1 (\pi) \\
 &= \pi^2 DA_0 + 2\pi^2 DA_1 . \quad (2.3.9)
 \end{aligned}$$

The denominator of equation 2.3.1 now becomes

$$\pi^2 DA_0 + 2\pi^2 DA_1 + \int_{V1} L1\phi dV + \int_{V2} L2\phi dV + \int_{V3} L3\phi dV$$

or

$$\pi^2 DA_0 + 2\pi^2 DA_1 + 2\pi L_1 \int_0^{R_1} \phi r dr + 2\pi L_2 \int_{R_1}^{R_2} \phi r dr$$

$$+ 2\pi L_3 \int_0^{R_3} \phi r dr.$$

The integrals in this expression have already been evaluated in equation 2.3.3, so the denominator becomes

$$\pi^2 DA_0 + 2\pi^2 DA_1 + 2\pi L_1 (Co_1A_0 + C_{11}A_1) + 2\pi L_2 (Co_2A_0 + C_{12}A_1)$$

$$+ 2\pi L_3 (Co_3A_0 + C_{13}A_1) .$$

After collecting A_0 and A_1 terms, this becomes

$$A_0 T_1 + A_1 T_2 ,$$

where

$$T_1 = 2\pi \left[\frac{\pi D}{2} + L_1(Co_1) + L_2(Co_2) + L_3(Co_3) \right]$$

and

$$T_2 = 2\pi [\pi D + L_1(C_{11}) + L_2(C_{12}) + L_3(C_{13})] .$$

In a similar manner, the numerator can be rearranged to obtain

$$A_0U_1 + A_1U_2 ,$$

where

$$U_1 = 2\pi [M_1(C_{01}) + M_2(C_{02}) + M_3(C_{03})]$$

and

$$U_2 = 2\pi [M_1(C_{11}) + M_2(C_{12}) + M_3(C_{13})] .$$

Substituting the final expressions for the denominator and the numerator back into equation 2.3.1 results in the equation

$$K = \frac{A_0U_1 + A_1U_2}{A_0T_1 + A_1T_2} . \quad (2.3.10)$$

Since the reactor is constrained to be critical this equation becomes

$$1.0 = \frac{A_0U_1 + A_1U_2}{A_0T_1 + A_1T_2} . \quad (2.3.11)$$

After a few manipulations, equation 2.3.11 can be written

$$aA_0 + bA_1 = 0 , \quad (2.3.12)$$

where

$$a = U_1 - T_1$$

and

$$b = U_2 - T_2 .$$

The total thermal power level of the core is constrained to be constant. This condition is expressed mathematically by the equation

$$\begin{aligned} \frac{\text{Power}}{G \times \text{AFL}} &= 2\pi \int_0^{R_1} [N_{11}(\sigma_{f1}) + N_{21}(\sigma_{f2})] \phi r dr \\ &+ 2\pi \int_{R_1}^{R_2} [N_{12}(\sigma_{f1}) + N_{22}(\sigma_{f2})] \phi r dr \\ &+ 2\pi \int_{R_2}^{R_3} [N_{13}(\sigma_{f1}) + N_{23}(\sigma_{f2})] \phi r dr \end{aligned} \quad (2.3.13)$$

where $G = 3.204 \times 10^{-17}$ megawatts per fission and AFL is the active fuel length of the core. Equation 2.3.13 can be rewritten as

$$\begin{aligned}
\frac{\text{Power}}{\text{GxAFL}} &= 2\pi [N_{11}(\sigma f_1) + N_{21}(\sigma f_2)] \int_0^{R_1} \phi r dr \\
&+ 2\pi [N_{12}(\sigma f_1) + N_{22}(\sigma f_2)] \int_{R_1}^{R_2} \phi r dr \\
&+ 2\pi [N_{13}(\sigma f_1) + N_{23}(\sigma f_2)] \int_{R_2}^{R_3} \phi r dr. \quad (2.3.14)
\end{aligned}$$

The integrals in equation 2.3.14 are the same integrals evaluated in equation 2.3.3. So equation 2.3.14 becomes

$$\begin{aligned}
\frac{\text{Power}}{\text{GxAFL}} &= 2\pi A_0 [PR_1(C_01) + PR_2(C_02) + PR_3(C_03)] \\
&+ 2\pi A_1 [PR_1(C_{11}) + PR_2(C_{12}) + PR_3(C_{13})] \quad (2.3.15)
\end{aligned}$$

where

$$PR_1 = N_{11}(\sigma f_1) + N_{21}(\sigma f_2) ,$$

$$PR_2 = N_{12}(\sigma f_1) + N_{22}(\sigma f_2) ,$$

and

$$PR_3 = N_{13}(\sigma f_1) + N_{23}(\sigma f_2) .$$

Equation 2.3.15 can be written more compactly as

$$PW1 A_0 + PW2 A_1 = PRR \quad (2.3.16)$$

where

$$PRR = \frac{\text{Power}}{G \times AFL} ,$$

$$PW1 = 2\pi [PR1(Co1) + PR2(Co2) + PR3(Co3)]$$

and

$$PW2 = 2\pi [PR1(C11) + PR2(C12) + PR3(C13)] .$$

2.3.1 Solution Techniques

The coefficients A_0 and A_1 are now solved for by solving the linear system composed of equations 2.3.12 and 2.3.16. This is done by using the Gauss-Jordan [10] reduction method. The linear system is

$$PW1 A_0 + PW2 A_1 = PRR$$

$$aA_0 + bA_1 = 0 . \quad (2.3.17)$$

The augmented matrix of this linear system is

$$\begin{bmatrix} PW1 & & PW2 \\ a & & b \\ & & PRR \\ & & 0 \end{bmatrix}$$

To reduce this matrix to reduced row echelon form the following steps are taken.

$$\begin{bmatrix} 1 & \left(\frac{PW2}{PW1} \right) & \left(\frac{PRR}{PW1} \right) \\ a & b & 0 \end{bmatrix}$$

$$\begin{bmatrix} 1 & \left(\frac{PW2}{PW1} \right) & \left(\frac{PRR}{PW1} \right) \\ 0 & \left(b - \frac{aPW2}{PW1} \right) & \left(-\frac{aPRR}{PW1} \right) \end{bmatrix}$$

$$\begin{bmatrix} 1 & \left(\frac{PW2}{PW1} \right) & \left(\frac{PRR}{PW1} \right) \\ 0 & 1 & \left(\frac{-aPRR}{bPW1 - aPW2} \right) \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & \left(\frac{PRR}{PW1} + \frac{PW2(a)PRR}{b(PW1)^2 - a(PW1)PW2} \right) \\ 0 & 1 & \left(\frac{-aPRR}{bPW1 - aPW2} \right) \end{bmatrix}$$

Thus, the equations for A_0 and A_1 are

$$A_0 = \frac{PRR}{PW1} + \frac{PW2(a)PRR}{b(PW1)^2 - a(PW1)PW2} \quad (2.3.18)$$

and

$$A_1 = \frac{-a_{PRR}}{b_{PW1} - a_{PW2}} \quad (2.3.19)$$

2.4 Isotopic Concentrations

After solving for A_0 and A_1 , the flux is assumed to be constant for a period of time. The flux does vary in a real reactor with time. However, if the time period chosen is small enough, then this assumption is reasonably accurate. By assuming that the flux is constant for a period of time, the differential equations describing the atomic concentrations of the various isotopes in the core can readily be solved. That is, by starting with the initial atomic concentrations, which are known, the isotopic concentrations at any time during the period of constant flux can be easily obtained. The differential equations and the development of their solutions is shown below. The isotopes considered are U-235, U-238, Pu-239, Xe-135, I-135, Pm-149, Sm-149 and the lumped burnable poison isotope.

The rate of change of the U-235 concentration is entirely due to burnup so that

$$\frac{dN_{i1}}{dt} = -N_{i1}(\sigma_{a1})\phi. \quad (2.4.1)$$

Pu-239 is produced by the decay of U-239 into Np-239 which decays into Pu-239. As production occurs so does burnup, so that the rate of change of Pu-239 is

$$\frac{dN_{2i}}{dt} = [N_{3i}(\sigma_{a3}) - N_{2i}(\sigma_{a2})]\phi. \quad (2.4.2)$$

The rate of change of U-238 is due only to burnup so that

$$\frac{dN_{3i}}{dt} = -N_{3i}(\sigma_{a3})\phi. \quad (2.4.3)$$

Xe-135 is produced as a fission product of U-235 and Pu-239 fissions. Also Xe-135 is produced by the decay of I-135. Xe-135 decays to Cs-135 and is also burned up by the neutron flux. Thus, the rate of change of Xe-135 is

$$\begin{aligned} \frac{dP_{1i}}{dt} = & (\lambda_I)P_{2i} - (\lambda_X)P_{1i} \\ & + [\gamma_{X1}(N_{1i})\sigma_{f1} + \gamma_{X2}(N_{2i})\sigma_{f2} - \sigma_{a4}(P_{1i})]\phi. \end{aligned} \quad (2.4.4)$$

I-135 is produced as a fission product of U-235 and Pu-239 fissions and is depleted by decaying to Xe-135 so that its rate of change is

$$\frac{dP_{2i}}{dt} = [\gamma_{I1}(N_{1i})\sigma_{f1} + \gamma_{I2}(N_{2i})\sigma_{f2}]\phi - \lambda_I(P_{2i}). \quad (2.4.5)$$

Pm-149, like I-135 and Xe-135, is fission product of U-235 and Pu-239 fissions. Pm-149 depletes by decaying to Sm-149; so the rate of change of Pm-149 is

$$\frac{dP_{4i}}{dt} = -\lambda_{Pm}(P_{4i}) + [\gamma_{Pm1}(N_{1i})\sigma_{f1} + \gamma_{Pm2}(N_{2i})\sigma_{f2}]\phi. \quad (2.4.6)$$

Sm-149, produced by the decay of Pm-149, is reduced by burnup. Thus the rate of change of Sm-149 is

$$\frac{dP_{3i}}{dt} = \lambda_{Pm}(P_{4i}) - \sigma_{a6}(P_{3i})\phi. \quad (2.4.7)$$

The lumped burnable poison isotope concentration is changed only by burnup so that it has a rate of change of

$$\frac{dO_{1i}}{dt} = -O_{1i}(\sigma_{a8})\phi. \quad (2.4.8)$$

Both sides of the equations 2.4.1 thru 2.4.8 are integrated over the area of the core to eliminate the radial dependence in the flux. The change in U-235 in the i th region of the core is given by the equation

$$\frac{dN_{1i}}{dt} = [-N_{1i}(\sigma_{a1})FLUX(i)]/\Delta R(i), \quad (2.4.9)$$

where FLUX(i) is the integral of the flux over the ith region of the core defined by equations 2.4.10-2.4.12 and $\Delta R(i)$ is the area of the ith region of the core defined by equations 2.4.13-2.4.15.

$$\text{FLUX}(1) = 2\pi \int_0^{R1} (A\cos B_1 r + A\sin B_2 r) r dr \quad (2.4.10)$$

$$\text{FLUX}(2) = 2\pi \int_{R1}^{R2} (A\cos B_1 r + A\sin B_2 r) r dr \quad (2.4.11)$$

$$\text{FLUX}(3) = 2\pi \int_{R2}^{R3} (A\cos B_1 r + A\sin B_2 r) r dr \quad (2.4.12)$$

$$\Delta R(1) = \pi R1^2 \quad (2.4.13)$$

$$\Delta R(2) = \pi(R2^2 - R1^2) \quad (2.4.14)$$

$$\Delta R(3) = \pi(R3^2 - R2^2) \quad (2.4.15)$$

The rate of change of Pu-239 is given by

$$\frac{dN_{2i}}{dt} = [N_{3i}(\sigma_3) - N_{2i}(\sigma_2)]\text{FLUX}(i)/\Delta R(i) \quad (2.4.16)$$

and the rate of change in U-238 is given by

$$\frac{dN3i}{dt} = [-N3i(\sigma a3)FLUX(i)]/\Delta R(i) . \quad (2.4.17)$$

The rates of change of Xe-135, I-135, Sm-149 and Pm-149 are

$$\begin{aligned} \text{(Xe-135)} \quad \frac{dP1i}{dt} = & [\lambda I(P2i) - \lambda X(P1i) + [\gamma X1(N1i)\sigma f1 + \gamma X2(N2i)\sigma f2 \\ & - \sigma a4(P1i)] \times FLUX(i)]/\Delta R(i) , \end{aligned} \quad (2.4.18)$$

$$\begin{aligned} \text{(I-135)} \quad \frac{dP2i}{dt} = & [-\lambda I(P2i) + [\gamma I1(N1i)\sigma f1 + \gamma I2(N2i)\sigma f2] \\ & \times FLUX(i)]/\Delta R(i) \end{aligned} \quad (2.4.19)$$

$$\text{(Sm-149)} \quad \frac{dP3i}{dt} = \lambda Pm(P4i) - P3i(\sigma a6)FLUX(i)/\Delta R(i) \quad (2.4.20)$$

and

$$\begin{aligned} \text{(Pm-149)} \quad \frac{dP4i}{dt} = & -\lambda Pm(P4i) + [\gamma Pm1(N1i)\sigma f1 + \gamma Pm2(N2i)\sigma f2] \\ & \times FLUX(i)/\Delta R(i) \end{aligned} \quad (2.4.21)$$

respectively. The lumped burnable poison has a rate of change given by

$$\frac{dO1i}{dt} = [-O1i(\sigma a8) FLUX(i)]/\Delta R(i) . \quad (2.4.22)$$

The differential equation for U-235 can easily be solved by separating variables and integrating both sides over time to obtain

$$\ln\left[\frac{N_{1i}(t)}{N_{1i}(o)}\right] = [-(\sigma_{a1})\text{FLUX}(i)/\Delta R(i)]t \quad (2.4.23)$$

where "t" is some time during the interval over which the flux is constant, $N_{1i}(t)$ is the isotopic concentration of U-235 in the "ith" region of the core at time "t" and $N_{1i}(o)$ is the initial isotopic concentration of U-235 in the "ith" region of the core. The same notation with respect to time is used in the equations which follow for all of the isotopes. Taking the exponential of both sides of equation 2.4.23 and rearranging yields

$$N_{1i}(t) = N_{1i}(o)\exp[-\alpha_{1i}(t)] \quad (2.4.24)$$

where

$$\alpha_{1i} = (\sigma_{a1})\text{FLUX}(i)/\Delta R(i).$$

The differential equations for the rate of change of U-238 (Eq. 2.4.17) and the rate of change of the lumped burnable poison (Eq. 2.4.22) can be solved in the same manner to obtain

$$N_{3i}(t) = N_{3i}(o)\exp[-\alpha_{3i}(t)] \quad (2.4.25)$$

$$O_{1i}(t) = O_{1i}(o)\exp[-\alpha_{8i}(t)] \quad (2.4.26)$$

where

$$\alpha_{3i} = (\sigma_{a3}) \text{FLUX}(i)/\Delta R(i)$$

and

$$\alpha_{8i} = (\sigma_{a8}) \text{FLUX}(i)/\Delta R(i).$$

Equation 2.4.16 (the rate of change of Pu-239) can be solved by substituting the solution for equation 2.4.17 (the rate of change of U-238) into equation 2.4.16 and multiplying both sides of the resulting equation by the integration factor

$$\exp [\alpha_{2i}(t)]$$

where

$$\alpha_{2i} = (\sigma_{a2})\text{FLUX}(i)/\Delta R(i).$$

The expression obtained is

$$\exp [\alpha_2 i(t)] \frac{dN_{2i}}{dt} = - (N_{2i})\alpha_2 i(\exp [\alpha_2 i(t)]) \\ + N_{3i(o)}(\alpha_3 i) \exp [(\alpha_2 i - \alpha_3 i)t]. \quad (2.4.27)$$

Equation 2.4.27 can be rewritten as

$$\frac{d}{dt} (\exp [\alpha_2 i(t)] N_{2i}) = N_{3i(o)}(\alpha_3 i) \exp [(\alpha_3 i - \alpha_2 i)t]. \quad (2.4.28)$$

Integrating both sides of this equation over time, the expression

$$\exp [\alpha_2 i(t)] (N_{2i}(t)) - N_{2i(o)} \\ = \frac{N_{3i(o)}(\alpha_3 i)}{(\alpha_2 i - \alpha_3 i)} (\exp [(\alpha_2 i - \alpha_3 i)t] - 1) \quad (2.4.29)$$

is obtained.

After some rearranging, the concentration of Pu-239 is found to be

$$N_{2i}(t) = N_{2i(o)} \exp [-\alpha_2 i(t)] \\ + \frac{N_{3i(o)}(\alpha_3 i)}{(\alpha_2 i - \alpha_3 i)} (\exp [(-\alpha_3 i)t] - \exp [-\alpha_2 i(t)]). \quad (2.4.30)$$

To solve the differential equations for Xe-135, I-135, Sm-149 and Pm-149, first the assumption is made that the U-235 and Pu-239 terms in the equations are constants. This introduces only a small error since the concentrations of U-235 and Pu-239 vary slightly over the time intervals to be considered (one day or less). Next, integration factors are used to solve equations 2.4.19 and 2.4.21 for I-135 and Pm-149 respectively. The results are for Pm-149 are

$$P_{4i}(t) = P_{4i}(o) \exp [-\alpha_{7i}(t)] + \frac{(1 - \exp[-\alpha_{7i}(t)])}{\alpha_{7i}} (E_1 \times N_{1i}(o) + F_1 \times N_{2i}(o)) , \quad (2.4.31)$$

where

$$\alpha_{7i} = \frac{\lambda_{Pm}}{\Delta R(i)} ,$$

$$F_1 = \frac{\gamma_{Pm2} (\sigma_{f2}) \text{FLUX}(i)}{\Delta R(i)}$$

and

$$E_1 = \frac{\gamma_{Pm1} (\sigma_{f1}) \text{FLUX}(i)}{\Delta R(i)}$$

Likewise the poison iodine is given by the relation

$$P_{2i}(t) = P_{2i}(o) \exp [-\alpha_{5i}(t)] + \frac{(1 - \exp[-\alpha_{5i}(t)])}{\alpha_{5i}} (E_2 \times N_{1i}(o) + F_2 \times N_{2i}(o)) , \quad (2.4.32)$$

where

$$E_2 = \frac{\gamma_{I1} (\sigma_{f1}) \text{FLUX}(i)}{\Delta R(i)} ,$$

$$F_2 = \frac{\gamma_{I2} (\sigma_{f2}) \text{FLUX}(i)}{\Delta R(i)}$$

and

$$\alpha_5 = \lambda I.$$

Finally, to solve equations 2.4.18 (the rate of change of Xe-135) and 2.4.20 (the rate of change of Sm-149), equation 2.4.31 (for Pm-149) is substituted into equation 2.4.20 and equation 2.4.32 (for I-135) is substituted into equation 2.4.18 and integration factors are used in the same manner in which equation 2.4.16 was solved. The resulting equation for Xe-135 is found to be

$$P_{1i}(t) = P_{1i}(o) \exp [-\alpha_{4i}(t)] + \frac{(1 - \exp [-\alpha_{4i}(t)])}{\alpha_{4i}} (E_3 \times N_{1i}(o) + F_3 \times N_{2i}(o))$$

$$\begin{aligned}
& + \frac{\alpha_5 i P_{2i}(o)}{(\alpha_4 i - \alpha_5 i)} (\exp [-\alpha_5 i(t)] - \exp [-\alpha_4 i(t)]) \\
& + \frac{(1 - \exp [-\alpha_4 i(t)])}{\alpha_4 i} (E_2 \times N_{1i}(o) + F_2 \times N_{2i}(o)) \\
& - \frac{(\exp [-\alpha_5 i(t)] - \exp [-\alpha_4 i(t)])}{(\alpha_4 i - \alpha_5 i)} (E_2 \times N_{1i}(o) \\
& + F_2 \times N_{2i}(o)) , \tag{2.4.33}
\end{aligned}$$

where

$$E_3 = \frac{\gamma X_1(\sigma f_1) FLUX(i)}{\Delta R(i)} ,$$

$$F_3 = \frac{\gamma X_2(\sigma f_2) FLUX(i)}{\Delta R(i)}$$

and

$$\alpha_4 i = \frac{\lambda X + (\sigma a_4) FLUX(i)}{\Delta R(i)} .$$

Similarly, the equation for Sm-149 is found to be

$$\begin{aligned}
P_{3i}(t) = & P_{3i}(o) \exp [-\alpha_{6i}(t)] \\
& + \frac{\alpha_{7i} P_{4i}(o)}{(\alpha_{6i} - \alpha_{7i})} (\exp [-\alpha_{7i}(t)] - \exp [-\alpha_{6i}(t)]) \\
& + \frac{(1 - \exp [-\alpha_{6i}(t)])}{\alpha_{6i}} (E_1 \times N_{1i}(o) + F_1 \times N_{2i}(o)) \\
& - \frac{(\exp [-\alpha_{7i}(t)] - \exp [-\alpha_{6i}(t)])}{(\alpha_{6i} - \alpha_{7i})} (E_1 \times N_{1i}(o) \\
& + F_1 \times N_{2i}(o)) , \tag{2.4.34}
\end{aligned}$$

where

$$\alpha_{6i} = \frac{(\sigma_{a6}) \text{FLUX}(i)}{\Delta R(i)}$$

The equations above describe the isotopic concentrations at the end of the period of time (or time interval) over which the flux is assumed to be constant. These concentrations are also the initial concentrations for the next time interval and they are used to calculate the new flux. These steps are repeated until the end of the core life is reached at 466 days. The final result is the concentrations of each of the main isotopes at regular time intervals over the life of the core.

CHAPTER 3

RESULTS

3.1 Computer Program

The mathematical models described in the previous chapter were used as the basis for the computer program "MAY19". This program computes and prints out the concentrations of U-235, Pu-239, Sm-149, Xe-135, U-238, Pm-149, I-135, the lumped burnable poison isotope and the soluble boron every hour for the first 24 hours and every 24 hours for the next 15 days. The program then computes the concentrations for every day for the next 450 days but only prints out the computed values every 30 days. The program also computes and prints out the values of the two coefficients A_0 and A_1 used in the flux approximation. The computational and printing scheme is the same as the one used for the concentrations.

The sample data used in this program corresponds to the parameters of the Babcock and Wilcox 2568 megawatt (thermal) core used in Three Mile Island Unit 1 [5,6]. Table 3-1 lists these data.

A flowchart of the MAY19 program is shown in Figure 3.1. It is important to note how the values of A_0 and A_1 are computed by this

TABLE 3-1

SAMPLE REACTOR CORE PHYSICAL DATA

	Region I	Region II	Region III
No. of Fuel Assemblies	9	100	68
Wt. % U-235 (Initial)	2.43	2.38	3.01
<hr/>			
Total No. of Fuel Assemblies		177	
Height of Active Fuel		365.8 cm	
Fuel Material		UO ₂	
Form		cylindrical pellets	
Pellet Diameter		0.94 cm	
Percent Theoretical Density		92.5	
No. of Fuel Rods Per Fuel Assembly		208	
No. of Control Rod Guide Tubes Per F.A.		16	
Fuel Assembly Pitch		12.81 cm	
Fuel Rod Outside Diameter		1.09 cm	
Fuel Rod Cladding Thickness		0.067 cm	
Cladding Material (Fuel Rod)		Zircalloy-4	
No. of Full Length Control Rods		61	
No. of Part Length Control Rods		8	
Control Rod Poison		Ag(80%)-In(15%) Cd(5%)	
Control Rod Cladding Material		SS-304	
Control Rod O.D.		1.143 cm	
Control Rod Cladding Thickness		0.053 cm	
Number of Burnable Poison Rods		68	
Poison Material		B ₄ ¹⁰ C-Al ₂ O ₃	
Average Poison Loading, %B ₄ C In B ₄ C-Al ₂ O ₃		1.27	
Poison Rod Clad Material		Zircalloy-4	
Poison Rod Cladding Thickness		0.089 cm	
Poison Rod O.D.		1.143 cm	
R1		36.9 cm	
R2		128.5 cm	
R3		163.7 cm	
Coolant Average Temperature at Power		304°C	
Coolant Operating Pressure		15.2x10 ⁶ N/m ²	

TABLE 3-2

COMPARISON OF ISOTOPIC
CONCENTRATIONS AT THE END
OF 450 DAYS COMPUTED BY
MAY19, FUELBURN2 AND THE PROGRAM
BASED ON MODEL_a

<u>MAY19 CONCENTRATIONS</u>		<u>FUELBURN2 CONCENTRATIONS</u>		<u>MODEL_a CONCENTRATIONS</u>	
U-235	$7.740 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$	$1.009 \times 10^{20} \frac{\text{atoms}}{\text{cm}^3}$	$7.519 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$		
Pu-239	$9.196 \times 10^{18} \frac{\text{atoms}}{\text{cm}^3}$	$2.922 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$	$9.750 \times 10^{18} \frac{\text{atoms}}{\text{cm}^3}$		
U-238	$6.649 \times 10^{21} \frac{\text{atoms}}{\text{cm}^3}$	$6.603 \times 10^{21} \frac{\text{atoms}}{\text{cm}^3}$	$6.654 \times 10^{21} \frac{\text{atoms}}{\text{cm}^3}$		

	<u>DIFFERENCE BETWEEN MAY19 AND MODEL_a CONCENTRATIONS</u>	<u>DIFFERENCE BETWEEN FUELBURN2 AND MODEL_a CONCENTRATIONS</u>
U-235	$2.210 \times 10^{18} \frac{\text{atoms}}{\text{cm}^3}$	$2.571 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$
Pu-239	$5.540 \times 10^{17} \frac{\text{atoms}}{\text{cm}^3}$	$1.947 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$
U-238	$5.000 \times 10^{18} \frac{\text{atoms}}{\text{cm}^3}$	$5.100 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$

	<u>DIFFERENCE BETWEEN FUELBURN2 AND MAY19 CONCENTRATIONS</u>
U-235	$2.350 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$
Pu-239	$2.002 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$
U-238	$4.600 \times 10^{19} \frac{\text{atoms}}{\text{cm}^3}$

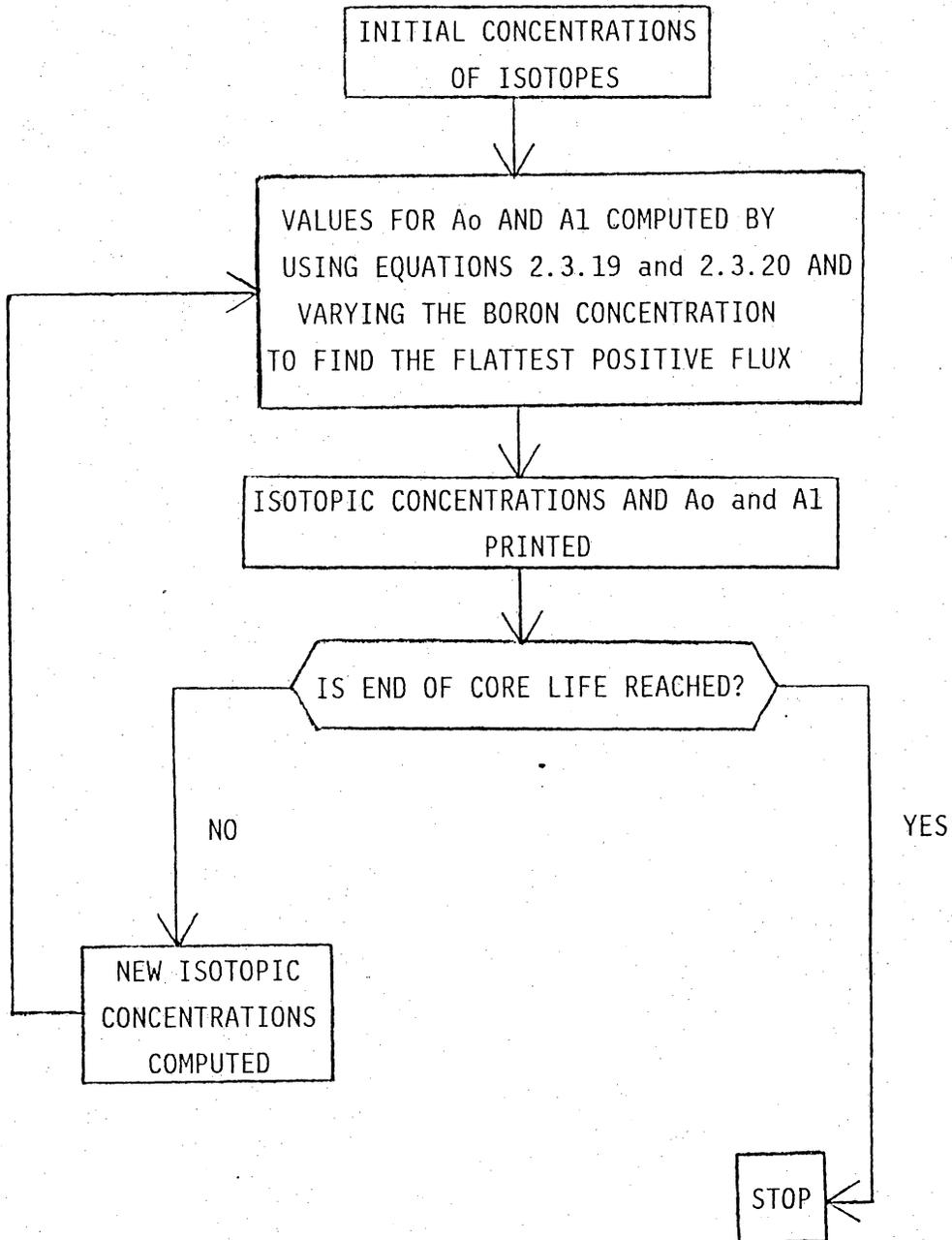


FIGURE 3.1

FLOW CHART OF COMPUTER PROGRAM

MAY19

program. The boron concentration is varied from 0 ppm to 5000 ppm and the values of A_0 and A_1 are computed (using equations 2.3.19 and 2.3.20) at intervals of 50 ppm over the entire range.

For each pair of A_0 and A_1 values computed, there is a corresponding flux. Each of these fluxes is checked at intervals of 1/50th of the core radius to see if it assumes a negative value between the center of the core and the outer edge of the core. In this manner the program determines the range of the boron concentration over which the flux is positive. The program then calculates the A_0 and A_1 coefficients at intervals of 25 ppm boron over this range and selects the values of A_0 and A_1 which produce the flattest positive flux. The MAY19 program determines these values of A_0 and A_1 by inserting every set of A_0 and A_1 coefficients calculated over the positive flux range into equation 3.1.1 and selecting that set of A_0 and A_1 coefficients which produces the smallest value of SUMDEV.

$$\text{SUMDEV} = \sum_{n=1}^{25} \left| \left(\frac{A_0 \cos[B_1(nR_3/50)] + A_1 \sin[B_2(nR_3/50)]}{A_0} \right) - 1 \right| \quad (3.1.1)$$

The cross sections used were temperature-adjusted thermal cross sections. They were computed using the equation

$$\sigma = \frac{\pi}{2} g_a(T) \sigma(E_0) (T_0/T)^{1/2} \quad (3.1.2)$$

where σ is the temperature-adjusted thermal microscopic cross section, $\sigma(E_0)$ is the microscopic cross section at .0253eV, T_0 is 293.61°Kelvin, T is the temperature of the core in degrees Kelvin and $g_a(T)$ is the non 1/V or Wescott factor. The non 1/V factors used came from Lamarsh [4].

3.2 Flux Approximation

The flux shapes generated by the MAY19 program at 0 hours, 226 days and 466 days are shown in Figures 3.2, 3.3 and 3.4, respectively. Within the limits of the model, these flux shapes correspond to the flux shape one would expect in an operating reactor where a flat flux is important in achieving uniform fuel burnup. Note that the mathematical model constrains the flux to start declining at one half the radius of the core and thus cannot produce a flux shape which remains flat past this point in the core.

