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PHOEBE – A CODE FOR CALCULATING BETA AND GAMMA ACTIVITY AND SPECTRA FOR ^{235}U FISSION PRODUCTS

E. D. Arnold

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ORNL-3931

Contract No. W-7405-eng-26

CHEMICAL TECHNOLOGY DIVISION

PHOEBE – A CODE FOR CALCULATING BETA AND GAMMA ACTIVITY AND SPECTRA FOR ^{235}U FISSION PRODUCTS

E. D. Arnold

JULY 1966

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PREFACE

Phoebe was another name for Artemis, the goddess of the moon, wild animals, and hunting in Greek mythology. Thus, she was the personification of the moon. Locally and more recently, PHOEBE, the name for the computer code presented here, represents a condensation of the words PHOtons, Energy, and BEtas, seeming to ignore the lunar overtones. However, one of the original reasons for developing the PHOEBE code was to obtain a computer program that would give a reasonable estimate to the activity of fission products generated by a series of short exposure tests of the Rover experimental reactor, the prototype of the nuclear moon rocket.

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PHOEBE – A CODE FOR CALCULATING BETA AND GAMMA ACTIVITY AND SPECTRA FOR ^{235}U FISSION PRODUCTS

E. D. Arnold

ABSTRACT

A computer code, PHOEBE, is presented for calculating the decay properties of mixed fission products resulting from the fission of ^{235}U. Fission product beta and gamma activity and spectra are calculated for these fission products as a function of power, irradiation time, and decay time. Either constant or variable power may be specified for the reactor operation period.

The code contains a permanent data section that describes the release rates as a function of time since fission. A discussion of these data functions; that is, how they were obtained, how they are used, and how they may be modified is included.

An older version of this code was released on a temporary unpublished basis several years ago. However, the variable-power section has been completely rewritten, and those who have been using the old form of the code should either replace their old decks with the new version or recompile any programs which use PHOEBE as a subroutine.

A complete code package will be made available from the Radiation Shielding Information Center. Inquiries or requests for the code package may be mailed to:

Codes Coordinator
Radiation Shielding Information Center
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, Tennessee 37830

or telephoned to:

Area code 615, 483-8611, Ext. 3-6944, or

FTS xx-615-483-6944.

1. INTRODUCTION

The PHOEBE code* was developed to calculate the decay properties of mixed fission products resulting from the fission of ^{235}U. Fission product beta and gamma activity and spectra are the primary quantities calculated by the code. A total of 12 gamma groups are used to describe the gamma spectra. Results are outputted in terms of gamma photon-emission rates for each group, gamma energy emission rates for each group, total gamma emission rate, total gamma energy emission rate, beta particle emission rate, total average beta energy emission rate, and total energy release rate.

The PHOEBE code is a revised and expanded version of the Internuclear Company's EAPRR code. The partitioning size for the time dimension was halved in the case of PHOEBE, and the time range was extended from 10^8 to 10^9 seconds.

The data used as the permanent data section of the program were obtained from those tabulated in APEX-448 (ref. 1) except for those of the extended period, which were obtained by extrapolating the data of ref. 1 but with the restriction that the group totals as well as gross totals would not exceed those imposed by the calculated data of Blomeke and Todd.[2]

PHOEBE allows the calculation of fission product activities as a function of time after reactor shutdown for either constant-power or variable-power operation. Several examples are included in Appendix I to illustrate these various methods.

This report presents in detail a discussion of gamma photon and energy release; beta particle and energy release; the fission rate function for variable power operation; the data library; input preparation, operation, and output; sample problems; and a FORTRAN list of the code.

2. GAMMA PHOTON AND ENERGY RELEASE

The gamma photon and energy release from ^{235}U fission products is calculated by the code for the range 1 to 10^9 seconds after an instantaneous fission event. The preparation for the calculation of the fission product photon, beta, and energy release for a reactor operation period τ at either constant or variable fission rate is outlined in Sect. 6 and Appendix I.

---

*The code has been written and compiled for the CDC-1604, IBM-7090, and the IBM System/360 computers.

As in ref. 1, the photons are classified first into seven energy groups covering the energy range between 0.1 and 5.5 Mev. The group limits are the same as given by Perkins and King.[3] In addition, Group VII of the P-K data is split into six individual subgroups so that a total of 12 groups are considered. The group limits are listed in the following table.

Table 1. The Energy-Group Definitions

12-Group Subdivision	Perkins & King Groups	Energy Range (in Mev)	Average Energy (in Mev)
1	I	0.1-0.4	0.3
2	II	0.4-0.9	0.63
3	III	0.9-1.35	1.10
4	IV	1.35-1.8	1.55
5	V	1.8-2.2	1.99
6	VI	2.2-2.6	2.38
7-12	VII	2.6-5.5	Varies between 3.5 and about 3.1
	(Group VII Subgroups)		
7	VII, a	2.6-3.0	2.75
8	VII, b	3.0-3.5	3.25
9	VII, c	3.5-4.0	3.7
10	VII, d	4.0-4.5	4.22
11	VII, e	4.5-5.0	4.70
12	VII, f	5.0-5.5	5.25

For short times after fission (1 to 1550 sec), experimental results of Oak Ridge National Laboratory[4,5] were available and were used directly by the Internuclear group.[1] For long time periods (1550 to 10^8 sec), computed decay curves obtained by Perkins and King[3] were adapted[1] from their publication. The two sets of data are in good agreement and can be combined. The data for time periods of 10^8 to 10^9 sec were obtained by extrapolating the P-K data under the restriction that those groups which fell within a given group of the Blomeke and Todd[2] compilation extrapolated with the same slope as that of the given B-T group. An additional restriction imposed was that the total gamma photon release rate and gamma energy release rate was approximately equal to and extrapolated with the same slope as that of the Blomeke and Todd data.

The photon release rates are shown in Figs. 1 and 2. Figure 1 covers the range 1 to 10^5 sec, while Fig. 2 covers the range 10^5 to 10^9 sec.

Knabe and Putnam[1] calculated the photon release rates from the P-K data by dividing the group energy release rate data by the average energy for each group. This technique is reliable since they found that the average energy for each group remained almost constant over the range 1 to 10^7 sec.

Tables 2-1 to 2-3 and 3-1 to 3-3 list the photon release rate data, which are carried as part of the permanent data for the code. Values can be changed and incorporated as part of the data deck by using the FORMATS described in Sect. 5.

The group comparison of B-T vs that of P-K can be shown by the following tabulation:

Blomeke and Todd		Perkins and King	
Group No.	Energy Range (Mw)	Group No.	Energy Range (Mw)
I	<0.25	I	0.1-0.4
II	0.25-1.0	II	0.4-0.9
III	1.0-1.7	III	0.9-1.35
		IV	1.35-1.8
IV	>1.7	V	1.8-2.2
		VI	2.2-2.6
		VII	2.6-5.5

Thus, in the extrapolation, P-K Group I extrapolated with the same slope as B-T Group I; P-K Group II extrapolated with the same slope as B-T Group II; the sum of P-K Groups III and IV extrapolated with the same slope as B-T Group III; and the sum of P-K Groups V, VI, and VII extrapolated with the same slope as B-T Group IV.

Figure 3 also illustrates the comparison of the Perkins and King groups with those of Blomeke and Todd. The curves are either actual P-K data (including their sums) or extrapolations (dashed portions) of the data while the labeled points correspond to B-T group data.

The basic data for the PHOEBE code are represented by a function for the photon number release rate per fission versus time after fission for each of the twelve energy groups and an average energy for each group.

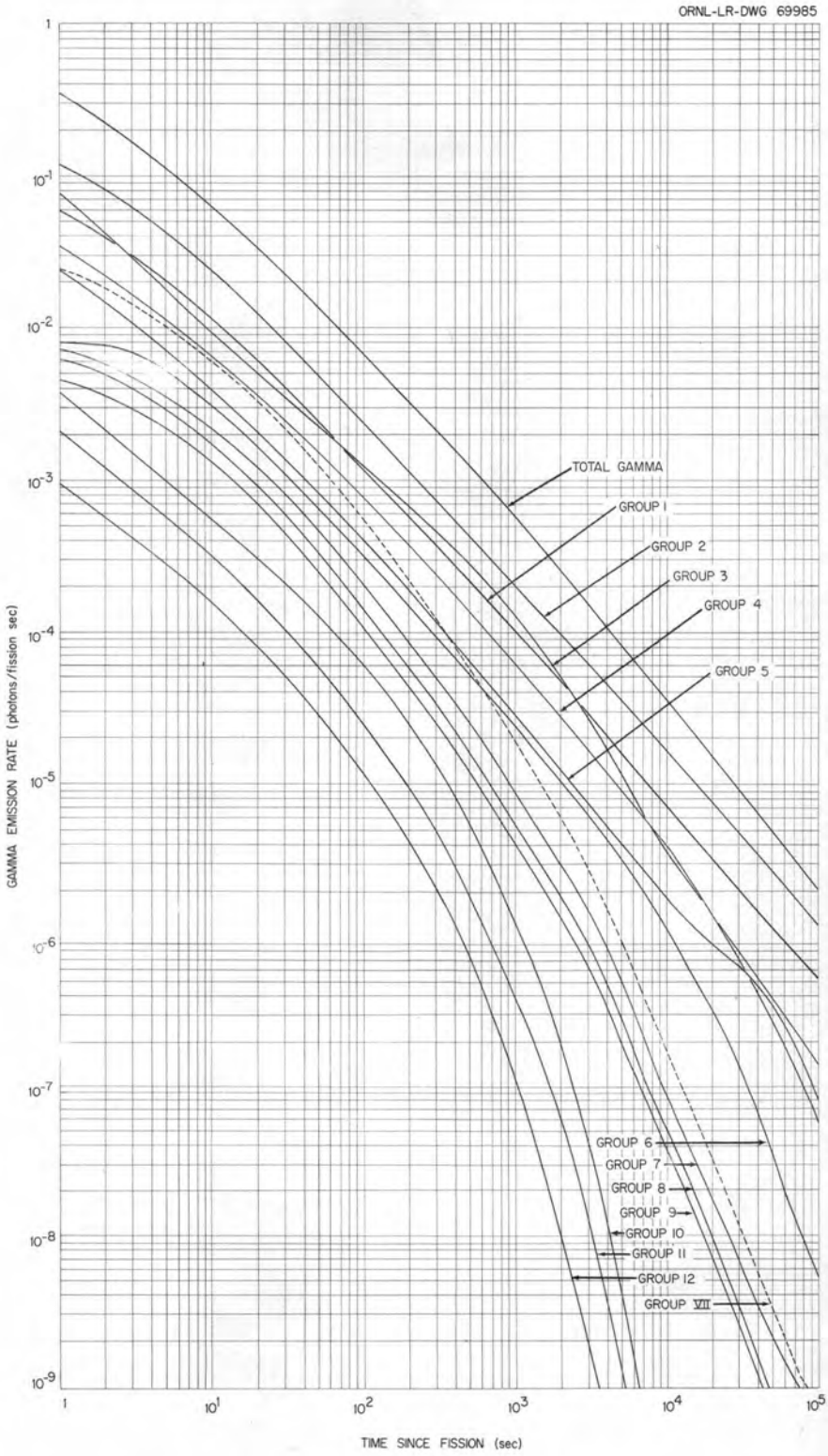

Fig. 1. Photons/Fission-second for an Instantaneous Event vs Time Since Fission (time range 1-10^5 sec).

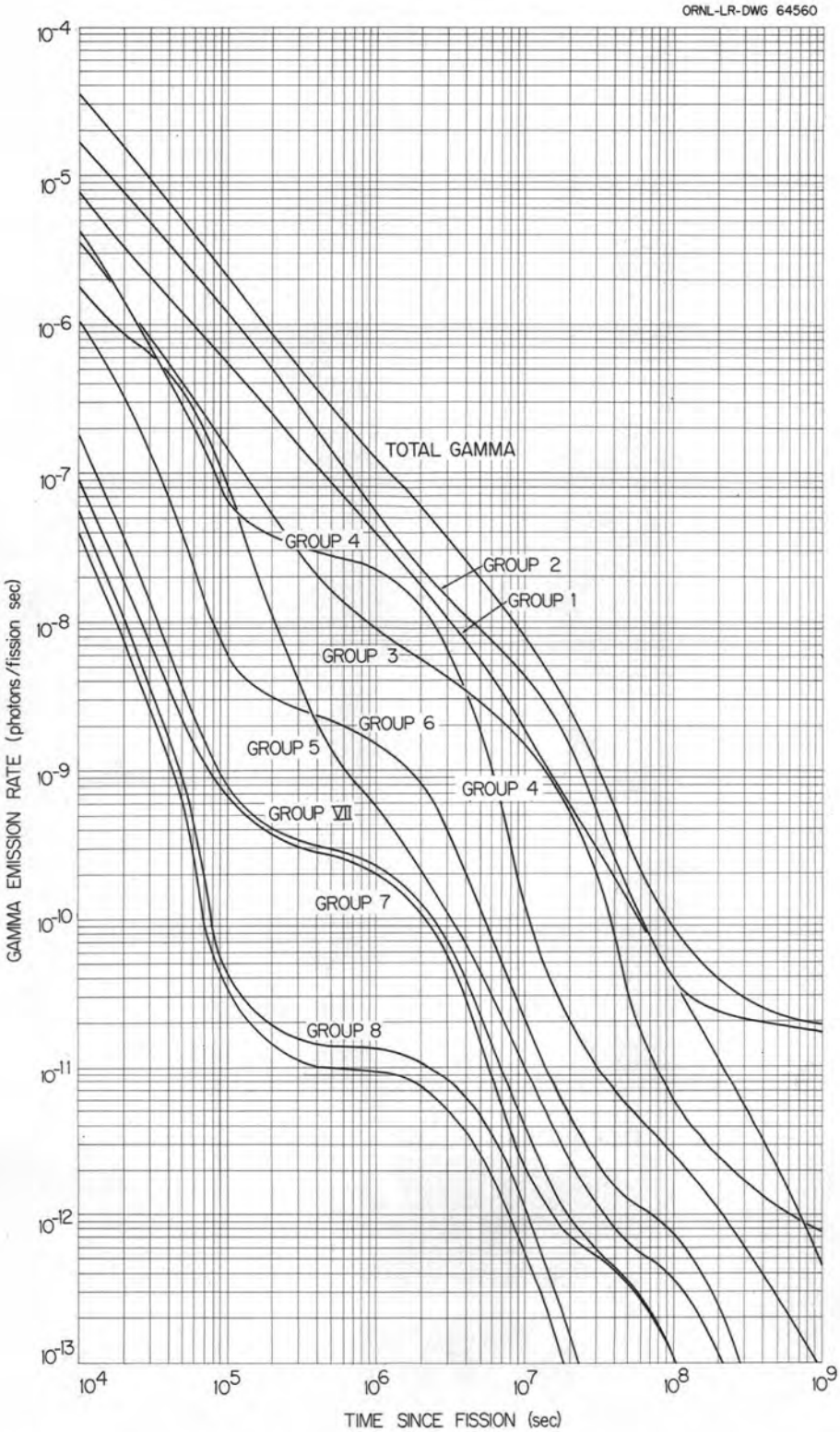

Fig. 2. Photons/Fission-second for an Instantaneous Event vs Time Since Fission (time range 10^4-10^9 sec).

TABLE 2-1. GAMMA PHOTON RELEASE RATE DATA

GAMMA PHOTONS/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

GAMMA PHOTON RELEASE RATES FOR

I	TIME (SECONDS)	GROUP 1 E(AV)= .30	GROUP 2 E(AV)= .63	GROUP 3 E(AV)=1.10	GROUP 4 E(AV)=1.55	GROUP 5 E(AV)=1.99	GROUP 6 E(AV)=2.38
1	1.000000E+00	5.900E-02	1.200E-01	7.600E-02	3.430E-02	2.390E-02	8.300E-03
2	1.467799E+00	4.750E-02	9.700E-02	5.400E-02	2.730E-02	1.830E-02	8.000E-03
3	2.154435E+00	3.780E-02	7.700E-02	3.820E-02	2.130E-02	1.390E-02	7.550E-03
4	3.162278E+00	2.880E-02	5.910E-02	2.700E-02	1.600E-02	1.030E-02	6.700E-03
5	4.641589E+00	2.150E-02	4.430E-02	1.910E-02	1.200E-02	7.510E-03	5.390E-03
6	6.812921E+00	1.570E-02	3.270E-02	1.330E-02	8.850E-03	5.370E-03	4.050E-03
7	1.000000E+01	1.120E-02	2.390E-02	9.600E-03	6.500E-03	3.800E-03	3.000E-03
8	1.467799E+01	8.000E-03	1.650E-02	6.800E-03	4.650E-03	2.700E-03	2.110E-03
9	2.154435E+01	5.400E-03	1.120E-02	4.800E-03	3.340E-03	1.890E-03	1.490E-03
10	3.162278E+01	3.650E-03	7.650E-03	3.400E-03	2.350E-03	1.270E-03	1.020E-03
11	4.641589E+01	2.460E-03	5.100E-03	2.400E-03	1.600E-03	8.700E-04	6.850E-04
12	6.812921E+01	1.660E-03	3.430E-03	1.670E-03	1.100E-03	5.750E-04	4.600E-04
13	1.000000E+02	1.120E-03	2.290E-03	1.200E-03	7.490E-04	3.880E-04	3.030E-04
14	1.467799E+02	7.600E-04	1.530E-03	8.500E-04	5.000E-04	2.520E-04	2.000E-04
15	2.154435E+02	5.050E-04	1.020E-03	6.100E-04	3.390E-04	1.690E-04	1.310E-04
16	3.162278E+02	3.400E-04	6.850E-04	4.300E-04	2.250E-04	1.090E-04	8.500E-05
17	4.641589E+02	2.280E-04	4.440E-04	2.950E-04	1.470E-04	7.000E-05	5.480E-05
18	6.812921E+02	1.500E-04	3.010E-04	1.970E-04	9.650E-05	4.400E-05	3.550E-05
19	1.000000E+03	1.000E-04	2.000E-04	1.270E-04	6.150E-05	2.800E-05	2.310E-05

