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ZODIAC-G: A CODE FOR MULTIGROUP,
MULTIREGION BURNUP CALCULATIONS

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3000 STEVENS DRIVE, P. O. BOX 990, RICHLAND, WASHINGTON 99352

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ZODIAC-G: A CODE FOR MULTIGROUP,
MULTIREGION BURNUP CALCULATIONS

R. H. Holeman and D. D. Matsumoto

Reactor Physics Department
Physics and Engineering Division

May 1971

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
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ABSTRACT

The ZODIAC-G computer code is designed to do one-dimensional, multi-group, multiregion burnup analysis of nuclear reactor fuel. The code is written for use on the UNIVAC 1108 computer. ZODIAC-G includes the reactor physics codes HRG, THERMOS, HFN, CLERKC, and ALCHEMY which are chained together for efficient use. ZODIAC-G is extremely flexible, thus it requires more input data than some other burnup codes. Microscopic cross sections can be recalculated whenever desired during a burnup calculation. Non-burnup problems can be run very easily by using component codes of ZODIAC-G.

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I. INTRODUCTION

The ZODIAC-G Computer code is designed to do multigroup, multiregion, burnup analysis of nuclear reactor fuel. The code is written for use on the UNIVAC 1108 computer and represents an improvement over its predecessor, ZODIAC2,⁽¹⁾ written for use on the IBM 7090 computer. ZODIAC-G is a combination of two operating systems of reactor physics codes which are chained together for efficient use. The first package, known as HTH code,⁽²⁾ is comprised of the reactor physics codes HRG,⁽³⁾ THERMOS,⁽⁴⁾ and HFN.⁽⁵⁾ The second system is a burnup package consisting of HFN, CLERK,⁽⁶⁾ and ALCHEMY,⁽⁷⁾ which was extracted from the ZODIAC2 system and made into an independent fast reactor burnup system with the name ZODIAC-F (or WITTLE).⁽⁸⁾ The ZODIAC-F package lacked only the codes necessary for cross section generation, which were supplied by properly linking the required sections from the HTH package.

In performing a reactor burnup analysis with ZODIAC-G, the multigroup cross sections are determined by the codes HRG and THERMOS, the multigroup fluxes and the reactivity are determined by HFN, and the isotope transmutations are determined by ALCHEMY. Unique features of the code include: recalculation of microscopic cross sections at each burnup time step, multiregion burnup, and complete flexibility concerning the spectrum of the reactor and the isotope to be burned. The multiregion burnup is limited to one space dimension because HFN is one dimensional. In addition to the complete multiregion burnup mode described previously, ZODIAC-G can operate in several other modes. These modes are summarized below.

- WITTLE mode - Fast reactor burnup.
- Non-burnup mode.
- HTH mode.

The fast reactor burnup mode allows one to do a burnup analysis in which no recalculation of multigroup cross sections is done. The non-burnup mode allows individual segments of the total ZODIAC-G system to be utilized in a non-linked fashion. In other words, it is possible to run a series of HRG cases or a series of THERMOS cases, etc. The advantage of being able to utilize one segment of the ZODIAC-G code circumvents the possibility of calculational differences that can occur with different versions of a particular code. The HTH mode allows one to do one-dimensional reactivity survey studies where the generation of cross sections and determination of multigroup fluxes and reactivity can be accomplished in one pass.

A description of each code segment in the ZODIAC-G system can be found in the respective documents referenced. A complete set of input instructions is included in this report in order that the user of the code would not be required to seek further reference when running the ZODIAC-G code. In addition, the specialized linkage required to combine the individual programs results in some minor modifications to the input required to execute various individual portions of the system. The ZODIAC-G code described in this report has been fully evaluated and may therefore be used with a reasonable degree of confidence. However, the ZODIAC-G user is urged to keep in mind the general rule regarding computing tools: All results obtained from a computer program, regardless of the length of its history of reliability, should be carefully examined for three reasons

- (1) Program errors may be assumed to exist in normally unused paths of flow; this is particularly pertinent for codes having a large number of options.