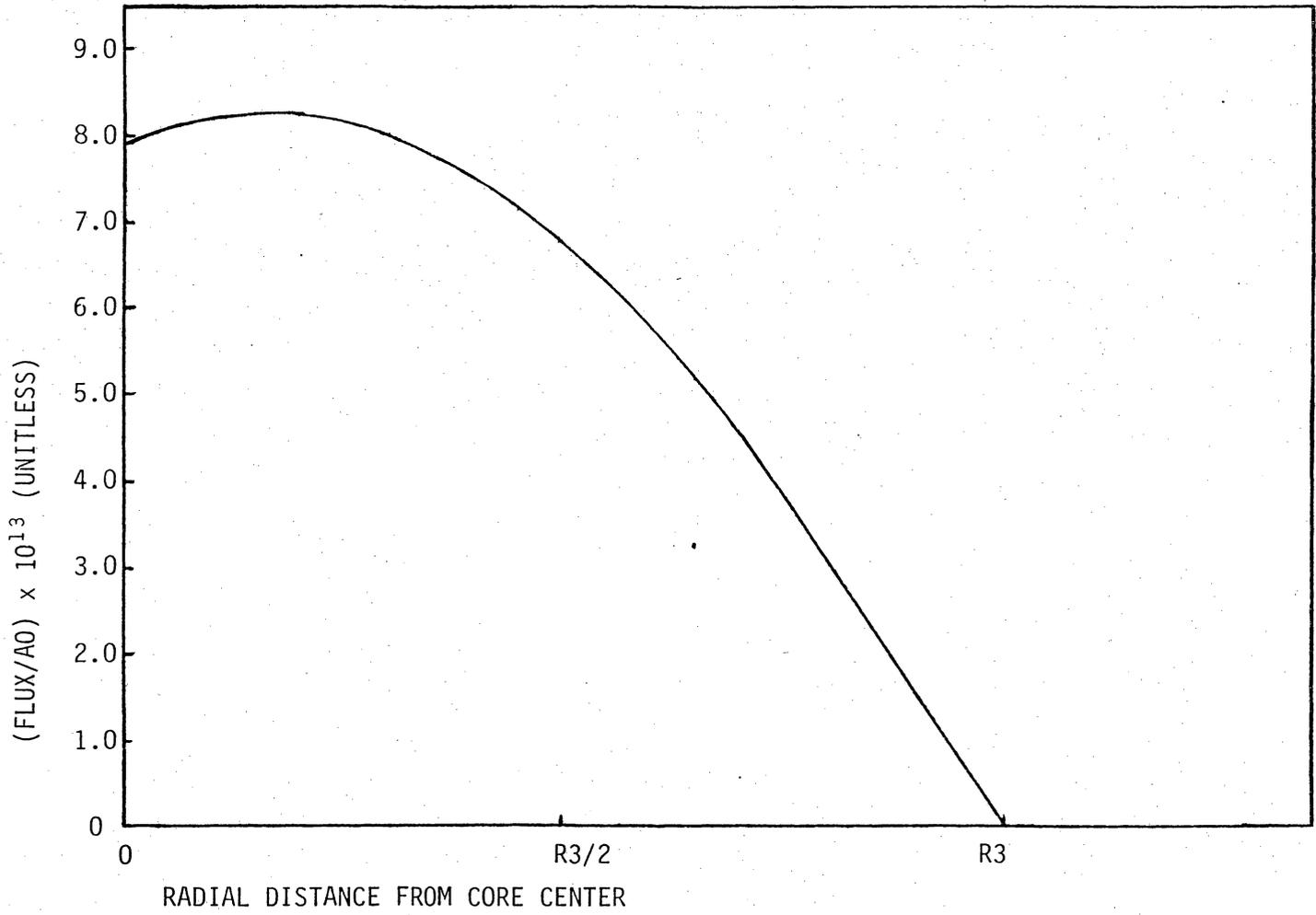


FIGURE 3.2
FLUX SHAPE AT 0 HOURS

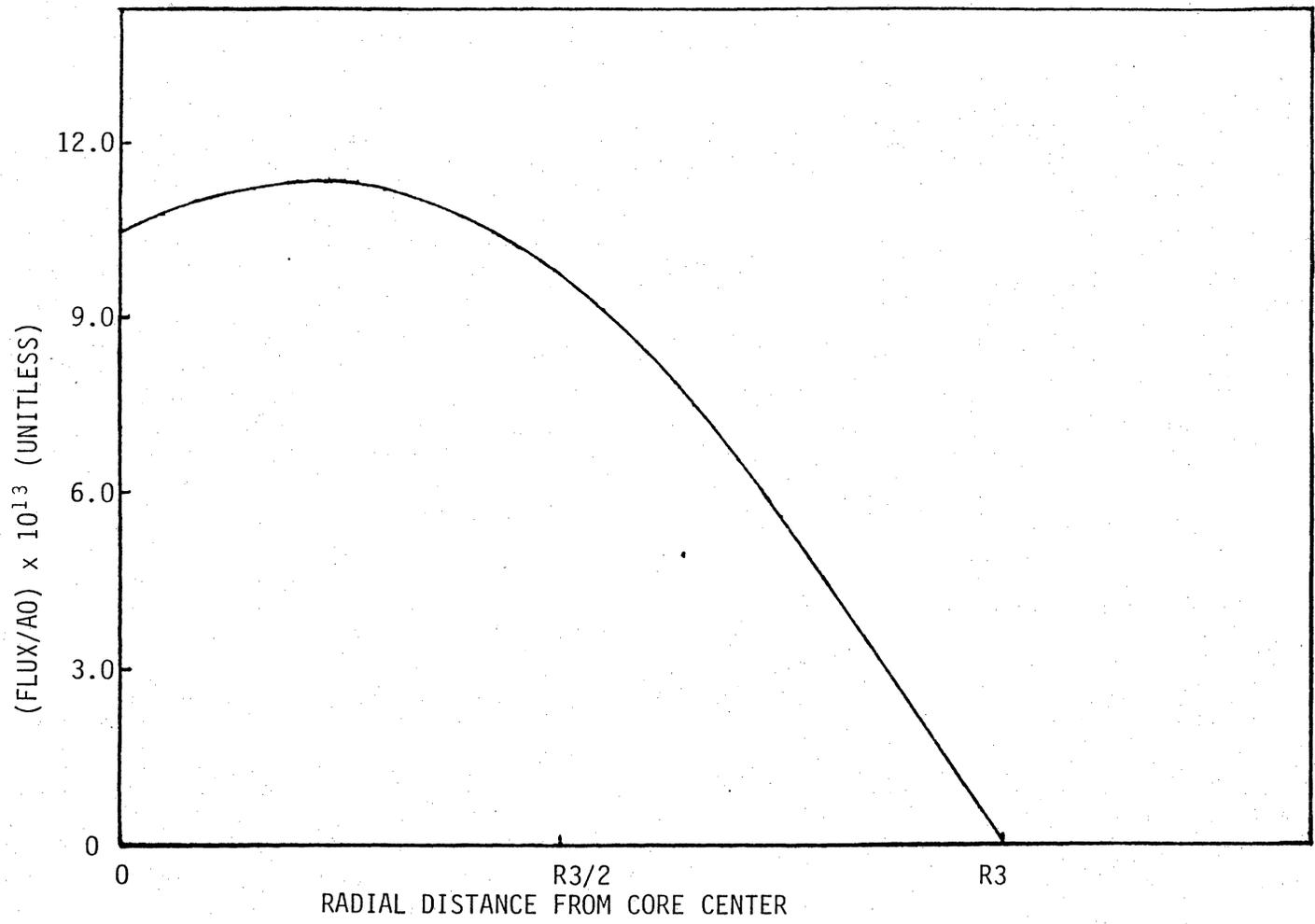


FIGURE 3.3
FLUX SHAPE AT 226.0 DAYS

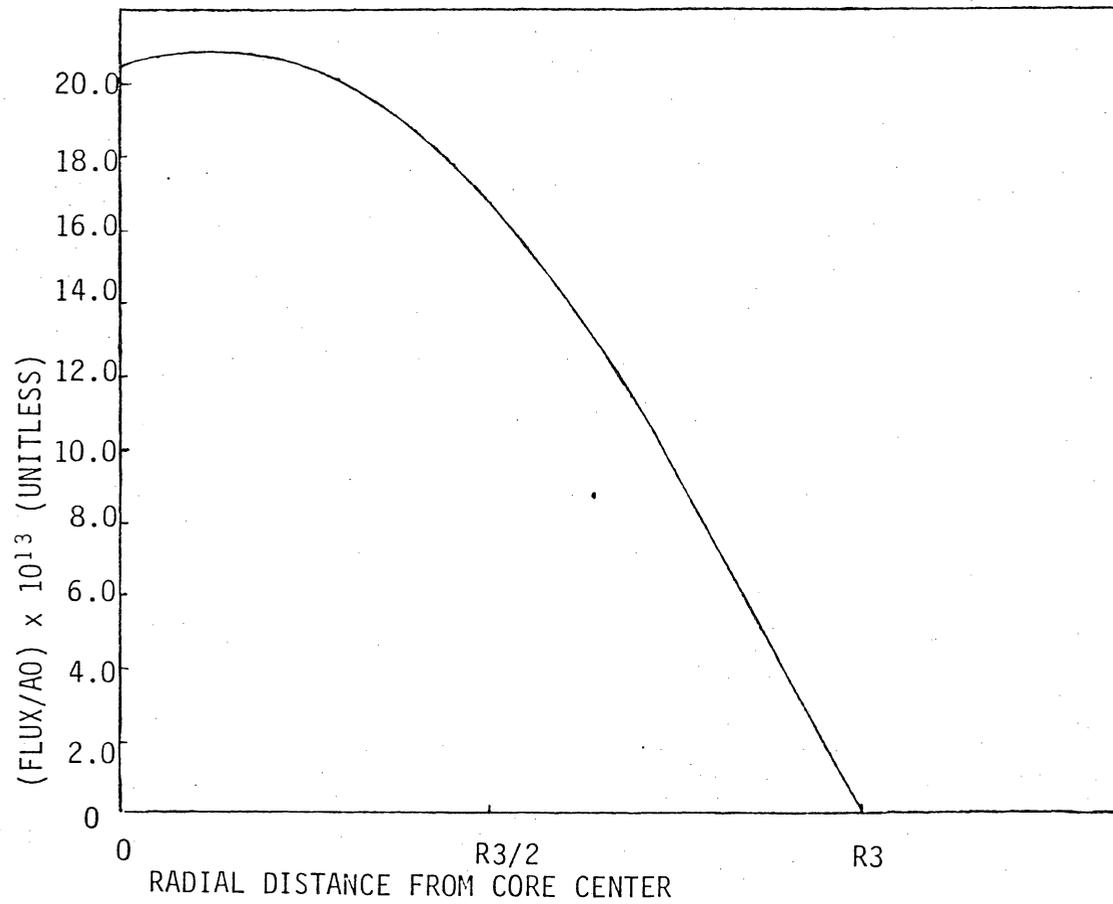


FIGURE 3.4
FLUX SHAPE AT 466.0 DAYS

Figures 3.5, 3.6 and 3.7 show the average core flux magnitude from 0 hours to 466 days. These figures show that the magnitude of the flux generated by MAY19 increases steadily over core life just as the thermal flux in an operating reactor increases over core life in order to maintain constant power with fewer fissile isotopes. The erratic behavior of the average core flux from 0-24 hours was attributed to the inefficiency of the algorithm (does not converge on the flattest flux) used in MAY19 to determine the flux.

The average (over core life) flux magnitude in the outermost region of the sample core was computed by MAY19 to be 2.53×10^{13} neutrons/cm²-second. The average (over core life) flux magnitude at the core boundary of the Midland core was determined from Table 4.3-21 of the Midland Final Safety Analysis Report [4] to be 3.58×10^{13} neutrons/cm²-second. (An average flux magnitude for the Midland core was used because the Midland core is very similar to the sample core used in MAY19.) The average flux magnitude computed by MAY19 differs from the average flux magnitude for the Midland core by 29%.

The flux shapes generated by MAY19 were fairly flat and the average core flux magnitudes generated by MAY19 increased steadily over core life. Also, the average (over core life) flux magnitude generated by MAY19 for the outermost region of the sample core was within an order of magnitude of the average (over core life) flux magnitude at the core

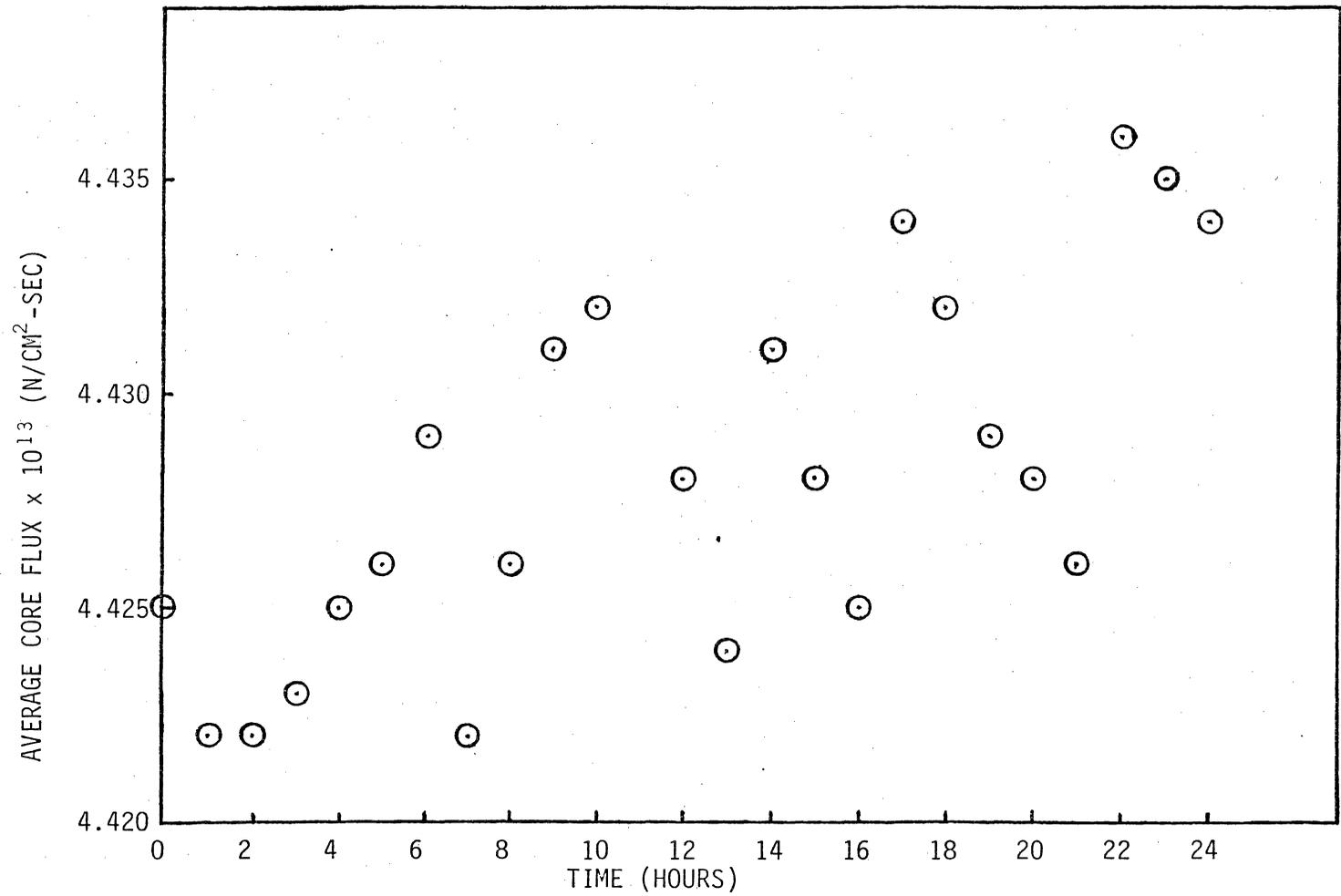


FIGURE 3.5
AVERAGE CORE FLUX 0-24 HOURS

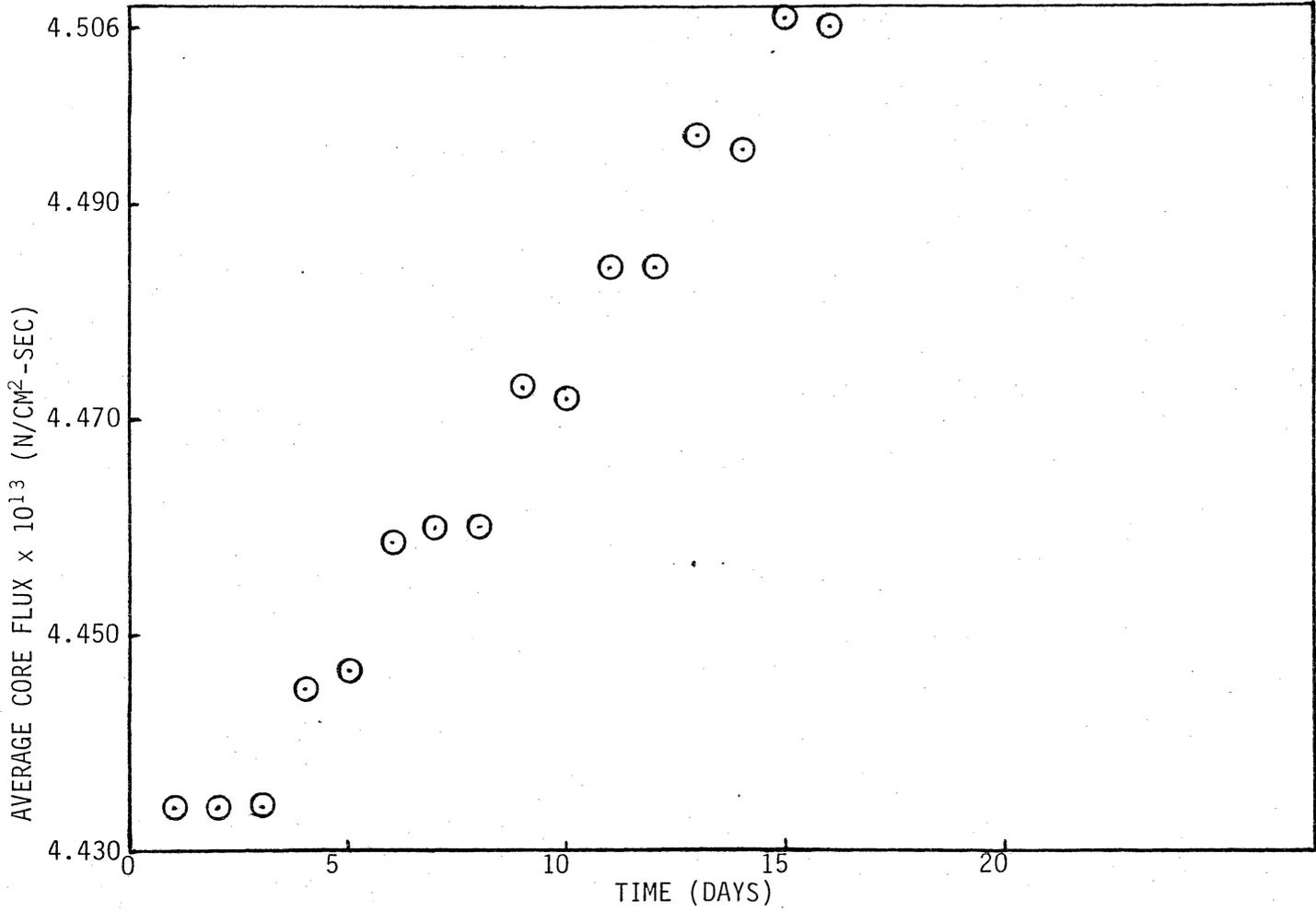


FIGURE 3.6
AVERAGE CORE FLUX 2-16 DAYS

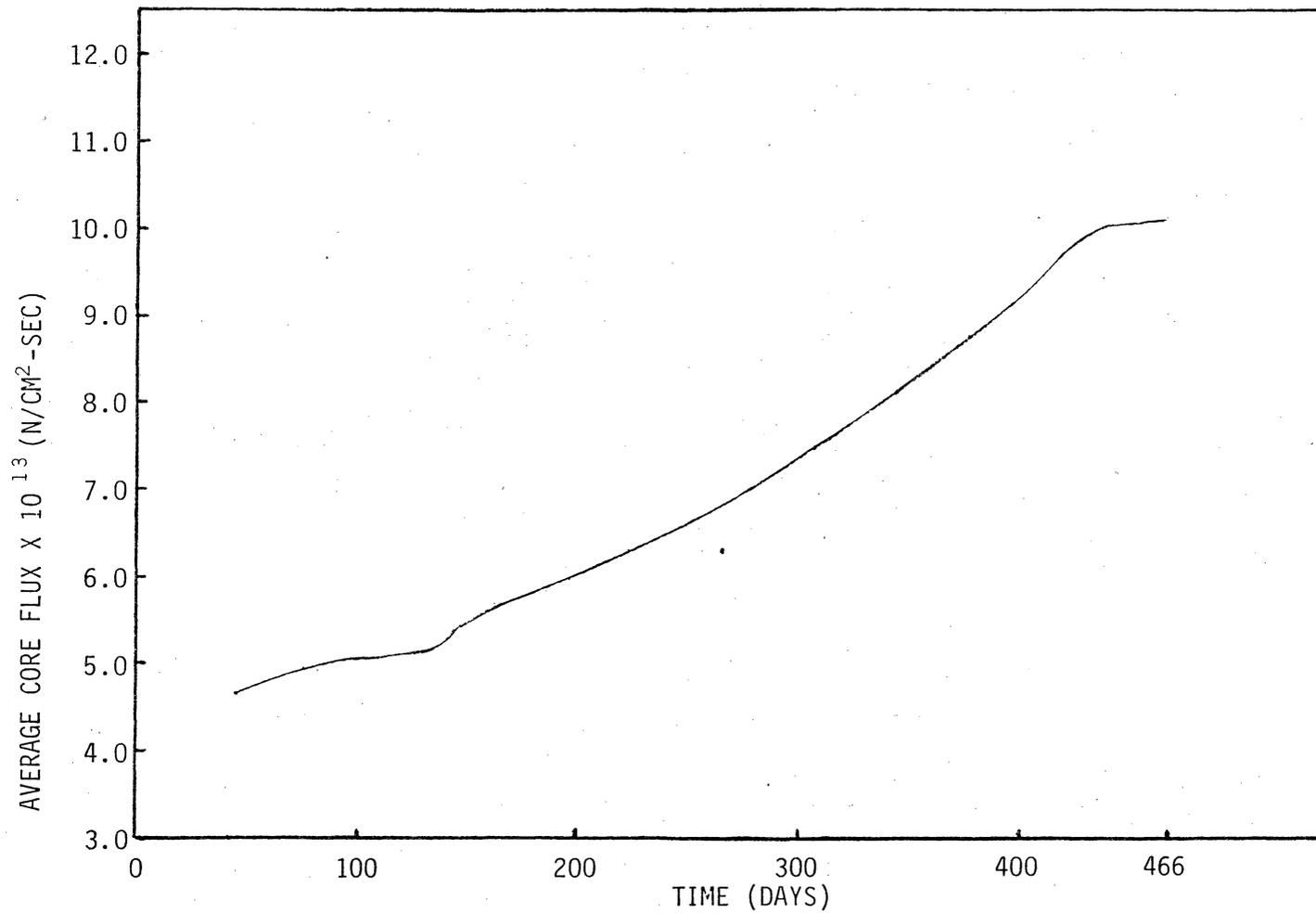


FIGURE 3.7
AVERAGE CORE FLUX 46-466 DAYS

boundary of the Midland core. For all the reasons cited above, the flux generating portion of the MAY19 program was considered acceptable.

3.3 Isotopic Concentrations

Figures 3.8 and 3.9 show the behavior of U-235 and Pu-239 over core life. The shapes of these curves compare well with the curves of Pu-239 buildup and U-235 depletion shown in Figure 13-2 of Graves [5].

Figure 3.10 shows the behavior of total fissile isotopes (U-235 and Pu-239) over core life. This figure shows a steady decrease in the total fissile isotope inventory over core life which is what actually occurs in a non-breeding reactor.

Figure 3.11 shows the behavior of the lumped burnable poison (LBP) isotope (B-10) over core life. No curve was found to compare with this figure. However, the large reduction in the LBP isotope over core life shown in Figure 3.11 is the general trend one would expect in a real reactor.

Figure 3.12 is a graph showing how the U-238 concentration changes over core life. The curve shown in Figure 3.12 has a slope which starts negative and becomes more negative. By comparison, Figure 2-11 of Levine [9], which also shows the depletion of U-238, has a curve with a slope which starts negative and becomes less negative. This discrepancy was not due to an error in the mathematics of the MAY19 model or an error in the MAY19 programming. It is a characteristic of the MAY19 model attributed to the cross sections used.