TABLE 2-2. GAMMA PHOTON RELEASE RATE DATA

GAMMA PHOTONS/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

I	TIME (SECONDS)	GAMMA PHOTON RELEASE RATES FOR GROUP 1 E(AV)= .30	GROUP 2 E(AV)= .63	GROUP 3 E(AV)=1.10	GROUP 4 E(AV)=1.55	GROUP 5 E(AV)=1.99	GROUP 6 E(AV)=2.38
20	1.467799E+03	6.500E-05	1.320E-04	7.850E-05	4.000E-05	1.750E-05	1.470E-05
21	2.154435E+03	4.280E-05	8.700E-05	4.500E-05	2.530E-05	1.110E-05	9.250E-06
22	3.162278E+03	2.800E-05	5.800E-05	2.480E-05	1.610E-05	7.010E-06	5.800E-06
23	4.641589E+03	1.780E-05	3.800E-05	1.350E-05	1.020E-05	4.410E-06	3.510E-06
24	6.812921E+03	1.120E-05	2.480E-05	6.800E-06	6.400E-06	2.750E-06	2.000E-06
25	1.000000E+04	7.200E-06	1.650E-05	3.580E-06	4.100E-06	1.750E-06	1.050E-06
26	1.467799E+04	4.700E-06	1.050E-05	2.120E-06	2.300E-06	1.150E-06	5.500E-07
27	2.154435E+04	3.020E-06	6.900E-06	1.230E-06	1.220E-06	8.200E-07	2.830E-07
28	3.162278E+04	1.980E-06	4.450E-06	7.400E-07	6.450E-07	5.950E-07	1.250E-07
29	4.641589E+04	1.280E-06	2.900E-06	4.200E-07	3.200E-07	3.800E-07	4.200E-08
30	6.812921E+04	8.200E-07	1.820E-06	2.480E-07	1.440E-07	2.000E-07	1.410E-08
31	1.000000E+05	5.400E-07	1.200E-06	1.420E-07	6.200E-08	8.000E-08	5.800E-09
32	1.467799E+05	3.450E-07	7.380E-07	8.100E-08	4.460E-08	2.500E-08	3.800E-09
33	2.154435E+05	2.270E-07	4.500E-07	4.700E-08	3.600E-08	8.500E-09	3.050E-09
34	3.162278E+05	1.470E-07	2.610E-07	2.730E-08	3.150E-08	3.350E-09	2.600E-09
35	4.641589E+05	9.300E-08	1.560E-07	1.700E-08	2.880E-08	1.550E-09	2.190E-09
36	6.812921E+05	6.000E-08	9.000E-08	1.190E-08	2.590E-08	8.800E-10	1.850E-09
37	1.000000E+06	3.800E-08	5.450E-08	9.000E-09	2.290E-08	5.400E-10	1.500E-09

TABLE 2-3. GAMMA PHOTON RELEASE RATE DATA

GAMMA PHOTONS/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

GAMMA PHOTON RELEASE RATES FOR

I	TIME (SECONDS)	GROUP 1 E(AV)= .30	GROUP 2 E(AV)= .63	GROUP 3 E(AV)=1.10	GROUP 4 E(AV)=1.55	GROUP 5 E(AV)=1.99	GROUP 6 E(AV)=2.38
38	1.467799E+06	2.420E-08	3.350E-08	6.900E-09	1.750E-08	3.300E-10	1.120E-09
39	2.154435E+06	1.550E-08	2.150E-08	5.300E-09	1.170E-08	1.900E-10	7.200E-10
40	3.162278E+06	1.010E-08	1.420E-08	4.050E-09	5.850E-09	1.030E-10	3.380E-10
41	4.641589E+06	6.000E-09	9.500E-09	3.000E-09	2.180E-09	5.000E-11	1.400E-10
42	6.812921E+06	3.400E-09	6.500E-09	2.180E-09	5.666E-10	2.280E-11	5.400E-11
43	1.000000E+07	1.840E-09	4.250E-09	1.460E-09	1.200E-10	9.900E-12	2.000E-11
44	1.467799E+07	9.750E-10	2.490E-09	8.800E-10	3.900E-11	4.140E-12	8.450E-12
45	2.154435E+07	5.000E-10	1.230E-09	4.600E-10	1.700E-11	2.000E-12	4.000E-12
46	3.162278E+07	2.640E-10	4.600E-10	1.750E-10	9.350E-12	1.100E-12	2.210E-12
47	4.641589E+07	1.330E-10	1.750E-10	3.830E-11	5.800E-12	6.750E-13	1.330E-12
48	6.812921E+07	7.100E-11	7.800E-11	1.220E-11	3.730E-12	4.950E-13	1.010E-12
49	1.000000E+08	3.800E-11	3.800E-11	5.900E-12	2.450E-12	3.600E-13	7.250E-13
50	1.467799E+08	1.900E-11	2.800E-11	3.400E-12	1.550E-12	1.970E-13	4.200E-13
51	2.154435E+08	9.700E-12	2.320E-11	2.200E-12	9.500E-13	9.500E-14	1.950E-13
52	3.162278E+08	4.800E-12	2.080E-11	1.600E-12	5.500E-13	3.100E-14	6.200E-14
53	4.641589E+08	2.270E-12	1.960E-11	1.200E-12	2.900E-13	7.400E-15	1.340E-14
54	6.812921E+08	1.010E-12	1.850E-11	9.500E-13	1.520E-13	1.770E-15	3.600E-15
55	1.000000E+09	4.400E-13	1.790E-11	7.600E-13	8.600E-14	5.700E-16	1.130E-15

TABLE 3-1. GAMMA PHOTON RELEASE RATE DATA

GAMMA PHOTONS/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

I	TIME (SECONDS)	GAMMA PHOTON RELEASE RATES FOR GROUP 7 E(AV)=2.75	GROUP 8 E(AV)=3.25	GROUP 9 E(AV)=3.70	GROUP 10 E(AV)=4.22	GROUP 11 E(AV)=4.70	GROUP 12 E(AV)=5.25
1	1.000000E+00	7.300E-03	6.250E-03	4.600E-03	3.700E-03	2.030E-03	9.200E-04
2	1.467799E+00	6.500E-03	5.520E-03	4.050E-03	2.700E-03	1.520E-03	7.000E-04
3	2.154435E+00	5.580E-03	4.680E-03	3.450E-03	2.000E-03	1.120E-03	5.300E-04
4	3.162278E+00	4.580E-03	3.830E-03	2.830E-03	1.450E-03	8.300E-04	3.950E-04
5	4.641589E+00	3.650E-03	3.000E-03	2.200E-03	1.070E-03	6.000E-04	2.940E-04
6	6.812921E+00	2.810E-03	2.300E-03	1.700E-03	7.700E-04	4.310E-04	2.130E-04
7	1.000000E+01	2.111E-03	1.690E-03	1.230E-03	5.600E-04	3.050E-04	1.510E-04
8	1.467799E+01	1.550E-03	1.190E-03	9.000E-04	4.000E-04	2.150E-04	1.070E-04
9	2.154435E+01	1.100E-03	8.250E-04	6.180E-04	2.800E-04	1.480E-04	7.400E-05
10	3.162278E+01	7.600E-04	5.400E-04	4.080E-04	1.960E-04	1.000E-04	5.000E-05
11	4.641589E+01	5.000E-04	3.500E-04	2.680E-04	1.320E-04	6.350E-05	3.200E-05
12	6.812921E+01	3.222E-04	2.200E-04	1.690E-04	8.950E-05	4.000E-05	1.950E-05
13	1.000000E+02	2.000E-04	1.400E-04	1.010E-04	5.750E-05	2.450E-05	1.180E-05
14	1.467799E+02	1.240E-04	9.250E-05	6.350E-05	3.650E-05	1.440E-05	6.600E-06
15	2.154435E+02	7.600E-05	5.100E-05	3.800E-05	2.150E-05	8.200E-06	3.650E-06
16	3.162278E+02	4.500E-05	3.010E-05	2.250E-05	1.220E-05	4.420E-06	1.800E-06
17	4.641589E+02	2.690E-05	1.700E-05	1.300E-05	6.250E-06	2.150E-06	8.250E-07
18	6.812921E+02	1.520E-05	9.650E-06	7.200E-06	2.850E-06	9.420E-07	3.270E-07
19	1.000000E+03	8.600E-06	5.420E-06	4.000E-06	1.200E-06	3.960E-07	1.180E-07

TABLE 3-2. GAMMA PHOTON RELEASE RATE DATA

GAMMA PHOTONS/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

I	TIME (SECONDS)	GAMMA PHOTON RELEASE RATES FOR GROUP 7 E(AV)=2.75	GROUP 8 E(AV)=3.25	GROUP 9 E(AV)=3.70	GROUP 10 E(AV)=4.22	GROUP 11 E(AV)=4.70	GROUP 12 E(AV)=5.25
20	1.467799E+03	4.670E-06	3.000E-06	2.200E-06	4.820E-07	1.530E-07	3.200E-08
21	2.154435E+03	2.600E-06	1.560E-06	1.120E-06	1.590E-07	4.900E-08	7.900E-09
22	3.162278E+03	1.320E-06	8.000E-07	5.600E-07	3.750E-08	1.150E-08	1.700E-09
23	4.641589E+03	6.000E-07	3.410E-07	2.400E-07	6.200E-09	1.800E-09	2.400E-10
24	6.812921E+03	2.300E-07	1.240E-07	9.500E-08	7.000E-10	1.900E-10	3.150E-11
25	1.000000E+04	8.850E-08	5.200E-08	3.800E-08	7.000E-11	1.750E-11	3.700E-12
26	1.467799E+04	3.650E-08	2.150E-08	1.500E-08	8.000E-12	1.900E-12	4.750E-13
27	2.154435E+04	1.480E-08	8.300E-09	6.000E-09	1.000E-12	2.450E-13	6.500E-14
28	3.162278E+04	6.200E-09	3.050E-09	2.222E-09	1.300E-13	3.000E-14	8.500E-15
29	4.641589E+04	2.340E-09	9.700E-10	7.000E-10	1.500E-14	3.800E-15	1.050E-15
30	6.812921E+04	1.190E-09	2.050E-10	9.050E-11	1.800E-15	5.000E-16	1.450E-16
31	1.000000E+05	7.000E-10	4.800E-11	3.300E-11	2.400E-16	7.000E-17	2.200E-17
32	1.467799E+05	4.660E-10	2.580E-11	1.960E-11	3.200E-17	9.300E-18	2.900E-18
33	2.154435E+05	3.550E-10	1.850E-11	1.390E-11	4.110E-18	1.200E-18	3.770E-19
34	3.162278E+05	3.030E-10	1.530E-11	1.140E-11	0	0	0
35	4.641589E+05	2.750E-10	1.410E-11	1.010E-11	0	0	0
36	6.812921E+05	2.420E-10	1.390E-11	9.800E-12	0	0	0
37	1.000000E+06	2.000E-10	1.330E-11	9.500E-12	0	0	0

TABLE 3-3. GAMMA PHOTON RELEASE RATE DATA

GAMMA PHOTONS/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

		GAMMA PHOTON RELEASE RATES FOR					
I	TIME (SECONDS)	GROUP 7 E(AV)=2.75	GROUP 8 E(AV)=3.25	GROUP 9 E(AV)=3.70	GROUP 10 E(AV)=4.22	GROUP 11 E(AV)=4.70	GROUP 12 E(AV)=5.25
38	1.467799E+06	1.470E-10	1.220E-11	8.600E-12	0	0	0
39	2.154435E+06	9.500E-11	1.050E-11	7.000E-12	0	0	0
40	3.162278E+06	5.050E-11	7.800E-12	4.800E-12	0	0	0
41	4.641589E+06	1.900E-11	5.000E-12	2.800E-12	0	0	0
42	6.812921E+06	5.600E-12	2.630E-12	1.400E-12	0	0	0
43	1.000000E+07	2.100E-12	1.100E-12	5.700E-13	0	0	0
44	1.467799E+07	1.020E-12	3.750E-13	1.870E-13	0	0	0
45	2.154435E+07	6.700E-13	1.250E-13	4.600E-14	0	0	0
46	3.162278E+07	5.050E-13	3.600E-14	1.100E-14	0	0	0
47	4.641589E+07	3.500E-13	1.000E-14	1.200E-15	0	0	0
48	6.812921E+07	2.070E-13	2.100E-15	9.100E-17	0	0	0
49	1.000000E+08	1.050E-13	3.100E-16	1.500E-18	0	0	0
50	1.467799E+08	3.600E-14	3.300E-17	0	0	0	0
51	2.154435E+08	9.000E-15	3.000E-18	0	0	0	0
52	3.162278E+08	1.200E-15	0	0	0	0	0
53	4.641589E+08	4.400E-17	0	0	0	0	0
54	6.812921E+08	1.600E-18	0	0	0	0	0
55	1.000000E+09	1.300E-20	0	0	0	0	0

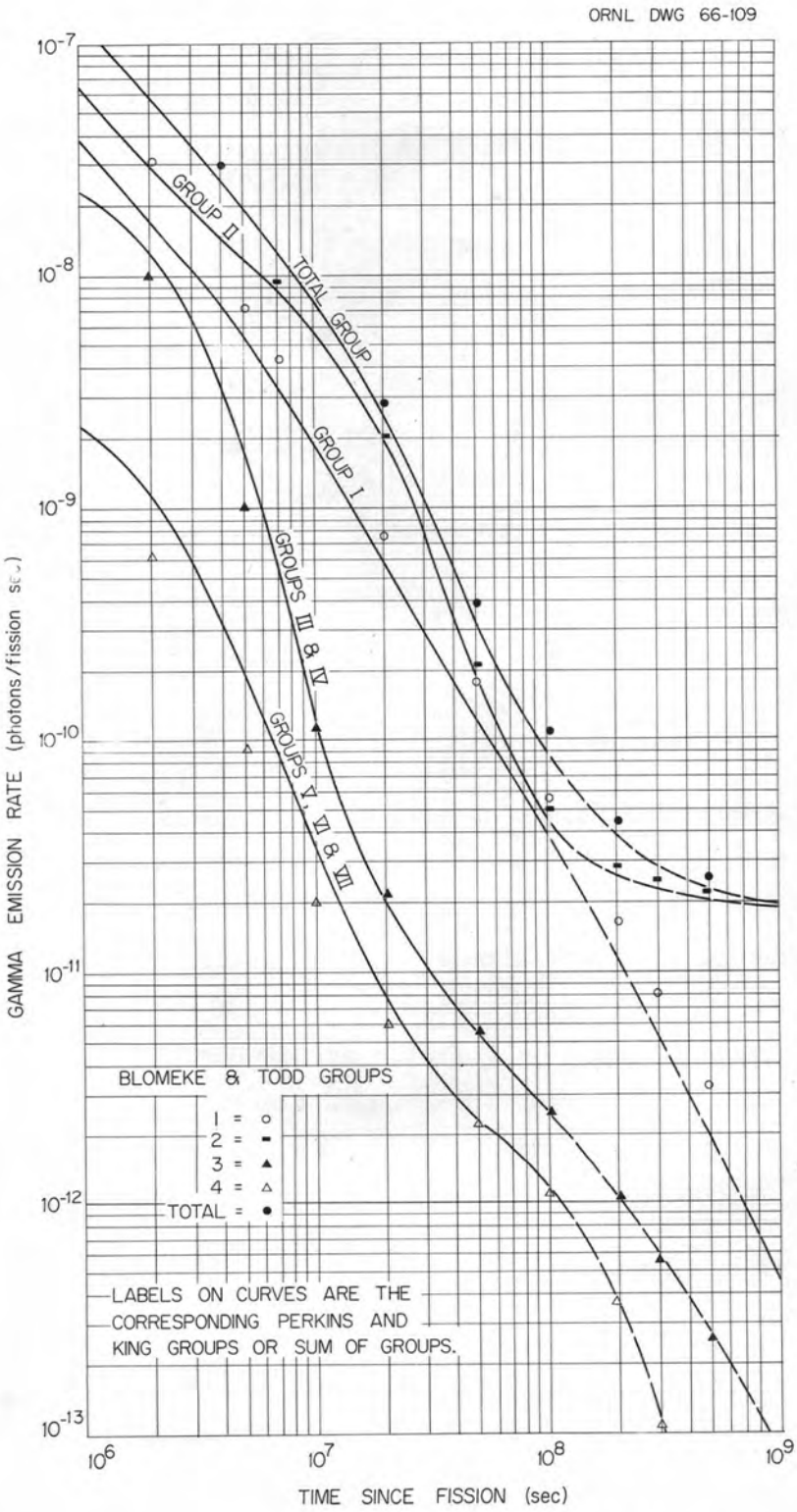

Fig. 3. Comparison of PHOEBE Data with Four Group Data of Blomeke and Todd.

Definitions:

$f_g(x)$ ≡ Photon number release rate per fission for the gth group (photons/fission-sec).

x ≡ The time following an instantaneous event of fissions at $x = 0$ (sec).

$R(t')$ ≡ The fission rate at time t' sec (fission/sec).

t' ≡ The time following the start of fissions in a reactor (sec).

τ ≡ The maximum value of t', that is, the total operating time of the reactor (sec).

t ≡ The time since shutdown of the reactor, that is, elapsed time following the point at which $R(t')$ becomes effectively zero for the final period (sec).

In addition to the basic data, it is implied that $R(t')$ is a known function (constant or step) of t', and that τ and t are given.

From these data, the following are derived:

$F_g(\tau,t)$ ≡ the photon number release rate for the gth energy group following a reactor operating time, τ sec, and a shutdown time, t sec (photons/sec).

$U_g(\tau) \equiv F_g(\tau,0)$ ≡ the photon number release rate for the gth group during reactor operation but after an operating period of τ sec (photons/sec).

$H_g(\tau,t) \equiv F_g(\tau,t) \cdot \bar{E}_g$ ≡ the gamma energy release rate for the gth energy group following a reactor operating time, τ sec, and a shutdown time, t sec (Mev/sec).

$\bar{E}_g$ ≡ average photon energy for the gth energy group (Mev).

The values of $f_g(x)$ are listed for x ranging from 1 sec to 10^9 sec (31.7 years). There is a maximum of 55 values of $f_g(x)$ given for each of the energy groups. The values of $f_g(x)$ and the corresponding value of x are indexed by n, such that $1 \leqq n \leqq 55$. The partitioning of the x (time) dimension is such that

$$x_{n+1} = 1.467799\, x_n ,$$

and

$$\ell n \frac{x_{n+1}}{x_n} = 0.383764 \text{ for any value of } n.$$

This partitioning is chosen so that the loss of accuracy is small compared with the accuracy of the basic data if a linear interpolation is assumed on a log-log plot of $f_g(x)$ vs x. This is equivalent to the statement that there is no significant error in the assumption that

$$f_g(x) = A_{g,n} x^{a_{g,n}} \tag{1}$$

for

$$x_n \leqq x < x_{n+1} ,$$

where $A_{g,n}$ and $a_{g,n}$ are constants.