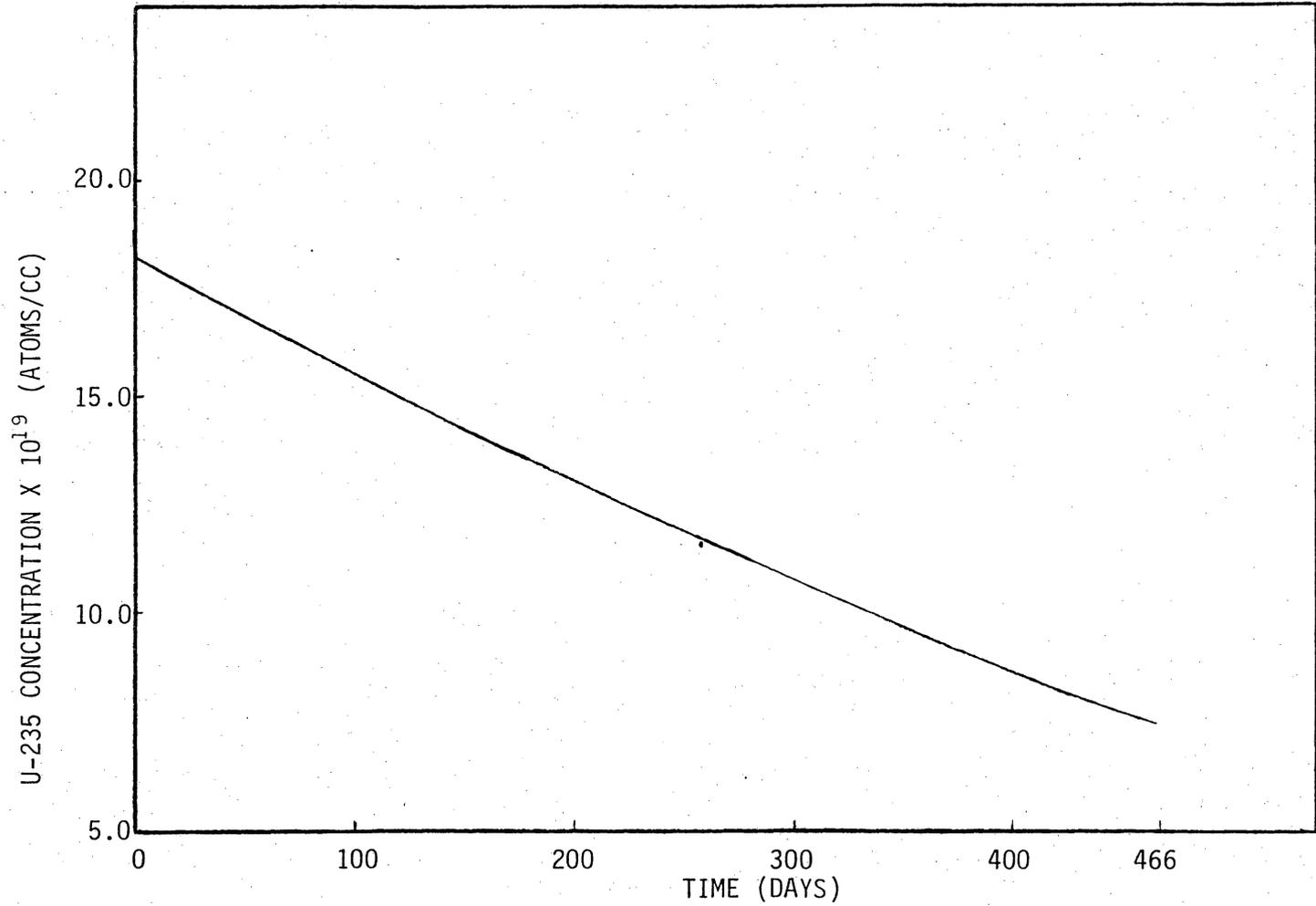


FIGURE 3.8
AVERAGE CORE U-235 CONCENTRATION 0-466 DAYS

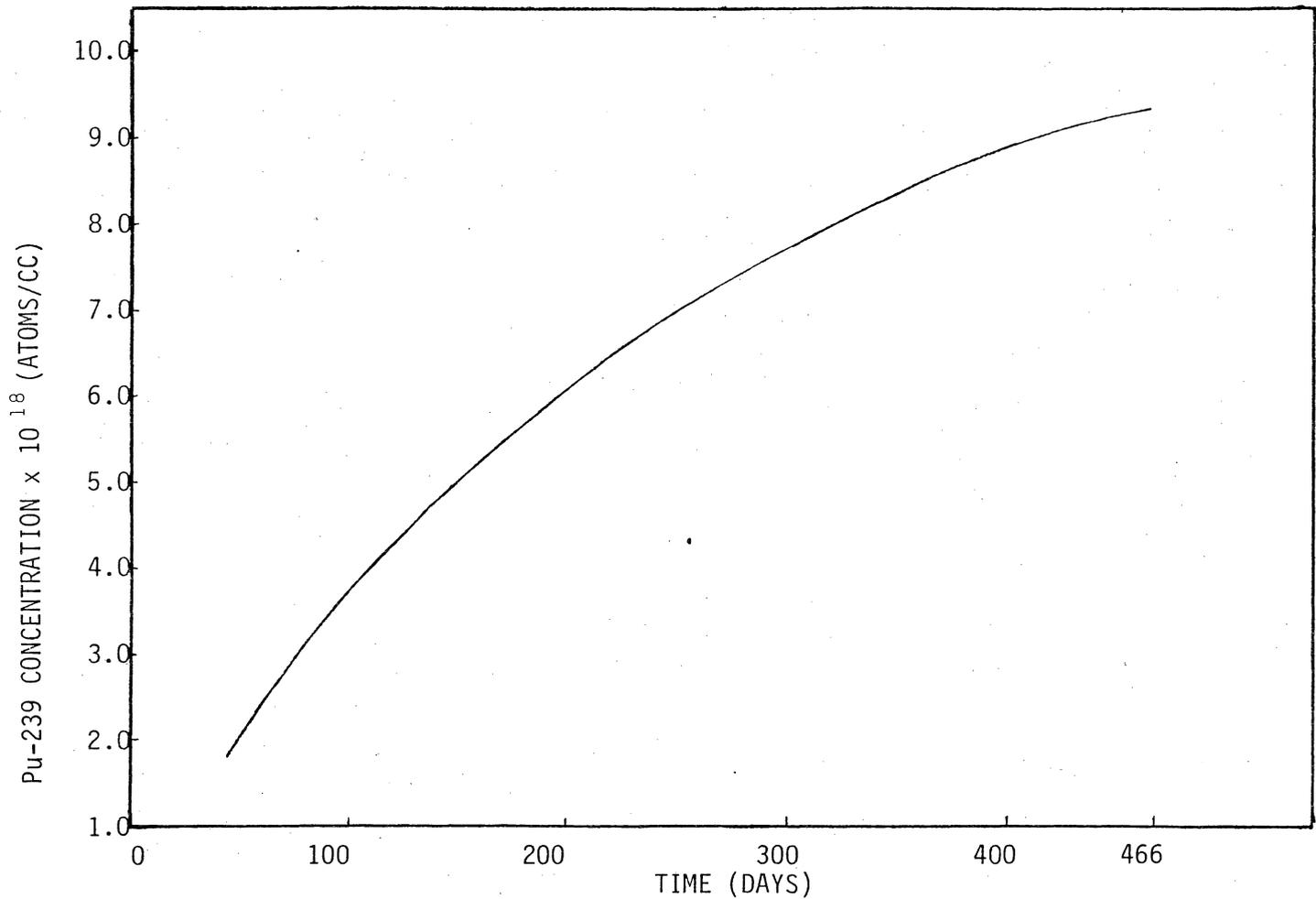


FIGURE 3.9
AVERAGE CORE Pu-239 CONCENTRATION 46-466 DAYS

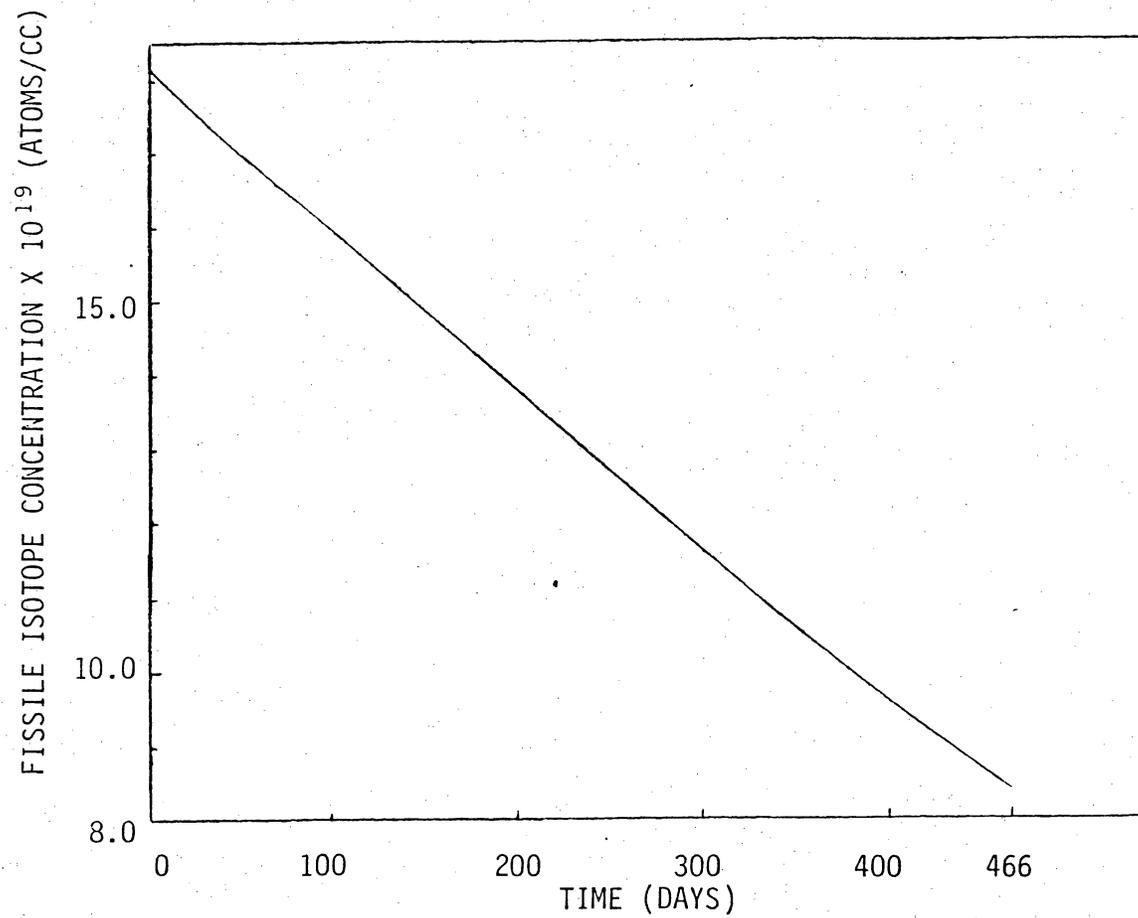


FIGURE 3.10
AVERAGE CORE FISSILE ISOTOPE (U-235 AND Pu-139) CONCENTRATION 0-466 DAYS

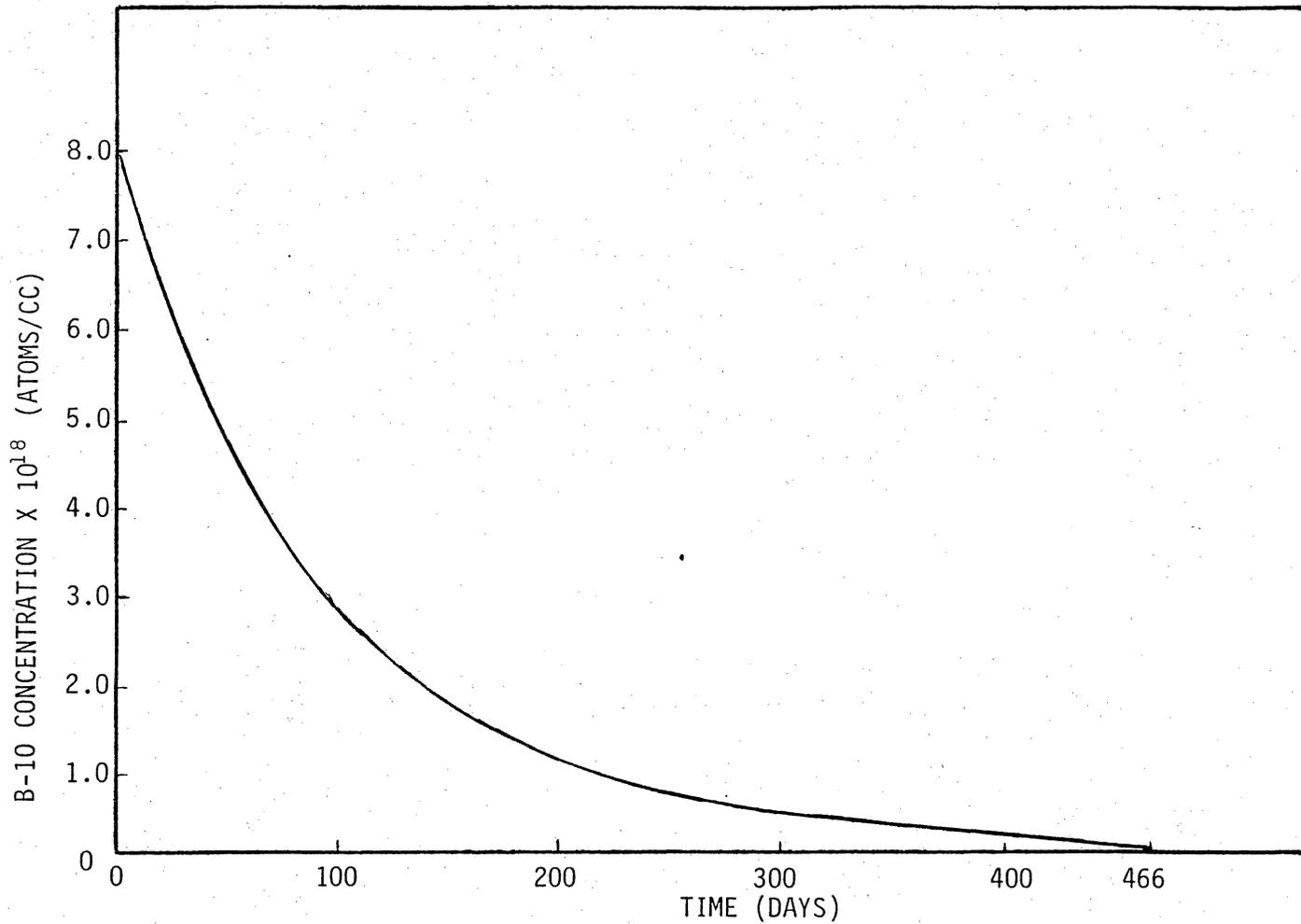


FIGURE 3.11
AVERAGE CORE LBP ISOTOPE (B-10) CONCENTRATION 0-466 DAYS

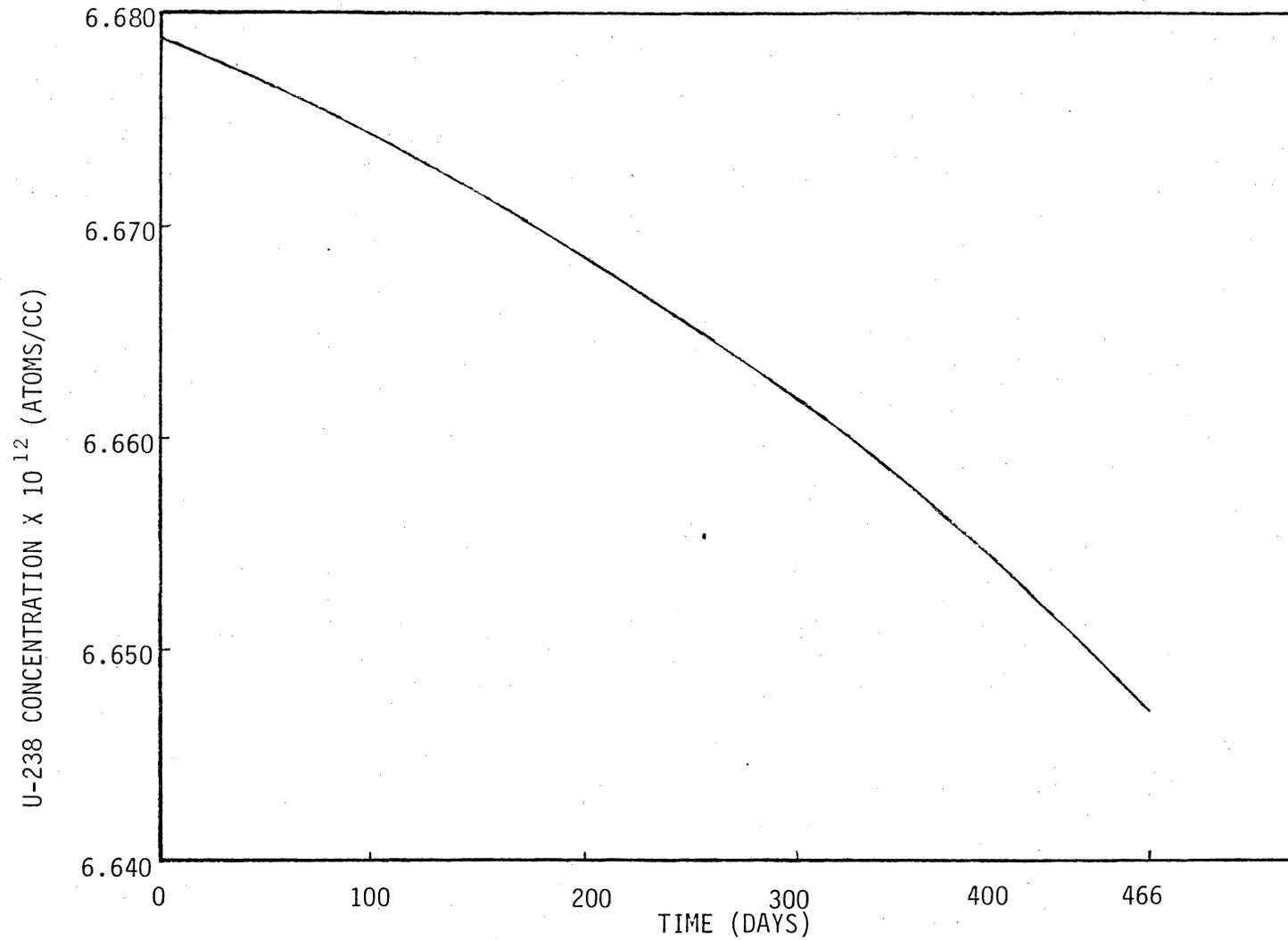


FIGURE 3.12
AVERAGE CORE U-238 CONCENTRATION 0-466 DAYS

To more fully understand how Figure 3.12 was generated and to confirm that there was no error in its generation, Figure 3.13 was made. Figure 3.13 was based on the assumption that the rate of increase of the flux was constant from 376 days to 406 days. As can be seen in Figure 3.7, this was not a bad assumption. The curve in Figure 3.12 was the result of depleting the U-238 concentration in steps of one day using equation 2.4.25 until the end of core life was reached at 466 days. Thus, the line segments in Figure 3.13 are exponential (in accordance with equation 2.4.25) although they appear to be straight lines.

When Figure 3.13 was made, it was found that the daily changes in the U-238 concentration from 376 to 379 days were -1.168×10^{17} atoms/cc, -1.17×10^{17} atoms/cc and -1.174×10^{17} atoms/cc. The decrease in the U-238 concentration gets larger with each time step. Since the time steps remain constant, the slope of the curve in Figure 3.13 must become more negative with each time step. Figure 3.12 is the result of adding many figures like Figure 3.13 together. Thus, the curve in Figure 3.12 (with its increasingly negative slope) is a correct depiction of how the MAY19 model depletes the U-238 in the sample core.

Figures 3.14, 3.15, and 3.16 show the behavior of I-135 over core life and Figures 3.17, 3.18 and 3.19 show the behavior of Xe-135 over core life. These figures show Xe-135 and I-135 rising exponentially to their equilibrium values in about 48 hours. The exponential shapes of the curves in Figures 3.14 and 3.17 are very similar to the shapes of the curves in Figure 15-3 in Duderstadt and Hamilton [2]. Figures 3.16 and 3.19 show both the I-135 and the X-135 as decreasing over core life

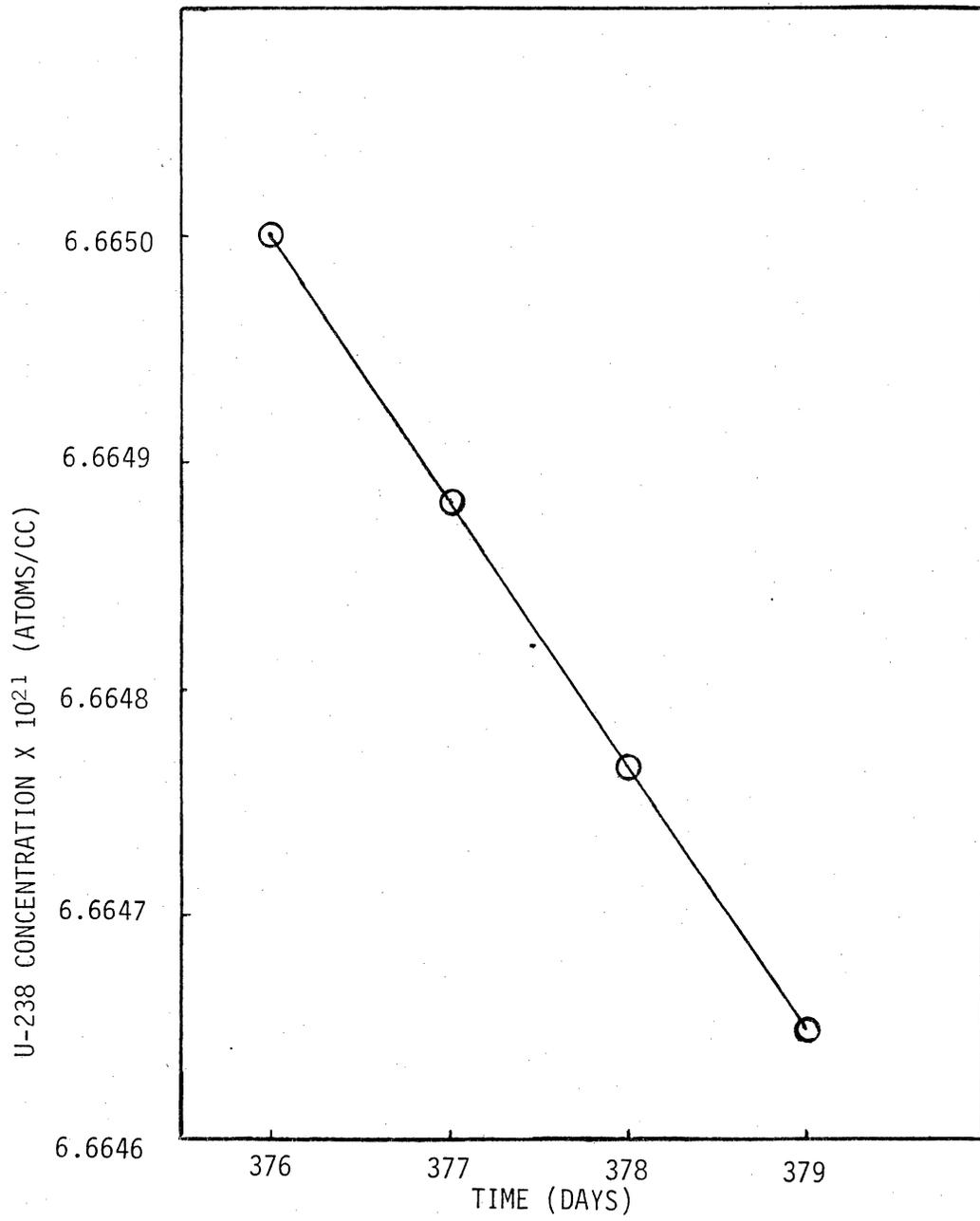


FIGURE 3.13
REGION 2 U-238 CONCENTRATION

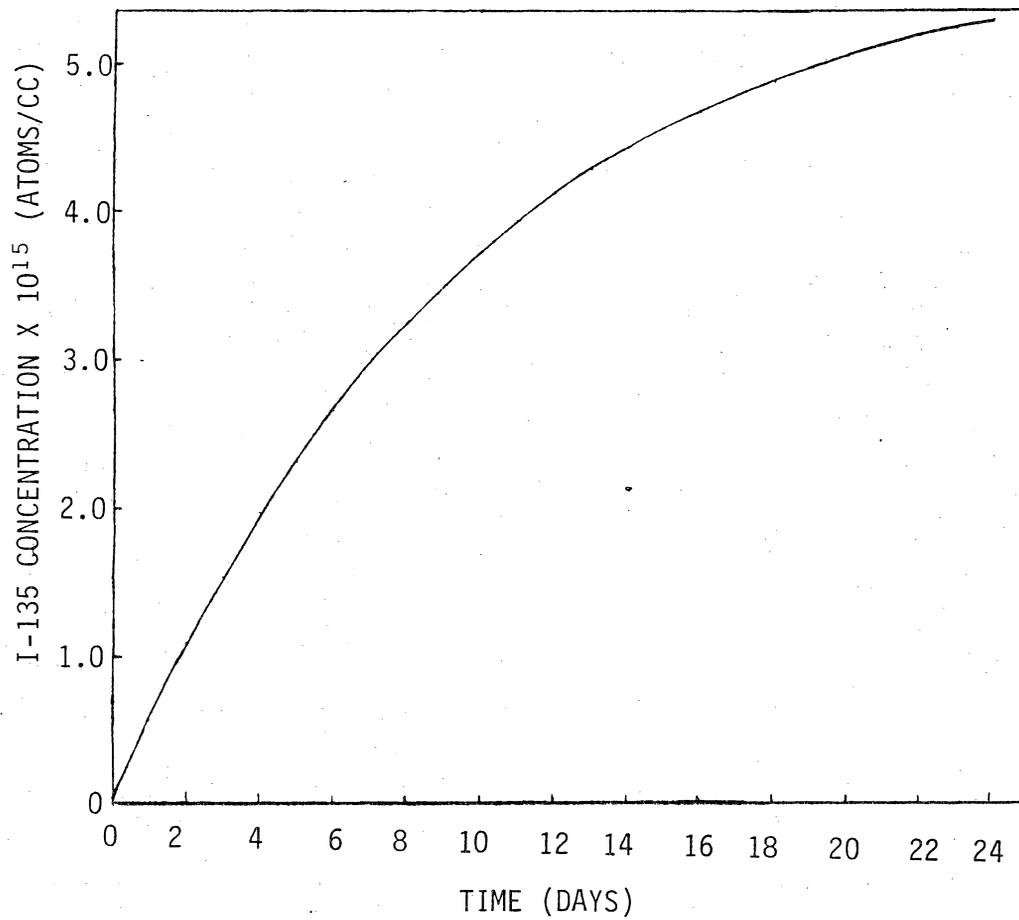


FIGURE 3.14
AVERAGE CORE I-135 CONCENTRATION 0-24 HOURS

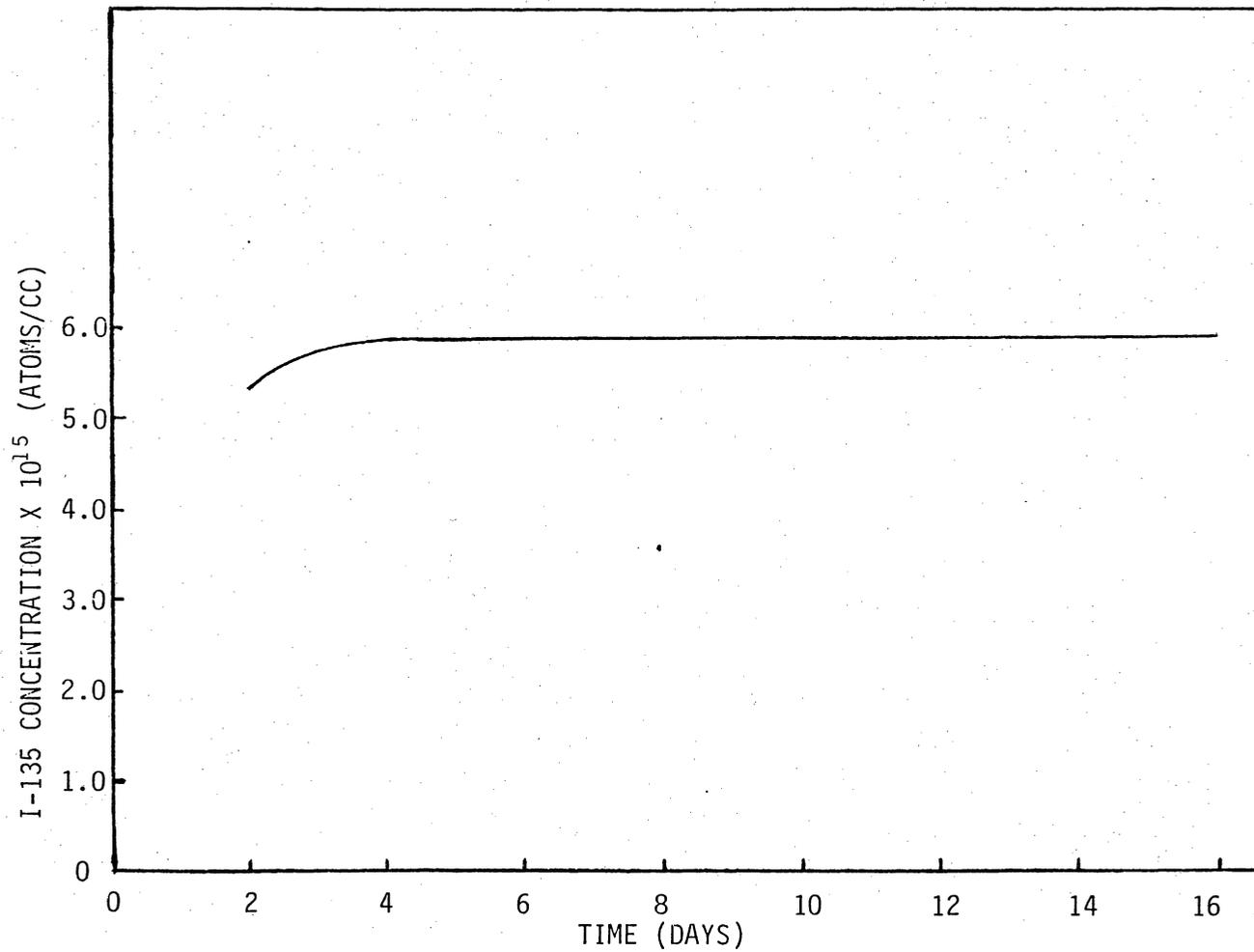


FIGURE 3.15
AVERAGE CORE I-135 CONCENTRATION 2-16 DAYS

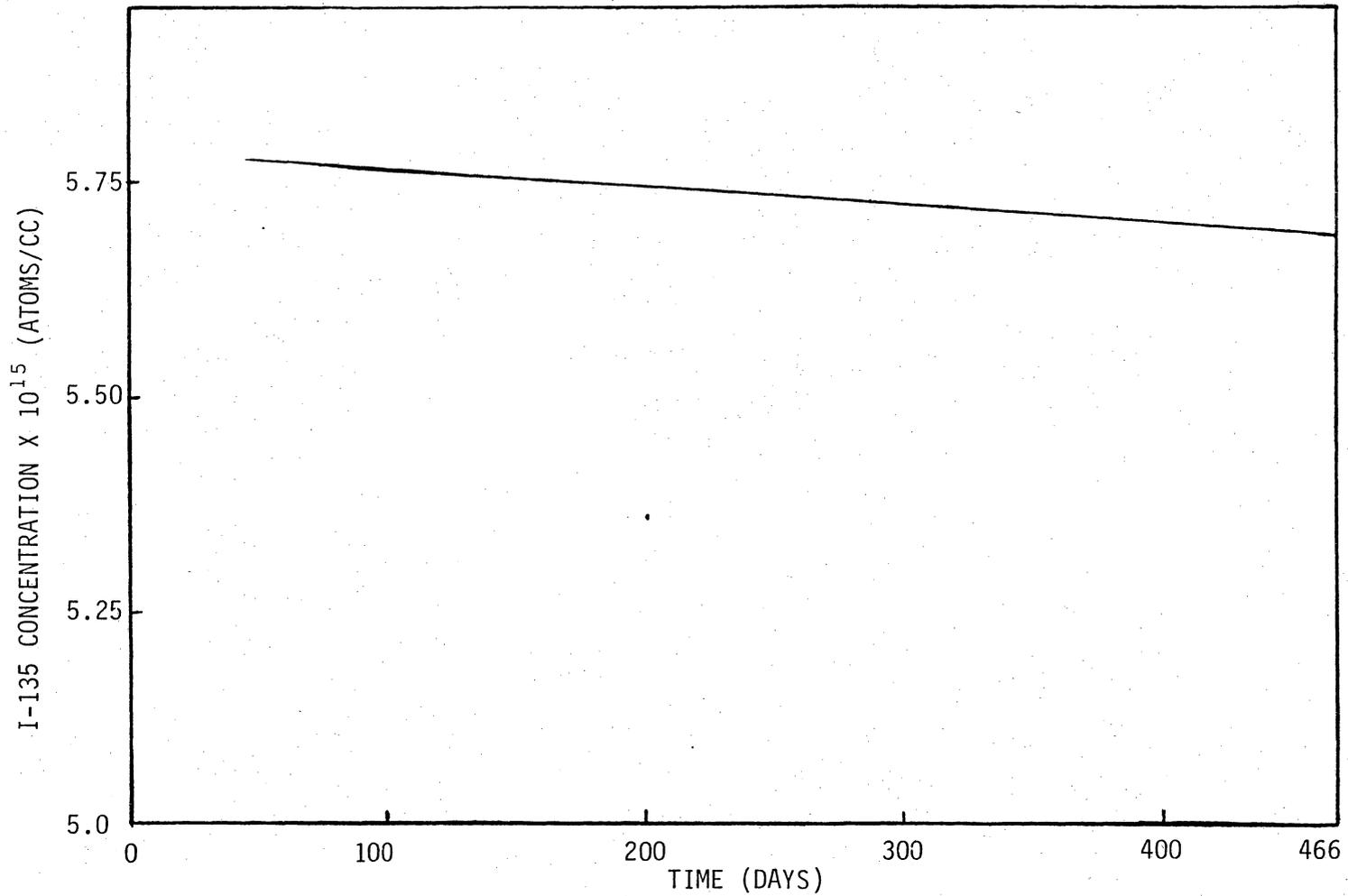


FIGURE 3.16
AVERAGE CORE I-135 CONCENTRATION 46-466 DAYS

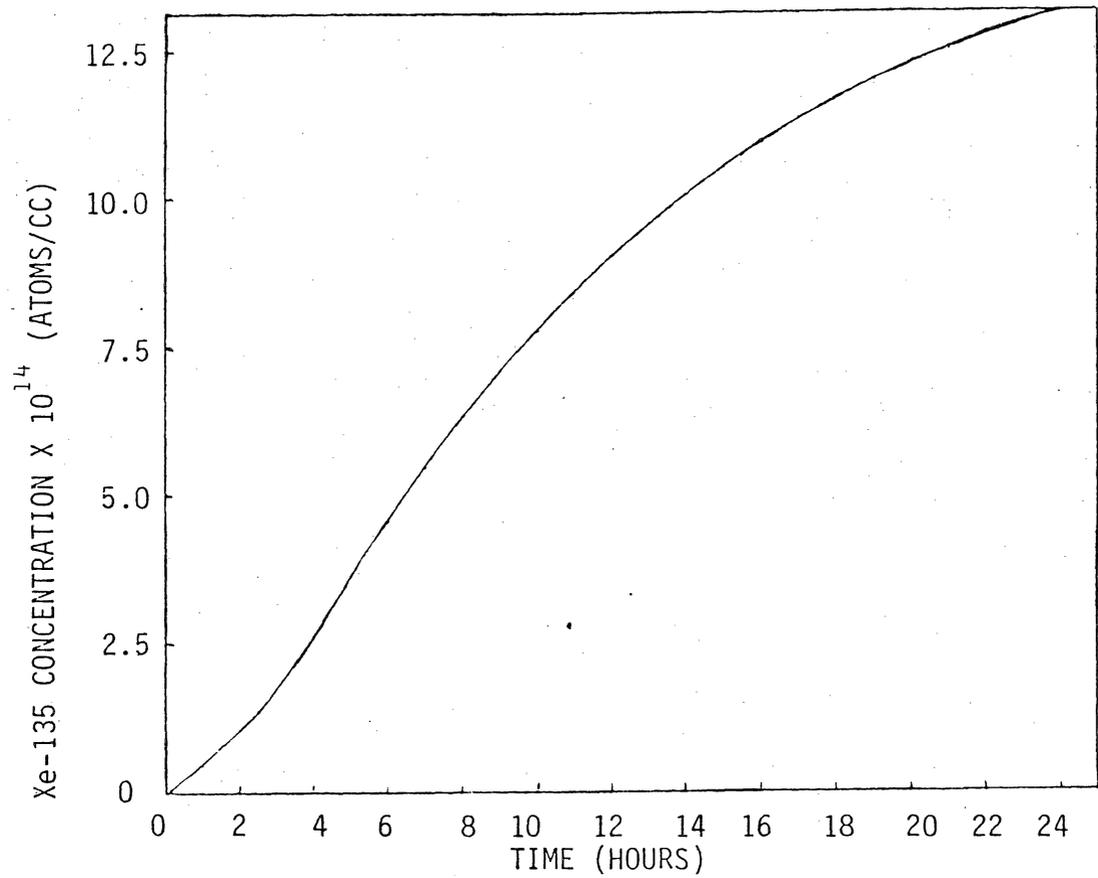


FIGURE 3.17
AVERAGE CORE Xe-135 CONCENTRATION 0-24 HOURS

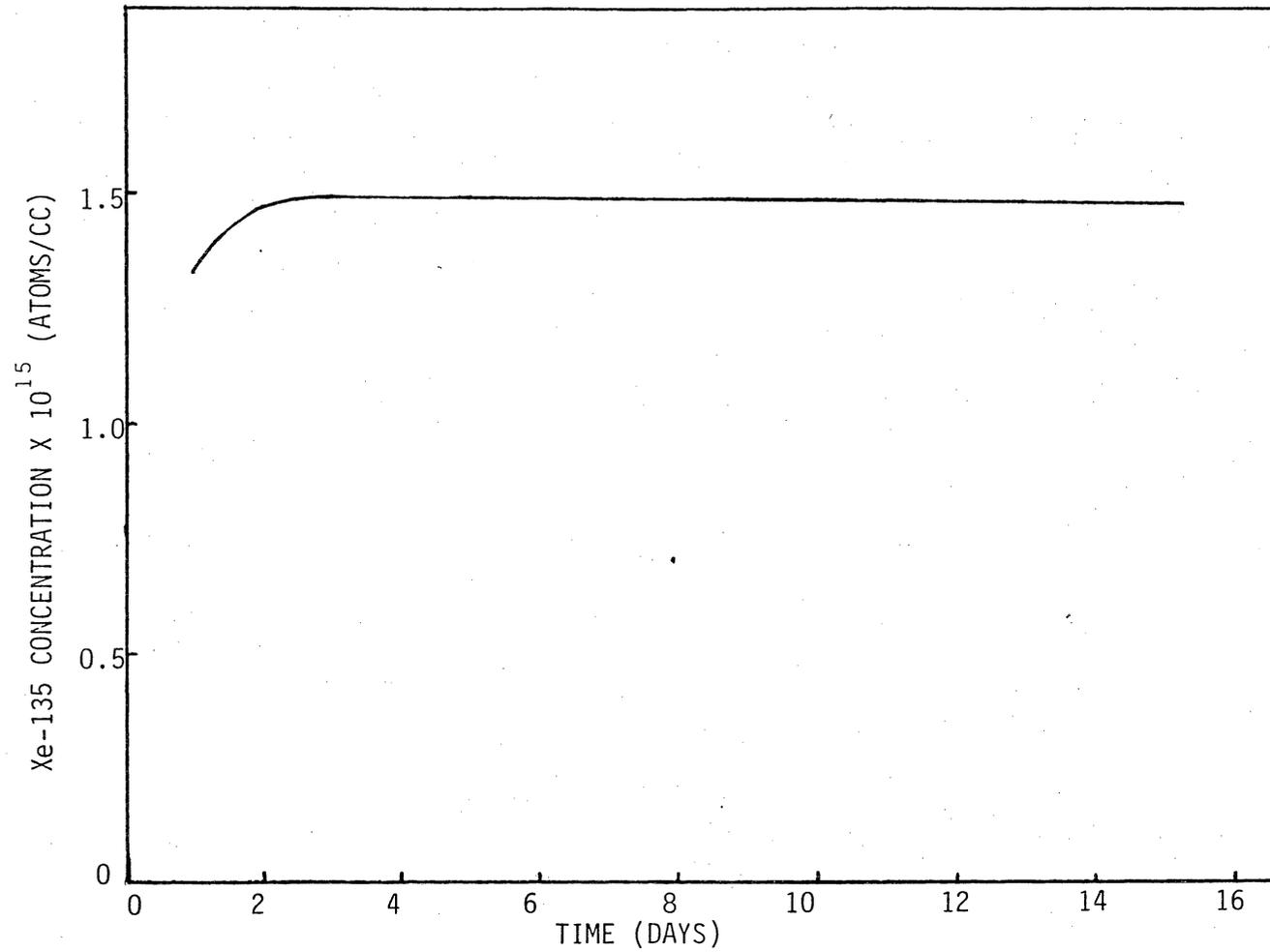


FIGURE 3.18
AVERAGE CORE Xe-135 CONCENTRATION 2-16 DAYS

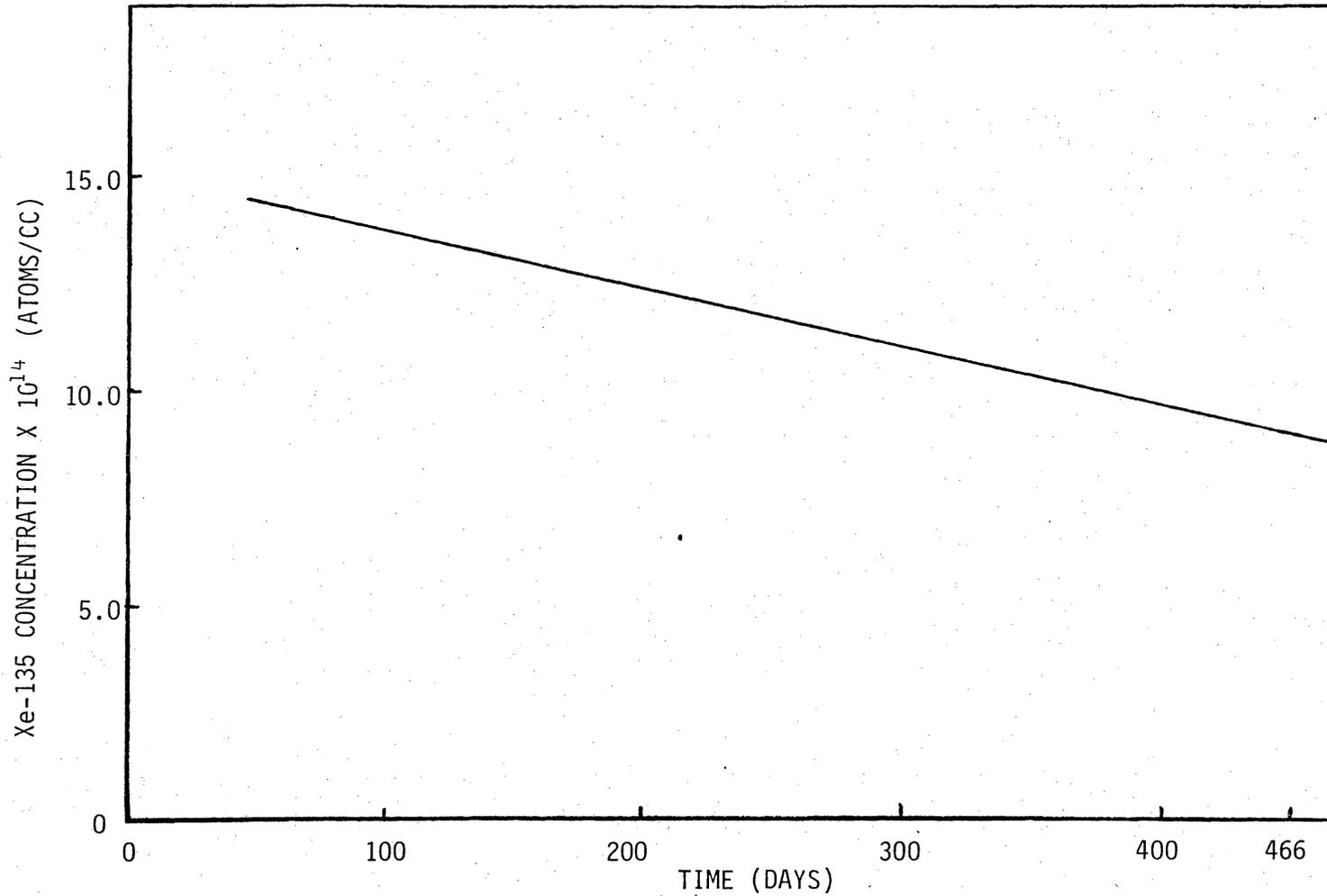


FIGURE 3.19
AVERAGE CORE Xe-135 CONCENTRATION 46-466 DAYS

after equilibrium is attained. This decrease in the equilibrium concentrations of I-135 and Xe-135 was due to the net decrease in the fission yield of I-135 and Xe-135 over core life.

Figures 3.20, 3.21 and 3.22 show the behavior of Sm-149 over core life. These curves show Sm-149 rising to its equilibrium concentration in about 150 days and then decreasing as the number of fissile nuclei in the core decrease. According to page 291 of Lamarsh [4] Sm-149 should have come into equilibrium in a few days. Since no error was found in the MAY19 mathematics or coding, this discrepancy was attributed to the cross sections used.

Figures 3.23, 3.24 and 3.25 show the behavior of Pm-149 over core life. Figures 3.24 and 3.25 show the Pm-149 coming into equilibrium in about 16 days and then gradually increasing over the remainder of core life. The equilibrium time of 16 days is roughly correct according to page 291 of Lamarsh [4]. The increase in the Pm-149 concentration was due to the net increase in the fission yield of Pm-149 over core life.

Figures 3.26, 3.27 and 3.28 show the behavior of the soluble boron concentration over core life. These figures show the soluble boron concentration increasing between 24 hours and about 106 days. This increase in soluble boron was in disagreement with Figure 7.18 of Lamarsh [4]. Once again, this discrepancy was not due to an error in mathematics or programming. The effective core multiplication factor - disregarding the soluble boron - went up between 24 hours and about 106 days. Thus, the MAY19 model kept the core critical by increasing the