The function $F_g(\tau,t)$, as defined, is determined by the value of an integral as follows:

$$F_g(\tau,t) = \int_0^\tau R(t') \, f_g(\tau + t - t') \, dt' ; \tag{2}$$

but, let $x = \tau + t - t'$, then

$$F_g(\tau,t) = \int_0^\tau R(\tau + t - x) \, f_g(x) \, dx . \tag{3}$$

Using the assumption that linear log-log interpolation is accurate, then

$$R(\tau + t - x) \, f_g(x) = A_{g,n} x^{a_{g,n}} \tag{4}$$

for $x_n \leqq x < x_{n+1}$.

On this basis, Eq. 3 becomes, after integrating piece-wise,

$$F_g(\tau,t) = \frac{A_{g,i}\left(x_{i+1}^{a_{g,i}+1} - t^{a_{g,i}+1}\right)}{a_{g,i}+1} + \sum_{n=i+1}^{n=j-1} \frac{A_{g,n}\left(x_{n+1}^{a_{g,n}+1} - x_n^{a_{g,n}+1}\right)}{a_{g,n}+1}$$

$$+ \frac{A_{g,j}\left[(t+\tau)^{a_{g,j}+1} - x_j^{a_{g,j}+1}\right]}{a_{g,j}+1} , \quad (5)$$

where $x_i \leqq t < x_{i+1}$, $x_j \leqq t + \tau < x_{j+1}$, $1 \leqq t$,* and $j \geqq i + 1$. If $j = 1$, $t + \tau$ replaces x_{i+1} in the first term of Eq. 5, and the other terms are omitted.

For any n, $1 \leqq n \leqq 55$,

$$a_{g,n} = \left[1/\ell n\left(\frac{x_{n+1}}{x_n}\right)\right] \ell n \left[\frac{R\left(\tau + t - x_{n+1}\right) f_g\left(x_{n+1}\right)}{R\left(\tau + t - x_n\right) f_g\left(x_n\right)}\right] , \quad (6)$$

or, for the chosen partitioning,

$$a_{g,n} = 2.605767 \ \ell n \left[\frac{R\left(\tau + t - x_{n+1}\right) f_g\left(x_{n+1}\right)}{R\left(\tau + t - x_n\right) f_g\left(x_n\right)}\right] , \quad (7)$$

and

$$A_{g,n} = [R(\tau + t - x_n) \ f_g(x_n)]/x_n^{a_{g,n}} . \quad (8)$$

For numerical calculations on a digital computer, it is more convenient and efficient to express $F_g(\tau,t)$ as follows:

---

*Note: If $t < 1$ [as for $U_g(\tau) = F_g(\tau,0)$], use $t = 1$ in Eq. 4 for the lower limit of the interval of integration. The result is correct because the basic data are derived on the assumption that the proper number of photons per fission is obtained from the integral,

$\int_1^\infty f(x)dx$, instead of from the integral, $\int_0^\infty f(x)dx$.

$$F_g(\tau,t)$$

$$= \frac{\left\{R\left(\tau+t-x_{i+1}\right)\left[f_g\left(x_{i+1}\right)\right]\left(x_{i+1}\right) - R\left(\tau+t-x_i\right)\left[f_g\left(x_i\right)\right]\left(x_i\right)\left(\frac{t}{x_i}\right)^{a_{g,i}+1}\right\}}{a_{g,i}+1}$$

$$+ \frac{\sum_{n=i+1}^{n=j-1}\left\{R\left(\tau+t-x_{n+1}\right)\left[f_g\left(x_{n+1}\right)\right]\left(x_{n+1}\right) - R\left(\tau+t-x_n\right)\left[f_g\left(x_n\right)\right]\left(x_n\right)\right\}}{a_{g,n}+1}$$

$$+ \frac{\left\{R\left(\tau+t-x_{j+1}\right)\left[f_g\left(x_{j+1}\right)\right]\left(x_{j+1}\right)\left(\frac{\tau+t}{x_{j+1}}\right)^{a_{g,j}+1} - R\left(\tau+t-x_j\right)\left[f_g\left(x_j\right)\right]\left(x_j\right)\right\}}{a_{g,j}+1} \quad . \tag{9}$$

The index i is chosen such that $x_i \leqq t \leqq x_{i+1}$, and the index j is chosen such that $x_j \leqq \tau + t \leqq x_{j+1}$. It is restricted that $i \geqq 1$, $x_1 = 1$, $j \leqq 54$, $x_{55} = 10^9$, $t \geqq 1$ (sec), and $\tau + t \leqq 10^9$. Equation 9 applies for $j > i + 1$, with the summation term neglected when $j \leqq i + 1$. When $j = i$, the proper expression for $F_g(\tau,t)$ is:

$$F_g(\tau,t) = \left\{R\left(\tau + t - x_{i+1}\right)\left[f_g\left(x_{i+1}\right)\right]\left(x_{i+1}\right)\left(\frac{\tau + t}{x_{i+1}}\right)^{a_{g,i}+1}\right.$$

$$\left. - R\left(\tau + t - x_i\right)\left[f_g\left(x_i\right)\right]\left(x_i\right)\left(\frac{t}{x_i}\right)^{a_{g,i}+1}\right\} \Big/ \left(a_{g,i} + 1\right) \quad . \tag{10}$$

One of the properties of $f_g(x)$ is that

$$\int_{x_n}^{x_{n+1}} f_g(x)\,dx$$

is about the same order of magnitude for every value of n; the integral shows a slight tendency to decrease as n increases, for the chosen partitioning. This property guarantees that if $R(\tau + t - x)$ is practically zero over a time range small compared with the interval x_n to x_{n+1}, then the error is very small if the decrease in R is neglected entirely. It follows that the numerical integration represented by Eq. 9 for $F_g(\tau,t)$ is justified in most practical cases, and that, in unusual cases in which $R(\tau + t - x)$ varies rapidly and strongly, suitable averages of the R function can be easily constructed.

3. BETA PARTICLE AND ENERGY RELEASE

Knabe and Putnam[1] give the following expression for the rate at which beta particle energy is released after an instantaneous fission event:

$$m(t) = 1.9t^{-1.2} - 1.15t^{-1.957} - 10.9(t + 10^5)^{-1.366}, \qquad (11)$$

which is probably correct within ±20% in the interval $2 \leqq t \leqq 3 \times 10^7$ sec, with

$m(t)$ = beta particle energy release rate (Mev/sec),
t = time since fission (sec).

The formula overestimates the energy release rate beyond 3×10^7 sec. However, the Blomeke and Todd data were used for the range beyond 3×10^7 sec.

This formula may be used to obtain the beta energy decay rate at a time $\geqq 1$ sec, following any history of fissions in a time interval 0 to τ. Let $R(t')$ be the fission rate (fissions/sec at time t'), then the beta energy decay rate (Mev/sec) after a decay time t is:

$$M(\tau,t) = \int_0^{\tau} R(t')\, m(\tau + t - t')dt' , \tag{12}$$

where the integral is expected to have the same accuracy as that for $m(\tau + t - t')$ for $t + \tau \leqq 3 \times 10^7$ sec.

The rate at which the beta particles are emitted following an instantaneous fission event is represented by the formula:[1]

$$p(t) = t^{-1.115} - 0.7t^{-1.561} \text{ (beta particles/fission-sec)} . \tag{13}$$

The error is estimated to be less than about ±25% for $2 \leqq t \leqq 10^7$ sec. Again, the Blomeke and Todd data were used for the range beyond 10^7 sec. This formula may also be integrated to obtain the beta particle decay rate at a time $t \geqq 1$ sec following any history of fissions in a time interval 0 to τ. Let $R(t')$ be the fission rate (fissions/sec at time t'), then the beta particle release rate (beta particles/sec) after a decay time t is:

$$P(\tau,t) = \int_0^{\tau} R(t')\, p(\tau + t - t')dt' . \tag{14}$$

These two equations (Eqs. 12 and 14) are analogous to Eq. 2 for the function $F_g(\tau,t)$ described in the previous section. Thus the code handles the beta particle and beta energy release rates as if they were two additional groups appended to the gamma data.

Tables 4-1 to 4-3 list the beta particle and energy release rate data which is carried as part of the permanent data for the code. In addition, these tables also list the calculated average beta energy per particle. The data are those listed by Knabe and Putnam,[1] Perkins and King,[3] and Miller[6] except for the range of 3×10^7 to 10^9 sec, which were calculated by the author from the data of Blomeke and Todd.[2]

4. THE FISSION RATE FUNCTION FOR VARIABLE-POWER OPERATION

The fission rate function, $R(\tau + t - x_n)$ is constant for constant power operation and therefore poses no problem. However, when the power varies considerably during reactor operation (e.g., during reactor shutdowns

TABLE 4-1. BETA PARTICLE AND ENERGY RELEASE RATE DATA

BETAS AND BETA MEV/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

I	TIME (SECONDS)	BETAS PER FISSION-SECOND	BETA MEV PER FISSION-SECOND	AVG. BETA ENERGY MEV/PARTICLE
1	1.000000E+00	3.000E-01	7.500E-01	2.500
2	1.467799E+00	2.520E-01	6.280E-01	2.492
3	2.154435E+00	2.050E-01	5.000E-01	2.439
4	3.162278E+00	1.580E-01	3.700E-01	2.342
5	4.641589E+00	1.180E-01	2.500E-01	2.119
6	6.812921E+00	8.500E-02	1.680E-01	1.976
7	1.000000E+01	6.000E-02	1.050E-01	1.750
8	1.467799E+01	4.000E-02	7.000E-02	1.750
9	2.154435E+01	2.670E-02	4.500E-02	1.685
10	3.162278E+01	1.720E-02	2.850E-02	1.657
11	4.641589E+01	1.100E-02	1.770E-02	1.609
12	6.812921E+01	7.410E-03	1.150E-02	1.552
13	1.000000E+02	5.200E-03	7.450E-03	1.433
14	1.467799E+02	3.500E-03	4.700E-03	1.343
15	2.154435E+02	2.350E-03	3.000E-03	1.277
16	3.162278E+02	1.530E-03	1.870E-03	1.222
17	4.641589E+02	1.000E-03	1.110E-03	1.110
18	6.812921E+02	6.420E-04	7.400E-04	1.153
19	1.000000E+03	4.250E-04	4.800E-04	1.129

TABLE 4-2. BETA PARTICLE AND ENERGY RELEASE RATE DATA

BETAS AND BETA MEV/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

I	TIME (SECONDS)	BETAS PER FISSION-SECOND	BETA MEV PER FISSION-SECOND	AVG. BETA ENERGY MEV/PARTICLE
20	1.467799E+03	2.820E-04	3.000E-04	1.064
21	2.154435E+03	1.850E-04	1.850E-04	1.000
22	3.162278E+03	1.220E-04	1.190E-04	.975
23	4.641589E+03	8.000E-05	7.500E-05	.938
24	6.812921E+03	5.220E-05	4.650E-05	.891
25	1.000000E+04	3.500E-05	2.990E-05	.854
26	1.467799E+04	2.230E-05	1.780E-05	.798
27	2.154435E+04	1.450E-05	1.050E-05	.724
28	3.162278E+04	9.500E-06	6.500E-06	.684
29	4.641589E+04	6.100E-06	3.900E-06	.639
30	6.812921E+04	3.980E-06	2.220E-06	.558
31	1.000000E+05	2.600E-06	1.150E-06	.442
32	1.467799E+05	1.620E-06	6.600E-07	.407
33	2.154435E+05	1.050E-06	4.000E-07	.381
34	3.162278E+05	7.150E-07	2.445E-07	.342
35	4.641589E+05	4.700E-07	1.440E-07	.306
36	6.812921E+05	2.985E-07	8.660E-08	.290
37	1.000000E+06	1.945E-07	5.170E-08	.266

TABLE 4-3, BETA PARTICLE AND ENERGY RELEASE RATE DATA

BETAS AND BETA MEV/FISSION-SECOND VERSUS TIME AFTER AN INSTANTANEOUS FISSION

I	TIME (SECONDS)	BETAS PER FISSION-SECOND	BETA MEV PER FISSION-SECOND	AVG. BETA ENERGY MEV/PARTICLE
38	1.467799E+06	1.277E-07	3.460E-08	.271
39	2.154435E+06	8.310E-08	2.250E-08	.271
40	3.162278E+06	5.375E-08	1.493E-08	.278
41	4.641589E+06	3.510E-08	1.000E-08	.285
42	6.812921E+06	2.220E-08	6.480E-09	.292
43	1.000000E+07	1.428E-08	4.320E-09	.303
44	1.467799E+07	8.760E-09	2.845E-09	.325
45	2.154435E+07	5.223E-09	1.832E-09	.351
46	3.162278E+07	3.000E-09	1.115E-09	.372
47	4.641589E+07	1.580E-09	6.210E-10	.393
48	6.812921E+07	8.190E-10	3.330E-10	.407
49	1.000000E+08	4.800E-10	1.733E-10	.361
50	1.467799E+08	3.025E-10	9.610E-11	.318
51	2.154435E+08	2.075E-10	6.190E-11	.298
52	3.162278E+08	1.500E-10	4.350E-11	.290
53	4.641589E+08	1.152E-10	3.290E-11	.286
54	6.812921E+08	9.490E-11	2.675E-11	.282
55	1.000000E+09	8.300E-11	2.300E-11	.277

or where the fissile material concentration varies with time at constant flux) a reasonable averaging technique must be employed which accounts for the total amount of fissions that have occurred and which also gives a fission rate weighted average to the decay time following fission. The averaging technique depends on the number of time intervals x_n spanned by the total irradiation plus decay period.

If one time period x_n to x_{n+1} spans the entire irradiation time plus decay time range, then

$$R(\tau + t - x_{n+1}) = R(\tau + t - x_n) = \frac{\sum_m R_m \cdot \tau'_m}{\tau} , \tag{15}$$

where

R_m = fission rate during an incremental irradiation period τ'_m,
τ'_m = length of incremental irradiation period,
τ = total length of irradiation period.

If several (but not necessarily all) incremental irradiation periods of varying fission rates span a time range of x_{n+1} to x_n, as diagrammed in Fig. 4, it becomes necessary to time weight the average fission rate. Weighting is necessary and desirable since those fission products formed at the beginning of an irradiation period have decayed for a longer time than those formed at the end of the same irradiation period. In Fig. 4 the solid line represents the actual fission rate during time periods k, k - 1, and k + 1; and the long dashed lines represent the calculated average fission rates, $\overline{R}(\tau + t - x_k)$, for these same periods. A new fission rate function (the heavy line in Fig. 4) which varies as a straight line on a log-log plot is then found to represent the variation in fission rate over the time span $x_{k+1} - x_k$. Thus the fission rate function may be represented by an expression like:

$$R(x) = Gx^b . \tag{16}$$

The fission rate function [actually the end points (R_k and P_{k+1}) on the line between x_k and x_{k+1}] is found as follows:

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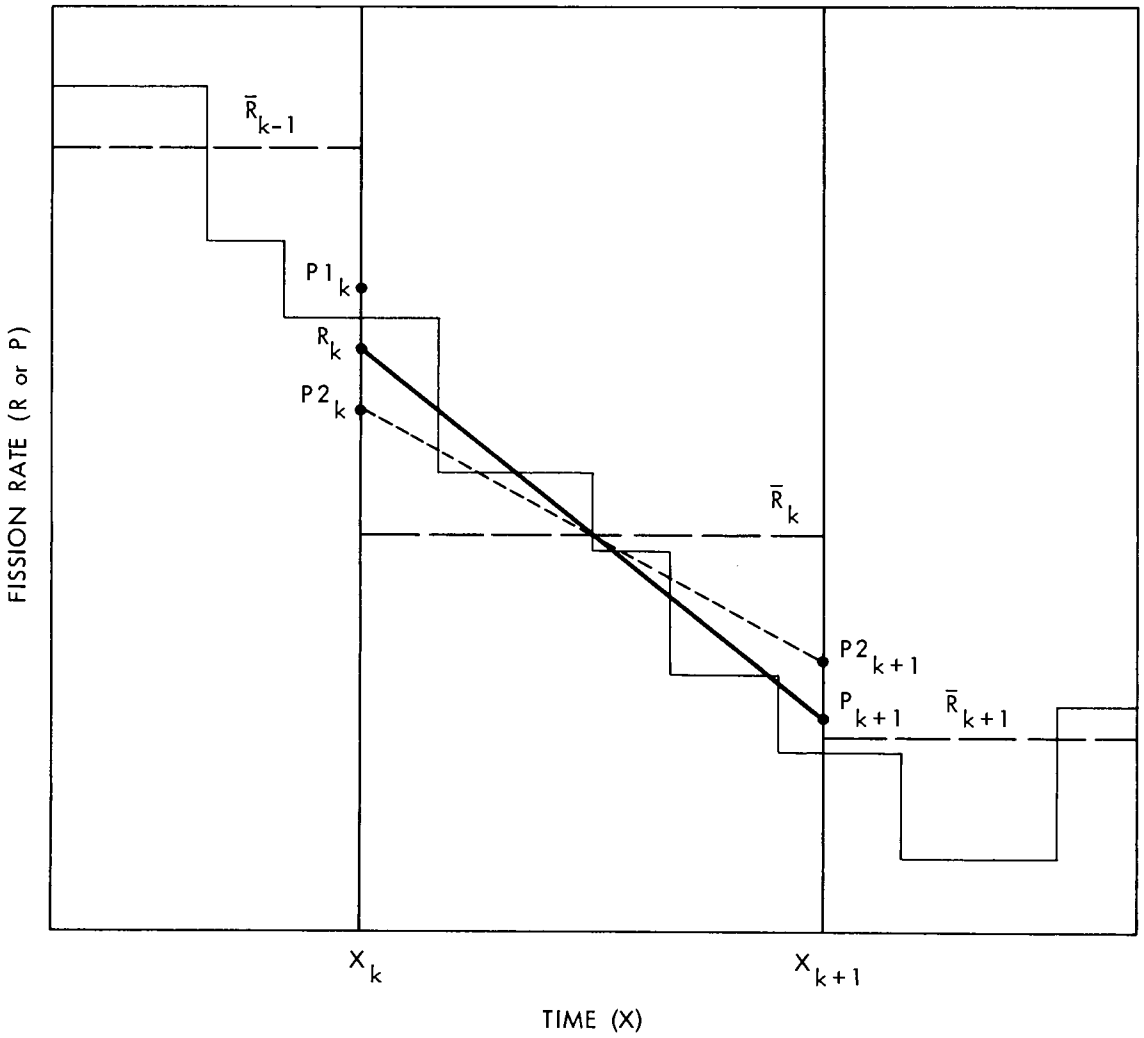

Fig. 4. Graphical Representation of Average Fission Rate Functions.