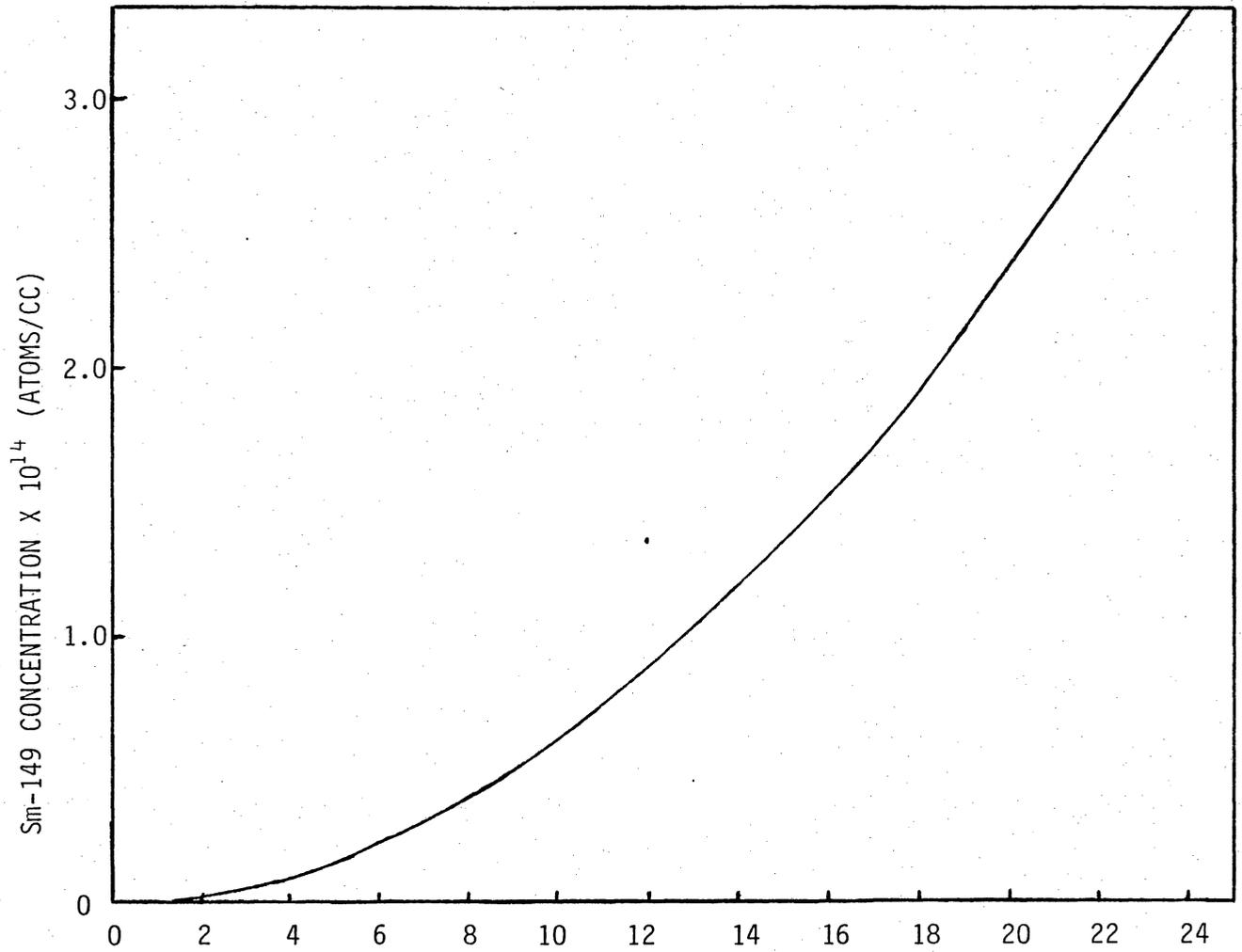


FIGURE 3.20
AVERAGE CORE Sm-149 CONCENTRATION 0-24 HOURS

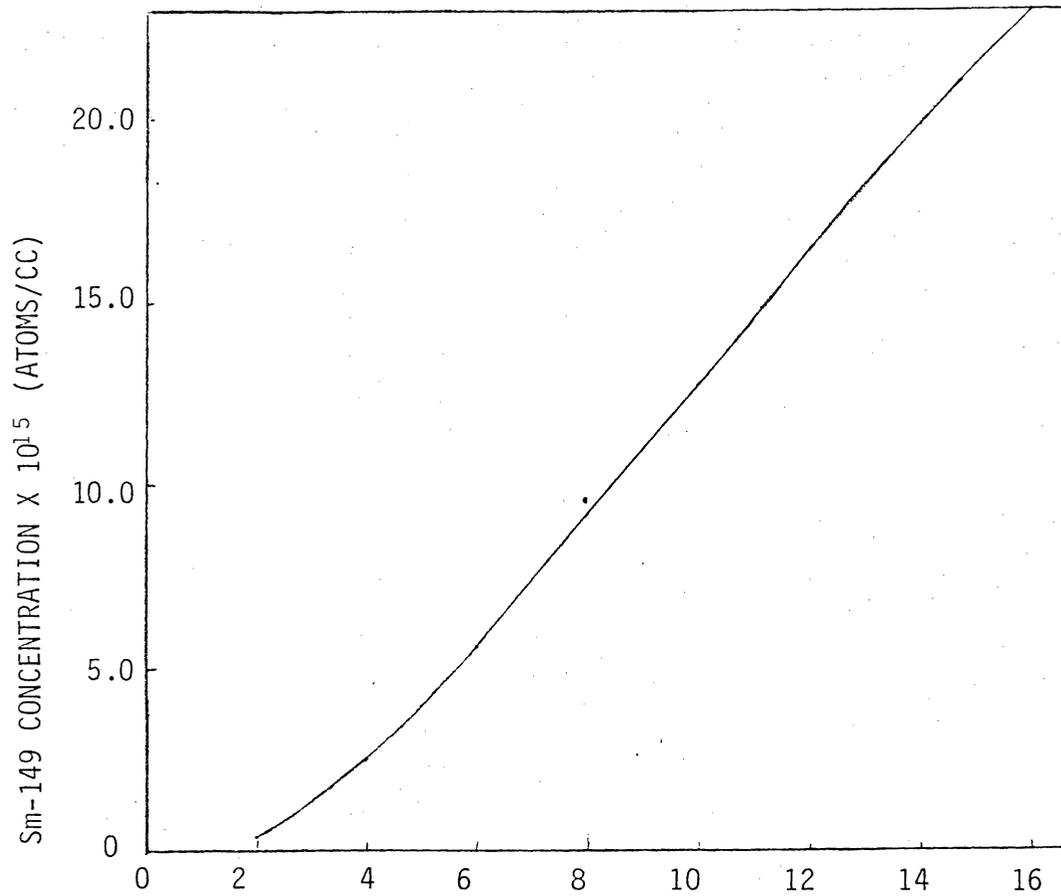


FIGURE 3.21
AVERAGE CORE Sm-149 CONCENTRATION 2-16 DAYS

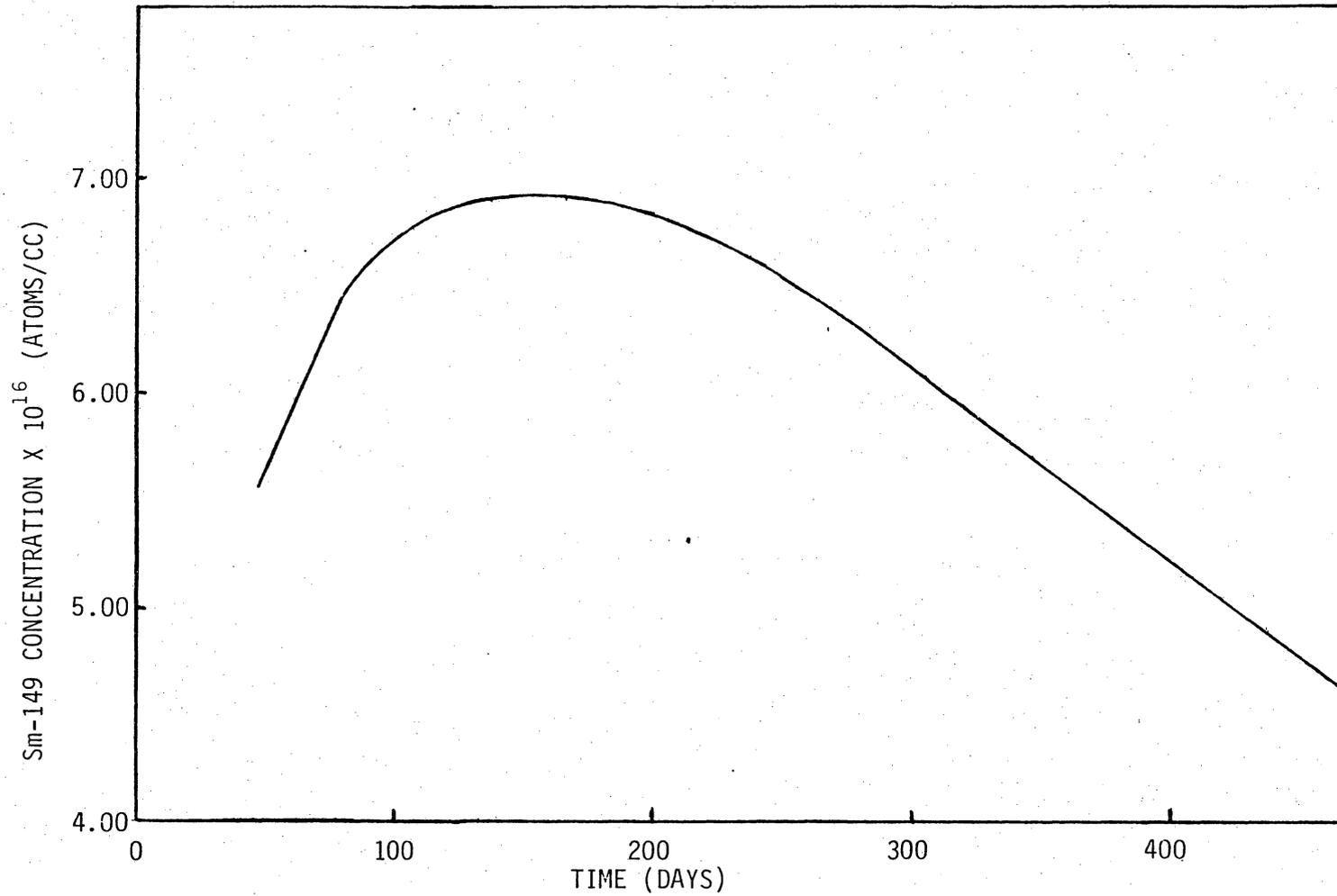


FIGURE 3.22
AVERAGE CORE Sm-149 CONCENTRATION 46-466 DAYS

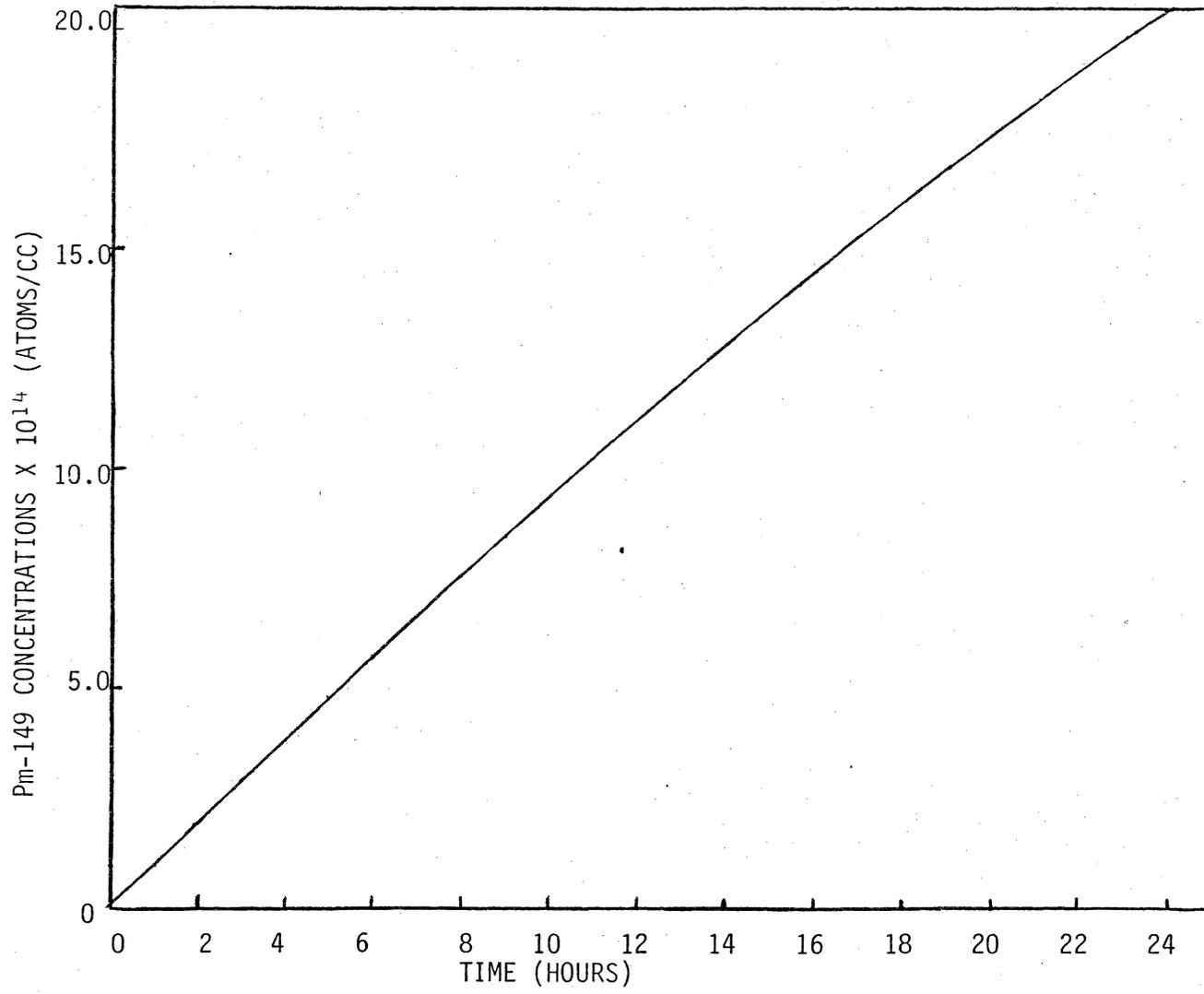


FIGURE 3.23 AVERAGE CORE Pm-149 CONCENTRATION 0-24 HOURS

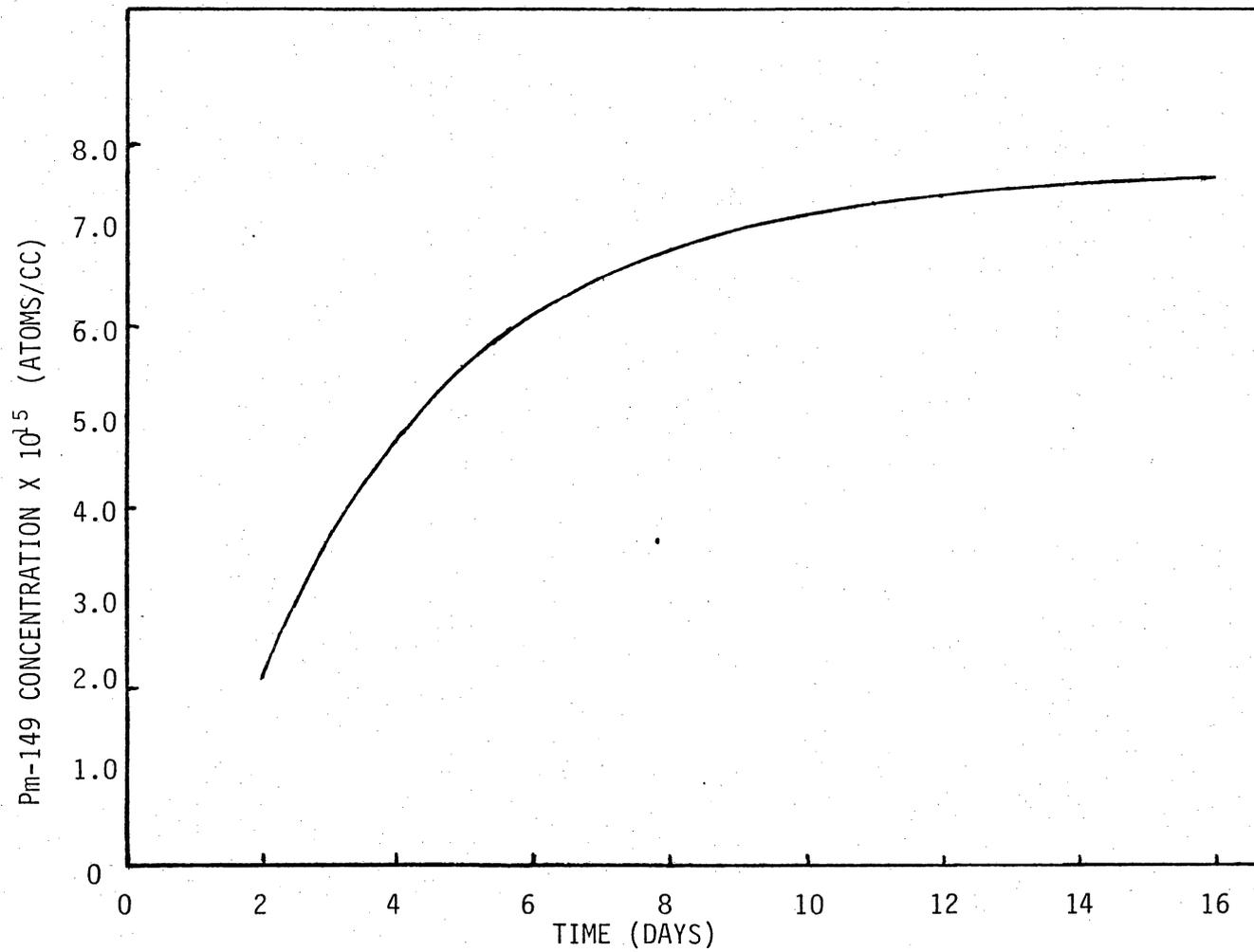


FIGURE 3.24
AVERAGE CORE Pm-149 CONCENTRATION 2-16 DAYS

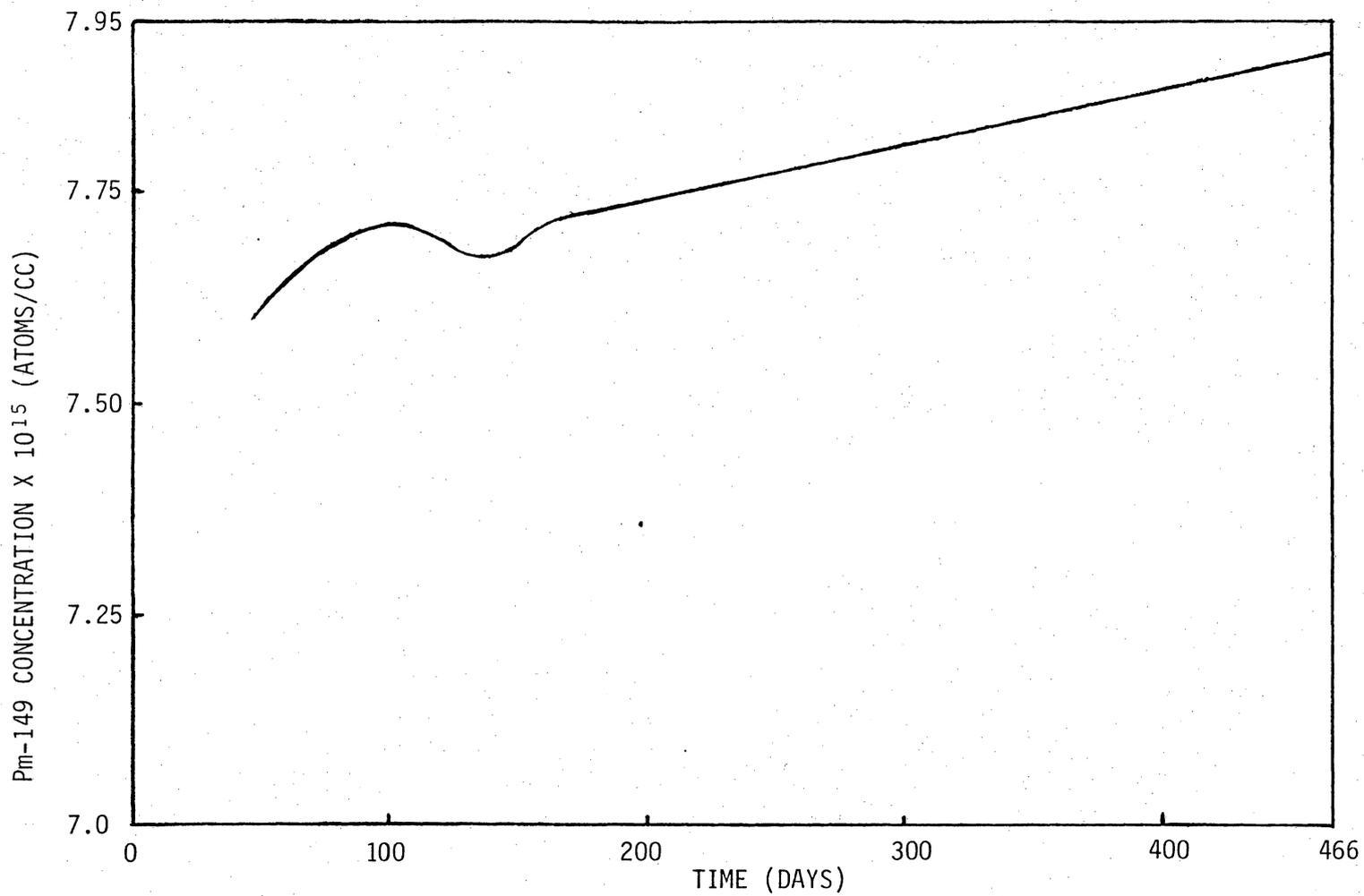


FIGURE 3.25
AVERAGE CORE Pm-149 CONCENTRATION 46-466 DAYS

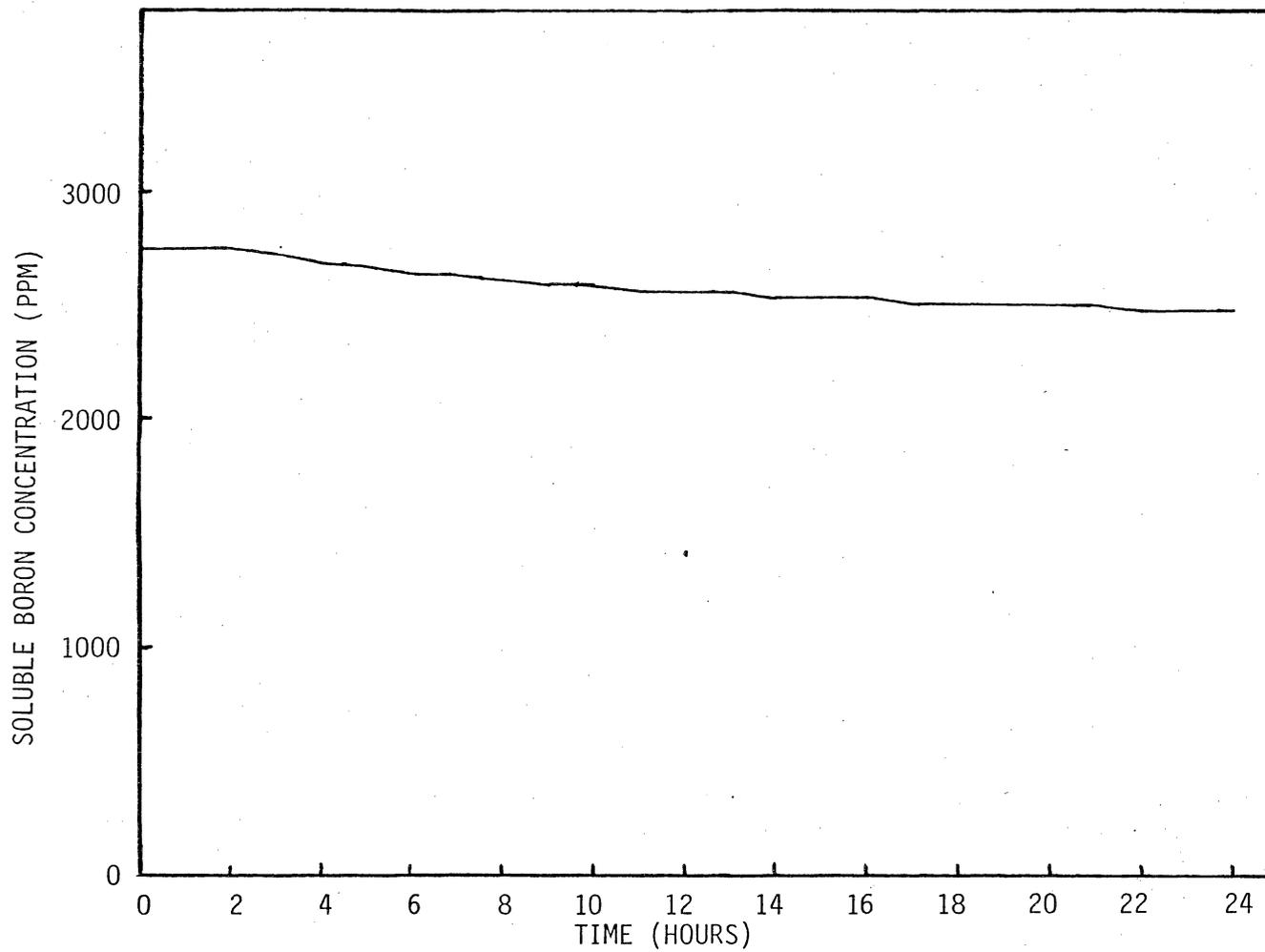


FIGURE 3.26
SOLUBLE BORON CONCENTRATION 0-24 HOURS

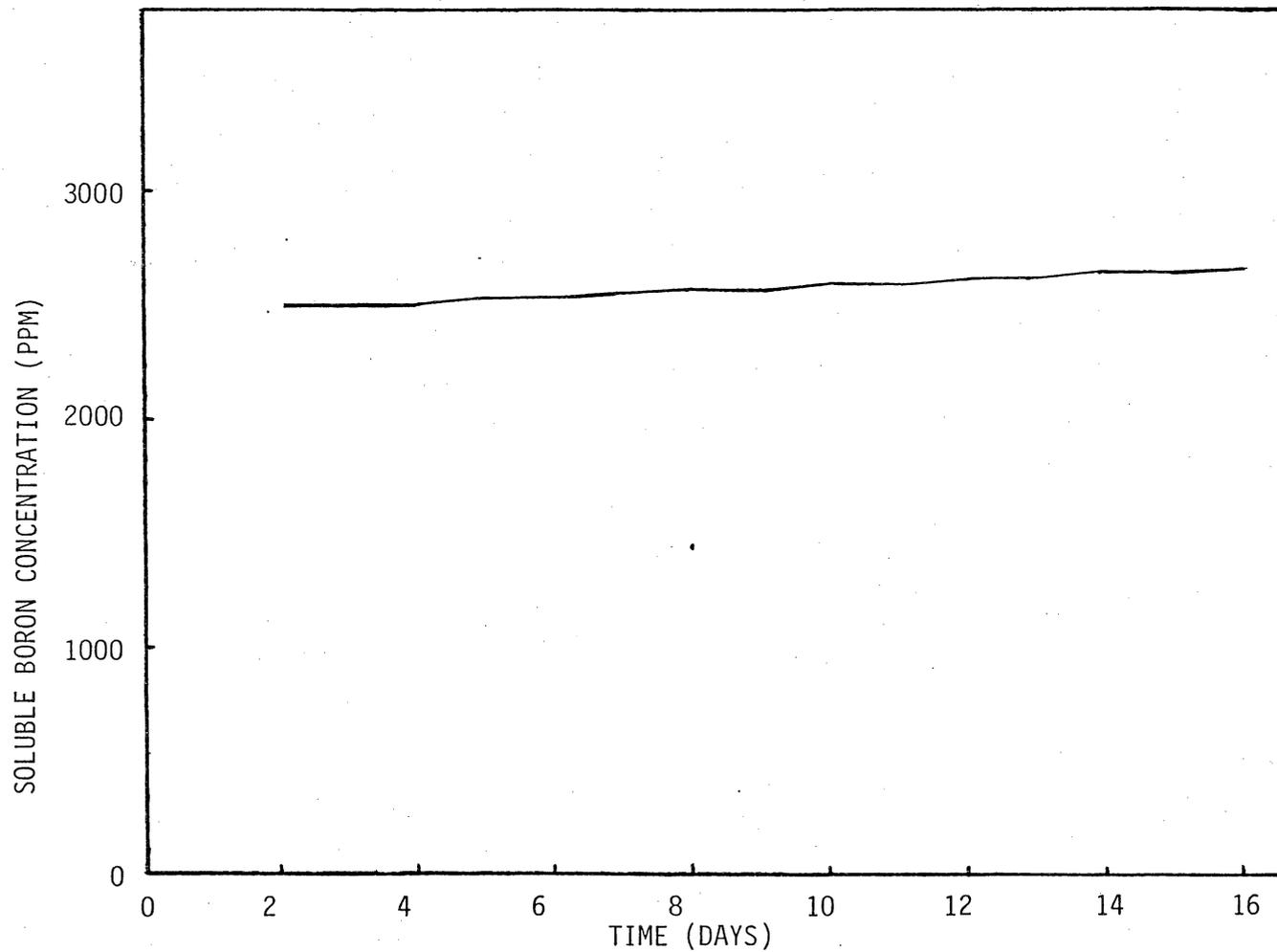


FIGURE 3.27
SOLUBLE BORON CONCENTRATION 2-16 DAYS

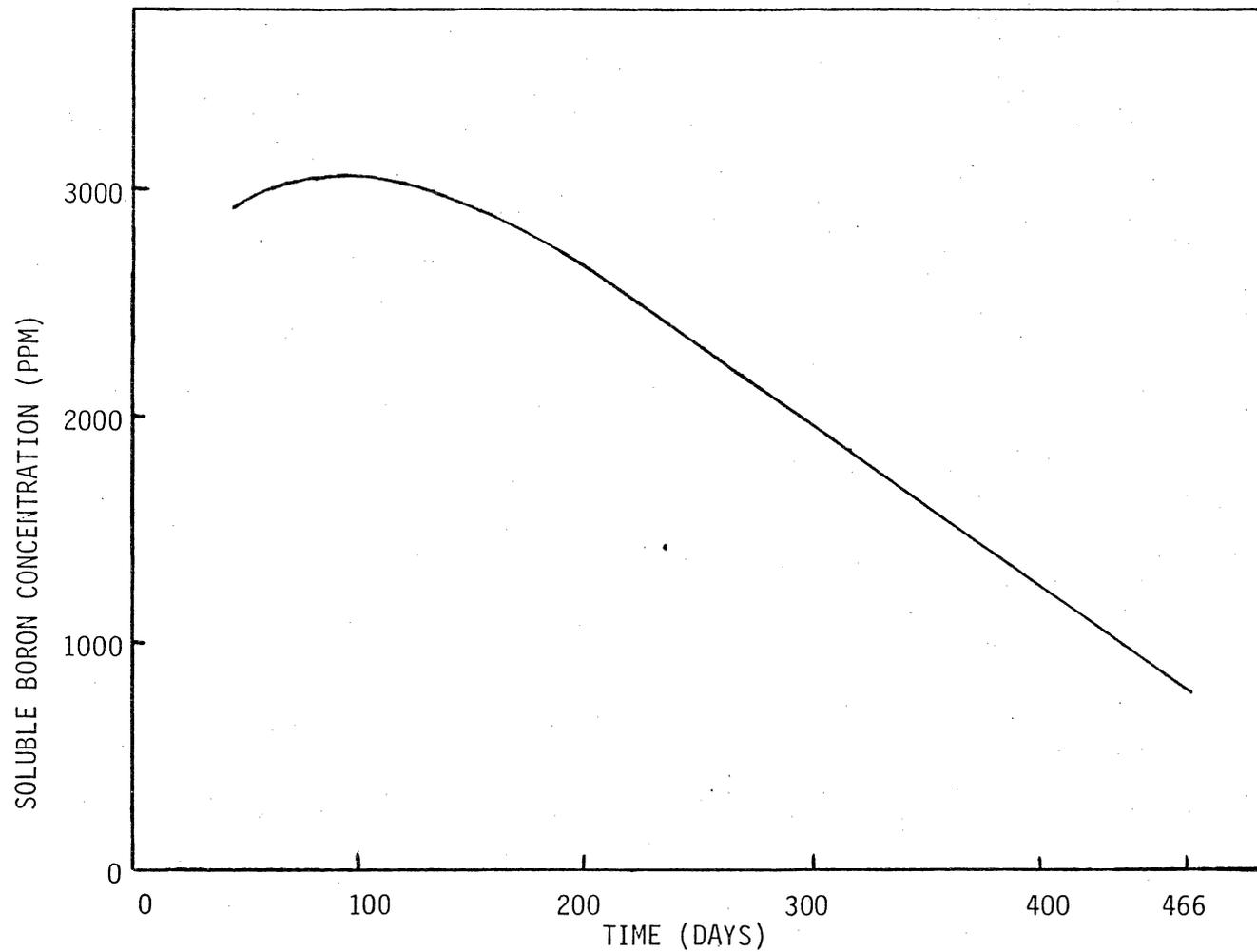


FIGURE 3.28
SOLUBLE BORON CONCENTRATION 46-466 DAYS

soluble boron concentration. The increase in the effective core multiplication factor - disregarding soluble boron - was attributed again to the cross sections used.

The isotopic concentrations generated by MAY19 were also compared to the concentrations generated by the computer code FUELBURN2 [2] after FUELBURN2 was loaded with input data equivalent to the input data loaded into MAY19. Because FUELBURN2 is based upon a zero-dimensional model, the MAY19 input data had to be averaged over the core before it could be put into FUELBURN2. Although FUELBURN2 is based on a zero-dimensional mathematical model, FUELBURN2 utilizes three energy groups and equivalent cross sections (cross sections which preserve the reaction rates) for each energy group. Thus, FUELBURN2 was assumed more accurate than MAY19.

3.3.1 Relative Accuracy Between MAY19 and FUELBURN 2

The programs FUELBURN2 and MAY19 differ in several ways. FUELBURN2 is based upon a zero-dimensional model and utilizes three-group diffusion theory and equivalent cross sections. MAY19 is based on a one-dimensional (radial) model and utilizes one-group diffusion theory and temperature adjusted thermal cross sections. The isotopic concentration input data for FUELBURN2 are core averaged values. The isotopic concentration input data for MAY19 are regionally averaged values. Likewise, the output from FUELBURN2 consists of isotopic concentrations which are core averages and the output from MAY19 consists of isotopic

concentrations which are regional averages. The flux computed by FUELURN2 is assumed to be constant over the core. The flux computed by MAY19 varies as a function of the radial distance from the center of the core. In MAY19 the time steps over which the flux is assumed to be constant are 24 hours long. In FUELURN2 the time steps over which the flux is assumed to be constant are 720 hours long.

In light of the above differences between FUELURN2 and MAY19, the question arose, was the assumption that FUELURN2 was more accurate than MAY19 because FUELURN2 utilized three-group diffusion theory and equivalent cross sections instead of one-group diffusion theory and temperature adjusted thermal cross sections still reasonable? That is, because FUELURN2 used average core isotopic concentrations, treated the flux as being constant over the core and assumed that the flux was constant over a time period of 720 hours, perhaps FUELURN2 was not as accurate as MAY19 in computing isotopic concentrations over core life.

To resolve this question, first the observation was made that if two fuel burnup models are exactly the same except that one uses one-group diffusion theory and temperature adjusted thermal cross sections and one uses three-group diffusion theory and equivalent cross sections, then the model using three-group diffusion theory and equivalent cross sections is generally more accurate than the model which uses one-group diffusion theory and temperature-adjusted thermal cross sections.

Next, a new fuel burnup model, very similar to the model of FUELURN2, was constructed. The main difference between these two

models was that the new model, hereafter referred to as MODEL_a, utilized one-group diffusion theory and temperature adjusted thermal cross sections instead of three-group diffusion theory and equivalent cross sections. Thus, the model of FUELBURN2 was known to be more accurate than MODEL_a.

The isotopic concentrations of U-235, Pu-239 and U-238 at the end of 450 days were computed by a program based on MODEL_a and compared to the isotopic concentrations of U-235, Pu-239 and U-238 computed by FUELBURN2 and MAY19. (See Table 3-2). No assumption was made about the relative accuracy between MAY19 and the program based on MODEL_a. The results, as shown in Table 3-2, do not allow one to conclude with absolute certainty that FUELBURN2 is more accurate than MAY19. However, since the concentrations computed by MAY19 are so much closer to the concentrations computed by the program based on MODEL_a than those computed by FUELBURN2, one can say that FUELBURN2 is probably more accurate than MAY19. The percentage differences between U-235, Pu-239 and U-238 concentrations computed by MAY19 and FUELBURN2 were 23.3%, 68.5%, and 0.7%, respectively.

This section was not concerned with how the two different types of cross section sets (one-group thermal and three-group equivalent) affected the accuracy of the isotopic concentrations computed. Nor was this section concerned with the relative accuracy between the MAY19 program algorithm and the FUELBURN2 program algorithm. The intent of the section was to determine the relative accuracy between the MAY19

program -- one-group thermal cross section set combination and the
FUELBURN2 program -- three-group equivalent cross section set
combination.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

For the reasons stated in Chapter 3, the flux generating portion of the MAY19 program was considered acceptable. The isotopic concentrations computed by the MAY19 program were also discussed in Chapter 3. This discussion brought out that except for the few noted discrepancies, the behavior over core life of the isotopic concentrations computed by MAY19 was in agreement with the general trends one would expect in an operating power reactor and/or with the shapes of the curves in graphs from other sources. The discussion in Chapter 3 also brought out the fact that the concentrations of U-235, U-238 and Pu-239 computed by MAY19 at 450 days differed by less than 100% from the concentrations of the same isotopes computed by FUELBURN2 at 450 days. For these reasons, the portion of the MAY19 program which computed the isotopic concentrations was considered acceptable. Thus, the overall performance of the MAY19 program was considered acceptable. This does not mean there is no room for improvement in the code. Some of the possible ways to improve the speed and accuracy and decrease the cost of running the code are discussed in the paragraph below.

The current version of MAY19 requires the code user to input data by editing the main program and recompiling MAY19. While this has the advantage of giving the user an explanation of each variable as he enters it (via comment statements in the coding), this method of

inputting data can be costly if the system being used charges a lot for compilation. To remedy this, a data file could be set up on a separate unit and accessed by inserting read statements in the main program of MAY19. This would also require a slight change in the job control language used to execute MAY19. On a UNIVAC system, this would require an "@ USE" statement in the runstream.

MAY19 selects the flattest positive flux by computing the value of the flux many times for many different values of boron concentration. The final flux selected is only approximately the flattest positive flux. That is, the flux selected is the flattest of a set of fluxes tested. It should be possible to improve both the speed and accuracy of the flux approximating portion of MAY19 by utilizing a numerical technique which converges on the flattest positive flux. Depending on the approach used, this could also significantly reduce the computer memory needed to run MAY19. This approach was not taken initially because of the added time and expense which would have been needed to get MAY19 debugged and running.

If MAY19 were changed from a one energy-group code to a two or three energy-group code this would certainly improve the accuracy of MAY19. However, there is at least one problem in doing this. For example, going to two energy groups would add two more unknown flux coefficients without adding any more constraints. Thus, there would be two many unknowns and not enough equations to solve the system for the flux. This problem could be solved, but probably not within the original framework of the model on which MAY19 is based.

In conclusion, MAY19 is not accurate enough for engineering uses, but is accurate enough to be useful for educational purposes. Also, the simplicity (gained by the loss of accuracy) of the MAY19 code makes MAY19 more understandable to nuclear engineering students. There is room for improvement in the code, but any large improvements in the accuracy would probably mean a major rewrite as well as the end of the simplicity of the code.

REFERENCES

1. Babcock & Wilcox, Steam/Its Generation and Use, Babcock & Wilcox, New York, N.Y., 1978.
2. Duderstadt, J.J. and L.J. Hamilton, Nuclear Reactor Analysis, John Wiley and Sons, Inc., N.Y., 1976.
3. Edlund, M.C., "Fuel Management Module, FM-1, Fuel Burnup in Slow Neutron Fission Reactors," Report on National Science Foundation Grant GZ-2888, 1974.
4. Final Safety Analysis Report, Midland Plant - Units 1 and 2, Volume 15, Consumers Power Company.
5. Graves, H.W., Jr., Nuclear Fuel Management, John Wiley and Sons, Inc., N.Y., 1979.
6. International Atomic Energy Agency handout given to participants at the International Atomic Energy Agency fuels calculation workshop in Vienna, Austria, Nov., 1980.
7. Kolman, Bernard, Introductory Linear Algebra, Macmillan Publishing Co., Inc., New York, N.Y., 1976.
8. Lamarsh, J.R., Introduction to Nuclear Engineering, Addison-Wesley Publishing Co., Reading, Mass., 1975.
9. Levine, s.H., "In-Core Fuel Management," Pennsylvania State University, 1980.
10. Milton, L.J., and R.E. Prael, "A User's Manual for the Monte Carlo Code VIM," FRA Technical Memorandum No. 84, Applied Physics Division, ANL, Feb. 1976.
11. Mosteller, R.D., "Incorporation of Commercial Reactor Codes into a Nuclear Engineering Course," Trans. Am. Nucl. Soc., 26-99 (June 1977).
12. Raymond, W.J., "Pressurized Water Reactor Startup Testing," Thesis Virginia Polytechnic Institute and State University, 1975.

APPENDIX

COMPILATION AND EXECUTION OF MAY19 PROGRAM

ASG, A DLG MAY 19.

ELT, L DIG* MAY 19. MAY 19 SUB

ELT BR1 SL74R1 12/30/82 05:30:56 (14)

```
1.      13      SUBROUTINE FFLUX(FF,GG,HH)
2.      10      IMPLICIT REAL*8(A-H,J-Z),INTEGER(I)
3.      10      COMMON A,B,DESTRU,VFM1,VFM2,VFM3,SIGMA9,CO1,CO2,CO3,C11,C12,C13,
4.      12      XD,P1,P2,PW,P1,PROD,L1,L2,L3
5.      10      DIMENSION DESTRU(3)
6.      10      DIMENSION PROD(3)
7.      10      CF=3.9667E16
8.      10      L1=DESTRU(1)+FF*VFM1*CF*SIGMA9
9.      10      L2=DESTRU(2)+FF*VFM2*CF*SIGMA9
10.     10      L3=DESTRU(3)+FF*VFM3*CF*SIGMA9
11.     10      CC=2.0*PI*((L1*CO1)+(L2*CO2)+(L3*CO3))
12.     10      DD=2.0*PI*((L1*C11)+(L2*C12)+(L3*C13))
13.     10      LK1=PI*PI*D
14.     10      LK2=2.0*PI*PI*D
15.     10      GG1=CC+LK1
16.     10      GG2=DD+LK2
17.     10      C1=A-GG1
18.     10      C2=B-GG2
19.     10      HH=(-C1*PW)/((C2*P1)-(C1*P2))
20.     10      GG=(PW-(P2*HH))/P1
21.     10      RETURN
22.     10      END
```

END ELT. ERRORS: NONE. TIME: 0.185 SEC. IMAGE COUNT: 22

FOR.S DLG* MAY19.MAY19A
 FOR 4R1T-01-MM/12/30-82:05:30 56 (10.)
 1114 376

MAIN PROGRAM

STORAGE USED: CODE(1) 003144; DATA(0) 007226; BLANK COMMON(2) 000064

EXTERNAL REFERENCES (BLOCK, NAME)

0003 FFLUX
 0004 TINTR\$
 0005 DMATH\$
 0006 XPDR\$
 0007 DSIN\$
 0010 DCOS\$
 0011 NIOCB\$
 0012 NNWFS\$
 0013 NSCR\$
 0014 DEXP\$
 0015 NSTOP\$
 0016 NBFO\$

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0001	001160	101L	0001	003126	122L	0001	003140	124L	0001	002166	202L	0001	002205	206L
0001	002175	208L	0001	002217	209L	0001	002226	220L	0001	002244	230L	0001	000335	260G
0000	006442	27F	0000	006460	28F	0000	006515	29F	0000	006537	37F	0001	001171	376G
0000	006421	40F	0001	001267	410G	0000	006400	42F	0001	001327	422G	0001	001354	430G
0000	006552	453D	0000	006557	460D	0000	006564	463D	0000	006571	465D	0000	006603	475D
0000	006610	500D	0000	006615	502D	0001	001530	515G	0001	001541	524G	0001	001557	533G
0001	001601	544G	0001	001620	552G	0000	006376	56F	0001	001730	600G	0001	001755	611G
0000	006342	62F	0001	002017	626G	0000	006345	63F	0000	006351	64F	0000	006627	663D
0000	006637	673D	0000	006647	707D	0000	006657	717D	0001	001446	72L	0001	001512	73L
0000	006667	731D	0000	006677	736D	0000	006302	74F	0000	006704	740D	0000	006711	742D
0000	006717	744G	0000	006717	746G	0000	006373	75F	0001	002335	762G	0001	001715	77L
0001	001430	78L	0002	D 000000	A	0000	D 005707	AFL	0000	D 005755	AREA 1	0000	D 005757	AREA 2
0000	D 005761	AREA 3	0000	D 005403	ARRAY	0000	D 006220	AS 1	0000	D 006226	AS 2	0000	D 006212	AX 1
0000	D 006202	AX 2	0000	D 006125	AO	0000	D 006127	A 1	0002	D 000002	B	0000	D 006164	BC
0000	D 006140	BCMAX	0000	D 006136	BCMIN	0000	D 000323	BCN	0000	D 000633	BCON	0000	D 000013	BCPOS
0000	D 006236	BCS 1	0000	D 006232	BCX 1	0000	D 006234	BCX 2	0000	D 001453	BORCON	0000	D 006222	BS 1
0000	D 006230	BS 2	0000	D 006214	BX 1	0000	D 006204	BX 2	0000	D 005771	B 1	0000	D 005773	B 2
0000	D 005717	CCTH	0000	D 005543	CF	0000	D 005651	CPP 1	0000	D 005653	CPP 2	0000	D 005655	CPP 3
0000	D 005741	CRFA	0000	D 005725	CRL	0000	D 005731	CRR	0000	D 006224	CS 1	0000	D 006216	CX 1
0000	D 006206	CX 2	0002	D 000022	CO 1	0002	D 000024	CO 2	0002	D 000026	CO 3	0002	D 000030	C 11
0002	D 000032	C 12	0002	D 000034	C 13	0002	D 000036	D	0002	D 000004	DESTRU	0000	D 006157	DEV
0000	D 006210	DX 1	0000	D 006274	EQ 1	0000	D 006300	EQPM	0000	D 006276	EQSM	0000	D 006272	EQXE
0000	D 006244	ES 1	0000	D 006246	ES 2	0000	D 006240	EX 1	0000	D 006242	EX 2	0000	D 005723	FAP
0000	D 005715	FCTH	0000	D 006172	FLUX	0000	D 006134	FLX	0000	D 005373	FLXINT	0000	D 006155	FLXX
0000	D 005713	FR	0000	D 005735	FRFA	0000	D 005711	FRR	0000	D 005753	G	0000	D 005575	GAMI 1
0000	D 005577	GAMI 2	0000	D 005605	GAMPM 1	0000	D 005607	GAMPM 2	0000	D 005601	GAMX 1	0000	D 005603	GAMX 2
0000	D 006144	GGG	0000	D 006174	GM 1	0000	D 006176	GM 2	0000	D 006200	GM 3	0000	D 005617	H
0000	D 006142	HHH	0000	I 005775	I	0000	I 006122	II	0000	I 006163	III	0000	I 006152	IX
0000	I 006133	IXX	0000	I 000002	J	0000	I 000006	JJ	0000	I 000007	JJJ	0000	I 000001	K
0000	I 000010	KK	0000	I 000011	KKK	0000	D 006146	KX	0000	I 000003	L	0000	D 005611	LAMI
0000	D 005615	LAMPM	0000	D 005613	LAMX	0000	D 005675	LBPCON	0000	D 005721	LCTH	0000	I 000004	LL
0000	I 000005	LLL	0000	D 005737	LRFA	0000	D 005727	LRL	0000	D 005733	LRR	0002	D 000056	L 1
0002	D 000060	L 2	0002	D 000062	L 3	0000	D 006161	MINSUM	0000	D 005677	MODCON	0000	I 000000	N

0000 D 005657 NFABP1	0000 D 005661 NFABP2	0000 D 005663 NFABP3	0000 D 005635 NFACF1	0000 D 005637 NFACF2
0000 D 005641 NFACF3	0000 D 005643 NFACP1	0000 D 005645 NFACP2	0000 D 005647 NFACP3	0000 I 000012 NN
0000 D 005627 NOFAT1	0000 D 005631 NOFAT2	0000 D 005633 NOFAT3	0000 D 005621 NOFA1	0000 D 005623 NOFA2
0000 D 005625 NOFA3	0000 D 005571 NU1	0000 D 005573 NU2	0002 D 000046 P1	0002 D 000050 PROD
0000 D 005535 PRODD	0002 D 000044 PW	0002 D 000040 P1	0002 D 000042 P2	0000 D 005505 Q
0000 D 005776 R	0000 D 005745 REG1	0000 D 005747 REG2	0000 D 005751 REG3	0000 D 006131 RR1
0000 D 006153 RX	0000 D 005763 R1	0000 D 005765 R2	0000 D 005767 R3	0000 D 005671 SIGCRC
0000 D 005667 SIGCRP	0000 D 005665 SIGFRC	0000 D 005705 SIGH20	0000 D 005703 SIGMA0	0000 D 005701 SIGMAT
0000 D 005545 SIGMA1	0000 D 005547 SIGMA2	0000 D 005551 SIGMA3	0000 D 005553 SIGMA4	0000 D 005555 SIGMA5
0000 D 005557 SIGMA6	0000 D 005561 SIGMA7	0000 D 005563 SIGMA8	0002 D 000020 SIGMA9	0000 D 005565 SIGMF1
0000 D 005567 SIGMF2	0000 D 005673 SIGPRC	0000 D 006262 SM1	0000 D 006264 SM2	0000 D 006266 SM3
0000 D 006270 SM4	0000 D 006120 STEPS	0000 D 006166 STPSAV	0000 D 005477 STRUCT	0000 D 006150 SUMDEV
0000 D 005743 THPW	0000 D 006114 TOTAL	0000 D 006116 TPS	0000 D 006010 VCR	0000 D 006014 VCRC
0000 D 006012 VCRP	0000 D 006002 VFA	0000 D 006056 VFBPC1	0000 D 006060 VFBPC2	0000 D 006062 VFBPC3
0000 D 006072 VFBPP1	0000 D 006074 VFBPP2	0000 D 006076 VFBPP3	0000 D 006006 VFC	0000 D 006032 VFCC
0000 D 006064 VFCPP1	0000 D 006066 VFCPP2	0000 D 006070 VFCPP3	0000 D 006030 VFCP	0000 D 006034 VFCPP1
0000 D 006036 VFCPP2	0000 D 006040 VFCPP3	0000 D 006050 VFCRC1	0000 D 006052 VFCRC2	0000 D 006054 VFCRC3
0000 D 006042 VFCRP1	0000 D 006044 VFCRP2	0000 D 006046 VFCRP3	0000 D 006024 VFF	0000 D 006026 VFCC
0000 D 006102 VFMC1	0000 D 006104 VFMC2	0000 D 006106 VFMC3	0000 D 006110 VFMC3	0000 D 006112 VFMLBP
0000 D 006100 VFMD	0002 D 000012 VFM1	0002 D 000014 VFM2	0002 D 000016 VFM3	0000 D 006000 VFR
0000 D 006004 VFU	0000 D 006022 VLC	0000 D 006020 VLP	0000 D 006016 VLR	0000 D 006250 XE1
0000 D 006252 XE2	0000 D 006254 XE3	0000 D 006256 XE4	0000 D 006260 XE5	0000 D 006170 Y
0000 D 006123 Z				

00100	1*	C	THIS PROGRAM COMPUTES THE CONCENTRATIONS OF U-235,U-238.	000000
00100	2*	C	PU-239,XE-135,I-135,SM-149,PM-149,SOLUBLE BORON AND LUMPED	000000
00100	3*	C	BURNABLE POISON IN EACH OF THE THREE REGIONS OF A TYPICAL	000000
00100	4*	C	PWR OVER CORE LIFE. THE FUEL IS ASSUMED TO BE IN THE FORM OF	000000
00100	5*	C	FUEL RODS COMPOSED OF UO2 PELLETS WITH A DENSITY OF 92.5	000000
00100	6*	C	PERCENT THEORETICAL DENSITY. THE THEORETICAL DENSITY IS SET AT	000000
00100	7*	C	10.96 GRAMS PER CC. THE REACTOR IS ASSUMED TO BE AT A	000000
00100	8*	C	CONSTANT PRESSURE AND TEMPERATURE AND AT A CONSTANT POWER	000000
00100	9*	C	INPUT BY THE USER.THE COMPUTATIONS ARE CARRIES OUT FOR 466	000000
00100	10*	C	DAYS. ANY LUMPED BURNABLE POISON IS ASSUMED TO BE IN THE	000000
00100	11*	C	FORM OF CLAD RODS INSERTED INTO THE FUEL ASSEMBLIES.	000000
00100	12*	C	THE CONTROL ROD POSITIONS ARE TREATED AS BEING CONSTANT.	000000
00100	13*	C	ONLY THE RADIAL DIMENSION IS CONSIDERED.	000000
00100	14*	C	ONLY ONE GROUP DIFFUSION THEORY IN USED AND EACH OF THE	000000
00100	15*	C	THREE FUEL ENRICHMENT REGIONS IS HOMOGENIZED.	000000
00100	16*	C	THE FLUX IS APPROXIMATED BY THE EXPRESSION	000000
00100	17*	C		000000
00100	18*	C	FLUX=AO* $\cos(B1 \cdot R)$ +A1* $\sin(B2 \cdot R)$	000000
00100	19*	C		000000
00100	20*	C	WHERE	000000
00100	21*	C		000000
00100	22*	C	$B1=(3 \cdot \pi / 2 \cdot \text{RADIUS OF CORE})$.	000000
00100	23*	C		000000
00100	24*	C	$B2=(\pi / 2 \cdot \text{RADIUS OF CORE})$	000000
00100	25*	C		000000
00100	26*	C	AND	000000
00100	27*	C		000000
00100	28*	C	AO AND A1 ARE VARIABLE COEFFICIENTS WHICH ARE COMPUTED	000000
00100	29*	C	BY THE PROGRAM FOR EACH TIME STEP.	000000
00100	30*	C	THE CONCENTRATIONS OF THE ISOTOPES CONSIDERED ARE STORED IN THE	000000
00100	31*	C	ARRAY 'ARRAY(10,3)' SHOWN BELOW.	000000
00100	32*	C		000000
00100	33*	C		000000

00100	34*	C	ARRAY(1,1) IS THE U-235 CONC. IN REGION 1	000000
00100	35*	C		000000
00100	36*	C	ARRAY(1,2) IS THE U-235 CONC. IN REGION 2	000000
00100	37*	C		000000
00100	38*	C	ARRAY(1,3) IS THE U-235 CONC. IN REGION 3	000000
00100	39*	C		000000
00100	40*	C	ARRAY(2,1) IS THE PU-239 CONC. IN REGION 1	000000
00100	41*	C		000000
00100	42*	C	ARRAY(2,2) IN THE PU-239 CONC. IN REGION 2	000000
00100	43*	C		000000
00100	44*	C	ARRAY(2,3) IS THE PU-239 CONC. IN REGION 3	000000
00100	45*	C		000000
00100	46*	C	ARRAY(3,1) IS THE U-238 CONC. IN REGION 1	000000
00100	47*	C		000000
00100	48*	C	ARRAY(3,2) IS THE U-238 CONC. IN REGION 2	000000
00100	49*	C		000000
00100	50*	C	ARRAY(3,3) IS THE U-238 CONC. IN REGION 3	000000
00100	51*	C		000000
00100	52*	C	ARRAY(4,1) IS THE XE-135 CONC. IN REGION 1	000000
00100	53*	C		000000
00100	54*	C	ARRAY(4,2) IS THE XE-135 CONC. IN REGION 2	000000
00100	55*	C		000000
00100	56*	C	ARRAY(4,3) IS THE XE-135 CONC. IN REGION 3	000000
00100	57*	C		000000
00100	58*	C	ARRAY(5,1) IS THE I-135 CONC. IN REGION 1	000000
00100	59*	C		000000
00100	60*	C	ARRAY(5,2) IS THE I-135 CONC. IN REGION 2	000000
00100	61*	C		000000
00100	62*	C	ARRAY(5,3) IS THE I-135 CONC. IN REGION 3	000000
00100	63*	C		000000
00100	64*	C	ARRAY(6,1) IS THE SM-149 CONC. IN REGION 1	000000
00100	65*	C		000000
00100	66*	C	ARRAY(6,2) IS THE SM-149 CONC. IN REGION 2	000000
00100	67*	C		000000
00100	68*	C	ARRAY(6,3) IS THE SM-149 CONC. IN REGION 3	000000
00100	69*	C		000000
00100	70*	C	ARRAY(7,1) IS THE PM-149 CONC. IN REGION 1	000000
00100	71*	C		000000
00100	72*	C	ARRAY(7,2) IS THE PM-149 CONC. IN REGION 2	000000
00100	73*	C		000000
00100	74*	C	ARRAY(7,3) IS THE PM-149 CONC. IN REGION 3	000000
00100	75*	C		000000
00100	76*	C	ARRAY(8,1) IS THE LUMPED BURNABLE POISON CONC. IN REGION 1	000000
00100	77*	C		000000
00100	78*	C	ARRAY(8,2) IS THE LUMPED BURNABLE POISON CONC. IN REGION 2	000000
00100	79*	C		000000
00100	80*	C	ARRAY(8,3) IS THE LUMPED BURNABLE POISON CONC. IN REGION 3	000000
00100	81*	C		000000
00100	82*	C	ARRAY(9,1) IS THE SOLUBLE BORDON CONC. IN REGION 1	000000
00100	83*	C		000000
00100	84*	C	ARRAY(9,2) IS THE SOLUBLE BORDON CONC. IN REGION 2	000000
00100	85*	C		000000
00100	86*	C	ARRAY(9,3) IS THE SOLBULE BORDON CONC. IN REGION 3	000000
00100	87*	C		000000
00101	88*		IMPLICIT REAL*8(A-H,J-Z),INTEGER(I)	000000
00103	89*		INTEGER N,K,J,L,LL,LLL,JJ,JJJ,KK,KKK,NN	000001
00104	90*		DIMENSION BCPOS(100)	000001
00105	91*		DIMENSION BCN(100)	000001
00106	92*		DIMENSION BCON(200)	000001
00107	93*		DIMENSION BORCON(5,200)	000001

00110	94*	DIMENSION FLXINT(4)	000001
00111	95*	DIMENSION ARRAY(10,3)	000001
00112	96*	DIMENSION PROD(3)	000001
00113	97*	DIMENSION DESTRU(3)	000001
00114	98*	DIMENSION STRUCT(3)	000001
00115	99*	DIMENSION O(2,6)	000001
00116	100*	DIMENSION PRODD(3)	000001
00117	101*	COMMON A,B,DESTRU,VFM1,VFM2,VFM3,SIGMA9,CO1,CO2,CO3,C11,C12,C13,	000001
00117	102*	XD,P1,P2,PW,PI,PROD,L1,L2,L3	000001
00117	103*	C	000001
00117	104*	C INPUT DATA	000001
00117	105*	C	000001
00120	106*	CF=3.9667E16	000001
00121	107*	PI=3.141592653589793	000003
00121	108*	C	000003
00121	109*	C SIGMA1 IS THE U-235 MICRO. ABSORP. X-SECTION IN CM**2 AT THE	000003
00121	110*	C OPERATING TEMPERATURE	000003
00121	111*	C	000003
00122	112*	C SIGMA1=411E-24.	000004
00122	113*	C	000004
00122	114*	C SIGMA2 IS THE PU-239 MICRO. ABSORP. X-SECTION IN CM**2 AT THE	000004
00122	115*	C OPERATING TEMPERATURE	000004
00122	116*	C	000004
00123	117*	C SIGMA2=1054E-24	000005
00123	118*	C	000005
00123	119*	C SIGMA3 IS THE U-238 MICRO. ABSORP. X-SECTION IN CM**2 AT THE	000005
00123	120*	C OPERATING TEMPERATURE	000005
00123	121*	C	000005
00124	122*	C SIGMA3=1.72E-24	000011
00124	123*	C	000011
00124	124*	C SIGMA4 IS THE XE-135 MICRO. ABSORP. X-SECTION IN CM**2 AT THE	000011
00124	125*	C OPERATING TEMPERATURE	000011
00124	126*	C	000011
00125	127*	C SIGMA4=2.08E-18	000013
00125	128*	C	000013
00125	129*	C SIGMA5 IS THE I-135 MICRO. ABSORP. X-SECTION IN CM**2 AT THE	000013
00125	130*	C OPERATING TEMPERATURE	000013
00125	131*	C	000013
00126	132*	C SIGMA5=4.42E-24	000014
00126	133*	C	000014
00126	134*	C SIGMA6 IS THE SM-149 MICRO. ABSORP. X-SECTION IN CM**2 AT THE	000014
00126	135*	C OPERATING TEMPERATURE	000014
00126	136*	C	000014
00127	137*	C SIGMA6=7569E-24	000015
00127	138*	C	000015
00127	139*	C SIGMA7 IS THE PM-149 MICRO. ABSORP X-SECTION IN CM**2 AT THE	000015
00127	140*	C OPERATING TEMPERATURE	000015
00127	141*	C	000015
00130	142*	C SIGMA7=37.9E-24	000021
00130	143*	C	000021
00130	144*	C SIGMA8 IS THE LUMPED BURNABLE POISON MICRO. ABSORP. X-SECTION IN CM**2 AT	000021
00130	145*	C OPERATING TEMPERATURE	000021
00130	146*	C	000021
00131	147*	C SIGMA8=2408E-24	000023
00131	148*	C	000023
00131	149*	C SIGMA9 IS THE SOLUBLE BORON MICRO.ABSORP. X-SECTION IN CM**2	000023
00131	150*	C AT THE OPERATING TEMPERATURE	000023
00131	151*	C	000023
00132	152*	C SIGMA9=477E-24	000024
00132	153*	C	000024

00132	154*	C	SIGMF1 IS THE U-235 MICRO. FISSION X-SECTION IN CM**2	000024
00132	155*	C	AT THE OPERATING TEMPERATURE	000024
00132	156*	C		000024
00133	157*		SIGMF1=342E-24	000025
00133	158*	C		000025
00133	159*	C	SIGMF2 IS THE PU-239 MICRO. FISSION X-SECTION IN CM**2	000025
00133	160*	C	AT THE OPERATING TEMPERATURE	000025
00133	161*	C		000025
00134	162*		SIGMF2=698E-24	000031
00134	163*	C		000031
00134	164*	C	NU1 IS THE NEUTRONS/FISSION FOR U-235	000031
00134	165*	C		000031
00135	166*		NU1=2.418	000033
00135	167*	C		000033
00135	168*	C	NU2 IS THE NEUTRONS/FISSION FOR PU-239	000033
00135	169*	C		000033
00136	170*		NU2=2.871	000034
00136	171*	C		000034
00136	172*	C	GAMI1 IS THE YIELD OF I-149 ATOMS PER U-235 FISSION	000034
00136	173*	C		000034
00137	174*		GAMI1=0.0639	000035
00137	175*	C		000035
00137	176*	C	GAMI2 IS THE YIELD OF I-149 ATOMS PER PU239 FISSION	000035
00137	177*	C		000035
00140	178*		GAMI2=0.0604	000041
00140	179*	C		000041
00140	180*	C	GAMX1 IS THE YIELD OF XE-135 ATOMS PER U-235 FISSION	000041
00140	181*	C		000041
00141	182*		GAMX1=0.00237	000043
00141	183*	C		000043
00141	184*	C	GAMX2 IS THE YIELD OF XE-135 ATOMS PER PU-239 FISSION	000043
00141	185*	C		000043
00142	186*		GAMX2=0.0105	000044
00142	187*	C		000044
00142	38*	C	GAMPM1 IS THE YIELD OF PM-149 ATOMS PER U-235 FISSION	000044
00142	189*	C		000044
00143	190*		GAMPM1=0.01071	000045
00143	191*	C		000045
00143	192*	C	GAMPM2 IS THE YIELD OF PM-149 ATOMS PER PU-239 FISSION	000045
00143	193*	C		000045
00144	194*		GAMPM2=0.0121	000051
00144	195*	C		000051
00144	196*	C	LAMI IS THE I-135 DECAY CONSTANT IN 1/SECONDS	000051
00144	197*	C		000051
00145	198*		LAMI=2.87E-5	000053
00145	199*	C		000053
00145	200*	C	LAMX IS THE XE-135 DECAY CONSTANT IN 1/SECONDS,	000053
00145	201*	C		000053
00146	202*		LAMX=2.09E-5	000054
00146	203*	C		000054
00146	204*	C	LAMPM IS THE PM-149 DECAY CONSTANT IN 1/SECONDS	000054
00146	205*	C		000054
00147	206*		LAMPM=3.63E-6	000055
00147	207*	C		000055
00147	208*	C	D IS THE CORE DIFFUSION COEFFICIENT IN CM	000055
00147	209*	C		000055
00150	210*		D=0.395	000061
00150	211*	C		000061
00150	212*	C	H IS THE TIME STEP IN SECONDS	000061
00150	213*	C		000061

00151	214*		H=3600.0	000063
00151	215*	C		000063
00151	216*	C	NOFA1 IS THE TOTAL NUMBER OF FUEL ASSEMBLIES IN REGION 1	000063
00151	217*	C		000063
00152	218*		NOFA1=9.0	000064
00152	219*	C		000064
00152	220*	C	NOFA2 IS THE TOTAL NUMBER OF FUEL ASSEMBLIES IN REGION 2	000064
00152	221*	C		000064
00153	222*		NOFA2=100.0	000065
00153	223*	C		000065
00153	224*	C	NOFA3 IS THE TOTAL NUMBER OF FUEL ASSEMBLIES IN REGION 3	000065
00153	225*	C		000065
00154	226*		NOFA3=68.0	000071
00154	227*	C		000071
00154	228*	C	NOFAT1 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 1 WITH	000071
00154	229*	C	NO CONTROL RODS OR LUMPED BURNABLE POISON RODS	000071
00154	230*	C		000071
00155	231*		NOFAT1=4.0	000073
00155	232*	C		000073
00155	233*	C	NOFAT2 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 2 WITH	000073
00155	234*	C	NO CONTROL RODS OR LUMPED BURNABLE POISON RODS	000073
00155	235*	C		000073
00156	236*		NOFAT2=44.0	000074
00156	237*	C		000074
00156	238*	C	NOFAT3 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 3 WITH	000074
00156	239*	C	NO CONTROL RODS OR LUMPED BURNABLE POISON RODS	000074
00156	240*	C		000074
00157	241*		NOFAT3=44.0	000075
00157	242*	C		000075
00157	243*	C	NFACF1 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 1 WITH	000075
00157	244*	C	CONTROL RODS FULLY INSERTED	000075
00157	245*	C		000075
00160	246*		NFACF1=1.0	000075
00160	247*	C		000075
00160	248*	C	NFACF2 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 2 WITH	000075
00160	249*	C	CONTROL RODS FULLY INSERTED	000075
00160	250*	C		000075
00161	251*		NFACF2=0.0	000102
00161	252*	C		000102
00161	253*	C	NFACF3 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 3 WITH	000102
00161	254*	C	CONTROL RODS FULLY INSERTED	000102
00161	255*	C		000102
00162	256*		NFACF3=8.0	000104
00162	257*	C		000104
00162	258*	C	NFACF1 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 1 WITH	000104
00162	259*	C	CONTROL RODS PARTIALLY INSERTED	000104
00162	260*	C		000104
00163	261*		NFACF1=0.0	000105
00163	262*	C		000105
00163	263*	C	NFACF2 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 2 WITH	000105
00163	264*	C	CONTROL RODS PARTIALLY INSERTED	000105
00163	265*	C		000105
00164	266*		NFACF2=8.0	000105
00164	267*	C		000105
00164	268*	C	NFACF3 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 3 WITH	000105
00164	269*	C	CONTROL RODS PARTIALLY INSERTED	000105
00164	270*	C		000105
00165	271*		NFACF3=0.0	000105
00165	272*	C		000105
00165	273*	C	CPP1 IS THE PERCENT THE PARTIALLY INSERTED CONTROL RODS IN REGION	000105

00165	274.	C	1 ARE INSERTED DIVIDED BY 100.0	000105
00165	275.	C		000105
00166	276.	C	CPP1=0.0	000105
00166	277.	C		000105
00166	278.	C	CPP2 IS THE PERCENT THE PARTIAILY INSERTED CONTROL RODS IN REGION	000105
00166	279.	C	2 ARE INSERTED DIVIDED BY 100.0	000105
00166	280.	C		000105
00167	281.	C	CPP2=0.25	000105
00167	282.	C		000105
00167	283.	C	CPP3 IS THE PERCENT THE PARTIALLY INSERTED CONTROL RODS IN REGION	000105
00167	284.	C	3 ARE INSERTED DIVIDED BY 100.0	000105
00167	285.	C		000105
00170	286.	C	CPP3=0.0	000106
00170	287.	C		000106
00170	288.	C	NFABP1 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 1 WITH	000106
00170	289.	C	LUMPED BURNABLE POISON RODS	000106
00170	290.	C		000106
00171	291.	C	NFABP1=4.0	000106
00171	292.	C		000106
00171	293.	C	NFABP2 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 3 WITH	000106
00171	294.	C	LUMPED BURNABLE POISON RODS	000106
00171	295.	C		000106
00172	296.	C	NFABP2=48.0	000106
00172	297.	C		000106
00172	298.	C	NFABP3 IS THE NUMBER OF FUEL ASSEMBLIES IN REGION 3 WITH	000106
00172	299.	C	LUMPED BURNABLE POISON RODS	000106
00172	300.	C		000106
00173	301.	C	NFABP3=16.0	000120
00173	302.	C		000120
00173	303.	C	SIGFRC IS THE MACROSCOPIC ABSORPTION CROSS SECTION OF THE	000120
00173	304.	C	FUEL ROD CLADDING MATERIAL IN CM-1 AT THE OPER. TEMP.	000120
00173	305.	C		000120
00174	306.	C	SIGFRC=54.59E-4	000121
00174	307.	C		000121
00174	308.	C	SIGCRP IS THE MACROSCOPIC ABSORPTION CROSS SECTION OF THE	000121
00174	309.	C	CONTROL ROD POISON IN CM-1 AT THE OPERATING TEMPERATURE	000121
00174	310.	C		000121
00175	311.	C	SIGCRP=4375E-4	000122
00175	312.	C		000122
00175	313.	C	SIGCRC IS THE MACROSCOPIC ABSORPTION CROSS SECTION OF THE	000122
00175	314.	C	CONTROL ROD CLADDING MATERIAL IN CM-1 AT THE OPER. TEMP.	000122
00175	315.	C		000122
00176	316.	C	SIGCRC=1637E-4	000126
00176	317.	C		000126
00176	318.	C	SIGPRC IS THE MACROSCOPIC ABSORPTION CROSS SECTION OF THE	000126
00176	319.	C	LUMPED BURNABLE POISON ROD CLADDING MATERIAL IN CM-1	000126
00176	320.	C	AT THE OPERATING TEMPERATURE	000126
00176	321.	C		000126
00177	322.	C	SIGPRC=54.59E-4	000130
00177	323.	C		000130
00177	324.	C	LBPCON IS THE ATOMIC CONCENTRATION OF THE LUMPED BURNABLE	000130
00177	325.	C	POISON ISOTOPE(E.G. B-10) PER CM**3 OF LUMPED BURNABLE	000130
00177	326.	C	POISON MATERIAL	000130
00177	327.	C		000130
00200	328.	C	LBPCON=9.5784E20	000130
00200	329.	C		000130
00200	330.	C	MODCON IS THE MOLECULAR CONCENTRATION OF THE MODERATOR IN	000130
00200	331.	C	MOLECULES/CM**3 AT THE OPERATING TEMPERATURE AND PRESSURE	000130
00200	332.	C		000130
00201	333.	C	MODCON=2.38E22	000132

00201	334*	C		000132
00201	335*	C	SIGMAT IS THE MACROSCOPIC CROSS SECTION OF THE LUMPED	000132
00201	336*	C	BURNABLE POISON MATERIAL EXCLUDING THE POISON ISOTOPE	000132
00201	337*	C	ITSELF IN CM-1 AT THE OPERATING TEMPERATURE	000132
00201	338*	C		000132
00202	339*	C	SIGMAT=27.608E-4	000134
00202	340*	C		000134
00202	341*	C	SIGMAO IS THE MICROSCOPIC CROSS SECTION OF OXYGEN IN CM**2	000134
00202	342*	C	AT THE OPERATING TEMPERATURE	000134
00202	343*	C		000134
00203	344*	C	SIGMAO=0.00013E-24	000137
00203	345*	C		000137
00203	346*	C	SIGH2O IS THE MICROSCOPIC CROSS SECTION OF WATER IN CM**2	000137
00203	347*	C	AT THE OPERATING TEMPERATURE	000137
00203	348*	C		000137
00204	349*	C	SIGH2O=0.419E-24	000141
00204	350*	C		000141
00204	351*	C	AFL IS THE ACTIVE FUEL LENGTH IN CM	000141
00204	352*	C		000141
00205	353*	C	AFL=365.76	000142
00205	354*	C		000142
00205	355*	C	FRR IS THE FUEL ROD RADIUS IN CM	000142
00205	356*	C		000142
00206	357*	C	FRR=0.546	000144
00206	358*	C		000144
00206	359*	C	FR IS THE FUEL PELLETT RADIUS IN CM	000144
00206	360*	C		000144
00207	361*	C	FR=0.470	000147
00207	362*	C		000147
00207	363*	C	FCTH IS THE FUEL CLAD THICKNESS IN CM	000147
00207	364*	C		000147
00210	365*	C	FCTH=0.067	000151
00210	366*	C		000151
00210	367*	C	CCTH IS THE CONTROL ROD CLAD THICKNESS IN CM	000151
00210	368*	C		000151
00211	369*	C	CCTH=0.053	000152
00211	370*	C		000152
00211	371*	C	LCTH IS THE LUMPED BURNABLE POISON ROD CLAD THICKNESS IN CM	000152
00211	372*	C		000152
00212	373*	C	LCTH=0.089	000154
00212	374*	C		000154
00212	375*	C	FAP IS THE FUEL ASSEMBLY PITCH IN CM	000154
00212	376*	C		000154
00213	377*	C	FAP=21.81	000160
00213	378*	C		000160
00213	379*	C	CRL IS THE CONTROL ROD LENGTH IN CM	000160
00213	380*	C		000160
00214	381*	C	CRL=340.36	000162
00214	382*	C		000162
00214	383*	C	LRL IS THE LUMPED BURNABLE POISON ROD LENGTH IN CM	000162
00214	384*	C		000162
00215	385*	C	LRL=320.04	000163
00215	386*	C		000163
00215	387*	C	CRR IS THE CONTROL ROD RADIUS IN CM	000163
00215	388*	C		000163
00216	389*	C	CRR=0.572	000164
00216	390*	C		000164
00216	391*	C	LRR IS THE LUMPED BURNABLE POISON ROD RADIUS IN CM	000164
00216	392*	C		000164
00217	393*	C	LRR=0.572	000170

00217	394*	C		000170
00217	395*	C	FRFA IS THE NUMBER OF FUEL RODS PER FUEL ASSEMBLY	000170
00217	396*	C		000170
00220	397*	C	FRFA=208.0	000171
00220	398*	C		000171
00220	399*	C	LRFA IS THE NUMBER OF LUMPED BURNABLE POISON RODS PER FUEL	000171
00220	400*	C	ASSEMBLY-APPLICABLE ONLY TO THOSE FUEL ASSEMBLIES WHICH CONTAIN	000171
00220	401*	C	LUMPED BURNABLE POISON RODS	000171
00220	402*	C		000171
00221	403*	C	LRFA=16.0	000173
00221	404*	C		000173
00221	405*	C	CRFA IS THE NUMBER OF CONTROL RODS PER FUEL ASSEMBLY-APPLICABLE	000173
00221	406*	C	ONLY TO THOSE FUEL ASSEMBLIES WHICH CONTAIN CONTROL RODS	000173
00221	407*	C		000173
00222	408*	C	CRFA=16.0	000174
00222	409*	C		000174
00222	410*	C	THPW IS THE THERMAL POWER OF THE CORE IN MW	000174
00222	411*	C		000174
00223	412*	C	THPW=2568.0	000174
00223	413*	C		000174
00223	414*	C	REG1 IS THE WEIGHT PERCENT OF U-235 ENRICHMENT IN REGION 1	000174
00223	415*	C	DIVIDED BY 100.0	000174
00223	416*	C		000174
00224	417*	C	REG1=0.0243	000175
00224	418*	C		000175
00224	419*	C	REG2 IS THE WEIGHT PERCENT OF U-235 ENRICHMENT IN REGION 2	000175
00224	420*	C	DIVIDED BY 100.0	000175
00224	421*	C		000175
00225	422*	C	REG2=0.0238	000202
00225	423*	C		000202
00225	424*	C	REG3 IS THE WEIGHT PERCENT OF U-235 ENRICHMENT IN REGION 3	000202
00225	425*	C	DIVIDED BY 100.0	000202
00225	426*	C		000202
00226	427*	C	REG3=0.0301	000204
00226	428*	C		000204
00226	429*	C	G IS THE AVERAGE MEGAWATTS PER FISSION	000204
00226	430*	C		000204
00227	431*	C	G=3.204E-17	000205
00227	432*	C		000205
00230	433*	C	ARRAY(2.1)=0.0	000206
00231	434*	C	ARRAY(2.2)=0.0	000212
00232	435*	C	ARRAY(2.3)=0.0	000213
00233	436*	C	ARRAY(4.1)=0.0	000214
00234	437*	C	ARRAY(4.2)=0.0	000215
00235	438*	C	ARRAY(4.3)=0.0	000216
00236	439*	C	ARRAY(5.1)=0.0	000217
00237	440*	C	ARRAY(5.2)=0.0	000220
00240	441*	C	ARRAY(5.3)=0.0	000221
00241	442*	C	ARRAY(6.1)=0.0	000222
00242	443*	C	ARRAY(6.2)=0.0	000223
00243	444*	C	ARRAY(6.3)=0.0	000224
00244	445*	C	ARRAY(7.1)=0.0	000225
00245	446*	C	ARRAY(7.2)=0.0	000226
00246	447*	C	ARRAY(7.3)=0.0	000227
00246	448*	C		000227
00246	449*	C	END OF INPUT DATA	000227
00246	450*	C		000227
00246	451*	C	THIS SECTION COMPUTES THE EQUIVALENT RADII OF THE REACTOR REGIONS AND B1	000227
00246	452*	C		000227
00247	453*	C	AREA1=FAP*FAP*NOFA1	000230

00250	454*	AREA2=FAP*FAP*NOFA2	000232
00251	455*	AREA3=FAP*FAP*NOFA3	000232
00252	456*	R1=(AREA1/PI)**0.5	000255
00253	457*	R2=((AREA1+AREA2)/PI)**0.5	000271
00254	458*	R3=((AREA1+AREA2+AREA3)/PI)**0.5	000303
00255	459*	B1=PI/(2.0*R3)	000313
00256	460*	B2=(PI/R3)	000316
00256	461*	C	000316
00256	462*	C THIS SECTION COMPUTES THE FLUX INTEGRAL COEFFICIENTS	000316
00256	463*	C CO1,CO2,CO3,C11,C12 AND C13	000316
00256	464*	C	000316
00257	465*	DO 600 I=1,4	000316
00262	466*	IF(I.EQ.1)R=0.0	000335
00264	467*	IF(I.EQ.2)R=R1	000342
00266	468*	IF(I.EQ.3)R=R2	000347
00270	469*	IF(I.EQ.4)R=R3	000354
00272	470*	Q(1,I)=((DCOS(B1*R))/(B1*B1))+((R*DSIN(B1*R))/B1)	000361
00273	471*	Q(2,I)=((DSIN(B2*R))/(B2*B2))-((R*DCOS(B2*R))/B2)	000377
00274	472*	600 CONTINUE	000421
00276	473*	CO1=Q(1,2)-Q(1,1)	000421
00277	474*	CO2=Q(1,3)-Q(1,2)	000423
00300	475*	CO3=Q(1,4)-Q(1,3)	000426
00301	476*	C11=Q(2,2)-Q(2,1)	000427
00302	477*	C12=Q(2,3)-Q(2,2)	000434
00303	478*	C13=Q(2,4)-Q(2,3)	000435
00303	479*	C	000435
00303	480*	C THIS SECTION CONSISTS OF VOLUME COMPUTATIONS	000435
00303	481*	C	000435
00303	482*	C VFR IS THE VOLUME OF FUEL RODS PER FUEL ASSEMBLY	000435
00303	483*	C	000435
00304	484*	VFR=(FRR**2)*PI*FRFA*AFL	000442
00304	485*	C	000442
00304	486*	C VFA IS THE VOLUME OF A FUEL ASSEMBLY	000442
00304	487*	C	000442
00305	488*	VFA=FAP*FAP*AFL	000443
00305	489*	C	000443
00305	490*	C VFU IS THE VOLUME OF FUEL PER FUEL ASSEMBLY	000443
00305	491*	C	000443
00306	492*	VFU=(FR**2)*PI*AFL*FRFA	000453
00306	493*	C	000453
00306	494*	C VFC IS THE VOLUME OF FUEL CLAD PER FUEL ASSEMBLY	000453
00306	495*	C	000453
00307	496*	VFC=VFR-(((FR-FCTH)**2)*PI*FRFA*AFL)	000457
00307	497*	C	000457
00307	498*	C VCR IS THE VOLUME OF CONTROL RODS PER FUEL ASSEMBLY FOR FULLY	000457
00307	499*	C INSERTED CONTROL RODS	000457
00307	500*	C	000457
00310	501*	VCR=CRFA*(CRR**2)*PI*CRL	000467
00310	502*	C	000467
00310	503*	C VCRP IS THE VOLUME OF CONTROL ROD POISON PER FUEL ASSEMBLY FOR	000467
00310	504*	C FULLY INSERTED CONTROL RODS	000467
00310	505*	C	000467
00311	506*	VCRP=((CRR-CCTH)**2)*PI*CRL*CRFA	000474
00311	507*	C	000474
00311	508*	C VCRC IS THE VOLUME OF CONTROL ROD CLADDING PER FUEL ASSEMBLY FOR	000474
00311	509*	C FULLY INSERTED CONTROL RODS	000474
00311	510*	C	000474
00312	511*	VCRC=VCR-VCRP	000504
00312	512*	C	000504
00312	513*	C VLR IS THE VOLUME OF LBP RODS PER FUEL ASSEMBLY	000504

00312	514*	C		000504
00313	515*		VLR=LRFA*(LRR**2)*PI*LRL	000504
00313	516*	C		000504
00313	517*	C	VLP IS THE VOLUME OF LBP ROD POISON MATERIAL PER FUEL ASSEMBLY	000504
00313	518*	C		000504
00314	519*		VLP=((LRR-LCTH)**2)*PI*LRL*LRFA	000511
00314	520*	C		000511
00314	521*	C	VLC IS THE VOLUME OF LBP ROD CLADDING PER FUEL ASSEMBLY	000511
00314	522*	C		000511
00315	523*		VLC=VLR-VLP	000525
00315	524*	C		000525
00315	525*	C		000525
00315	526*	C	THIS SECTION CONSISTS OF VOLUME FRACTION COMPUTATIONS	000525
00315	527*	C		000525
00315	528*	C	VFF IS THE FUEL VOLUME FRACTION PER FUEL ASSEMBLY	000525
00315	529*	C		000525
00316	530*		VFF=VFU/VFA	000525
00316	531*	C		000525
00316	532*	C	VFFC IS THE FUEL CLAD VOLUME FRACTION PER FUEL ASSEMBLY	000525
00316	533*	C		000525
00317	534*		VFFC=VFC/VFA	000527
00317	535*	C		000527
00317	536*	C	VFCP IS THE CONTROL ROD POISON VOLUME FRACTION PER FUEL ASSEMBLY	000527
00317	537*	C	FOR FULLY INSERTED CONTROL RODS	000527
00317	538*	C		000527
00320	539*		VFCP=VCRP/VFA	000530
00320	540*	C		000530
00320	541*	C	VFCC IS THE CONTROL ROD CLADDING VOLUME FRACTION PER FUEL ASSEMBLY	000530
00320	542*	C	FOR FULLY INSERTED CONTROL RODS	000530
00320	543*	C		000530
00321	544*		VFCC=VCRC/VFA	000541
00321	545*	C		000541
00321	546*	C	VFCPP1 IS THE CONTROL ROD POISON VOLUME FRACTION PER FUEL ASSEMBLY	000541
00321	547*	C	FOR PARTIALLY INSERTED CONTROL RODS IN REGION 1	000541
00321	548*	C		000541
00322	549*		VFCPP1=VFCP*CPP1	000543
00322	550*	C		000543
00322	551*	C	VFCPP2 IS THE CONTROL ROD POISON VOLUME FRACTION PER FUEL ASSEMBLY	000543
00322	552*	C	FOR PARTIALLY INSERTED CONTROL RODS IN REGION 2	000543
00322	553*	C		000544
00323	554*		VFCPP2=VFCP*CPP2	000544
00323	555*	C		000544
00323	556*	C	VFCPP3 IS THE CONTROL ROD POISON VOLUME FRACTION PER FUEL ASSEMBLY	000544
00323	557*	C	FOR PARTIALLY INSERTED CONTROL RODS IN REGION 3	000544
00323	558*	C		000544
00324	559*		VFCPP3=VFCP*CPP3	000551
00324	560*	C		000551
00324	561*	C	VFCRP1,VFCRP2 AND VFCRP3 ARE THE VOLUME FRACTIONS PER FUEL ASSEMBLY	000551
00324	562*	C	OF CONTROL ROD POISON FOR FULLY INSERTED CONTROL RODS IN REGION 1,	000551
00324	563*	C	REGION 2 AND REGION 3 RESPECTIVELY	000551
00324	564*	C		000551
00325	565*		VFCRP1=(NFACF1*VFCP+NFACP1*VFCPP1)/NOFA1	000552
00326	566*		VFCRP2=(NFACF2*VFCP+NFACP2*VFCPP2)/NOFA2	000556
00327	567*		VFCRP3=(NFACF3*VFCP+NFACP3*VFCPP3)/NOFA3	000566
00327	568*	C		000566
00327	569*	C	VFCRC1,VFCRC2 AND VFCRC3 ARE THE VOLUME FRACTIONS PER FUEL ASSEMBLY	000566
00327	570*	C	OF CONTROL ROD CLADDING FOR FULLY INSERTED CONTROL RODS IN REGION 1,	000566
00327	571*	C	REGION 2 AND REGION 3 RESPECTIVELY	000566
00327	572*	C		000566
00327	573*		VFCRC1=(NFACF1*VFCC+NFACP1*VFCPP1)/NOFA1	000576
00330				

00331	574*		VFCRC2=(NFACF2*VFCC+NFACP2*VFCPP2)/NOFA2	000601
00332	575*		VFCRC3=(NFACF3*VFCC+NFACP3*VFCPP3)/NOFA3	000610
00332	576*	C		000610
00332	577*	C	VFBCP1,VFBCP2 AND VFBCP3 ARE THE VOLUME FRACTIONS PER FUEL ASSEMBLY	000610
00332	578*	C	OF LUMPED BURNABLE POISON CLADDING FOR REGION 1,REGION 2 AND REGION 3	000610
00332	579*	C	RESPECTIVELY	000610
00332	580*	C		000610
00333	581*		VFBCP1=(NFABP1*(VLC/VFA))/NOFA1	000611
00334	582*		VFBCP2=(NFABP2*(VLC/VFA))/NOFA2	000617
00335	583*		VFBCP3=(NFABP3*(VLC/VFA))/NOFA3	000617
00335	584*	C		000617
00335	585*	C	VFCCP1,VFCCP2 AND VFCCP3 ARE THE VOLUME FRACTIONS PER FUEL ASSEMBLY	000617
00335	586*	C	OF CONTROL ROD CLADDING FOR PARTIALLY INSERTED CONTROL RODS FOR	000617
00335	587*	C	REGION 1,REGION 2 AND REGION 3 RESPECTIVELY	000617
00335	588*	C		000617
00336	589*		VFCCP1=(VFCC*CPP1)	000617
00337	590*		VFCCP2=(VFCC*CPP2)	000620
00340	591*		VFCCP3=(VFCC*CPP3)	000640
00340	592*	C		000640
00340	593*	C	VFBCP1,VFBCP2 AND VFBCP3 ARE THE VOLUME FRACTIONS PER FUEL ASSEMBLY	000640
00340	594*	C	OF LUMPED BURNABLE POISON ROD POISON MATERIAL FOR REGION 1,REGION 2 AND	000640
00340	595*	C	REGION 3 RESPECTIVELY	000640
00340	596*	C		000640
00341	597*		VFBCP1=(NFABP1*(VLP/VFA))/NOFA1	000644
00342	598*		VFBCP2=(NFABP2*(VLP/VFA))/NOFA2	000645
00343	599*		VFBCP3=(NFABP3*(VLP/VFA))/NOFA3	000645
00343	600*	C		000645
00343	601*	C	VFMOD IS THE MODERATOR VOLUME FRACTION FOR A FUEL ASSEMBLY WITHOUT	000645
00343	602*	C	LBP OR CONTROL RODS	000645
00343	603*	C		000645
00344	604*		VFMOD=(VFA-VFR-(0.003*VFA))/VFA	000645
00344	605*	C		000645
00344	606*	C	VFMCN IS THE MODERATOR VOLUME FRACTION FOR A FUEL ASSEMBLY WITH	000645
00344	607*	C	FULLY INSERTED CONTROL RODS	000645
00344	608*	C		000645
00345	609*		VFMCN=(VFA-VFR-VCR-(0.003*VFA))/VFA	000666
00345	610*	C		000666
00345	611*	C	VFMCN1,VFMCN2 AND VFMCN3 ARE THE MODERATOR VOLUME FRACTIONS PER FUEL ASSE	000666
00345	612*	C	WITH PARTIALLY INSERTED CONTROL RODS FOR REGION 1,REGION 2 AND REGION 3	000666
00345	613*	C	RESPECTIVELY	000666
00345	614*	C		000666
00346	615*		VFMCN1=(VFA-VFR-(VCR*CPP1)-(0.003*VFA))/VFA	000673
00347	616*		VFMCN2=(VFA-VFR-(VCR*CPP2)-(0.003*VFA))/VFA	000707
00350	617*		VFMCN3=(VFA-VFR-(VCR*CPP3)-(0.003*VFA))/VFA	000712
00350	618*	C		000712
00350	619*	C	VFMLBP IS THE MODERATOR VOLUME FRACTION FOR FUEL ASSEMBLY WITH LBP RODS	000712
00350	620*	C		000712
00351	621*		VFMLBP=(VFA-VFR-(0.003*VFA)-VLR)/VFA	000722
00351	622*	C		000722
00351	623*	C		000722
00351	624*	C	THIS SECTION COMPUTES THE CONCENTRATIONS(ATOMS/CC) OF THE LBP	000722
00351	625*	C	POISON ISOTOPE,U-235 AND U-238	000722
00351	626*	C		000722
00352	627*		ARRAY(8,1)=LBPCON*VFBCP1	000730
00353	628*		ARRAY(8,2)=LBPCON*VFBCP2	000736
00354	629*		ARRAY(8,3)=LBPCON*VFBCP3	000737
00355	630*		TOTAL=2.26097E22*VFF	000737
00356	631*		ARRAY(1,1)=((REG1*238.0508*TOTAL)/(235.0439-(REG1*	000737
00356	632*		X235.0439)+(REG1*238.0508)))	000737
00357	633*		ARRAY(1,2)=((REG2*238.0508*TOTAL)/(235.0439-(REG2*	000753