1. Point $P1_k$ is determined from $P1_k = S_1\bar{R}_k + S_2\bar{R}_{k-1}$.

2. Point $P2_{k+1}$ is determined from $P2_{k+1} = S_3\bar{R}_k + S_4\bar{R}_{k+1}$.

3. Point $P2_k$ is determined from $P2_{k+1}$ by assuming that the area (on log-log plot) under the straight line joining $P2_k$ and $P2_{k+1}$ is equal to $\log \bar{R}_k(\log x_{k+1} - \log x_k)$ as follows:

   $\log P2_k = 2 \log \bar{R}_k - \log P2_{k+1}$ and $P2_k = e^{\log P2_k}$.

4. A point R_k' is determined as the log mean between $P1_k$ and $P2_k$.

5. The point P_{k+1} is found in an analogous manner to step 3 by

   $\log P_{k+1} = 2 \log \bar{R}_k - \log R_k'$.

6. Finally an adjusted value of R_k is found by multiplying R_k' by $S_5(1.012245)$; thus $R_k = S_5R_k'$. This value of 1.012245 (SLOPE5 in code) was chosen since this is the ratio between the arithmetic mean and the logarithmic mean of 1.0x and 1.467799x. The values of $\bar{R}_k$ were found from an arithmetic time averaging of the power over the timespan x_k to x_{k+1} (x_k to 1.467799 x_k). The value of the partitioning function chosen is thus small enough so that SLOPE5 should be a reasonable correction factor to make the transition from linear time to log time averaging. The S_i in steps 1, 2, and 6 are weight factors (read in as data on the first permanent data card as SLOPE1, SLOPE2, SLOPE3, SLOPE4, and SLOPE5) chosen by the user such that $S_1 + S_2 = 1$ and $S_3 + S_4 = 1$, with S_5 being selected as in step 6.

The weighting is accomplished by calculating an adjusted value of $A_{g,k}$ as follows (compare with Eq. 7):

$$A_{g,k} = 2.605767 \ \ell n \left[\frac{P_{k+1} \cdot f_g(x_{k+1})}{R_k \cdot f_g(x_k)} \right] . \tag{17}$$

The effect of these adjustments is to alter the average fission rate such that the total number of fissions during period k is unchanged; but the effective fission rate changes as illustrated by the heavy solid line on the figure. The actual details of the averaging and weighting calculations are given in the FORTRAN list in Appendix II.

5. DATA LIBRARY

The data library, which consists of the permanent data of the program, contains the following items:

1. Values of the weighting constants (S_1, S_2, S_3, S_4, S_5) read on card 0 as SLOPE1, SLOPE2, SLOPE3, SLOPE4, SLOPE5 with Format (5F12.8).

2. Values of x_i, the times at which decay data are given, read on cards 1 through 10, six times per card except for card 11, which contains only the last time. The values of x_i are read in as TIMEX(I), I = 1,55 with Format (6E12.6).

3. Values of $f_g(x_i)$, the photon number release rates per fission for the gth group, for each of the 12 gamma energy groups and at each value of x_i. A total of 83 cards (cards 11 through 93 are required for these data. The values of $f_g(x_i)$ are read in as FXGY(J,I), J = 1,2) I = 1,55 with Format (8E9.3). For I odd, the values of $f_g(x_i)$ for the first four groups fills the remainder of the card that contained the last four groups for the previous x_i, with the remaining eight groups filling the next card. The pattern is repeated until all 55 values of x_i are used.

4. Values of $f_g(x_i)$, the beta particle (g = 13) and beta energy (g = 14) release rates per fission for each value of x_i. A total of 14 cards (cards 94 through 107) are required for these data. Values of $f_{13}(x_i)$ are read in with eight values per card; the first 48 values require 6 cards, with the last seven values appearing on the seventh. The first value of $f_{14}(x_i)$ appears on the card containing the last seven values of $f_{13}(x_i)$. The next 48 values fill 6 cards, while the last six values appear on card 107. These values of $f_{13}(x_i)$ and $f_{14}(x_i)$ are read in as FXGY(J,I), I = 1,55, J = 13,14 with Format (8E9.3).

5. Values of $\overline{E}_g$, the average photon energy for the gth group are read in on cards 108 and 109 as AVEGY(J), J = 1,12 with Format (8E9.3).

New values for any part of the permanent data may be charged by the user by changing those cards in which the particular items appear.

6. INPUT PREPARATION, OPERATION, AND OUTPUT

6.1 Input Preparation

The PHOEBE data sheet for preparing input data is illustrated in Figs. 6-10 in Appendix I. This data sheet consists of four types of cards, which are used to describe the input data.

Card 1 (Identification Card). Any form of alphanumeric information may be filled in on this card in cols. 2 through 72.

Card 2 (Specification Card). This card gives several specification items necessary for the control and operation of the program as follows:

Col. 1-2. Num = Number of decay times for which activities are to be calculated--can be any number from 01 to 99.

Col. 3-4. Lum = Number of power-specification points necessary to describe the power-vs-irradiation-time function. Lum will either be 01 for constant-power operation or equal to the number ($\leq$ 55) of power-time specifications in cards 04n described below.

Col. 5-6. Inst. Case = 01 if constant-power operation is used, or 02 if variable-power operation is used.

Col. 7-8. Perm Data = 02 if a listing of the permanent data deck is desired; otherwise, leave blank.

Col. 9-10. Form = 00 (or blank) if 8E9.3 type format (as given here for cards of type 04n) is used, or = any integer if 6E12.6 format and an optional data sheet is used. This format would be necessary for only those cases in which operating-power times are short compared with down time.

Col. 11-12. Tape = A selected integer assigned as an extra tape to be written for the purpose of future listing; otherwise, columns are left blank. (Select 46 for 1604 or IBM System/360 or 9 for IBM-7090).

Col. 13-14. End File = Same integer as used for Tape if end of file is to be written on the extra tape following case being calculated. End file appears only on last case to be written on the extra tape, but not necessarily the last case of a given job provided that the remaining cases of the job are written on the standard output tape.

Col. 15-16. Last = 01 if case being calculated is last one to be written on extra tape; otherwise, leave blank. (See also comment on End File.)

Cards 3n (Irradiation and Decay Time Cards). All entries on these cards are written with Format (6E12.6), with the total irradiation time being assigned the first field and with the decay times following in the remaining fields for as many entries as required.

Cards 4 or 4n (Power Specification Cards). Either card 4 or cards 4n (but not both) are used to specify the operating power of the reactor. If the reactor operates at constant power, then the fission rate (fissions/sec) is entered on card 4 with Format (E9.3). If the reactor operates at variable power, then cards 4n are used to describe the fission rate specification. Specification of fission rates are entered as Power (1), Time (1), Power (2), Time (2), etc., with time being measured as accumulated time since reactor startup. Both Power (m) and Time (m) are entered in that order with Format (8E9.3). A maximum of 55 steps may be used to specify the power function. The two sketches in Fig. 5 illustrate how power and time are specified for two different cases of variable-power operation. The first sketch shows the case of continuously varying power being fitted with a series of steps having a height of Power(m) and a time width of [Time(m) - Time(m - 1)]. The second sketch shows an example of a typical power reactor irradiation with intermediate shutdown periods. In no case should P(k) be less than 10^{-4} x P(n). That is, during those

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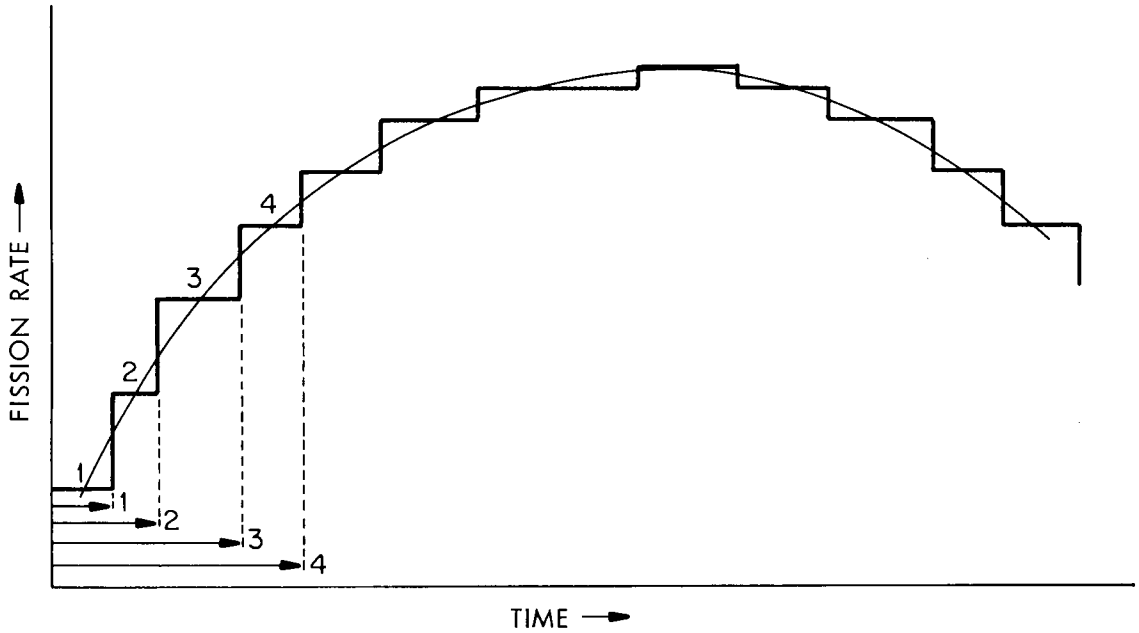
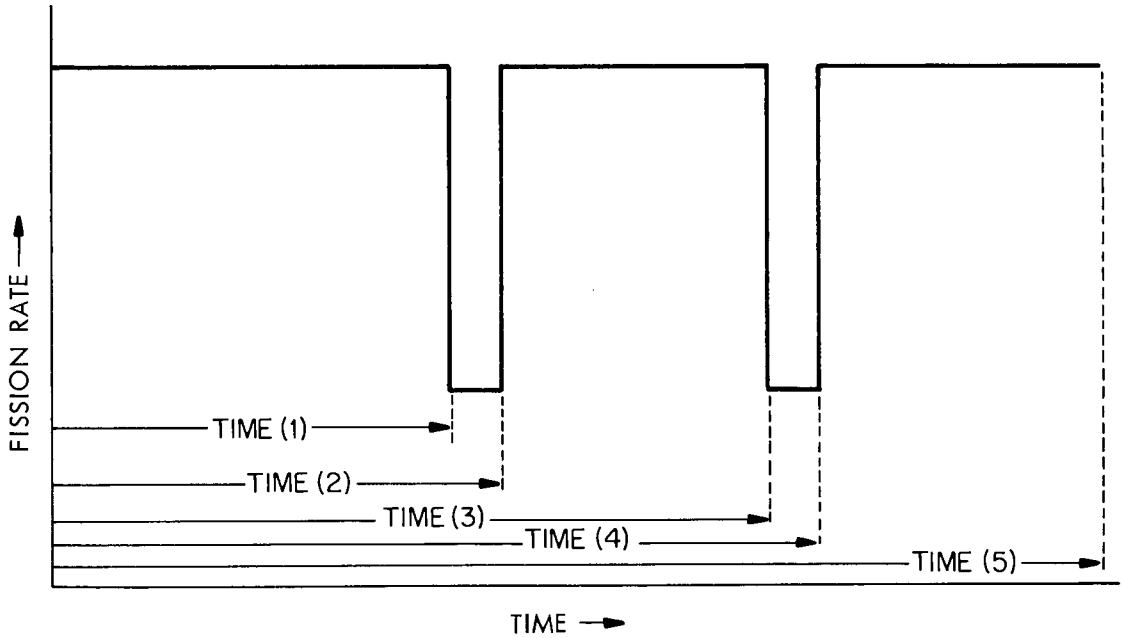


POWER FOR CONTINUOUSLY VARYING POWER LEVEL



POWER FOR OPERATING REACTOR WITH SHUTDOWN PERIODS

Fig. 5. Stepwise Representation of Reactor Operating Powers.

periods in which the reactor is shutdown, use $P(k) = 10^{-4} \times P(n)$ instead of zero. This is necessary because of the many logarithmic functions used in the program.

6.2 Operation

Only standard input and output tapes are required except on those occasions when a special save tape is to be written. In these cases the CDC-1604 or IBM System/360 versions uses Tape 46 as the save tape, with Tapes 50 and 51 being used for input and output respectively. The IBM-7090 version uses Tape 6 for output, and Tape 9 as the save tape.

6.3 Output

Three forms of output are produced. These are:

1. Permanent data list, which may be listed at the discretion of the user as described in Input Preparation.
2. Standard Case output, which lists operating time, decay time, average fission rate, and various forms of release rate data.*
3. Summary output which summarizes the gamma photon release rates, the beta particle and energy release rates, the total gamma energy release rates, the total energy release rates, and the total mass of fission products (this form of output is listed if the total number of decay times is equal to or greater than five).

The Standard Case and Summary output forms are both given in the sample problems given in Appendix I.

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*Those release rates on the result sheets for which units are not printed are to be interpreted as follows: photon release rate (photons/sec), energy release rates (gamma Mev/sec), beta release rate (particles/sec), beta energy release rate (beta Mev/sec), total energy release rate (Mev/sec).

APPENDIX I

Sample Problems

Five sample problems are given in this section to illustrate the various ways to handle input data preparation and output forms. Examples 1, 2, 3, and 5 all have the same total number of fissions and the same total irradiation time. Example 4 has a fission rate and irradiation time equal to that of one step for the variable power case (example 3). The examples are as follows:

1. Constant Power - 1×10^{19} fissions/sec over an operating time of 1×10^{7} sec.
2. Constant Power + One Variable Step - 9.091×10^{18} fissions/sec for 9.9×10^{6} sec + 10^{20} fissions/sec for 1×10^{5} sec.
3. Variable Power - 10 steps of 10^{20} fissions/sec for 1×10^{5} sec each, interspaced with 9 steps of 10^{16} fissions/sec ($\sim$ zero power) for 1×10^{6} sec each.
4. Constant Power - 10^{20} fissions/sec for 10^{5} sec of irradiation.
5. Parabolic Power - fission rate varying parabolically from 0 at zero time through a maximum of 1.422×10^{19} fissions/sec at 5×10^{6} sec and then to zero at 10^{7} sec with an average fission rate = 1×10^{19} fissions/sec. The parabola was fitted with 11 steps.

The data sheets* for these five cases are presented as Figs. 6 through 10.

The results of these cases are presented as follows:

1. Figure 11. Sample result sheet for the complete result set for a decay time of 1×10^{7} sec at constant power.
2. Figures 12 through 14. The three summary result sheets giving the most important results for all decay times at constant power.

---

*Tape 46 was used in this example to save the output for illustration purposes in this report itself.

3. Figures 15 through 18. The last page of the summary sheets for each of the remaining four cases which shows the beta particle, beta energy, and gross total release data.

4. Figure 19. A plot of the total energy release rates for all five cases, showing the type of fit to be expected from PHOEBE and also the effects of the various types of reactor operation on the release rates. The total running time for these five cases was 5.4 min on the CDC-1604.

In those cases that have been run at ORNL for constant-power operation in which comparisons with the gross totals (beta curies and total energy release) presented by Blomeke and Todd,[2] it has been found that the results of the PHOEBE calculations have been 3 to 7% higher than those of Blomeke and Todd over the decay-time range of 10^5 to 10^8 sec.

Although the data for the PHOEBE code are based on the fission products of ^{235}U, any set of data functions for other single or mixed fissile materials, provided that they are known, may be supplied by using the same format. If these functions are not known, estimates of fission product activities from other single or mixed fissile materials may be made, provided that one is willing to make the assumption that the gross properties of the fission products differ very little, whatever their sources. This is reasonable because the yields of individual fission products change from one fissile material to another – some increase while others decrease, but the total yield remains fixed. Thus we can make the assumption that a decrease in one chain is compensated by a corresponding increase in another.

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PHOEBE CODE DATA SHEET

REQUEST 10691 JOB TITLE PHOEBE REPORT TEST CASES WRITTEN BY E. D. Arnold DATE

IDENTIFICATION		01
1PHOEBE TEST CASE 1 CONSTANT POWER		
Num Lum Inst Case Perm Data Form Tape End File Last		02
23 01 01 46		
IRRADIATION TIME / DECAY TIME → (13, 25, 37, 49, 61)		03A
1.0 E+07 1.0 E+00 3.0 E+00 1.0 E+01 3.0 E+01 1.0 E+02		
3.0 E+02 1.0 E+03 3.0 E+03 1.0 E+04 3.0 E+04 1.0 E+05		03B
3.0 E+05 6.0 E+05 1.0 E+06 2.0 E+06 4.0 E+06 7.0 E+06		03C
1.0 E+07 2.0 E+07 3.0 E+07 4.0 E+07 5.0 E+07 6.0 E+07		03D
CONSTANT POWER		04
1.0 E+19		
POWER (1) (10) TIME (1) (19) POWER (2) (28) TIME (2) (37) POWER (3) (46) TIME (3) (55) POWER (4) (64) TIME (4) ETC		04A
. E+ . E+ . E+ . E+ . E+ . E+ . E+ . E+		
. E+ . E+ . E+ . E+ . E+ . E+ . E+ . E+		04B
. E+ . E+ . E+ . E+ . E+ . E+ . E+ . E+		04C
. E+ . E+ . E+ . E+ . E+ . E+ . E+ . E+		04D
. E+ . E+ . E+ . E+ . E+ . E+ . E+ . E+		04E
. E+ . E+ . E+ . E+ . E+ . E+ . E+ . E+		04F
. E+ . E+ . E+ . E+ . E+ . E+ . E+ . E+		04G
. E+ . E+ . E+ . E+ . E+ . E+ . E+ . E+		04H

KEYPUNCH AND CARD HANDLING NOTES:
ONLY CARD TYPE 04 OR 04N IS USED FOR A GIVEN CASE
OMIT ALL CARDS WHICH DO NOT HAVE WRITTEN INFORMATION
DECIMAL POINT, E, AND + SIGN ARE PUNCHED ONLY IN FIELDS WHICH HAVE WRITTEN INFORMATION

END FILE = 46 IF END OF FILE IS TO BE WRITTEN ON TAPE 46 FOLLOWING CASE BEING CALCULATED. END FILE APPEARS ONLY ON LAST CASE TO BE WRITTEN ON TAPE 46.

LAST = 01 IF CASE BEING CALCULATED IS LAST ONE TO BE WRITTEN ON TAPE 46. OTHERWISE LEAVE BLANK.

UCN-4512
(3 4-63)

ALL TIMES ARE IN SECONDS, POWER IN FISSIONS/SECOND
NUM = NUMBER OF DECAY TIMES
LUM = NUMBER OF POWER SPECIFICATION POINTS
INST CASE = 01 (FOR CONSTANT POWER OPERATION),
= 02 (FOR VARIABLE POWER OPERATION)
PERM DATA = 02 (FOR PERMANENT DATA PRINT OUT),
= BLANK OR 00 (IF DATA PRINT OUT IS NOT WANTED)
FORM = BLANK OR 00 IF 8E9.3 TYPE FORMAT (AS GIVEN HERE FOR CARDS OF TYPE 04N) IS USED
= ANY INTEGER IF 6E12.6 FORMAT AND OPTIONAL DATA SHEET IS USED
TAPE = 46 IF AN EXTRA TAPE IS TO BE WRITTEN, OTHERWISE COLUMNS CAN BE LEFT BLANK

Fig. 6. Data Sheet for PHOEBE Test Case 1.

PHOEBE CODE DATA SHEET

REQUEST 10691 JOB TITLE PHOEBE REPORT TEST CASES WRITTEN BY E. D. Arnold DATE

IDENTIFICATION (1–72)	PHOEBE TEST CASE 2 CONSTANT POWER + ONE VARIABLE STEP	01
Num Lum Inst Case Perm Data Form Tape End File Last	2 3 0 2 0 2 4 6	02
IRRADIATION TIME (1–13) / DECAY TIME → (13–25, 25–37, 37–49, 49–61)	1.0 E+071.0 E+003.0 E+001.0 E+013.0 E+011.0 E+02	03A
	3.0 E+021.0 E+033.0 E+031.0 E+043.0 E+041.0 E+05	03B
	3.0 E+056.0 E+051.0 E+062.0 E+064.0 E+067.0 E+06	03C
	1.0 E+072.0 E+073.0 E+074.0 E+075.0 E+076.0 E+07	03D
CONSTANT POWER	. E+	04
POWER (1) (1–10), TIME (1) (10–19), POWER (2) (19–28), TIME (2) (28–37), POWER (3) (37–46), TIME (3) (46–55), POWER (4) (55–64), TIME (4) (64–ETC)	9.091E+189.9 E+061.0 E+201.0 E+07. E+. E+. E+. E+. E+	04A
	. E+. E+. E+. E+. E+. E+. E+. E+. E+	04B
	. E+. E+. E+. E+. E+. E+. E+. E+. E+	04C
	. E+. E+. E+. E+. E+. E+. E+. E+. E+	04D
	. E+. E+. E+. E+. E+. E+. E+. E+. E+	04E
	. E+. E+. E+. E+. E+. E+. E+. E+. E+	04F
	. E+. E+. E+. E+. E+. E+. E+. E+. E+	04G
	. E+. E+. E+. E+. E+. E+. E+. E+. E+	04H

KEYPUNCH AND CARD HANDLING NOTES:
ONLY CARD TYPE 04 OR 04N IS USED FOR A GIVEN CASE
OMIT ALL CARDS WHICH DO NOT HAVE WRITTEN INFORMATION
DECIMAL POINT, E, AND + SIGN ARE PUNCHED ONLY IN FIELDS WHICH HAVE WRITTEN INFORMATION

END FILE = 46 IF END OF FILE IS TO BE WRITTEN ON TAPE 46 FOLLOWING CASE BEING CALCULATED. END FILE APPEARS ONLY ON LAST CASE TO BE WRITTEN ON TAPE 46.

LAST = 01 IF CASE BEING CALCULATED IS LAST ONE TO BE WRITTEN ON TAPE 46. OTHERWISE LEAVE BLANK.

ALL TIMES ARE IN SECONDS, POWER IN FISSIONS/SECOND
NUM = NUMBER OF DECAY TIMES
LUM = NUMBER OF POWER SPECIFICATION POINTS
INST CASE = 01 (FOR CONSTANT POWER OPERATION),
= 02 (FOR VARIABLE POWER OPERATION)
PERM DATA = 02 (FOR PERMANENT DATA PRINT OUT),
= BLANK OR 00 (IF DATA PRINT OUT IS NOT WANTED)
FORM = BLANK OR 00 IF 8E9.3 TYPE FORMAT (AS GIVEN HERE FOR CARDS OF TYPE 04N) IS USED
= ANY INTEGER IF 6E12.6 FORMAT AND OPTIONAL DATA SHEET IS USED
TAPE = 46 IF AN EXTRA TAPE IS TO BE WRITTEN, OTHERWISE COLUMNS CAN BE LEFT BLANK

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(3 4-63)

Fig. 7. Data Sheet for PHOEBE Test Case 2.

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PHOEBE CODE DATA SHEET

REQUEST 10691 JOB TITLE PHOEBE REPORT TEST CASES WRITTEN BY E. D. Arnold DATE

IDENTIFICATION (1–72)	1PHOEBE TEST CASE 3 VARIABLE POWER	01
Num Lum Inst Case Perm Data Form Tape End File Last	23 19 02 46	02
IRRADIATION TIME (1–13) / DECAY TIME (13–25, 25–37, 37–49, 49–61, 61–72)	1.0 E+07 1.0 E+00 3.0 E+00 1.0 E+01 3.0 E+01 1.0 E+02	03A
	3.0 E+02 1.0 E+03 3.0 E+03 1.0 E+04 3.0 E+04 1.0 E+05	03B
	3.0 E+05 6.0 E+05 1.0 E+06 2.0 E+06 4.0 E+06 7.0 E+06	03C
	1.0 E+07 2.0 E+07 3.0 E+07 4.0 E+07 5.0 E+07 6.0 E+07	03D
CONSTANT POWER	. E+	04
POWER (1) (1–10), TIME (1) (10–19), POWER (2) (19–28), TIME (2) (28–37), POWER (3) (37–46), TIME (3) (46–55), POWER (4) (55–64), TIME (4) (64–72), ETC	1.0 E+20 1.0 E+05 1.0 E+16 1.1 E+06 1.0 E+20 1.2 E+06 1.0 E+16 2.2 E+06	04A
	1.0 E+20 2.3 E+06 1.0 E+16 3.3 E+06 1.0 E+20 3.4 E+06 1.0 E+16 4.4 E+06	04B
	1.0 E+20 4.5 E+06 1.0 E+16 5.5 E+06 1.0 E+20 5.6 E+06 1.0 E+16 6.6 E+06	04C
	1.0 E+20 6.7 E+06 1.0 E+16 7.7 E+06 1.0 E+20 7.8 E+06 1.0 E+16 8.8 E+06	04D
	1.0 E+20 8.9 E+06 1.0 E+16 9.9 E+06 1.0 E+20 1.0 E+07 . E+ . E+	04E
	. E+ . E+ . E+ . E+ . E+ . E+ . E+	04F
	. E+ . E+ . E+ . E+ . E+ . E+ . E+	04G
	. E+ . E+ . E+ . E+ . E+ . E+ . E+	04H

KEYPUNCH AND CARD HANDLING NOTES:
ONLY CARD TYPE 04 OR 04N IS USED FOR A GIVEN CASE
OMIT ALL CARDS WHICH DO NOT HAVE WRITTEN INFORMATION
DECIMAL POINT, E, AND + SIGN ARE PUNCHED ONLY IN FIELDS WHICH HAVE WRITTEN INFORMATION

END FILE = 46 IF END OF FILE IS TO BE WRITTEN ON TAPE 46 FOLLOWING CASE BEING CALCULATED. END FILE APPEARS ONLY ON LAST CASE TO BE WRITTEN ON TAPE 46.

LAST = 01 IF CASE BEING CALCULATED IS LAST ONE TO BE WRITTEN ON TAPE 46. OTHERWISE LEAVE BLANK.

ALL TIMES ARE IN SECONDS, POWER IN FISSIONS/SECOND
NUM = NUMBER OF DECAY TIMES
LUM = NUMBER OF POWER SPECIFICATION POINTS
INST CASE = 01 (FOR CONSTANT POWER OPERATION),
= 02 (FOR VARIABLE POWER OPERATION)
PERM DATA = 02 (FOR PERMANENT DATA PRINT OUT),
= BLANK OR 00 (IF DATA PRINT OUT IS NOT WANTED)
FORM = BLANK OR 00 IF 8E9.3 TYPE FORMAT (AS GIVEN HERE FOR CARDS OF TYPE 04N) IS USED
= ANY INTEGER IF 6E12.6 FORMAT AND OPTIONAL DATA SHEET IS USED
TAPE = 46 IF AN EXTRA TAPE IS TO BE WRITTEN, OTHERWISE COLUMNS CAN BE LEFT BLANK

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(3 4-63)

Fig. 8. Data Sheet for PHOEBE Test Case 3.

ORNL DWG 66-5057

PHOEBE CODE DATA SHEET

REQUEST 10691 JOB TITLE PHOEBE REPORT TEST CASES WRITTEN BY E. D. Arnold DATE

IDENTIFICATION (columns 1–72; card number in columns 79–80)

Identification	Card
1PHOEBE TEST CASE 4 CONSTANT POWER (ONE 1.0E+05 SEC STEP)	01

Num	Lum	Inst Case	Perm Data	Form	Tape	End File	Last	Card
23	1	1			46			02

IRRADIATION TIME (columns 1–12); **DECAY TIME** → (columns 13, 25, 37, 49, 61)

Irradiation Time	Decay Time (13)	(25)	(37)	(49)	(61)	Card
1.0 E+05	1.0 E+00	3.0 E+00	1.0 E+01	3.0 E+01	1.0 E+02	03A
3.0 E+02	1.0 E+03	3.0 E+03	1.0 E+04	3.0 E+04	1.0 E+05	03B
3.0 E+05	6.0 E+05	1.0 E+06	2.0 E+06	4.0 E+06	7.0 E+06	03C
1.0 E+07	2.0 E+07	3.0 E+07	4.0 E+07	5.0 E+07	6.0 E+07	03D

CONSTANT POWER

Constant Power	Card
1.0 E+20	04

POWER (1)	TIME (1) (10)	POWER (2) (19)	TIME (2) (28)	POWER (3) (37)	TIME (3) (46)	POWER (4) (55)	TIME (4) (64)	ETC	Card
. E+	. E+	. E+	. E+	. E+	. E+	. E+	. E+		04A
. E+	. E+	. E+	. E+	. E+	. E+	. E+	. E+		04B
. E+	. E+	. E+	. E+	. E+	. E+	. E+	. E+		04C
. E+	. E+	. E+	. E+	. E+	. E+	. E+	. E+		04D
. E+	. E+	. E+	. E+	. E+	. E+	. E+	. E+		04E
. E+	. E+	. E+	. E+	. E+	. E+	. E+	. E+		04F
. E+	. E+	. E+	. E+	. E+	. E+	. E+	. E+		04G
. E+	. E+	. E+	. E+	. E+	. E+	. E+	. E+		04H

KEYPUNCH AND CARD HANDLING NOTES:
ONLY CARD TYPE 04 OR 04N IS USED FOR A GIVEN CASE
OMIT ALL CARDS WHICH DO NOT HAVE WRITTEN INFORMATION
DECIMAL POINT, E, AND + SIGN ARE PUNCHED ONLY IN FIELDS WHICH HAVE WRITTEN INFORMATION

END FILE = 46 IF END OF FILE IS TO BE WRITTEN ON TAPE 46 FOLLOWING CASE BEING CALCULATED. END FILE APPEARS ONLY ON LAST CASE TO BE WRITTEN ON TAPE 46.

LAST = 01 IF CASE BEING CALCULATED IS LAST ONE TO BE WRITTEN ON TAPE 46. OTHERWISE LEAVE BLANK.

UCN-4512
(3 4-63)

ALL TIMES ARE IN SECONDS, POWER IN FISSIONS/SECOND
NUM = NUMBER OF DECAY TIMES
LUM = NUMBER OF POWER SPECIFICATION POINTS
INST CASE = 01 (FOR CONSTANT POWER OPERATION),
= 02 (FOR VARIABLE POWER OPERATION)
PERM DATA = 02 (FOR PERMANENT DATA PRINT OUT),
= BLANK OR 00 (IF DATA PRINT OUT IS NOT WANTED)
FORM = BLANK OR 00 IF 8E9.3 TYPE FORMAT (AS GIVEN HERE FOR CARDS OF TYPE 04N) IS USED
= ANY INTEGER IF 6E12.6 FORMAT AND OPTIONAL DATA SHEET IS USED
TAPE = 46 IF AN EXTRA TAPE IS TO BE WRITTEN, OTHERWISE COLUMNS CAN BE LEFT BLANK

Fig. 9. Data Sheet for PHOEBE Test Case 4.

ORNL DWG 66-5058

PHOEBE CODE DATA SHEET

REQUEST 10691 JOB TITLE PHOEBE REPORT TEST CASES WRITTEN BY E. D. Arnold DATE

IDENTIFICATION										
1 PHOEBE TEST CASE 5 PARABOLIC POWER										01
Num	Lum	Inst Case	Perm Data	Form	Tape	End File	Last			
23	11	2			46	46	01			02
IRRADIATION TIME										
1.0	E+07	1.0	E+00	3.0	E+00	1.0	E+01	3.0	E+01	03A
3.0	E+02	1.0	E+03	3.0	E+03	1.0	E+04	3.0	E+04	03B
3.0	E+05	6.0	E+05	1.0	E+06	2.0	E+06	4.0	E+06	03C
1.0	E+07	2.0	E+07	3.0	E+07	4.0	E+07	5.0	E+07	03D
CONSTANT POWER										
.	E+									04
POWER (1)	TIME (1)	POWER (2)	TIME (2)	POWER (3)	TIME (3)	POWER (4)	TIME (4)	ETC		
2.62	E+18	5.0	E+05	6.03	E+18	1.5	E+06	9.63	E+18	04A
1.373	E+19	4.5	E+06	1.422	E+19	5.5	E+06	1.373	E+19	04B
9.63	E+18	8.5	E+06	6.03	E+18	9.5	E+06	2.62	E+18	04C
.	E+	.	E+	.	E+	.	E+	.	E+	04D
.	E+	.	E+	.	E+	.	E+	.	E+	04E
.	E+	.	E+	.	E+	.	E+	.	E+	04F
.	E+	.	E+	.	E+	.	E+	.	E+	04G
.	E+	.	E+	.	E+	.	E+	.	E+	04H

KEYPUNCH AND CARD HANDLING NOTES:
ONLY CARD TYPE 04 OR 04N IS USED FOR A GIVEN CASE
OMIT ALL CARDS WHICH DO NOT HAVE WRITTEN INFORMATION
DECIMAL POINT, E, AND + SIGN ARE PUNCHED ONLY IN FIELDS WHICH HAVE WRITTEN INFORMATION

END FILE = 46 IF END OF FILE IS TO BE WRITTEN ON TAPE 46 FOLLOWING CASE BEING CALCULATED. END FILE APPEARS ONLY ON LAST CASE TO BE WRITTEN ON TAPE 46.

LAST = 01 IF CASE BEING CALCULATED IS LAST ONE TO BE WRITTEN ON TAPE 46. OTHERWISE LEAVE BLANK.

UCN-4512
(3 4-63)

ALL TIMES ARE IN SECONDS, POWER IN FISSIONS/SECOND
NUM = NUMBER OF DECAY TIMES
LUM = NUMBER OF POWER SPECIFICATION POINTS
INST CASE = 01 (FOR CONSTANT POWER OPERATION),
= 02 (FOR VARIABLE POWER OPERATION)
PERM DATA = 02 (FOR PERMANENT DATA PRINT OUT),
= BLANK OR 00 (IF DATA PRINT OUT IS NOT WANTED)
FORM = BLANK OR 00 IF 8E9.3 TYPE FORMAT (AS GIVEN HERE FOR CARDS OF TYPE 04N) IS USED
= ANY INTEGER IF 6E12.6 FORMAT AND OPTIONAL DATA SHEET IS USED
TAPE = 46 IF AN EXTRA TAPE IS TO BE WRITTEN, OTHERWISE COLUMNS CAN BE LEFT BLANK

Fig. 10. Data Sheet for PHOEBE Test Case 5.

```
PHOEBE TEST CASE 1 CONSTANT POWER
OPERATING TIME =   1.000000E+07          TIME AFTER SHUTDOWN =   1.000000E+07
AVERAGE FISSION RATE DURING IRRADIATION PERIOD (FISSIONS/SECOND)  =   1.000000E+19
PHOTON RELEASE RATES =    1.020E+17    2.510E+17    8.872E+16    4.741E+15    4.648E+14    9.427E+14
PHOTON RELEASE RATES =    1.140E+14    4.340E+13    2.131E+13            0            0            0
ENERGY RELEASE RATES =    3.060E+16    1.581E+17    9.759E+16    7.349E+15    9.250E+14    2.244E+15
ENERGY RELEASE RATES =    3.135E+14    1.411E+14    7.885E+13            0            0            0
SUM PHOTON RELEASE =    4.481E+17
SUM PHOTON ENERGY RELEASE =    2.974E+17
BETA RELEASE RATE  =    8.974E+17
BETA ENERGY RELEASE RATE  =    2.893E+17
TOTAL ENERGY RELEASE RATE =    5.867E+17
GAMMA HEAT RATE (WATTS) =    4.763E+04
BETA HEAT RATE (WATTS)  =    4.634E+04
TOTAL HEAT RATE (WATTS) =    9.398E+04
TOTAL BETA ACTIVITY (CURIES)  =    2.425E+07
TOTAL GAMMA ACTIVITY (CURIES) =    1.211E+07
AVERAGE GAMMA ENERGY (MEV/PHOTON)  =    6.637E-01
AVERAGE BETA ENERGY (MEV/PARTICLE) =    3.224E-01
TOTAL FISSION PRODUCTS (GRAMS)  =    3.876E+04
SPECIFIC FP ACTIVITY (BETA CURIES/GRAM)  =    6.258E+02
SPECIFIC FP HEAT RATE (TOTAL WATTS/GRAM) =    2.425E+00
```

Fig. 11. Sample Result Sheet for the Complete Result Set. (There will be one sheet like this for each decay time.)