00357	634.		X235.0439)+(REG2*238.0508)))	000753
00360	635.		ARRAY(1,3)=((REG3*238.0508+TOTAL)/(235.0439-(REG3*	000754
00360	636.		X235.0439)+(REG3*238.0508)))	000754
00361	637.		ARRAY(3,1)=TOTAL-ARRAY(1,1)	000754
00362	638.		ARRAY(3,2)=TOTAL-ARRAY(1,2)	000754
00363	639.		ARRAY(3,3)=TOTAL-ARRAY(1,3)	000754
00363	640.	C		000754
00363	641.	C		000754
00363	642.	C	THIS SECTION COMPUTES THE VOLUME FRACTION OF THE MODERATOR	000754
00363	643.	C	FOR EACH REGION	000754
00363	644.	C		000754
00364	645.		VFM1=((NOFAT1*VFMOD)+(NFACF1*VFMCRC)+(NFABP1*VFMLBP)	000754
00364	646.		X+(NFACF1*VFMCRC))/NOFA1	000754
00365	647.		VFM2=((NOFAT2*VFMOD)+(NFACF1*VFMCRC)+(NFABP2*VFMLBP)	001026
00365	648.		X+(NFACF2*VFMCRC))/NOFA2	001026
00366	649.		VFM3=((NOFAT3*VFMOD)+(NFACF3*VFMCRC)+(NFABP3*VFMLBP)	001036
00366	650.		X+(NFACF3*VFMCRC))/NOFA3	001036
00366	651.	C		001036
00366	652.	C		001036
00366	653.	C	THIS SECTION COMPUTES THE TOTAL REGIONAL MACROSCOPIC ABSORPTION CROSS SEC	001036
00366	654.	C	FOR THE STRUCTURAL MATERIALS. THESE MATERIALS ARE ASSUMED TO HAVE	001036
00366	655.	C	CONSTANT CROSS SECTIONS	001036
00366	656.	C		001036
00367	657.		STRUCT(1)=(SIGFRC+VFFC)+(SIGCRP+VFCRP1)+(SIGCRC+VFCRC1)+	001046
00367	658.		X(SIGPRC+VFBPC1)+(SIGMAT+VFBPP1)+(VFM1*SIGH20+MODCON)+	001046
00367	659.		X(0.003*1637.2E-4)+(TOTAL*2.0*SIGMA0)	001046
00370	660.		STRUCT(2)=(SIGFRC+VFFC)+(SIGCRP+VFCRP2)+(SIGCRC+VFCRC2)+	001105
00370	661.		X(SIGPRC+VFBPC2)+(SIGMAT+VFBPP2)+(VFM2*SIGH20+MODCON)+	001105
00370	662.		X(0.003*1637.2E-4)+(TOTAL*2.0*SIGMA0)	001105
00371	663.		STRUCT(3)=(SIGFRC+VFFC)+(SIGCRP+VFCRP3)+(SIGCRC+VFCRC3)+	001124
00371	664.		X(SIGPRC+VFBPC3)+(SIGMAT+VFBPP3)+(VFM3*SIGH20+MODCON)+	001124
00371	665.		X(0.003*1637.2E-4)+(TOTAL*2.0*SIGMA0)	001124
00371	666.	C		001124
00371	667.	C		001124
00372	668.		TPS=30.0	001146
00373	669.		STEPS=0.0	001150
00373	670.	C		001150
00373	671.	C		001150
00373	672.	C	MAIN LOOP STARTS	001150
00373	673.	C		001150
00373	674.	C	THIS SECTION COMPUTES THE CRITICALITY CONSTRAINT COEFFICIENTS A AND B	001150
00373	675.	C	AND THE POWER CONSTRAINT COEFFICIENTS P1,P2 AND PW	001150
00373	676.	C		001150
00374	677.	101	CONTINUE	001150
00375	678.		DO 11 N=1,3	001150
00400	679.		PROD(N)=ARRAY(1,N)*SIGMF1+NU1+ARRAY(2,N)*SIGMF2+NU2	001171
00401	680.		DESTRU(N)=ARRAY(1,N)*SIGMA1+ARRAY(2,N)*SIGMA2+ARRAY(3,N)*	001200
00401	681.		XSIGMA3+ARRAY(4,N)*SIGMA4+ARRAY(5,N)*SIGMA5+ARRAY(6,N)*	001200
00401	682.		XSIGMA6+ARRAY(7,N)*SIGMA7+ARRAY(8,N)*SIGMA8+STRUCT(N)	001200
00402	683.		PRODD(N)=ARRAY(1,N)*SIGMF1+ARRAY(2,N)*SIGMF2	001207
00403	684.	11	CONTINUE	001240
00405	685.		A=2.0*PI*(PROD(1)*C01+PROD(2)*C02+PROD(3)*C03)	001240
00406	686.		B=2.0*PI*(PROD(1)*C11+PROD(2)*C12+PROD(3)*C13)	001247
00407	687.		DO 76 II=1,100	001265
00412	688.		BCPOS(II)=0.0	001265
00413	689.	76	CONTINUE	001271
00415	690.		P1=2.0*PI*(C01*PRODD(1)+C02*PRODD(2)+C03*PRODD(3))	001271
00416	691.		P2=2.0*PI*(C11*PRODD(1)+C12*PRODD(2)+C13*PRODD(3))	001300
00417	692.		PW=THPW/(AFL*G)	001312
00417	693.	C		001312

00417	694*	C			001312
00417	695*	C		THIS SECTION COMPUTES THE MAXIMUM AND MINIMUM BORON CONCENTRATIONS	001312
00417	696*	C		(BCMAX AND BCMIN) WHICH YIELD A POSITIVE FLUX	001312
00417	697*	C			001312
00420	698*			L=1.0	001314
00421	699*			DO 70 J=1,5001,50	001327
00424	700*			Z=J-1	001331
00425	701*			CALL FFLUX(Z,AO,A1)	001341
00426	702*			RR1=0	001347
00427	703*			DO 71 IXX=1,50	001354
00432	704*			FLX=(AO*DCOS(B1*RR1))+(A1*DSIN(B2*RR1))	001354
00433	705*			IF(FLX.LT.0.0)GO TO 78	001374
00435	706*			RR1=IXX*(R3/50)	001400
00436	707*	71		CONTINUE	001407
00440	708*			BCPOS(L)=Z	001407
00441	709*			L=L+1.0	001414
00442	710*	78		CONTINUE	001431
00443	711*	70		CONTINUE	001431
00445	712*			IF(BCPOS(1).EQ.0.0)GO TO 72	001431
00447	713*			BCMIN=BCPOS(1)	001433
00450	714*			L=L-1	001436
00451	715*			BCMAX=BCPOS(L)	001437
00452	716*			GO TO 73	001437
00452	717*	C			001437
00452	718*	C			001437
00452	719*	C		THIS SECTION WRITES AN ERROR MESSAGE IF NO POSITIVE FLUX CAN	001437
00452	720*	C		BE FOUND	001437
00452	721*	C			001437
00453	722*	72		WRITE(6,74)	001446
00455	723*	74		FORMAT(1X,'SCAN OF BORON CONCENTRATION OVER THE RANGE OF ',/	
00455	724*			X1X,'0-5000PPM AT INTERVALS OF 50 PPM UNABLE TO FIND',/	
00455	725*			X1X,' ANY VALUES OF BORON CONCENTRATION WHICH YIELD',/	
00455	726*			X1X,' A POSITIVE FLUX.')	
00456	727*			HHH=0	
00457	728*			CALL FFLUX(HHH,AO,A1)	001452
00460	729*			WRITE(6,62)	001457
00462	730*	62		FORMAT(1X,'AT 0 PPM')	
00463	731*			WRITE(6,64)	
00465	732*			WRITE(6,75)PROD,L1,L2,L3	
00473	733*			GGG=5000	
00474	734*			CALL FFLUX(GGG,AO,A1)	001472
00475	735*			WRITE(6,63)	001477
00477	736*	63		FORMAT(/1X,'AT 5000 PPM')	
00500	737*			WRITE(6,64)	
00502	738*			WRITE(6,75)PROD,L1,L2,L3	
00510	739*	64		FORMAT(/1X,' PROD(1) ', ' PROD(2) ', ' PROD(3) ',	
00510	740*			X' ABSORP(1) ', ' ABSORP(2) ', ' ABSORP(3) ')	
00511	741*	75		FORMAT(1X,6(E12.5))	
00512	742*			GO TO 124	
00512	743*	C			
00512	744*	C			
00512	745*	C		THIS SECTION FINDS THE BORON CONCENTRATION(BC) BETWEEN BCMAX AND	
00512	746*	C		BCMIN WHICH GIVES THE FLATTEST FLUX AND THE FLUX COEFFICIENTS	
00512	747*	C		AO AND A1 WHICH CORRESPOND TO THAT FLUX	
00512	748*	C			
00513	749*	73		CONTINUE	001512
00514	750*			DO 86 I=1,L	001512
00517	751*			BCN(I)=BCPOS(I)+25	001530
00520	752*	86		CONTINUE	001533
00522	753*			N=1	001533

00523	754*		DO 87 J=1,L	001541
00526	755*		BCON(N)=BCPOS(J)	001543
00527	756*		N=(J+2)+1	001545
00530	757*	87	CONTINUE	001557
00532	758*		DO 88 J=1,L	001557
00535	759*		N=2*J	001557
00536	760*		BCON(N)=BCN(J)	001561
00537	761*	88	CONTINUE	001566
00541	762*		LL=1.0	001566
00542	763*		LLL=2*L	001571
00543	764*		DO 77 N=1,LLL	001572
00546	765*		KX=BCON(N)	001603
00547	766*		CALL FFLUX (KX,AO,A1)	001603
00550	767*		SUMDEV=0.0	001613
00551	768*		DO 79 IX=1,25	001620
00554	769*		RX=IX*(R3/50)	001620
00555	770*		FLXX=(AO*DCOS(B1*RX))+(A1*DSIN(B2*RX))	001625
00556	771*		IF (FLXX.LT.O.O)GO TO 77	001646
00560	772*		DEV=DABS((FLXX/AO)-1.0)	001652
00561	773*		SUMDEV=SUMDEV+DEV	001654
00562	774*	79	CONTINUE	001656
00564	775*	56	FORMAT(1X,E12.5)	001656
00565	776*		BORCON(1,LL)=LL	001656
00566	777*		BORCON(2,LL)=SUMDEV	001672
00567	778*		BORCON(3,LL)=AO	001672
00570	779*		BORCON(4,LL)=A1	001672
00571	780*		BORCON(5,LL)=KX	001673
00572	781*		LL=LL+1.0	001674
00573	782*	77	CONTINUE	001717
00575	783*		JJ=LL-2	001717
00576	784*		MINSUM=BORCON(2,1)	001721
00577	785*		DO 80 KK=1,JJ	001730
00602	786*		KKK=KK+1	001730
00603	787*		IF (MINSUM.GT.BORCON(2,KKK))MINSUM=BORCON(2,KKK)	001732
00605	788*	80	CONTINUE	001746
00607	789*		JJJ=JJ+1	001746
00610	790*		DO 81 NN=1,JJJ	001750
00613	791*		IF (BORCON(2,NN).EQ.MINSUM)III=BORCON(1,NN)	001752
00615	792*	81	CONTINUE	001767
00617	793*		ARRAY(9,1)=BORCON(5,III)*VFM1*CF	001767
00620	794*		ARRAY(9,2)=BORCON(5,III)*VFM2*CF	001771
00621	795*		ARRAY(9,3)=BORCON(5,III)*VFM3*CF	001771
00622	796*		BC=BORCON(5,III)	001771
00623	797*		AO=BORCON(3,III)	001771
00624	798*		A1=BORCON(4,III)	001771
00624	799*	C		001771
00624	800*	C		001771
00624	801*	C	THIS SECTION COMPUTES THE INTEGRAL OF THE FLUX OVER EACH REGION	001771
00624	802*	C		001771
00625	803*		DO 61 K=1,4	002017
00630	804*		IF (K.EQ.1)R=0.0	002017
00632	805*		IF (K.EQ.2)R=R1	002024
00634	806*		IF (K.EQ.3)R=R2	002031
00636	807*		IF (K.EQ.4)R=R3	002036
00640	808*		FLXINT(K)={((DCOS(B1*R)/(B1*B1))+((R*DSIN(B1*R))/B1))*2.0*PI*AO)+	002043
00640	809*		X(((DSIN(B2*R)/(B2*B2))-((R*DCOS(B2*R))/B2))*2.0*PI*A1)	002043
00641	810*	61	CONTINUE	002112
00643	811*		ARRAY(10,1)=FLXINT(2)-FLXINT(1)	002112
00644	812*		ARRAY(10,2)=FLXINT(3)-FLXINT(2)	002114
00645	813*		ARRAY(10,3)=FLXINT(4)-FLXINT(3)	002117

```

00646 814* IF (ARRAY(10,1).LT.0.0)ARRAY(10,1)=1.0 002117
00650 815* IF (ARRAY(10,2).LT.0.0)ARRAY(10,2)=1.0 002131
00652 816* IF (ARRAY(10,3).LT.0.0)ARRAY(10,3)=1.0 002137
00652 817* C 002137
00652 818* C 002137
00654 819* STPSAV=STEPS 002145
00654 820* C 002145
00654 821* C 002145
00654 822* C THIS SECTION WRITES THE OUTPUT FOR CERTAIN ITERATIONS 002145
00654 823* C 002145
00655 824* IF (STEPS.EQ.473.0)GO TO 209 002147
00657 825* IF (STEPS.GT.39.0)GO TO 208 002147
00661 826* IF (STEPS.GT.24.0)GO TO 202 002155
00663 827* 201 WRITE(6,40)STEPS,BC,BCMIN 002161
00670 828* GO TO 220
00671 829* 202 CONTINUE 002166
00672 830* STEPS=STEPS-23.0 002166
00673 831* 207 WRITE(6,42)STEPS,BC,BCMIN 002167
00700 832* GO TO 220
00701 833* 208 STEPS=STEPS-39.0 002175
00702 834* IF (STEPS.EQ.TPS)GO TO 206 002176
00704 835* STEPS=STPSAV 002176
00705 836* GO TO 230 002203
00706 837* 206 STEPS=STEPS+16.0 002205
00707 838* 205 WRITE(6,42)STEPS,BC,BCMIN 002206
00714 839* TPS=TPS+30.0
00715 840* GO TO 220 002214
00716 841* 209 STEPS=STEPS-23.0 002217
00717 842* 210 WRITE(6,42)STEPS,BC,BCMIN 002220
00724 843* GO TO 220
00725 844* 42 FORMAT(/1X,F5.1,' DAYS', ' 'BC=' ,E10.5,' PPM', ' 002226
00725 845* X BCMIN=' ,E10.5,' PPM', ' 002226
00726 846* 40 FORMAT(/1X,F5.1,' HOURS', ' 'BC=' ,E10.5,' PPM', ' 002226
00726 847* X BCMIN=' ,E10.5,' PPM', ' 002226
00727 848* 220 CONTINUE 002226
00730 849* STEPS=STPSAV 002226
00731 850* WRITE(6,27)AO,A1,BCMAX 002227
00736 851* WRITE(6,37)
00740 852* WRITE(6,28)
00742 853* WRITE(6,29)((ARRAY(J,K),J=1,10),K=1,3)
00753 854* 27 FORMAT(1X,' AO=' ,E10.5,' A1=' ,E10.5,' BCMAX=' 002244
00753 855* X,E10.5,' PPM') 002244
00754 856* 28 FORMAT(1X,' U-235 ' , ' PU-239 ' , ' U-238 ' , 002244
00754 857* X' XE-135 ' , ' I-135 ' , ' SM-149 ' , 002244
00754 858* X' PM-149 ' , ' LBP ' , ' B ' , 002244
00754 859* X' OF FLUX ' ) 002244
00755 860* 29 FORMAT(1X,10(E11.4,' '), ' REGION 1' /1X, 002244
00755 861* X10(E11.4,' '), ' REGION 2' /1X, 002244
00755 862* X10(E11.4,' '), ' REGION 3' ) 002244
00756 863* 37 FORMAT(/38X,' ISOTOPIC CONCENTRATIONS(ATOMS/CC)',38X,' INTEGRAL' ) 002244
00757 864* 230 CONTINUE 002244
00757 865* C 002244
00757 866* C 002244
00757 867* C THIS SECTION COMPUTES THE NEW ISOTOPIC CONCENTRATIONS 002244
00757 868* C AFTER EACH TIME STEP OF CONSTANT FLUX 002244
00757 869* C 002244
00760 870* Y=1.0/(PI*R1*R1) 002244
00761 871* DO 60 K=1,3 002335
00764 872* IF (K.EQ.2)Y=1.0/(PI*(R2+R2-R1*R1)) 002335
00766 873* IF (K.EQ.3)Y=1.0/(PI*(R3+R3-R2*R2)) 002342

```

00770	874*	IF(K.EQ.1)FLUX=ARRAY(10,1)	002347
00772	875*	IF(K.EQ.2)FLUX=ARRAY(10,2)	002354
00774	876*	IF(K.EQ.3)FLUX=ARRAY(10,3)	002361
00776	877*	GM1=SIGMA1*FLUX*Y	002366
00777	878*	GM2=SIGMA2*FLUX*Y	002370
01000	879*	GM3=SIGMA3*FLUX*Y	002405
01001	880*	AX2=LAMX+(SIGMA4*FLUX*Y)	002406
01002	881*	BX2=GAMX1*SIGMF1*FLUX*Y	002413
01003	882*	CX2=GAMX2*SIGMF2*FLUX*Y	002417
01004	883*	DX1=LAMI	002423
01005	884*	AX1=LAMI	002426
01006	885*	BX1=GAMI1*SIGMF1*FLUX*Y	002440
01007	886*	CX1=GAMI2*SIGMF2*FLUX*Y	002441
01010	887*	AS1=LAMPM	002446
01011	888*	BS1=GAMPM1*SIGMF1*FLUX*Y	002461
01012	889*	CS1=GAMPM2*SIGMF2*FLUX*Y	002464
01013	890*	AS2=SIGMA6*FLUX*Y	002465
01014	891*	BS2=LAMPM	002472
01015	892*	BCX1=BX1*ARRAY(1,K)+CX1*ARRAY(2,K)	002475
01016	893*	BCX2=BX2*ARRAY(1,K)+CX2*ARRAY(2,K)	002502
01017	894*	BCS1=BS1*ARRAY(1,K)+CS1*ARRAY(2,K)	002512
01020	895*	EX1=DEXP(-AX1*H)-DEXP(-AX2*H)	002514
01021	896*	EX2=1.0-DEXP(-AX2*H)	002531
01022	897*	ES1=DEXP(-AS1*H)-DEXP(-AS2*H)	002543
01023	898*	ES2=1.0-DEXP(-AS2*H)	002554
01024	899*	XE1=DEXP(-AX2*H)*ARRAY(4,K)	002566
01025	900*	XE2=(BCX2*EX2)/AX2	002600
01026	901*	XE3=(DX1*ARRAY(5,K)*EX1)/(AX2-AX1)	002601
01027	902*	XE4=BCX1*EX2/(AX2)	002610
01030	903*	XE5=-((BCX1*EX1)/(AX2-AX1))	002614
01031	904*	SM1=DEXP(-AS2*H)*ARRAY(6,K)	002622
01032	905*	SM2=(BS2*ARRAY(7,K)*ES1)/(AS2-AS1)	002635
01033	906*	SM3=((BS2*BCS1*ES2)/(AS1*AS2))	002642
01034	907*	SM4=-(((BS2*BCS1*ES1)/(AS1*(AS2-AS1))))	002651
01035	908*	ARRAY(4,K)=XE1+XE2+XE3+XE4+XE5	002661
01036	909*	IF(STEPS.EQ.1.0)ARRAY(4,K)=XE2+XE4+XE5	002661
01040	910*	ARRAY(5,K)=DEXP(-AX1*H)*ARRAY(5,K)+((-DEXP(-AX1*H)+1.0)*BCX1)/AX1	002676
01041	911*	ARRAY(6,K)=SM1+SM2+SM3+SM4	002706
01042	912*	IF(STEPS.EQ.1.0)ARRAY(6,K)=SM3+SM4	002706
01044	913*	ARRAY(7,K)=DEXP(-AS1*H)*ARRAY(7,K)+((1.0-DEXP(-AS1*H))*BCS1)/AS1	002722
01045	914*	ARRAY(2,K)=DEXP(-GM2*H)*ARRAY(2,K)+(GM3*ARRAY(3,K)*(DEXP(-GM3*H)-	002731
01045	915*	XDEXP(-GM2*H))/(GM2-GM3))	002731
01046	916*	ARRAY(3,K)=DEXP(-GM3*H)*ARRAY(3,K)	002745
01047	917*	ARRAY(1,K)=DEXP(-GM1*H)*ARRAY(1,K)	002766
01047	918*	THIS SECTION LIMITS XE-135,I-135,PM-149 AND SM-149	002766
01047	919*	C CONCENTRATIONS TO EQUILIBRIUM VALUES	002766
01050	920*	EQXE=(((GAMI1+GAMX1)*ARRAY(1,K)+SIGMF1*(GAMI2+GAMX2)	002777
01050	921*	X*ARRAY(2,K)+SIGMF2*FLUX)/((LAMX/Y)+SIGMA4*FLUX)	002777
01051	922*	EQI=((GAMI1*SIGMF1*ARRAY(1,K)+GAMI2*SIGMF2*ARRAY(2,K)	003012
01051	923*	X)/FLUX)/(LAMI/Y)	003012
01052	924*	EQSM=(GAMPM1*SIGMF1*ARRAY(1,K)+GAMPM2*SIGMF2*ARRAY(2,K	003012
01052	925*	X)/SIGMA6	003012
01053	926*	EOPM=((GAMPM1*SIGMF1*ARRAY(1,K)+GAMPM2*SIGMF2*ARRAY(2,K)	003032
01053	927*	X)/FLUX)/(LAMPM/Y)	003032
01054	928*	IF(ARRAY(4,K).GE.EQXE)ARRAY(4,K)=EQXE	003046
01056	929*	IF(ARRAY(5,K).GE.EQI)ARRAY(5,K)=EQI	003056
01060	930*	IF(ARRAY(6,K).GE.EQSM)ARRAY(6,K)=EQSM	003064
01062	931*	IF(ARRAY(7,K).GE.EOPM)ARRAY(7,K)=EOPM	003072
01064	932*	ARRAY(8,K)=ARRAY(8,K)*DEXP(-SIGMA8*(FLUX*Y)*H)	003100
01065	933*	60 CONTINUE	003115

O1065	934*	C		003115
O1065	935*	C		003115
O1067	936*		IF(STEPS.GE.24.0)GO TO 122	003115
O1071	937*		STEPS=STEPS+1.0	003121
O1072	938*		GO TO 101	003123
O1073	939*	122	H=86400.0	003126
O1074	940*		IF(STEPS.GE.489.0)GO TO 124	003127
O1076	941*		STEPS=STEPS+1.0	003133
O1077	942*		GO TO 101	003135
O1100	943*	124	CONTINUE	003140
O1101	944*		STOP	003140
O1102	945*		END	003143

END OF COMPILATION: NO DIAGNOSTICS.

@MAP.S DLG*MAY19.MAP,DLG*MAY19.MAY19A
 MAP 30R1-5 SLIB74 12/30/82 05:31:09 (3)
 1. IN DLG*MAY19.MAY19A
 2. IN DLG*MAY19.MAY19SUB
 3. END

AFQM STATUS OF OUTPUT ELEMENT=CLRAFCM
 QUARTER/THIRD WORD INSENSITIVE

ADDRESS LIMITS 001000 004447 1832 IBANK WORDS DECIMAL
 040000 053422 5907 DBANK WORDS DECIMAL
 STARTING ADDRESS 001161

SEGMENT	\$MAINS	001000 004447	040000 053422			
CLOSE\$/FOR-4R1-01	\$(1)	001000 001024	\$(2)	040000 040003	08 OCT 80	16:36:03
	\$(037)	INFO-010-LC				
NTABS\$/FOR-4R1-01			\$(2)	040004 040066	08 OCT 80	16:37:34
FORCOM\$/FCE-10R1A-02			\$(2)	040067 040074	08 OCT 82	10:49:10
CBEPFORV\$/RLIB-74R1-01					13 JUL 79	15:05:47
MOEROS\$(COMMONBLOCK)				040075 040100		
TINTR\$/FOR-4R1-08			\$(2)	040101 041434	11 OCT 82	14:17:12
			\$(034)	MOEROS		
NRECA\$/FOR-4R1-01			\$(2)	041435 041547	08 OCT 80	16:37:21
NSCR\$/FOR-4R1-01			\$(2)	041550 041713	08 OCT 80	16:37:22
			\$(4)	NSOSOS		
NSOSOS\$(COMMONBLOCK)				041714 041716		
NBFO\$/FOR-4R1-01			\$(2)	041717 044020	08 OCT 80	16:36:36
			\$(4)	NSOSOS		
CERU\$/RLIB-73R1-19					06 AUG 82	16:26:17
NERCOM\$/FOR-4R1-01	\$(1)	001025 001104	\$(2)	044021 044034	08 OCT 80	16:36:50
CBEP\$CML/CML-1R1-01					22 JUL 81	19:17:52
ERU\$/RLIB-74R1-01					13 JUL 79	15:12:46
FORVCOM\$/FOR-4R1-01			\$(2)	044035 044044	08 OCT 80	16:36:16
NSTOP\$/FOR-4R1-07	\$(1)	001105 001160	\$(2)	044045 044055	25 JAN 82	16:07:46
BLANK\$COMMON(COMMONBLOCK)				044056 044141		
MAY19A	\$(1)	001161 004324	\$(0)	044142 053367	30 DEC 82	05:31:08
	\$(3)	INFO-010-LC	\$(2)	BLANK\$COMMON		
MAY19SUB	\$(1)	004325 004447	\$(0)	053370 053422	23 AUG 82	04:58:26
	\$(3)	INFO-010-LC	\$(2)	BLANK\$COMMON		

COMMON BANKS REFERENCED

0400002 0400004 0400006
 SYSS\$RLIB\$. LEVEL
 END MAP. ERRORS: 0 TIME: 9.912 STORAGE: 24726/11/044777/0107777

@XQT DLG*MAY19.MAY19A

.O HOURS BC= .27500+04 PPM BCMIN= .24500+04 PPM
 AO= .79575+14 A1= .11706+14 BCMAX= .28500+04 PPM

U-235 PU-239 U-238 ISOTOPIC CONCENTRATIONS(ATOMS/CC) PM-149 LBP 8 INTEGRAL OF FLUX
 XE-135 I-135 SM-149

.1688+21	.0000	.6692+22	.0000	.0000	.0000	.0000	.9183+19	.6223+20	.3526+18	REGION 1
.1653+21	.0000	.6696+22	.0000	.0000	.0000	.0000	.9917+19	.6304+20	.2842+19	REGION 2
.2091+21	.0000	.6652+22	.0000	.0000	.0000	.0000	.4861+19	.6289+20	.5323+18	REGION 3
1.0 HOURS		BC= .27500+04 PPM	BCMIN= .24500+04 PPM							
AO= .72618+14		A1= .16702+14	BCMAX= .28000+04 PPM							
ISOTOPIC CONCENTRATIONS (ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1688+21	.3412+16	.6692+22	.7311+14	.1039+16	.1192+13	.1821+15	.9176+19	.6223+20	.3333+18	REGION 1
.1653+21	.2477+16	.6696+22	.5525+14	.7384+15	.8470+12	.1294+15	.9912+19	.6304+20	.2844+19	REGION 2
.2091+21	.6777+15	.6652+22	.2176+14	.2572+15	.2951+12	.4507+14	.4861+19	.6289+20	.5466+18	REGION 3
2.0 HOURS		BC= .27500+04 PPM	BCMIN= .24500+04 PPM							
AO= .73166+14		A1= .16313+14	BCMAX= .28000+04 PPM							
ISOTOPIC CONCENTRATIONS (ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1688+21	.6637+16	.6692+22	.6996+14	.1919+16	.1127+13	.3519+15	.9170+19	.6223+20	.3348+18	REGION 1
.1653+21	.4955+16	.6696+22	.5527+14	.1405+16	.8475+12	.2572+15	.9907+19	.6304+20	.2844+19	REGION 2
.2091+21	.1374+16	.6652+22	.2232+14	.4960+15	.3030+12	.9077+14	.4860+19	.6289+20	.5455+18	REGION 3
3.0 HOURS		BC= .27250+04 PPM	BCMIN= .24500+04 PPM							
AO= .73661+14		A1= .15961+14	BCMAX= .28000+04 PPM							
ISOTOPIC CONCENTRATIONS (ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1687+21	.9875+16	.6692+22	.2434+15	.2718+16	.6820+13	.5203+15	.9164+19	.6166+20	.3362+18	REGION 1
.1653+21	.7433+16	.6696+22	.1949+15	.2006+16	.5031+13	.3834+15	.9902+19	.6246+20	.2844+19	REGION 2
.2091+21	.2068+16	.6652+22	.8454+14	.7109+15	.1784+13	.1358+15	.4859+19	.6232+20	.5445+18	REGION 3
4.0 HOURS		BC= .27000+04 PPM	BCMIN= .24000+04 PPM							
AO= .75538+14		A1= .14617+14	BCMAX= .28000+04 PPM							
ISOTOPIC CONCENTRATIONS (ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1687+21	.1313+17	.6692+22	.3897+15	.3441+16	.1469+14	.6871+15	.9158+19	.6110+20	.3414+18	REGION 1
.1653+21	.9910+16	.6696+22	.3235+15	.2548+16	.1084+14	.5079+15	.9897+19	.6189+20	.2844+19	REGION 2
.2091+21	.2762+16	.6652+22	.1545+15	.9042+15	.3847+13	.1801+15	.4859+19	.6175+20	.5407+18	REGION 3
5.0 HOURS		BC= .26750+04 PPM	BCMIN= .24000+04 PPM							
AO= .78774+14		A1= .12299+14	BCMAX= .27500+04 PPM							
ISOTOPIC CONCENTRATIONS (ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1687+21	.1643+17	.6692+22	.5148+15	.4110+16	.2472+14	.8545+15	.9151+19	.6053+20	.3504+18	REGION 1
.1653+21	.1239+17	.6696+22	.4409+15	.3036+16	.1826+14	.6308+15	.9892+19	.6132+20	.2843+19	REGION 2
.2091+21	.3450+16	.6652+22	.2288+15	.1077+16	.6483+13	.2236+15	.4858+19	.6118+20	.5341+18	REGION 3
6.0 HOURS		BC= .26500+04 PPM	BCMIN= .23500+04 PPM							
AO= .83338+14		A1= .90266+13	BCMAX= .27500+04 PPM							
ISOTOPIC CONCENTRATIONS (ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1687+21	.1981+17	.6692+22	.6214+15	.4738+16	.3693+14	.1024+16	.9145+19	.5996+20	.3630+18	REGION 1
.1652+21	.1486+17	.6696+22	.5477+15	.3477+16	.2726+14	.7520+15	.9887+19	.6074+20	.2842+19	REGION 2
.2090+21	.4130+16	.6652+22	.3050+15	.1229+16	.9678+13	.2659+15	.4857+19	.6061+20	.5247+18	REGION 3
7.0 HOURS		BC= .26500+04 PPM	BCMIN= .23500+04 PPM							
AO= .70744+14		A1= .18069+14	BCMAX= .27000+04 PPM							

ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.1687+21	.2332+17	.6692+22	.7112+15	.5343+16	.5136+14	.1198+16	.9138+19	.5996+20	.3282+18	REGION 1
.1652+21	.1734+17	.6696+22	.6446+15	.3874+16	.3782+14	.8716+15	.9881+19	.6074+20	.2845+19	REGION 2
.2090+21	.4798+16	.6652+22	.3814+15	.1362+16	.1342+14	.3069+15	.4857+19	.6061+20	.5507+18	REGION 3
8.0 HOURS		BC= .26250+04 PPM	BCMIN= .23500+04 PPM							
AO= .77343+14		A1= .13337+14	BCMAX= .27000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.1686+21	.2649+17	.6692+22	.8243+15	.5785+16	.6790+14	.1352+16	.9132+19	.5940+20	.3464+18	REGION 1
.1652+21	.1981+17	.6696+22	.7320+15	.4232+16	.4991+14	.9898+15	.9876+19	.6017+20	.2844+19	REGION 2
.2090+21	.5499+16	.6652+22	.4546+15	.1494+16	.1770+14	.3495+15	.4856+19	.6004+20	.5371+18	REGION 3
9.0 HOURS		BC= .26000+04 PPM	BCMIN= .23000+04 PPM							
AO= .85338+14		A1= .76024+13	BCMAX= .27000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.1686+21	.2983+17	.6692+22	.8986+15	.6237+16	.8646+14	.1514+16	.9126+19	.5883+20	.3686+18	REGION 1
.1652+21	.2229+17	.6696+22	.8113+15	.4555+16	.6352+14	.1106+16	.9871+19	.5960+20	.2842+19	REGION 2
.2090+21	.6182+16	.6652+22	.5271+15	.1607+16	.2253+14	.3905+15	.4855+19	.5946+20	.5207+18	REGION 3
10.0 HOURS		BC= .26000+04 PPM	BCMIN= .23000+04 PPM							
AO= .76121+14		A1= .14221+14	BCMAX= .27000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.1686+21	.3339+17	.6692+22	.9469+15	.6711+16	.1071+15	.1684+16	.9119+19	.5883+20	.3431+18	REGION 1
.1652+21	.2476+17	.6696+22	.8829+15	.4846+16	.7861+14	.1221+16	.9866+19	.5960+20	.2845+19	REGION 2
.2090+21	.6845+16	.6652+22	.5977+15	.1701+16	.2787+14	.4295+15	.4854+19	.5946+20	.5397+18	REGION 3
11.0 HOURS		BC= .25750+04 PPM	BCMIN= .23000+04 PPM							
AO= .85754+14		A1= .73113+13	BCMAX= .26500+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.1686+21	.3670+17	.6692+22	.1030+16	.7062+16	.1299+15	.1839+16	.9112+19	.5827+20	.3697+18	REGION 1
.1652+21	.2723+17	.6696+22	.9474+15	.5109+16	.9518+14	.1335+16	.9861+19	.5902+20	.2843+19	REGION 2
.2090+21	.7532+16	.6652+22	.6623+15	.1795+16	.3373+14	.4696+15	.4854+19	.5889+20	.5199+18	REGION 3
12.0 HOURS		BC= .25750+04 PPM	BCMIN= .23000+04 PPM							
AO= .78243+14		A1= .12705+14	BCMAX= .26500+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.1686+21	.4027+17	.6692+22	.1067+16	.7458+16	.1547+15	.2006+16	.9106+19	.5827+20	.3490+18	REGION 1
.1652+21	.2970+17	.6696+22	.1006+16	.5346+16	.1132+15	.1447+16	.9856+19	.5902+20	.2845+19	REGION 2
.2090+21	.8193+16	.6652+22	.7257+15	.1870+16	.4010+14	.5075+15	.4853+19	.5889+20	.5354+18	REGION 3
13.0 HOURS		BC= .25750+04 PPM	BCMIN= .23000+04 PPM							
AO= .71064+14		A1= .17861+14	BCMAX= .26500+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.1685+21	.4363+17	.6692+22	.1137+16	.7753+16	.1816+15	.2160+16	.9099+19	.5827+20	.3291+18	REGION 1
.1651+21	.3217+17	.6696+22	.1058+16	.5559+16	.1326+15	.1558+16	.9851+19	.5902+20	.2846+19	REGION 2
.2090+21	.8875+16	.6652+22	.7826+15	.1945+16	.4697+14	.5463+15	.4852+19	.5889+20	.5503+18	REGION 3