ORNL DWG 66-5047

PHOEBE TEST CASE 1 CONSTANT POWER

OPERATING TIME = 1.000000E+07 AVERAGE FISSION RATE (FISSIONS/SECOND) = 1.000000E+19

GAMMA PHOTON RELEASE RATE DATA

GAMMA PHOTONS/SECOND VERSUS TIME FOLLOWING REACTOR DISCHARGE

GAMMA PHOTON RELEASE RATES FOR

DECAY TIME (SECONDS)	GROUP 1 E(AV)= .30	GROUP 2 E(AV)= .63	GROUP 3 E(AV)=1.10	GROUP 4 E(AV)=1.55	GROUP 5 E(AV)=1.99	GROUP 6 E(AV)=2.38
1.000000E+00	1.234E+19	2.510E+19	1.035E+19	6.727E+18	3.370E+18	2.356E+18
3.000000E+00	1.152E+19	2.343E+19	9.466E+18	6.261E+18	3.061E+18	2.204E+18
1.000000E+01	1.029E+19	2.087E+19	8.386E+18	5.568E+18	2.634E+18	1.893E+18
3.000000E+01	9.020E+18	1.822E+19	7.272E+18	4.802E+18	2.197E+18	1.549E+18
1.000000E+02	7.650E+18	1.538E+19	5.915E+18	3.904E+18	1.719E+18	1.170E+18
3.000000E+02	6.440E+18	1.294E+19	4.512E+18	3.099E+18	1.315E+18	8.532E+17
1.000000E+03	5.187E+18	1.045E+19	2.896E+18	2.293E+18	9.376E+17	5.527E+17
3.000000E+03	4.152E+18	8.344E+18	1.732E+18	1.670E+18	6.628E+17	3.238E+17
1.000000E+04	3.188E+18	6.254E+18	1.056E+18	1.118E+18	4.247E+17	1.444E+17
3.000000E+04	2.449E+18	4.582E+18	7.347E+17	7.824E+17	2.323E+17	6.509E+16
1.000000E+05	1.751E+18	3.018E+18	5.120E+17	6.276E+17	5.233E+16	4.382E+16
3.000000E+05	1.205E+18	1.895E+18	3.914E+17	5.474E+17	1.604E+16	3.695E+16
6.000000E+05	9.043E+17	1.390E+18	3.388E+17	4.604E+17	1.038E+16	3.026E+16
1.000000E+06	7.071E+17	1.104E+18	3.011E+17	3.620E+17	7.441E+15	2.350E+16
2.000000E+06	4.735E+17	7.913E+17	2.437E+17	1.908E+17	4.149E+15	1.265E+16
4.000000E+06	2.751E+17	5.359E+17	1.787E+17	5.359E+16	1.853E+15	4.575E+15
7.000000E+06	1.555E+17	3.564E+17	1.233E+17	1.176E+16	8.228E+14	1.740E+15
1.000000E+07	1.020E+17	2.510E+17	8.872E+16	4.741E+15	4.648E+14	9.427E+14
2.000000E+07	4.025E+16	8.883E+16	3.335E+16	1.392E+15	1.634E+14	3.274E+14
3.000000E+07	2.239E+16	3.674E+16	1.241E+16	8.333E+14	9.778E+13	1.955E+14
4.000000E+07	1.423E+16	1.936E+16	4.552E+15	6.070E+14	7.104E+13	1.405E+14
5.000000E+07	1.014E+16	1.235E+16	2.348E+15	4.788E+14	5.897E+13	1.180E+14
6.000000E+07	7.700E+15	8.672E+15	1.423E+15	3.947E+14	5.149E+13	1.046E+14

Fig. 12. Sample of First Page of Summary Results.

ORNL DWG 66-5048

PHOEBE TEST CASE 1 CONSTANT POWER

OPERATING TIME = 1.000000E+07 AVERAGE FISSION RATE (FISSIONS/SECOND) = 1.000000E+19

GAMMA PHOTON RELEASE RATE DATA

GAMMA PHOTONS/SECOND VERSUS TIME FOLLOWING REACTOR DISCHARGE

GAMMA PHOTON RELEASE RATES FOR

DECAY TIME (SECONDS)	GROUP 7 E(AV)=2.75	GROUP 8 E(AV)=3.25	GROUP 9 E(AV)=3.70	GROUP 10 E(AV)=4.22	GROUP 11 E(AV)=4.70	GROUP 12 E(AV)=5.25
1.000000E+00	1.292E+18	9.402E+17	6.966E+17	3.358E+17	1.623E+17	7.681E+16
3.000000E+00	1.176E+18	8.419E+17	6.243E+17	2.905E+17	1.369E+17	6.498E+16
1.000000E+01	9.618E+17	6.666E+17	4.953E+17	2.294E+17	1.027E+17	4.824E+16
3.000000E+01	7.096E+17	4.752E+17	3.520E+17	1.644E+17	6.810E+16	3.099E+16
1.000000E+02	4.393E+17	2.867E+17	2.092E+17	9.127E+16	3.392E+16	1.408E+16
3.000000E+02	2.487E+17	1.526E+17	1.129E+17	3.665E+16	1.246E+16	4.338E+15
1.000000E+03	1.100E+17	6.364E+16	4.600E+16	6.623E+15	2.104E+15	4.609E+14
3.000000E+03	4.024E+16	2.018E+16	1.442E+16	3.716E+14	1.108E+14	1.603E+13
1.000000E+04	1.212E+16	3.996E+15	2.799E+15	1.519E+12	3.714E+11	8.561E+10
3.000000E+04	6.982E+15	1.043E+15	6.877E+14	1.137E+10	2.740E+09	7.718E+08
1.000000E+05	5.658E+15	5.969E+14	3.831E+14	5.758E+07	1.677E+07	5.255E+06
3.000000E+05	4.839E+15	5.533E+14	3.504E+14	1.434E+06	4.187E+05	1.315E+05
6.000000E+05	4.012E+15	5.129E+14	3.206E+14	0	0	0
1.000000E+06	3.120E+15	4.619E+14	2.837E+14	0	0	0
2.000000E+06	1.686E+15	3.489E+14	2.033E+14	0	0	0
4.000000E+06	5.481E+14	1.956E+14	1.056E+14	0	0	0
7.000000E+06	1.903E+14	8.718E+13	4.493E+13	0	0	0
1.000000E+07	1.140E+14	4.340E+13	2.131E+13	0	0	0
2.000000E+07	6.071E+13	8.441E+12	2.975E+12	0	0	0
3.000000E+07	4.608E+13	2.695E+12	6.885E+11	0	0	0
4.000000E+07	3.601E+13	1.134E+12	1.544E+11	0	0	0
5.000000E+07	2.787E+13	5.160E+11	4.120E+10	0	0	0
6.000000E+07	2.213E+13	2.590E+11	1.306E+10	0	0	0

Fig. 13. Sample of Second Page of Summary Results.

ORNL DWG 66-5049

PHOEBE TEST CASE 1 CONSTANT POWER

OPERATING TIME = 1.000000E+07 AVERAGE FISSION RATE (FISSIONS/SECOND) = 1.000000E+19

TOTAL FISSION PRODUCTS (GRAMS) = 3.876E+04

BETA PARTICLE, BETA ENERGY, AND GROSS TOTAL RELEASED DATA

PARTICLE AND ENERGY RELEASE RATES (PER SECOND) FOR

DECAY TIME (SECONDS)	BETA PARTICLES	BETA ENERGY (MEV)	TOTAL GAMMA PHOTONS	TOTAL GAMMA ENERGY (MEV)	TOTAL ENERGY (MEV)
1.000000E+00	5.953E+19	7.512E+19	6.375E+19	6.541E+19	1.405E+20
3.000000E+00	5.515E+19	6.440E+19	5.908E+19	6.016E+19	1.246E+20
1.000000E+01	4.846E+19	5.069E+19	5.215E+19	5.219E+19	1.029E+20
3.000000E+01	4.209E+19	3.976E+19	4.486E+19	4.366E+19	8.342E+19
1.000000E+02	3.587E+19	2.997E+19	3.682E+19	3.428E+19	6.425E+19
3.000000E+02	3.028E+19	2.259E+19	2.973E+19	2.633E+19	4.892E+19
1.000000E+03	2.483E+19	1.632E+19	2.254E+19	1.878E+19	3.509E+19
3.000000E+03	2.036E+19	1.165E+19	1.696E+19	1.332E+19	2.497E+19
1.000000E+04	1.595E+19	7.611E+18	1.220E+19	9.037E+18	1.665E+19
3.000000E+04	1.241E+19	4.885E+18	8.854E+18	6.284E+18	1.117E+19
1.000000E+05	9.062E+18	2.895E+18	6.011E+18	4.190E+18	7.085E+18
3.000000E+05	6.496E+18	1.875E+18	4.097E+18	2.971E+18	4.845E+18
6.000000E+05	5.018E+18	1.405E+18	3.139E+18	2.340E+18	3.746E+18
1.000000E+06	4.045E+18	1.133E+18	2.509E+18	1.882E+18	3.014E+18
2.000000E+06	2.863E+18	8.189E+17	1.718E+18	1.249E+18	2.068E+18
4.000000E+06	1.870E+18	5.538E+17	1.051E+18	7.158E+17	1.271E+18
7.000000E+06	1.228E+18	3.793E+17	6.499E+17	4.318E+17	8.111E+17
1.000000E+07	8.974E+17	2.893E+17	4.481E+17	2.974E+17	5.867E+17
2.000000E+07	4.312E+17	1.540E+17	1.644E+17	1.032E+17	2.622E+17
3.000000E+07	2.568E+17	9.667E+16	7.271E+16	4.550E+16	1.423E+17
4.000000E+07	1.679E+17	6.555E+16	3.899E+16	2.299E+16	8.854E+16
5.000000E+07	1.189E+17	4.742E+16	2.552E+16	1.452E+16	6.205E+16
6.000000E+07	8.924E+16	3.609E+16	1.837E+16	1.036E+16	4.645E+16

Fig. 14. Sample of Third Page of Summary Results.

ORNL DWG 66-5050

PHOEBE TEST CASE 2 CONSTANT POWER + ONE VARIABLE STEP

OPERATING TIME = 1.000000E+07 AVERAGE FISSION RATE (FISSIONS/SECOND) = 1.000009E+19

TOTAL FISSION PRODUCTS (GRAMS) = 3.876E+04

BETA PARTICLE, BETA ENERGY, AND GROSS TOTAL RELEASE DATA

PARTICLE AND ENERGY RELEASE RATES (PER SECOND) FOR

DECAY TIME (SECONDS)	BETA PARTICLES	BETA ENERGY (MEV)	TOTAL GAMMA PHOTONS	TOTAL GAMMA ENERGY (MEV)	TOTAL ENERGY (MEV)
1.000000E+00	5.165E+20	7.296E+20	5.867E+20	6.200E+20	1.350E+21
3.000000E+00	4.724E+20	6.217E+20	5.397E+20	5.672E+20	1.189E+21
1.000000E+01	4.051E+20	4.837E+20	4.700E+20	4.870E+20	9.707E+20
3.000000E+01	3.410E+20	3.738E+20	3.967E+20	4.012E+20	7.749E+20
1.000000E+02	2.784E+20	2.753E+20	3.158E+20	3.068E+20	5.821E+20
3.000000E+02	2.223E+20	2.011E+20	2.444E+20	2.269E+20	4.279E+20
1.000000E+03	1.675E+20	1.380E+20	1.723E+20	1.509E+20	2.889E+20
3.000000E+03	1.229E+20	9.123E+19	1.164E+20	9.616E+19	1.874E+20
1.000000E+04	7.985E+19	5.108E+19	6.953E+19	5.373E+19	1.048E+20
3.000000E+04	4.792E+19	2.521E+19	3.866E+19	2.737E+19	5.308E+19
1.000000E+05	2.355E+19	8.944E+18	1.714E+19	1.130E+19	2.024E+19
3.000000E+05	1.162E+19	3.586E+18	7.451E+18	5.106E+18	8.692E+18
6.000000E+05	7.502E+18	2.134E+18	4.730E+18	3.445E+18	5.579E+18
1.000000E+06	5.161E+18	1.428E+18	3.248E+18	2.453E+18	3.890E+18
2.000000E+06	3.468E+18	9.787E+17	2.134E+18	1.599E+18	2.578E+18
4.000000E+06	2.066E+18	6.072E+17	1.176E+18	8.118E+17	1.419E+18
7.000000E+06	1.284E+18	3.949E+17	6.841E+17	4.547E+17	8.495E+17
1.000000E+07	9.239E+17	2.968E+17	4.637E+17	3.077E+17	6.045E+17
2.000000E+07	4.458E+17	1.587E+17	1.730E+17	1.141E+17	2.728E+17
3.000000E+07	2.640E+17	9.918E+16	7.566E+16	4.752E+16	1.468E+17
4.000000E+07	1.697E+17	6.624E+16	3.950E+16	2.331E+16	8.955E+16
5.000000E+07	1.198E+17	4.775E+16	2.570E+16	1.473E+16	6.248E+16
6.000000E+07	8.975E+16	3.629E+16	1.848E+16	1.043E+16	4.672E+16

Fig. 15. Third Summary Result Sheet for PHOEBE Test Case 2.

ORNL DWG 66-5051

PHOEBE TEST CASE 3 VARIABLE POWER

OPERATING TIME = 1.000000E+07 AVERAGE FISSION RATE (FISSIONS/SECOND) = 1.000900E+19

TOTAL FISSION PRODUCTS (GRAMS) = 3.879E+04

BETA PARTICLE, BETA ENERGY, AND GROSS TOTAL RELEASE DATA

PARTICLE AND ENERGY RELEASE RATES (PER SECOND) FOR

DECAY TIME (SECONDS)	BETA PARTICLES	BETA ENERGY (MEV)	TOTAL GAMMA PHOTONS	TOTAL GAMMA ENERGY (MEV)	TOTAL ENERGY (MEV)
1.000000E+00	5.124E+20	7.281E+20	5.838E+20	6.181E+20	1.346E+21
3.000000E+00	4.684E+20	6.202E+20	5.368E+20	5.653E+20	1.186E+21
1.000000E+01	4.010E+20	4.823E+20	4.671E+20	4.851E+20	9.674E+20
3.000000E+01	3.370E+20	3.723E+20	3.936E+20	3.993E+20	7.716E+20
1.000000E+02	2.744E+20	2.738E+20	3.129E+20	3.050E+20	5.788E+20
3.000000E+02	2.183E+20	1.996E+20	2.416E+20	2.250E+20	4.247E+20
1.000000E+03	1.636E+20	1.366E+20	1.695E+20	1.491E+20	2.857E+20
3.000000E+03	1.190E+20	8.984E+19	1.137E+20	9.440E+19	1.842E+20
1.000000E+04	7.610E+19	4.974E+19	6.689E+19	5.203E+19	1.018E+20
3.000000E+04	4.445E+19	2.398E+19	3.624E+19	2.631E+19	5.029E+19
1.000000E+05	2.096E+19	8.082E+18	1.540E+19	1.016E+19	1.824E+19
3.000000E+05	9.975E+18	3.101E+18	6.388E+18	4.363E+18	7.464E+18
6.000000E+05	6.618E+18	1.893E+18	4.156E+18	3.023E+18	4.915E+18
1.000000E+06	4.567E+18	1.272E+18	2.846E+18	2.137E+18	3.408E+18
2.000000E+06	3.288E+18	9.313E+17	2.010E+18	1.496E+18	2.427E+18
4.000000E+06	1.941E+18	5.733E+17	1.095E+18	7.513E+17	1.325E+18
7.000000E+06	1.215E+18	3.764E+17	6.415E+17	4.253E+17	8.027E+17
1.000000E+07	9.182E+17	2.953E+17	4.602E+17	3.054E+17	6.006E+17
2.000000E+07	4.429E+17	1.578E+17	1.712E+17	1.128E+17	2.706E+17
3.000000E+07	2.622E+17	9.855E+16	7.478E+16	4.700E+16	1.456E+17
4.000000E+07	1.676E+17	6.550E+16	3.883E+16	2.237E+16	8.837E+16
5.000000E+07	1.199E+17	4.780E+16	2.572E+16	1.474E+16	6.254E+16
6.000000E+07	8.951E+16	3.620E+16	1.842E+16	1.039E+16	4.659E+16

Fig. 16. Third Summary Result Sheet for PHOEBE Test Case 3.

ORNL DWG 66-5052

PHOEBE TEST CASE 4 CONSTANT POWER (ONE 1.0E+05 SEC STEP)

OPERATING TIME = 1.000000E+05 AVERAGE FISSION RATE (FISSIONS/SECOND) = 1.000000E+20

TOTAL FISSION PRODUCTS (GRAMS) = 3.876E+03

BETA PARTICLE, BETA ENERGY, AND GROSS TOTAL RELEASE DATA

PARTICLE AND ENERGY RELEASE RATES (PER SECOND) FOR

DECAY TIME (SECONDS)	BETA PARTICLES	BETA ENERGY (MEV)	TOTAL GAMMA PHOTONS	TOTAL GAMMA ENERGY (MEV)	TOTAL ENERGY (MEV)
1.000000E+00	5.048E+20	7.223E+20	5.774E+20	6.123E+20	1.335E+21
3.000000E+00	4.611E+20	6.151E+20	5.307E+20	5.598E+20	1.175E+21
1.000000E+01	3.941E+20	4.780E+20	4.614E+20	4.800E+20	9.580E+20
3.000000E+01	3.305E+20	3.687E+20	3.886E+20	3.948E+20	7.634E+20
1.000000E+02	2.682E+20	2.708E+20	3.081E+20	3.010E+20	5.718E+20
3.000000E+02	2.124E+20	1.971E+20	2.376E+20	2.215E+20	4.186E+20
1.000000E+03	1.580E+20	1.344E+20	1.656E+20	1.461E+20	2.804E+20
3.000000E+03	1.139E+20	8.798E+19	1.102E+20	9.173E+19	1.797E+20
1.000000E+04	7.149E+19	4.827E+19	6.391E+19	4.977E+19	9.804E+19
3.000000E+04	4.022E+19	2.278E+19	3.360E+19	2.432E+19	4.710E+19
1.000000E+05	1.676E+19	6.916E+18	1.279E+19	8.195E+18	1.511E+19
3.000000E+05	6.447E+18	2.149E+18	4.225E+18	2.715E+18	4.863E+18
6.000000E+05	3.164E+18	9.244E+17	2.019E+18	1.414E+18	2.339E+18
1.000000E+06	1.845E+18	4.917E+17	1.202E+18	9.204E+17	1.412E+18
2.000000E+06	8.787E+17	2.379E+17	5.810E+17	4.697E+17	7.077E+17
4.000000E+06	4.084E+17	1.153E+17	2.491E+17	1.823E+17	2.976E+17
7.000000E+06	2.134E+17	6.250E+16	1.215E+17	8.174E+16	1.442E+17
1.000000E+07	1.419E+17	4.298E+16	7.648E+16	5.053E+16	9.361E+16
2.000000E+07	5.753E+16	1.988E+16	2.517E+16	1.674E+16	3.663E+16
3.000000E+07	3.230E+16	1.191E+16	1.025E+16	6.608E+15	1.852E+16
4.000000E+07	2.022E+16	7.777E+15	5.054E+15	3.048E+15	1.083E+16
5.000000E+07	1.389E+16	5.494E+15	3.050E+15	1.754E+15	7.258E+15
6.000000E+07	1.017E+16	4.087E+15	2.130E+15	1.209E+15	5.297E+15

Fig. 17. Third Summary Result Sheet for PHOEBE Test Case 4.

ORNL DWG 66-5053

PHOEBE TEST CASE 5 PARABOLIC POWER

OPERATING TIME = 1.000000E+07 AVERAGE FISSION RATE (FISSIONS/SECOND) = 1.000000E+19

TOTAL FISSION PRODUCTS (GRAMS) = 3.876E+04

BETA PARTICLE, BETA ENERGY, AND GROSS TOTAL RELEASE DATA

PARTICLE AND ENERGY RELEASE RATES (PER SECOND) FOR

DECAY TIME (SECONDS)	BETA PARTICLES	BETA ENERGY (MEV)	TOTAL GAMMA PHOTONS	TOTAL GAMMA ENERGY (MEV)	TOTAL ENERGY (MEV)
1.000000E+00	1.919E+19	2.079E+19	1.898E+19	1.886E+19	3.965E+19
3.000000E+00	1.804E+19	1.796E+19	1.775E+19	1.748E+19	3.544E+19
1.000000E+01	1.627E+19	1.435E+19	1.592E+19	1.537E+19	2.972E+19
3.000000E+01	1.459E+19	1.146E+19	1.400E+19	1.313E+19	2.459E+19
1.000000E+02	1.295E+19	8.883E+18	1.188E+19	1.065E+19	1.954E+19
3.000000E+02	1.148E+19	6.939E+18	1.001E+19	8.558E+18	1.550E+19
1.000000E+03	1.004E+19	5.284E+18	8.119E+18	6.557E+18	1.185E+19
3.000000E+03	8.857E+18	4.054E+18	6.645E+18	5.126E+18	9.180E+18
1.000000E+04	7.685E+18	2.985E+18	5.384E+18	3.992E+18	6.976E+18
3.000000E+04	6.717E+18	2.256E+18	4.478E+18	3.250E+18	5.506E+18
1.000000E+05	5.716E+18	1.698E+18	3.652E+18	2.642E+18	4.340E+18
3.000000E+05	4.759E+18	1.350E+18	2.963E+18	2.192E+18	3.532E+18
6.000000E+05	4.027E+18	1.134E+18	2.482E+18	1.837E+18	2.971E+18
1.000000E+06	3.455E+18	9.782E+17	2.104E+18	1.547E+18	2.525E+18
2.000000E+06	2.631E+18	7.587E+17	1.550E+18	1.100E+18	1.859E+18
4.000000E+06	1.796E+18	5.341E+17	1.001E+18	6.753E+17	1.210E+18
7.000000E+06	1.219E+18	3.774E+17	6.435E+17	4.273E+17	8.047E+17
1.000000E+07	8.977E+17	2.897E+17	4.475E+17	2.970E+17	5.867E+17
2.000000E+07	4.240E+17	1.521E+17	1.577E+17	1.036E+17	2.557E+17
3.000000E+07	2.538E+17	9.579E+16	7.070E+16	4.413E+16	1.399E+17
4.000000E+07	1.705E+17	6.651E+16	3.974E+16	2.346E+16	8.997E+16
5.000000E+07	1.198E+17	4.775E+16	2.570E+16	1.473E+16	6.248E+16
6.000000E+07	9.052E+16	3.660E+16	1.866E+16	1.053E+16	4.713E+16

Fig. 18. Third Summary Result Sheet for PHOEBE Test Case 5.

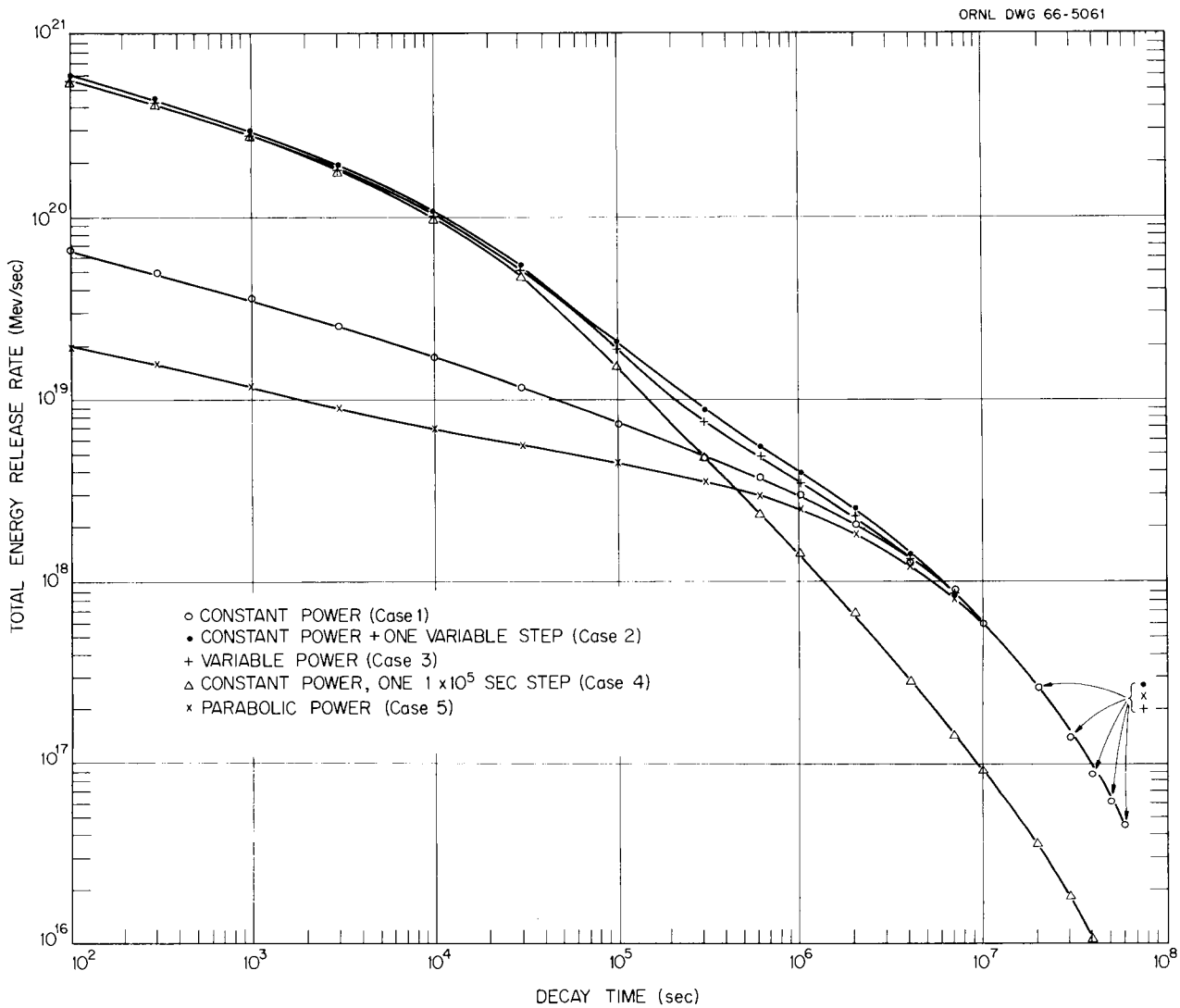

Fig. 19. Total Energy Release Rates for Sample Problems.

APPENDIX II

FORTRAN Listing of PHOEBE

The following 11 pages contain the complete FORTRAN listing of the CDC-1604 version of the code. Following this complete listing are those FORTRAN statements which have been revised to make PHOEBE operable on the IBM System/360 and IBM-7090. The System/360 and CDC-1604 versions differ only in the output Format statements, where a 1P decimal point control is used with E fields. The IBM-7090 version requires this same 1P decimal point control in E fields. However, in addition, read and write statements are changed to account for the different input and output tapes used on the Oak Ridge IBM-7090 Monitor. Also, the section between statement numbers 66 and 67 is changed to account for the limiting exponent size on the IBM-7090. Those changes which are needed for read and write statements are left to the user. However, the last two pages contain the corrected Format statements for the Oak Ridge IBM System/360 and IBM-7090 versions and the revised statements between statement numbers 66 and 67 for the IBM-7090.