14.0 HOURS		BC= .25500+04 PPM	BCMIN= .22500+04 PPM						
AO= .82820+14		A1= .94278+13	BCMAX= .26500+04 PPM						
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)									
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX
.1685+21	.4680+17	.6692+22	.1218+16	.7961+16	.2103+15	.2302+16	.9093+19	.5770+20	.3616+18
.1651+21	.3465+17	.6696+22	.1105+16	.5753+16	.1535+15	.1667+16	.9846+19	.5845+20	.2844+19
.2090+21	.9575+16	.6652+22	.8340+15	.2020+16	.5434+14	.5858+15	.4852+19	.5832+20	.5261+18
REGION 1									
REGION 2									
REGION 3									
15.0 HOURS		BC= .25500+04 PPM	BCMIN= .22500+04 PPM						
AO= .77509+14		A1= .13243+14	BCMAX= .26500+04 PPM						
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)									
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX
.1685+21	.5029+17	.6692+22	.1232+16	.8244+16	.2409+15	.2459+16	.9086+19	.5770+20	.3469+18
.1651+21	.3712+17	.6696+22	.1148+16	.5926+16	.1757+15	.1775+16	.9841+19	.5845+20	.2845+19
.2090+21	.1024+17	.6652+22	.8860+15	.2075+16	.6221+14	.6227+15	.4851+19	.5832+20	.5371+18
REGION 1									
REGION 2									
REGION 3									
16.0 HOURS		BC= .25500+04 PPM	BCMIN= .22500+04 PPM						
AO= .72339+14		A1= .16957+14	BCMAX= .26000+04 PPM						
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)									
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX
.1685+21	.5363+17	.6692+22	.1278+16	.8456+16	.2734+15	.2606+16	.9080+19	.5770+20	.3326+18
.1651+21	.3959+17	.6696+22	.1187+16	.6083+16	.1993+15	.1881+16	.9835+19	.5845+20	.2846+19
.2090+21	.1093+17	.6652+22	.9320+15	.2131+16	.7056+14	.6601+15	.4850+19	.5832+20	.5477+18
REGION 1									
REGION 2									
REGION 3									
17.0 HOURS		BC= .25250+04 PPM	BCMIN= .22500+04 PPM						
AO= .85975+14		A1= .71746+13	BCMAX= .26000+04 PPM						
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)									
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX
.1685+21	.5683+17	.6692+22	.1337+16	.8605+16	.3078+15	.2744+16	.9074+19	.5714+20	.3704+18
.1651+21	.4206+17	.6696+22	.1221+16	.6225+16	.2242+15	.1986+16	.9830+19	.5788+20	.2844+19
.2090+21	.1162+17	.6652+22	.9730+15	.2186+16	.7940+14	.6979+15	.4850+19	.5775+20	.5197+18
REGION 1									
REGION 2									
REGION 3									
18.0 HOURS		BC= .25250+04 PPM	BCMIN= .22500+04 PPM						
AO= .82431+14		A1= .97213+13	BCMAX= .26000+04 PPM						
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)									
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX
.1684+21	.6040+17	.6692+22	.1322+16	.8851+16	.3439+15	.2899+16	.9067+19	.5714+20	.3606+18
.1651+21	.4453+17	.6696+22	.1253+16	.6352+16	.2504+15	.2090+16	.9825+19	.5788+20	.2845+19
.2090+21	.1229+17	.6652+22	.1016+16	.2223+16	.8871+14	.7328+15	.4849+19	.5775+20	.5270+18
REGION 1									
REGION 2									
REGION 3									
19.0 HOURS		BC= .25250+04 PPM	BCMIN= .22500+04 PPM						
AO= .78802+14		A1= .12329+14	BCMAX= .26000+04 PPM						
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)									
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX
.1684+21	.6387+17	.6692+22	.1347+16	.9043+16	.3819+15	.3048+16	.9060+19	.5714+20	.3506+18
.1651+21	.4700+17	.6696+22	.1281+16	.6466+16	.2780+15	.2192+16	.9820+19	.5788+20	.2845+19
.2090+21	.1296+17	.6652+22	.1053+16	.2259+16	.9848+14	.7679+15	.4848+19	.5775+20	.5345+18
REGION 1									
REGION 2									
REGION 3									
20.0 HOURS		BC= .25250+04 PPM	BCMIN= .22500+04 PPM						
AO= .75365+14		A1= .14799+14	BCMAX= .26000+04 PPM						
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)									
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX

.1684+21	.6724+17	.6692+22	.1387+16	.9187+16	.4218+15	.3189+16	.9054+19	.5714+20	.3410+18	REGION 1	
.1650+21	.4947+17	.6696+22	.1307+16	.6570+16	.3068+15	.2293+16	.9815+19	.5788+20	.2846+19	REGION 2	
.2090+21	.1364+17	.6652+22	.1086+16	.2296+16	.1087+15	.8032+15	.4847+19	.5775+20	.5417+18	REGION 3	
21.0 HOURS											
AO= .72230+14	BC= .25250+04 PPM	BCMIN= .22500+04 PPM						BCMAX= .26000+04 PPM			
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)											
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX		
.1684+21	.7052+17	.6692+22	.1433+16	.9289+16	.4634+15	.3323+16	.9048+19	.5714+20	.3324+18	REGION 1	
.1650+21	.5194+17	.6696+22	.1329+16	.6664+16	.3369+15	.2393+16	.9810+19	.5788+20	.2847+19	REGION 2	
.2090+21	.1432+17	.6652+22	.1114+16	.2332+16	.1194+15	.8386+15	.4847+19	.5775+20	.5481+18	REGION 3	
22.0 HOURS											
AO= .87943+14	BC= .25000+04 PPM	BCMIN= .22000+04 PPM						BCMAX= .26000+04 PPM			
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)											
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX		
.1684+21	.7372+17	.6692+22	.1478+16	.9355+16	.5066+15	.3452+16	.9042+19	.5657+20	.3759+18	REGION 1	
.1650+21	.5441+17	.6696+22	.1350+16	.6748+16	.3683+15	.2491+16	.9805+19	.5730+20	.2844+19	REGION 2	
.2090+21	.1502+17	.6652+22	.1140+16	.2368+16	.1305+15	.8741+15	.4846+19	.5718+20	.5158+18	REGION 3	
23.0 HOURS											
AO= .86412+14	BC= .25000+04 PPM	BCMIN= .22500+04 PPM						BCMAX= .26000+04 PPM			
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)											
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX		
.1683+21	.7733+17	.6692+22	.1434+16	.9542+16	.5514+15	.3601+16	.9035+19	.5657+20	.3716+18	REGION 1	
.1650+21	.5687+17	.6696+22	.1369+16	.6824+16	.4008+15	.2588+16	.9800+19	.5730+20	.2844+19	REGION 2	
.2090+21	.1568+17	.6652+22	.1170+16	.2384+16	.1421+15	.9064+15	.4845+19	.5718+20	.5190+18	REGION 3	
24.0 HOURS											
AO= .84580+14	BC= .25000+04 PPM	BCMIN= .22000+04 PPM						BCMAX= .26000+04 PPM			
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)											
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX		
.1683+21	.8090+17	.6692+22	.1432+16	.9699+16	.5981+15	.3746+16	.9028+19	.5657+20	.3666+18	REGION 1	
.1650+21	.5934+17	.6696+22	.1386+16	.6892+16	.4346+15	.2684+16	.9795+19	.5730+20	.2845+19	REGION 2	
.2090+21	.1634+17	.6652+22	.1196+16	.2401+16	.1541+15	.9386+15	.4845+19	.5718+20	.5228+18	REGION 3	
2.0 DAYS											
AO= .82740+14	BC= .25000+04 PPM	BCMIN= .22000+04 PPM						BCMAX= .26000+04 PPM			
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)											
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX		
.1683+21	.8442+17	.6692+22	.1451+16	.9825+16	.6465+15	.3886+16	.9021+19	.5657+20	.3615+18	REGION 1	
.1650+21	.6180+17	.6696+22	.1401+16	.6953+16	.4695+15	.2778+16	.9790+19	.5730+20	.2846+19	REGION 2	
.2090+21	.1700+17	.6652+22	.1218+16	.2418+16	.1665+15	.9707+15	.4844+19	.5718+20	.5267+18	REGION 3	
3.0 DAYS											
AO= .74651+14	BC= .25000+04 PPM	BCMIN= .22000+04 PPM						BCMAX= .25500+04 PPM			
ISOTOPIIC CONCENTRATIONS(ATOMS/CC)											
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX		
.1678+21	.1674+18	.6692+22	.1626+16	.1075+17	.2254+16	.6705+16	.8864+19	.5657+20	.3393+18	REGION 1	
.1646+21	.1208+18	.6696+22	.1529+16	.7472+16	.1621+16	.4713+16	.9669+19	.5730+20	.2851+19	REGION 2	
.2088+21	.3306+17	.6652+22	.1392+16	.2576+16	.5765+15	.1634+16	.4828+19	.5718+20	.5442+18	REGION 3	
4.0 DAYS											
AO= .84709+14	BC= .25000+04 PPM	BCMIN= .22500+04 PPM						BCMAX= .26000+04 PPM			

ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	REGION	
.1673+21	.2448+18	.6692+22	.1623+16	.1013+17	.4484+16	.8520+16	.8719+19	.5657+20	.3673+18	REGION 1	
.1643+21	.1796+18	.6696+22	.1537+16	.7512+16	.3239+16	.6129+16	.9549+19	.5730+20	.2852+19	REGION 2	
.2087+21	.4963+17	.6652+22	.1417+16	.2668+16	.1164+16	.2149+16	.4811+19	.5718+20	.5244+18	REGION 3	
5.0 DAYS		BC= .25250+04 PPM	BCMIN= .22500+04 PPM								
AO= .77198+14		A1= .13767+14	BCMAX= .26000+04 PPM								
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	REGION	
.1668+21	.3278+18	.6692+22	.1625+16	.1089+17	.7100+16	.1014+17	.8565+19	.5714+20	.3467+18	REGION 1	
.1639+21	.2382+18	.6696+22	.1535+16	.7506+16	.5168+16	.7162+16	.9430+19	.5788+20	.2858+19	REGION 2	
.2086+21	.6557+17	.6652+22	.1404+16	.2576+16	.1879+16	.2490+16	.4795+19	.5775+20	.5407+18	REGION 3	
6.0 DAYS		BC= .25250+04 PPM	BCMIN= .22500+04 PPM								
AO= .88265+14		A1= .59168+13	BCMAX= .26000+04 PPM								
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	REGION	
.1663+21	.4057+18	.6692+22	.1621+16	.1030+17	.9986+16	.1110+17	.8422+19	.5714+20	.3775+18	REGION 1	
.1636+21	.2965+18	.6695+22	.1533+16	.7509+16	.7294+16	.7918+16	.9313+19	.5788+20	.2859+19	REGION 2	
.2085+21	.8198+17	.6652+22	.1414+16	.2650+16	.2680+16	.2767+16	.4778+19	.5775+20	.5189+18	REGION 3	
7.0 DAYS		BC= .25500+04 PPM	BCMIN= .23000+04 PPM								
AO= .80137+14		A1= .11837+14	BCMAX= .26500+04 PPM								
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	REGION	
.1658+21	.4897+18	.6692+22	.1623+16	.1114+17	.1297+17	.1211+17	.8269+19	.5770+20	.3551+18	REGION 1	
.1632+21	.3545+18	.6695+22	.1531+16	.7502+16	.9538+16	.8468+16	.9197+19	.5845+20	.2864+19	REGION 2	
.2083+21	.9771+17	.6652+22	.1397+16	.2547+16	.3543+16	.2932+16	.4762+19	.5832+20	.5365+18	REGION 3	
8.0 DAYS		BC= .25750+04 PPM	BCMIN= .23000+04 PPM								
AO= .70983+14		A1= .18491+14	BCMAX= .26500+04 PPM								
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	REGION	
.1653+21	.5682+18	.6692+22	.1619+16	.1051+17	.1607+17	.1262+17	.8127+19	.5827+20	.3300+18	REGION 1	
.1629+21	.4123+18	.6695+22	.1529+16	.7505+16	.1184+17	.8872+16	.9083+19	.5902+20	.2870+19	REGION 2	
.2082+21	.1139+18	.6652+22	.1408+16	.2626+16	.4444+16	.3082+16	.4746+19	.5889+20	.5562+18	REGION 3	
9.0 DAYS		BC= .25750+04 PPM	BCMIN= .23000+04 PPM								
AO= .81468+14		A1= .11060+14	BCMAX= .26500+04 PPM								
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	REGION	
.1649+21	.6406+18	.6692+22	.1603+16	.9749+16	.1915+17	.1271+17	.7998+19	.5827+20	.3592+18	REGION 1	
.1625+21	.4699+18	.6695+22	.1528+16	.7508+16	.1416+17	.9168+16	.8970+19	.5902+20	.2872+19	REGION 2	
.2081+21	.1308+18	.6652+22	.1426+16	.2721+16	.5379+16	.3226+16	.4729+19	.5889+20	.5356+18	REGION 3	
10.0 DAYS		BC= .26000+04 PPM	BCMIN= .23500+04 PPM								
AO= .72172+14		A1= .17816+14	BCMAX= .26500+04 PPM								
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	REGION	
.1644+21	.7189+18	.6692+22	.1606+16	.1054+17	.2207+17	.1308+17	.7860+19	.5883+20	.3336+18	REGION 1	
.1622+21	.5273+18	.6695+22	.1526+16	.7502+16	.1646+17	.9383+16	.8858+19	.5960+20	.2877+19	REGION 2	
.2080+21	.1469+18	.6652+22	.1412+16	.2626+16	.6339+16	.3295+16	.4712+19	.5946+20	.5556+18	REGION 3	

11.0 DAYS		BC= .26000+04 PPM	BCMIN= .23500+04 PPM							
AO= .82475+14		A1= .10518+14	BCMAX= .27000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1639+21	.7910+18	.6691+22	.1599+16	.9817+16	.2497+17	.1303+17	.7733+19	.5883+20	.3623+18	REGION 1
.1618+21	.5844+18	.6695+22	.1524+16	.7505+16	.1874+17	.9542+16	.8747+19	.5960+20	.2879+19	REGION 2
.2078+21	.1636+18	.6652+22	.1424+16	.2715+16	.7310+16	.3380+16	.4696+19	.5946+20	.5353+18	REGION 3
12.0 DAYS		BC= .26250+04 PPM	BCMIN= .23500+04 PPM							
AO= .72633+14		A1= .17665+14	BCMAX= .27000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1634+21	.8688+18	.6691+22	.1601+16	.1059+17	.2765+17	.1333+17	.7598+19	.5940+20	.3352+18	REGION 1
.1615+21	.6412+18	.6695+22	.1522+16	.7499+16	.2096+17	.9656+16	.8637+19	.6017+20	.2885+19	REGION 2
.2077+21	.1797+18	.6652+22	.1411+16	.2622+16	.8290+16	.3406+16	.4679+19	.6004+20	.5564+18	REGION 3
13.0 DAYS		BC= .26250+04 PPM	BCMIN= .23500+04 PPM							
AO= .82754+14		A1= .10499+14	BCMAX= .27000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1630+21	.9402+18	.6691+22	.1594+16	.9826+16	.3033+17	.1305+17	.7476+19	.5940+20	.3634+18	REGION 1
.1611+21	.6978+18	.6695+22	.1520+16	.7502+16	.2313+17	.9741+16	.8529+19	.6017+20	.2886+19	REGION 2
.2076+21	.1965+18	.6652+22	.1423+16	.2717+16	.9268+16	.3462+16	.4663+19	.6004+20	.5366+18	REGION 3
14.0 DAYS		BC= .26500+04 PPM	BCMIN= .24000+04 PPM							
AO= .72350+14		A1= .18048+14	BCMAX= .27000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1625+21	.1017+19	.6691+22	.1596+16	.1058+17	.3272+17	.1334+17	.7345+19	.5996+20	.3348+18	REGION 1
.1608+21	.7542+18	.6695+22	.1518+16	.7496+16	.2524+17	.9801+16	.8422+19	.6074+20	.2892+19	REGION 2
.2075+21	.2125+18	.6652+22	.1411+16	.2626+16	.1025+17	.3467+16	.4647+19	.6061+20	.5588+18	REGION 3
15.0 DAYS		BC= .26500+04 PPM	BCMIN= .24000+04 PPM							
AO= .82286+14		A1= .11018+14	BCMAX= .27000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1620+21	.1087+19	.6691+22	.1588+16	.9774+16	.3516+17	.1298+17	.7226+19	.5996+20	.3625+18	REGION 1
.1604+21	.8104+18	.6695+22	.1517+16	.7500+16	.2727+17	.9847+16	.8316+19	.6074+20	.2894+19	REGION 2
.2073+21	.2293+18	.6652+22	.1424+16	.2726+16	.1122+17	.3510+16	.4630+19	.6061+20	.5394+18	REGION 3
16.0 DAYS		BC= .26750+04 PPM	BCMIN= .24000+04 PPM							
AO= .71309+14		A1= .18975+14	BCMAX= .27500+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	
.1616+21	.1163+19	.6691+22	.1590+16	.1051+17	.3727+17	.1327+17	.7100+19	.6053+20	.3322+18	REGION 1
.1601+21	.8663+18	.6695+22	.1515+16	.7494+16	.2924+17	.9878+16	.8212+19	.6132+20	.2900+19	REGION 2
.2072+21	.2454+18	.6652+22	.1413+16	.2637+16	.1219+17	.3496+16	.4614+19	.6118+20	.5628+18	REGION 3
46.0 DAYS		BC= .29250+04 PPM	BCMIN= .27000+04 PPM							
AO= .88854+14		A1= .93158+13	BCMAX= .30000+04 PPM							
ISOTOPIC CONCENTRATIONS(ATOMS/CC)										
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	INTEGRAL OF FLUX	

.1475+21	.3196+19	.6688+22	.1503+16	.1004+17	.6724+17	.1298+17	.4162+19	.6619+20	.3865+18	REGION 1
.1498+21	.2436+19	.6693+22	.1459+16	.7456+16	.6250+17	.9940+16	.5572+19	.6705+20	.3018+19	REGION 2
.2035+21	.7299+18	.6651+22	.1422+16	.2742+16	.3674+17	.3566+16	.4147+19	.6690+20	.5563+18	REGION 3
76.0 DAYS		BC= .30500+04 PPM	ISOTOPIC CONCENTRATIONS(ATOMS/CC)						INTEGRAL	
AO= .85389+14		A1= .14990+14	BCMIN= .28500+04 PPM			BCMAX= .31000+04 PPM			OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B		
.1340+21	.4874+19	.6686+22	.1415+16	.9596+16	.6948+17	.1256+17	.2377+19	.6902+20	.3830+18	REGION 1
.1398+21	.3812+19	.6691+22	.1402+16	.7414+16	.7020+17	.9921+16	.3719+19	.6991+20	.3151+19	REGION 2
.1997+21	.1210+19	.6651+22	.1429+16	.2850+16	.5447+17	.3736+16	.3711+19	.6976+20	.5957+18	REGION 3
106.0 DAYS		BC= .30500+04 PPM	ISOTOPIC CONCENTRATIONS(ATOMS/CC)						INTEGRAL	
AO= .97619+14		A1= .98513+13	BCMIN= .28500+04 PPM			BCMAX= .31000+04 PPM			OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B		
.1209+21	.6277+19	.6683+22	.1332+16	.1010+17	.6529+17	.1363+17	.1299+19	.6902+20	.4238+18	REGION 1
.1301+21	.5013+19	.6689+22	.1342+16	.7372+16	.6856+17	.9901+16	.2437+19	.6991+20	.3300+19	REGION 2
.1958+21	.1681+19	.6650+22	.1412+16	.2828+16	.6707+17	.3718+16	.3310+19	.6976+20	.6073+18	REGION 3
136.0 DAYS		BC= .29750+04 PPM	ISOTOPIC CONCENTRATIONS(ATOMS/CC)						INTEGRAL	
AO= .10378+15		A1= .94076+13	BCMIN= .27500+04 PPM			BCMAX= .30500+04 PPM			OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B		
.1089+21	.7361+19	.6680+22	.1233+16	.9901+16	.6061+17	.1220+17	.7057+18	.6732+20	.4485+18	REGION 1
.1206+21	.6053+19	.6687+22	.1281+16	.7325+16	.6513+17	.9868+16	.1565+19	.6819+20	.3463+19	REGION 2
.1918+21	.2158+19	.6650+22	.1411+16	.2897+16	.7581+17	.3855+16	.2930+19	.6804+20	.6349+18	REGION 3
166.0 DAYS		BC= .28500+04 PPM	ISOTOPIC CONCENTRATIONS(ATOMS/CC)						INTEGRAL	
AO= .10329+15		A1= .14057+14	BCMIN= .25500+04 PPM			BCMAX= .29500+04 PPM			OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B		
.9765+20	.8226+19	.6677+22	.1154+16	.9470+16	.5617+17	.1237+17	.3718+18	.6449+20	.4555+18	REGION 1
.1114+21	.6948+19	.6685+22	.1219+16	.7270+16	.6167+17	.9835+16	.9825+18	.6533+20	.3642+19	REGION 2
.1876+21	.2632+19	.6649+22	.1415+16	.3030+16	.8151+17	.3998+16	.2577+19	.6518+20	.6794+18	REGION 3
196.0 DAYS		BC= .26750+04 PPM	ISOTOPIC CONCENTRATIONS(ATOMS/CC)						INTEGRAL	
AO= .11478+15		A1= .10756+14	BCMIN= .23500+04 PPM			BCMAX= .28000+04 PPM			OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B		
.8706+20	.8906+19	.6674+22	.1059+16	.8292+16	.5207+17	.1134+17	.1898+18	.6053+20	.4968+18	REGION 1
.1025+21	.7713+19	.6682+22	.1156+16	.7194+16	.5820+17	.9769+16	.6018+18	.6132+20	.3845+19	REGION 2
.1833+21	.3105+19	.6648+22	.1435+16	.3283+16	.8494+17	.4270+16	.2251+19	.6118+20	.7057+18	REGION 3
226.0 DAYS		BC= .25000+04 PPM	ISOTOPIC CONCENTRATIONS(ATOMS/CC)						INTEGRAL	
AO= .10464+15		A1= .23081+14	BCMIN= .21500+04 PPM			BCMAX= .26000+04 PPM			OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B		
.7710+20	.9437+19	.6670+22	.9794+15	.8381+16	.4784+17	.1152+17	.9309+17	.5657+20	.4784+18	REGION 1
.9381+20	.8360+19	.6680+22	.1092+16	.7134+16	.5473+17	.9724+16	.3585+18	.5730+20	.4057+19	REGION 2
.1789+21	.3574+19	.6648+22	.1426+16	.3344+16	.8683+17	.4379+16	.1952+19	.5718+20	.7777+18	REGION 3
256.0 DAYS		BC= .22750+04 PPM	ISOTOPIC CONCENTRATIONS(ATOMS/CC)						INTEGRAL	
AO= .12615+15		A1= .13925+14	BCMIN= .19000+04 PPM			BCMAX= .24000+04 PPM			OF FLUX	

ISOTOPIC CONCENTRATIONS(ATOMS/CC)							PM-149	LBP	B	INTEGRAL OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149						
.6783+20	.9841+19	.6667+22	.8969+15	.7798+16	.4381+17	.1077+17	.4398+17	.5148+20	.5500+18	REGION 1	
.8543+20	.8901+19	.6677+22	.1028+16	.7050+16	.5127+17	.9648+16	.2072+18	.5215+20	.4314+19	REGION 2	
.1744+21	.4041+19	.6647+22	.1429+16	.3529+16	.8746+17	.4603+16	.1677+19	.5203+20	.7969+18	REGION 3	
286.0 DAYS		BC= .20750+04 PPM	BCMIN= .16500+04 PPM			BCMAX= .22000+04 PPM					
AO= .11934+15		A1= .25040+14									
ISOTOPIC CONCENTRATIONS(ATOMS/CC)							PM-149	LBP	B	INTEGRAL OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149						
.5919+20	.1015+20	.6663+22	.8232+15	.7847+16	.3993+17	.1073+17	.1979+17	.4695+20	.5431+18	REGION 1	
.7735+20	.9350+19	.6674+22	.9644+15	.6979+16	.4786+17	.9589+16	.1157+18	.4756+20	.4574+19	REGION 2	
.1696+21	.4503+19	.6646+22	.1418+16	.3611+16	.8711+17	.4784+16	.1428+19	.4746+20	.8739+18	REGION 3	
316.0 DAYS		BC= .18500+04 PPM	BCMIN= .14000+04 PPM			BCMAX= .20000+04 PPM					
AO= .13245+15		A1= .23104+14									
ISOTOPIC CONCENTRATIONS(ATOMS/CC)							PM-149	LBP	B	INTEGRAL OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149						
.5117+20	.1037+20	.6659+22	.7515+15	.7737+16	.3631+17	.1066+17	.8434+16	.4186+20	.5938+18	REGION 1	
.6958+20	.9716+19	.6672+22	.9010+15	.6897+16	.4451+17	.9518+16	.6226+17	.4241+20	.4882+19	REGION 2	
.1648+21	.4960+19	.6645+22	.1408+16	.3729+16	.8526+17	.4948+16	.1204+19	.4231+20	.9225+18	REGION 3	
346.0 DAYS		BC= .16250+04 PPM	BCMIN= .11500+04 PPM			BCMAX= .17500+04 PPM					
AO= .14746+15		A1= .20690+14									
ISOTOPIC CONCENTRATIONS(ATOMS/CC)							PM-149	LBP	B	INTEGRAL OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149						
.4384+20	.1053+20	.6655+22	.6825+15	.7610+16	.3289+17	.1021+17	.3407+16	.3677+20	.6514+18	REGION 1	
.6215+20	.1001+20	.6668+22	.8386+15	.6809+16	.4124+17	.9423+16	.3211+17	.3725+20	.5226+19	REGION 2	
.1597+21	.5413+19	.6645+22	.1397+16	.3856+16	.8332+17	.5172+16	.1003+19	.3716+20	.9762+18	REGION 3	
376.0 DAYS		BC= .14000+04 PPM	BCMIN= .95000+03 PPM			BCMAX= .15500+04 PPM					
AO= .16728+15		A1= .15924+14									
ISOTOPIC CONCENTRATIONS(ATOMS/CC)							PM-149	LBP	B	INTEGRAL OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149						
.3714+20	.1064+20	.6650+22	.6185+15	.6916+16	.2985+17	.9802+16	.1290+16	.3168+20	.7245+18	REGION 1	
.5507+20	.1024+20	.6665+22	.7771+15	.6680+16	.3808+17	.9308+16	.1581+17	.3209+20	.5614+19	REGION 2	
.1544+21	.5858+19	.6644+22	.1393+16	.4123+16	.8128+17	.5455+16	.8244+18	.3202+20	.1031+19	REGION 3	
406.0 DAYS		BC= .12000+04 PPM	BCMIN= .70000+03 PPM			BCMAX= .13500+04 PPM					
AO= .17029+15		A1= .23508+14									
ISOTOPIC CONCENTRATIONS(ATOMS/CC)							PM-149	LBP	B	INTEGRAL OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149						
.3109+20	.1072+20	.6645+22	.5611+15	.7067+16	.2692+17	.9633+16	.4551+15	.2715+20	.7515+18	REGION 1	
.4836+20	.1042+20	.6661+22	.7179+15	.6592+16	.3503+17	.9214+16	.7392+16	.2751+20	.6019+19	REGION 2	
.1490+21	.6296+19	.6643+22	.1372+16	.4210+16	.7914+17	.5661+16	.6683+18	.2744+20	.1123+19	REGION 3	
436.0 DAYS		BC= .10000+04 PPM	BCMIN= .50000+03 PPM			BCMAX= .11500+04 PPM					
AO= .18175+15		A1= .26376+14									
ISOTOPIC CONCENTRATIONS(ATOMS/CC)							PM-149	LBP	B	INTEGRAL OF FLUX	
U-235	PU-239	U-238	XE-135	I-135	SM-149						
.2567+20	.1077+20	.6640+22	.5081+15	.6779+16	.2434+17	.9312+16	.1482+15	.2263+20	.8046+18	REGION 1	
.4206+20	.1055+20	.6658+22	.6607+15	.6469+16	.3213+17	.9093+16	.3263+16	.2292+20	.6477+19	REGION 2	
.1434+21	.6723+19	.6642+22	.1355+16	.4409+16	.7689+17	.5938+16	.5333+18	.2287+20	.1212+19	REGION 3	

450.0 DAYS
AO= .19842+15

BC= .90000+03 PPM
A1= .20507+14

BCMIN= .40000+03 PPM
BCMAX= .10500+04 PPM

ISOTOPIC CONCENTRATIONS(ATOMS/CC)									INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.2337+20	.1078+20	.6637+22	.4851+15	.6292+16	.2334+17	.9104+16	.8554+14	.2037+20	.8624+18	REGION 1
.3927+20	.1060+20	.6656+22	.6347+15	.6379+16	.3084+17	.9019+16	.2181+16	.2063+20	.6727+19	REGION 2
.1407+21	.6919+19	.6641+22	.1351+16	.4600+16	.7580+17	.6097+16	.4770+18	.2058+20	.1239+19	REGION 3

466.0 DAYS
AO= .20524+15

BC= .80000+03 PPM
A1= .22291+14

BCMIN= .30000+03 PPM
BCMAX= .95000+03 PPM

ISOTOPIC CONCENTRATIONS(ATOMS/CC)									INTEGRAL	
U-235	PU-239	U-238	XE-135	I-135	SM-149	PM-149	LBP	B	OF FLUX	
.2089+20	.1079+20	.6634+22	.4605+15	.6152+16	.2215+17	.8946+16	.4432+14	.1810+20	.8941+18	REGION 1
.3619+20	.1065+20	.6653+22	.6061+15	.6307+16	.2940+17	.8948+16	.1352+16	.1834+20	.7003+19	REGION 2
.1375+21	.7139+19	.6640+22	.1339+16	.4714+16	.7453+17	.6257+16	.4181+18	.1830+20	.1293+19	REGION 3

@BRKPT PRINT\$

**The vita has been removed from
the scanned document**

A ONE-DIMENSIONAL FUEL
BURNUP MODEL OF A PWR

by

D. L. Gilliatt

ABSTRACT

A fuel burnup model of a Pressurized Water Reactor (PWR) was developed based on one-group diffusion theory and used simple thermal cross sections. A computer program which simulates the depletion of the core of a PWR was written based on this model. The basic idea was to develop a fuel depletion program which could be readily understood by nuclear engineering students. Thus, accuracy was sacrificed for the sake of simplicity.

The model was based upon a typical PWR with three concentric regions in the radial direction of differing fuel enrichment. Each of the regions was homogenized and the concentrations of the isotopes in each region were considered constant over a time interval. The isotopes considered were U-235, Pu-239, U-238, Xe-135, I-135, Sm-149, Pm-149 and the lumped burnable poison isotope.

The flux was approximated by the sum of two trigonometric functions. The magnitude and shape of the flux were determined by holding power constant, constraining system to be critical and varying the soluble boron concentration to find the flattest possible positive flux. A flux magnitude computed in this manner was compared to a similar flux magnitude given in a Final Safety Analysis Report.

The concentrations of the isotopes were determined from the differential equations describing the rate of change of the concentrations. The behavior of the isotopes over core life was graphed and wherever possible compared to graphs from other sources. The concentrations calculated for U-235, U-238 and Pu-239 after 450 days were compared to the concentrations of the same isotopes calculated by a zero dimensional three-group model. The percentage difference between the concentrations determined by the two models varied from about 69% for Pu-239 to 1% for U-238.