PHOEBE lends itself quite well for use as a subroutine in other codes. As such, it has been used in three[7,8] additional codes at ORNL.

```
      PROGRAM PHOEBE

C     PHOEBE  -  A REVISED AND EXPANDED PROGRAM TO OBTAIN PHOTON,
C     BETA, AND ENERGY RELEASE RATES FROM U-235 FISSION PRODUCTS
C
      DIMENSION  TIMEX(55),FXGY(14,55),TEE(100),RELEAS(14,100),
     1ERELEA(12,100),AVEGY(12),INDEX(2),POWER(55),TIME(55),FIZ(55),
     2ARNOLD(55),ELDON(55),AAA(55),R(55),P(55),SABO(55),SABU(55),
     3PHOT(100),EPHOT(100),ETOT(100),GWATT(100),BWATT(100),WATTS(100),
     4BCURIE(100),GCURIE(100),GAVGE(100),BAVGE(100),GRMFP(100),
     5AVPOW(100),SPACT(100),SPWAT(100)
    1 FORMAT (72H
     1                    )
    2 FORMAT (6E12.6)
    3 FORMAT (8E9.3)
    4 FORMAT (36I2)
  205 FORMAT (5F12.8)
  204 READ (50,205) SLOPE1,SLOPE2,SLOPE3,SLOPE4,SLOPE5
  104 READ (50,2) (TIMEX(I), I=1,55)
  105 READ (50,3) ((FXGY(J,I), J=1,12), I=1,55)
  106 READ (50,3) ((FXGY(J,I), I=1,55), J=13,14)
  107 READ (50,3) (AVEGY(J), J=1,12)
   69 READ (50,1)
  109 READ (50,4) NUM,LUM,ITEST,IDATA,MFORM,MIT,MFIT,LAST
  100 READ (50,2) TAU, (TEE(L), L=1,NUM)
      IF (ITEST-1) 155,6,155
  155 IF (MFORM-1) 5,156,156
    5 READ (50,3) (POWER(M), TIME(M), M=1,LUM)
      GO TO 7
  156 READ (50,2) (POWER(M), TIME(M), M=1,LUM)
      GO TO 7
    6 READ (50,3) CONSTA
    7 DO 32  L=1,NUM
      SALAM = 0.0
      TALON = 0.0
  207 DO 31  J=1,14
```

```
      KAR = 1
      OMAR = TEE(L)
    8 DO 13  I=1,55
      IF (OMAR-TIMEX(I)) 9,11,13
    9 INDEX(KAR) = I-1
   12 KAR = KAR+1
      IF (KAR-2) 10,10,14
   10 OMAR = TEE(L)+TAU
      GO TO 8
   11 INDEX(KAR) = I
      GO TO 12
   13 CONTINUE
   14 IVAN = INDEX(2)+1
      JOHN = INDEX(1)
      IF (ITEST-1) 15,21,15
C
C (VARY POWER) - THIS SECTION OF CODE, BETWEEN HERE AND NEXT CARD
C MARKED (VARY POWER), CALCULATES THE POWER AVERAGING FACTORS FOR
C VARIABLE POWER OPERATION.
   15 MIKE = IVAN-1
      MARK = JOHN+1
  114 IF (MIKE-MARK) 16,17,17
   16 DO 141  M=1,LUM
      IF (M-1) 142,142,143
  142 POW = POWER(1)*TIME(1)
      GO TO 141
  143 POW = POW + POWER(M)*(TIME(M)-TIME(M-1))
  141 CONTINUE
  144 FIZ(JOHN) = POW/TAU
      FIZ(IVAN) = FIZ(JOHN)
      R(JOHN) = SLOPE5*FIZ(JOHN)
      P(IVAN) = FIZ(IVAN)
      GO TO 23
   17 DO 145  ME=1,LUM
      IF ((TAU+TEE(L)-TIME(ME))-TIMEX(MARK)) 146,146,145
  146 LIME = ME+1
```

```
      DELA = TIMEX(MARK)-(TAU+TEE(L)-TIME(ME))
      POWA = 0.0
      IF (LIME-LUM) 148,148,157
  145 CONTINUE
  157 FIZ(JOHN) = POWER(LUM)
      GO TO 158
  148 DO 149  MEE=LIME,LUM
      POWA = POWA + POWER(MEE)*(TIME(MEE)-TIME(MEE-1))
  149 CONTINUE
  151 FIZ(JOHN) = (POWA+POWER(LIME-1)*DELA)/
     1(DELA+TIME(LUM)-TIME(LIME-1))
  158 IF (MIKE-MARK) 169,169,168
  169 LEMON = LIME-2
      GO TO 167
  168 DO 165  MIL=1,LUM
      IF ((TAU+TEE(L)-TIME(MIL))-TIMEX(MIKE)) 166,166,165
  166 LEMON = MIL-1
      GO TO 167
  165 CONTINUE
  167 IF (LEMON-1) 152,153,153
  152 FIZ(MIKE) = POWER(1)
      FIZ(IVAN) = FIZ(MIKE)
      FIZIV = FIZ(IVAN)
      GO TO 223
  153 DELB = (TAU+TEE(L)-TIME(LEMON))-TIMEX(MIKE)
  164 DO 154  MA=1,LEMON
      IF (MA-1) 161,161,162
  161 POWB = POWER(1)*TIME(1)
      GO TO 154
  162 POWB = POWB+POWER(MA)*(TIME(MA)-TIME(MA-1))
  154 CONTINUE
  163 FIZ(MIKE) = (POWB+POWER(LEMON+1)*DELB)/(DELB+TIME(LEMON))
  552 FIZIV = ((2.0 - (SLOPE1 + SLOPE3))*FIZ(MIKE) -
     1SLOPE2*FIZ(MIKE-1))/SLOPE4
      IF (FIZIV) 553,553,223
  553 PEPE = ((2.0 - (SLOPE1 + SLOPE3))*LOGF(FIZ(MIKE)) -
```

```
   1SLOPE2*LOGF(FIZ(MIKE-1)))/SLOPE4
    FIZIV = EXPF(PEPE)
223 IF (MIKE-MARK) 224,224,18
 18 JAN = MIKE-1
 19 DO 20  I=MARK,JAN
171 SABO(I) = TAU+TEE(L)-TIMEX(I)
172 SABU(I) = TAU+TEE(L)-TIMEX(I+1)
119 DO 120  MI=1,LUM
    IF (SABO(I)-TIME(MI)) 115,115,120
115 LUKE = MI
    DELT1 = TIME(MI)-SABO(I)
116 DO 121  MII=1,LUM
    IF (SABU(I)-TIME(MII)) 117,117,121
117 JAMES = MII+1
217 IF (JAMES-LUKE) 218,218,219
219 FIZ(I) = POWER(LUKE)
    GO TO 20
218 DELT2 = TIME(MII)-SABU(I)
    RPOW = 0.0
173 DO 122  MEL=JAMES,LUKE
    IF (MEL-1) 174,174,177
174 RPOW = POWER(1)*TIME(1)
    GO TO 122
177 RPOW = RPOW+POWER(MEL)*(TIME(MEL)-TIME(MEL-1))
122 CONTINUE
    FIZ(I) = (RPOW+POWER(JAMES-1)*DELT2-POWER(LUKE)*DELT1)/
   1(SABO(I)-SABU(I))
    GO TO 20
121 CONTINUE
120 CONTINUE
 20 CONTINUE
224 DO 254  K = JOHN,MIKE
    IF (K-JOHN) 250,250,251
250 PLA1 = FIZ(JOHN)
    PA2 = SLOPE3*FIZ(JOHN) + SLOPE4*FIZ(MARK)
    TIM = LOGF(TEE(L)/TIMEX(JOHN))/LOGF(TIMEX(MARK)/TIMEX(JOHN))
```

```
      PA2 = PA2 + (FIZ(JOHN) - PA2)*TIM
      PEPE = LOGF(PA2)
      PLGA2 = 2.0*LOGF(FIZ(JOHN)) - PEPE
      PLA2 = EXPF(PLGA2)
      IF (ABSF(PLA2 - PLA1) - 0.005*PLA2) 599,599,598
  599 RJN = (PLA2 + PLA1)/2.0
      GO TO 597
  598 RJN = (PLA2 - PLA1)/LOGF(PLA2/PLA1)
  597 RLGJN = LOGF(RJN)
      IF (RLGJN - LOGF(0.0001*FIZ(JOHN))) 592,592,593
  592 RLGJN = LOGF(0.0001*FIZ(JOHN)) + RLGJN
  593 PEPE = 2.0*LOGF(FIZ(JOHN)) - RLGJN
      P(MARK) = EXPF(PEPE)
      SLOPM = (PEPE - RLGJN)/LOGF(TIMEX(MARK)/TEE(L))
      RMARG = (SLOPM*LOGF(TIMEX(JOHN)/TEE(L)) + RLGJN)
      R(JOHN) = SLOPE5*EXPF(RMARG)
      GO TO 254
  251 PLA1 = SLOPE1*FIZ(K) + SLOPE2*FIZ(K-1)
      IF (K-MIKE) 252,253,253
  252 PA2 = SLOPE3*FIZ(K) + SLOPE4*FIZ(K+1)
      RMARG = LOGF(PA2)
      PLGA2 = 2.0*LOGF(FIZ(K)) - RMARG
      PLA2 = EXPF(PLGA2)
      IF (ABSF(PLA2 - PLA1) - 0.005*PLA2) 596,596,595
  596 RSK = (PLA2 + PLA1)/2.0
      GO TO 594
  595 RSK = (PLA2 - PLA1)/LOGF(PLA2/PLA1)
  594 RLGSK = LOGF(RSK)
      IF (RLGSK - LOGF(0.0001*FIZ(K))) 572,572,573
  572 RLGSK = LOGF(0.0001*FIZ(K)) + RLGSK
  573 RMARG = 2.0*LOGF(FIZ(K)) - RLGSK
      IF (RMARG - LOGF(0.0001*FIZ(K))) 588,588,589
  588 RMARG = LOGF(0.0001*FIZ(K)) + RMARG
      RLGSK = 2.0*LOGF(FIZ(K)) - RMARG
  589 P(K+1) = EXPF(RMARG)
      R(K) = SLOPE5*EXPF(RLGSK)
```

```
      GO TO 254
  253 PA2 = SLOPE3*FIZ(MIKE) + SLOPE4*FIZIV
      PEPE = LOGF(PA2)
      PLGA2 = 2.0*LOGF(FIZ(MIKE)) - PEPE
      PLA2 = EXPF(PLGA2)
      TIM = LOGF(TIMEX(IVAN)/(TAU + TEE(L)))/
     1LOGF(TIMEX(IVAN)/TIMEX(MIKE))
      PLA1 = PLA1 + (FIZ(MIKE) - PLA1)*TIM
      IF (ABSF(PLA2 - PLA1) - 0.005*PLA2) 587,587,586
  587 RSK = (PLA2 + PLA1)/2.0
      GO TO 585
  586 RSK = (PLA2 - PLA1)/LOGF(PLA2/PLA1)
  585 RLGSK = LOGF(RSK)
      IF (RLGSK - LOGF(0.0001*FIZ(MIKE))) 583,583,584
  583 RLGSK = LOGF(0.0001*FIZ(MIKE)) + RLGSK
  584 RLGIV = 2.0*LOGF(FIZ(MIKE)) - RLGSK
      SLOPM = (RLGIV - RLGSK)/LOGF((TAU + TEE(L))/TIMEX(MIKE))
  525 RMARG = SLOPM*LOGF(TIMEX(IVAN)/TIMEX(MIKE)) + RLGSK
      R(MIKE) = SLOPE5*EXPF(RLGSK)
      IF (RMARG - LOGF(0.0001*FIZ(MIKE))) 576,576,577
  576 RMARG = LOGF(0.0001*FIZ(MIKE)) + RMARG
      SLOPM = (RMARG - LOGF(FIZ(MIKE)))/(LOGF(TIMEX(IVAN)) -
     1LOGF((TIMEX(MIKE) + TAU + TEE(L))/2.0))
      BINK = SLOPM*LOGF(TIMEX(MIKE)/TIMEX(IVAN)) + RMARG
      R(MIKE) = SLOPE5*EXPF(BINK)
  577 P(IVAN) = EXPF(RMARG)
      R(IVAN) = P(IVAN)
  254 CONTINUE
  575 GO TO 23
C (VARY POWER) - SEE NOTE PRECEEDING STATEMENT 15
C
   21 DO 22  I=JOHN,IVAN
   22 R(I) = CONSTA
   23 DO 67  K=JOHN,IVAN
  123 ARNOLD(K) = R(K)*FXGY(J,K)*TIMEX(K)
      IF (ITEST-1) 565,564,565
```

```
564 ELDON(K) = R(K)*FXGY(J,K+1)*TIMEX(K+1)
    GO TO 568
565 IF (IVAN-K) 567,567,566
567 IVANP = IVAN + 1
    ELDON(IVAN) = R(IVAN)*FXGY(J,IVANP)*TIMEX(IVANP)
    GO TO 568
566 ELDON(K) = P(K+1)*FXGY(J,K+1)*TIMEX(K+1)
568 IF (FXGY(J,K+1)) 65,65,64
 64 IF (ARNOLD(K)) 65,65,66
 65 AAA(K) = -2.605767
    GO TO 67
 66 IF (K-IVAN) 101,67,67
101 IF (ITEST-1) 233,234,233
234 AAA(K) = 2.605767*LOGF((R(K+1)*FXGY(J,K+1))/
   1(R(K)*FXGY(J,K))) + 1.0
    GO TO 67
233 AAA(K) = 2.605767*LOGF((P(K+1)*FXGY(J,K+1))/
   1(R(K)*FXGY(J,K))) + 1.0
 67 CONTINUE
    ISAAC = INDEX(1)+1
    JACOB = INDEX(2)-1
    IF (ISAAC-INDEX(2)) 26,24,24
 24 IF (INDEX(1)-INDEX(2)) 28,25,28
 25 K = INDEX(1)
125 RELEAS(J,L) = (ELDON(K)*((TAU+TEE(L))/TIMEX(K+1))**AAA(K) -
   1ARNOLD(K)*(TEE(L)/TIMEX(K))**AAA(K))/AAA(K)
    GO TO 95
 26 SAM = 0.0
    DO 27  I=ISAAC,JACOB
127 BUBBLE = (ELDON(I)-ARNOLD(I))/AAA(I)
 27 SAM = SAM+BUBBLE
    GO TO 75
 28 SAM = 0.0
 75 K = INDEX(1)
175 RANK = (ELDON(K)-ARNOLD(K)*(TEE(L)/TIMEX(K))**AAA(K))/AAA(K)
    K = INDEX(2)
```

```
176 ORDER = (ELDON(K)*((TAU+TEE(L))/TIMEX(K+1))**AAA(K) -
   1ARNOLD(K))/AAA(K)
    RELEAS(J,L) = SAM+ORDER+RANK
 95 IF (J-13) 30,31,31
 30 ERELEA(J,L) = RELEAS(J,L)*AVEGY(J)
    SALAM = SALAM+RELEAS(J,L)
    TALON = TALON+ERELEA(J,L)
 31 CONTINUE
131 PHOT(L) = SALAM
132 EPHOT(L) = TALON
133 ETOT(L) = EPHOT(L)+RELEAS(14,L)
134 GWATT(L) = EPHOT(L)*1.60186E-13
135 BWATT(L) = RELEAS(14,L)*1.60186E-13
136 WATTS(L) = GWATT(L) + BWATT(L)
137 BCURIE(L) = RELEAS(13,L)/(3.70E+10)
138 GCURIE(L) = PHOT(L)/(3.70E+10)
139 GAVGE(L) = EPHOT(L)/PHOT(L)
140 BAVGE(L) = RELEAS(14,L)/RELEAS(13,L)
301 IF (ITEST-1) 304,302,304
302 GRMFP(L) = TAU*CONSTA*233.5/(6.02486E+23)
238 AVPOW(L) = CONSTA
303 GO TO 309
304 GRAMF = 0.0
305 DO 307  M=1,LUM
315 IF (M-1) 316,316,306
316 GRAMF = GRAMF + POWER(1)*TIME(1)
317 GO TO 307
306 GRAMF = GRAMF + POWER(M)*(TIME(M)-TIME(M-1))
307 CONTINUE
308 GRMFP(L) = GRAMF*233.5/(6.02486E+23)
239 AVPOW(L) = GRAMF/TAU
309 SPACT(L) = BCURIE(L)/GRMFP(L)
310 SPWAT(L) = WATTS(L)/GRMFP(L)
 32 CONTINUE
182 IT = 51
249 IF (IDATA-1) 81,81,80
```

```
 80 WRITE (IT,78) (AVEGY(J), J=1,6)
180 WRITE (IT,178) (AVEGY(J), J=7,12)
179 DO 79  I=1,55
270 WRITE (IT,76) TIMEX(I)
271 WRITE (IT,77) (FXGY(J,I), J=1,6)
272 WRITE (IT,77) (FXGY(J,I), J=7,12)
273 WRITE (IT,43) (FXGY(J,I), J=13,14)
 79 CONTINUE
 81 DO 55  L=1,NUM
280 WRITE (IT,1)
281 WRITE (IT,44) TAU, TEE(L)
240 WRITE (IT,244) AVPOW(L)
282 WRITE (IT,45) (RELEAS(J,L), J=1,6)
283 WRITE (IT,45) (RELEAS(J,L), J=7,12)
284 WRITE (IT,46) (ERELEA(J,L), J=1,6)
285 WRITE (IT,46) (ERELEA(J,L), J=7,12)
286 WRITE (IT,60) PHOT(L)
287 WRITE (IT,61) EPHOT(L)
288 WRITE (IT,47) (RELEAS(13,L))
289 WRITE (IT,48) (RELEAS(14,L))
290 WRITE (IT,49) ETOT(L)
291 WRITE (IT,91) GWATT(L)
292 WRITE (IT,92) BWATT(L)
293 WRITE (IT,93) WATTS(L)
294 WRITE (IT,94) BCURIE(L)
295 WRITE (IT,195) GCURIE(L)
296 WRITE (IT,96) GAVGE(L)
297 WRITE (IT,97) BAVGE(L)
311 WRITE (IT,321) GRMFP(L)
312 WRITE (IT,322) SPACT(L)
313 WRITE (IT,333) SPWAT(L)
 55 CONTINUE
400 IF (NUM-4) 183,183,401
401 JAY = 1 $ KAY = 6
402 WRITE (IT,1) $ WRITE (IT,434) TAU,AVPOW(1)
    WRITE (IT,433)
```

```
403 WRITE (IT,452)
404 WRITE (IT,453) (J, J= JAY,KAY)
405 WRITE (IT,454) (AVEGY(J), J=JAY,KAY)
406 WRITE (IT,456) (TEE(LUX), (RELEAS(JOE,LUX), JOE=JAY,KAY),
   1LUX=1,NUM)
    IF (KAY-12) 427,428,428
427 JAY = 7 $ KAY = 12
472 IF (NUM-9) 473,473,402
473 WRITE (IT,433) $ WRITE (IT,433)
417 GO TO 404
428 WRITE (IT,1)
429 WRITE (IT,434) TAU,AVPOW(1)
529 WRITE (IT,321) GRMFP(1)
430 WRITE (IT,433)
431 WRITE (IT,462)
436 WRITE (IT,455) (TEE(LUX), RELEAS(13,LUX), RELEAS(14,LUX),
   1PHOT(LUX), EPHOT(LUX), ETOT(LUX), LUX=1,NUM)
183 IF (MIT-46) 269,184,269
184 IT = 46
185 MIT = 0
186 GO TO 249
269 IF (LAST) 69,69,266
266 END FILE MFIT
267 GO TO 69
 44 FORMAT (17HOOPERATING TIME =E15.6,30H          TIME AFTER SHUTDOWN
   1=E15.6)
244 FORMAT (68HOAVERAGE FISSION RATE DURING IRRADIATION PERIOD (FISSIO
   1NS/SECOND)  =E15.6)
 45 FORMAT (23HOPHOTON RELEASE RATES =6E13.3)
 46 FORMAT (23HOENERGY RELEASE RATES =6E13.3)
 47 FORMAT (21HOBETA RELEASE RATE  =E13.3)
 48 FORMAT (28HOBETA ENERGY RELEASE RATE  =E13.3)
 49 FORMAT (28HOTOTAL ENERGY RELEASE RATE =E13.3)
 61 FORMAT (28HOSUM PHOTON ENERGY RELEASE =E13.3)
 60 FORMAT (21HOSUM PHOTON RELEASE =E13.3)
 76 FORMAT (4HOX =E14.6)
```

```
 77 FORMAT (7HOF(X) =6E11.3)
 43 FORMAT (7HOF(X) =2E11.3)
 78 FORMAT (1H1,18HAVERAGE ENERGIES =6F8.3)
178 FORMAT (19HOAVERAGE ENERGIES =6F8.3)
 91 FORMAT (26HOGAMMA HEAT RATE (WATTS) =E13.3)
 92 FORMAT (26HOBETA HEAT RATE (WATTS)  =E13.3)
 93 FORMAT (26HOTOTAL HEAT RATE (WATTS) =E13.3)
 94 FORMAT (32HOTOTAL BETA ACTIVITY (CURIES)  =E13.3)
195 FORMAT (32HOTOTAL GAMMA ACTIVITY (CURIES) =E13.3)
 96 FORMAT (37HOAVERAGE GAMMA ENERGY (MEV/PHOTON)  =E13.3)
 97 FORMAT (37HOAVERAGE BETA ENERGY (MEV/PARTICLE) =E13.3)
321 FORMAT (34HOTOTAL FISSION PRODUCTS (GRAMS)  =E13.3)
322 FORMAT (43HOSPECIFIC FP ACTIVITY (BETA CURIES/GRAM)  =E13.3)
333 FORMAT (43HOSPECIFIC FP HEAT RATE (TOTAL WATTS/GRAM) =E13.3)
433 FORMAT (1HO)
452 FORMAT (1HO,33X,30HGAMMA PHOTON RELEASE RATE DATA/1HO,18X,60HGAMMA
   1 PHOTONS/SECOND VERSUS TIME FOLLOWING REACTOR DISCHARGE/1HO,42X,30
   2HGAMMA PHOTON RELEASE RATES FOR)
453 FORMAT (26HO     DECAY TIME       GROUPI3,5X,5HGROUPI3,5X,5HGROUPI3,
   15X,5HGROUPI3,5X,5HGROUPI3,5X,5HGROUPI3)
454 FORMAT (1H ,4X,9H(SECONDS),6X,6HE(AV)=F4.2,9H   E(AV)=F4.2,9H   E(
   1AV)=F4.2,9H   E(AV)=F4.2,9H   E(AV)=F4.2,9H   E(AV)=F4.2)
455 FORMAT (1HOE15.6,E16.3,4E15.3)
456 FORMAT (1HOE15.6,E14.3,5E13.3)
434 FORMAT (17HOOPERATING TIME =E15.6,8X,40HAVERAGE FISSION RATE (FISS
   1IONS/SECOND) =E15.6)
462 FORMAT (1HO,20X,56HBETA PARTICLE, BETA ENERGY, AND GROSS TOTAL REL
   1EASE DATA/1HO,31X,50HPARTICLE AND ENERGY RELEASE RATES (PER SECOND
   2) FOR/1HO,4X,10HDECAY TIME,10X,4HBETA,11X,4HBETA,8X,11HTOTAL GAMMA
   3,4X,26HTOTAL GAMMA   TOTAL ENERGY/14H     (SECONDS),9X,9HPARTICLES
   4,4X,12HENERGY (MEV),6X,25HPHOTONS      ENERGY (MEV),6X,5H(MEV))
    END PHOEBE
```

THE FOLLOWING CARDS LIST THE OUTPUT FORMAT STATEMENTS THAT SHOULD BE USED IN THE IBM SYSTEM/360 AND IBM-7090 VERSIONS OF THE CODE IN ORDER TO OBTAIN RESULTS IN THE FORM OF X.XXXE NM INSTEAD OF O.XXXE NM+1.

```
 44 FORMAT (17HOOPERATING TIME =1PE15.6,30H          TIME AFTER SHUTDOW
   1N =E15.6)
244 FORMAT (68HOAVERAGE FISSION RATE DURING IRRADIATION PERIOD (FISSIO
   1NS/SECOND)  =1PE15.6)
 45 FORMAT (23HOPHOTON RELEASE RATES =1P6E13.3)
 46 FORMAT (23HOENERGY RELEASE RATES =1P6E13.3)
 47 FORMAT (21HOBETA RELEASE RATE  =1PE13.3)
 48 FORMAT (28HOBETA ENERGY RELEASE RATE  =1PE13.3)
 49 FORMAT (28HOTOTAL ENERGY RELEASE RATE =1PE13.3)
 61 FORMAT (28HOSUM PHOTON ENERGY RELEASE =1PE13.3)
 60 FORMAT (21HOSUM PHOTON RELEASE =1PE13.3)
 76 FORMAT (4HOX =1PE14.6)
 77 FORMAT (7HOF(X) =1P6E11.3)
 43 FORMAT (7HOF(X) =1P2E11.3)
 78 FORMAT (1H1,18HAVERAGE ENERGIES =6F8.3)
178 FORMAT (19HOAVERAGE ENERGIES =6F8.3)
 91 FORMAT (26HOGAMMA HEAT RATE (WATTS) =1PE13.3)
 92 FORMAT (26HOBETA HEAT RATE (WATTS)  =1PE13.3)
 93 FORMAT (26HOTOTAL HEAT RATE (WATTS) =1PE13.3)
 94 FORMAT (32HOTOTAL BETA ACTIVITY (CURIES)  =1PE13.3)
195 FORMAT (32HOTOTAL GAMMA ACTIVITY (CURIES) =1PE13.3)
 96 FORMAT (37HOAVERAGE GAMMA ENERGY (MEV/PHOTON)  =1PE13.3)
 97 FORMAT (37HOAVERAGE BETA ENERGY (MEV/PARTICLE) =1PE13.3)
321 FORMAT (34HOTOTAL FISSION PRODUCTS (GRAMS)  =1PE13.3)
322 FORMAT (43HOSPECIFIC FP ACTIVITY (BETA CURIES/GRAM)  =1PE13.3)
333 FORMAT (43HOSPECIFIC FP HEAT RATE (TOTAL WATTS/GRAM) =1PE13.3)
433 FORMAT (1HO)
452 FORMAT (1HO,33X,30HGAMMA PHOTON RELEASE RATE DATA/1HO,18X,60HGAMMA
   1 PHOTONS/SECOND VERSUS TIME FOLLOWING REACTOR DISCHARGE/1HO,42X,30
   2HGAMMA PHOTON RELEASE RATES FOR)
```

```
453 FORMAT (26HO     DECAY TIME       GROUPI3,5X,5HGROUPI3,5X,5HGROUPI3,
   15X,5HGROUPI3,5X,5HGROUPI3,5X,5HGROUPI3)
454 FORMAT (1H ,4X,9H(SECONDS),6X,6HE(AV)=F4.2,9H   E(AV)=F4.2,9H   E(
   1AV)=F4.2,9H   E(AV)=F4.2,9H   E(AV)=F4.2,9H   E(AV)=F4.2)
455 FORMAT (1H01PE15.6,E16.3,4E15.3)
456 FORMAT (1H01PE15.6,E14.3,5E13.3)
434 FORMAT (17HOOPERATING TIME =1PE15.6,8X,40HAVERAGE FISSION RATE (FI
   1SSIONS/SECOND) =E15.6)
462 FORMAT (1HO,20X,56HBETA PARTICLE, BETA ENERGY, AND GROSS TOTAL REL
   1EASE DATA/1HO,31X,50HPARTICLE AND ENERGY RELEASE RATES (PER SECOND
   2) FOR/1HO,4X,10HDECAY TIME,10X,4HBETA,11X,4HBETA,8X,11HTOTAL GAMMA
   3,4X,26HTOTAL GAMMA   TOTAL ENERGY/14H     (SECONDS),9X,9HPARTICLES
   4,4X,12HENERGY (MEV),6X,25HPHOTONS      ENERGY (MEV),6X,5H(MEV))
```

THE FOLLOWING CARDS LIST THE FORTRAN STATEMENTS TO BE USED IN THE IBM-7090 VERSION OF THE CODE BETWEEN STATEMENT NUMBERS 66 AND 67 INCLUSIVE.

```
 66 IF (K-IVAN) 101,67,67
101 IF (ITEST-1) 233,234,233
234 AAA(K) = 2.605767*LOGF((R(K+1)*FXGY(J,K+1))/
   1(R(K)*FXGY(J,K))) + 1.0
    GO TO 67
233 IF (ABSF((P(K+1)*FXGY(J,K+1))/(R(K)*FXGY(J,K))) - 6.833E-09)
   1732,732,733
732 AAA(K) = -48.0
    GO TO 67
733 AAA(K) = 2.605767*LOGF((P(K+1)*FXGY(J,K+1))/
   1(R(K)*FXGY(J,K))) + 1.0
 67 CONTINUE
```

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