- (2) Program errors may possibly exist in areas of fairly wide use. These may fail to be exposed because of complacent usage or because the inter-relationship of data has been such that the influence of the errors was not noticeable.
- (3) For any code having complex and voluminous input, the probability of input error on the first attempt to run a problem, probably approaches 50%, depending upon the user. Fortunately, most input errors will either cause the problem to abort or will be evidenced by strange results.

Every effort has been made in ZODIAC-G to protect the user from disaster caused by input errors, but this is necessarily within the restrictions imposed by the input requirements of the different programs involved.

The following sections of this input documentation will try to describe the program flow and the interrelationship with the code input. Section 2 describes the program flow and gives a brief word about the function of the code segments. Section 3 details the card deck setup and gives some typical running times. Section 4 describes the limitations and restrictions concerning the ZODIAC-G input, as well as the card by card input of each of the code segments. Section 5 discusses the variety of restart methods and the circumstances that lead to a restart situation. Section 6 is Appendix A which contains the HRG fine group energy structure and the listings of the library nuclide identification numbers. Section 7 is Appendix B which contains a listing of a sample case for the burnup mode. Section 8 contains the references that are noted in the prior sections.

II. PROGRAM FLOW AND TERM DEFINITION

This section is required reading for those preparing to utilize the ZODIAC-G code. A description of the flow of a typical case for each mode gives a brief statement of the function performed and directions for proceeding to the next section of the code. Embedded in the text are descriptions of terms with meanings peculiar to ZODIAC-G.

The reader should refer frequently to the appropriate ZODIAC-G Flow Diagram (Figures I-IV), in order to establish a relationship between the code input and program flow. It should then be necessary to refer only to the ZODIAC-G Flow Diagram when preparing to submit data.

FIREUP is executed only at the start of each machine run. It reads the control card input to determine the mode of operation and the flow path to be taken during that machine pass. FIREUP transfers all other data input, which is called NUDATA, from the card reader to a drum file for use by other segments of the code. NUDATA includes all of the case input cards from the first HRG input card to the last CLERKC input card. Then FIREUP calls the appropriate mode control routine determined by the control card input.

There is a different control routine for each of the four modes in which ZODIAC-G can be used. These routines are known as BURN, NOBURN, HTHPRO, and WITTLE. The function of these routines is to control the sequence of flow through ZODIAC-G as determined by the FIREUP control cards and other card input. These routines require no additional input, as they perform no calculations nor print any output.

HRG is the first calculational segment of ZODIAC-G and it provides the non-thermal multigroup cross sections. HRG computes a slowing-down spectrum with 68 fine energy groups in either the B1 or P1 approximation. The calculated flux and current spectra are used to average the 68 group cross section data over as many as 32 broad groups.

THERMOS is used to compute microscopic thermal group cross sections up to 0.683 eV. THERMOS calculates a spatially dependent, thermal neutron spectrum by solving the integral transport equation with isotropic scatterings in either slab or cylindrical geometry. The ZODIAC-G version of THERMOS contains the revisions of D. R. Skeen and L. J. Page to the computational routines, but does not include the increased number of mixtures (8) and space points (30) allowed in BATTELLE/THERMOS.⁽⁴⁾ The coupling of the epithermal and thermal average cross sections occurs in THERMOS where they are prepared for HFN input.

HFN solves the multigroup diffusion equation in one dimension. Output includes spatial distribution of group fluxes, as well as the reactor fission eigenvalue. HFN creates a drum file containing cross sections, HFN material names with corresponding input concentrations, and group fluxes. This information is then available for use by CLERKC.

CLERKC forms the one-group burnup cross sections from the multigroup flux splits and microscopic cross sections. The burnup flux level and the power split between burnable regions is also calculated at this point. CLERKC composes and writes all ALCHEMY input to a drum file including the CLERKC names for use by ALCHEMY.

ALCHEMY numerically evaluates a matrix power series representation of the solution of the isotope balance equation for a homogeneous region. The calculated output is transferred to the REFIRE Data file (tape or drum) to be used as input in further calculations. The HFN group fluxes are dropped and the ALCHEMY-generated isotope concentrations added. The isotopes used in the ALCHEMY calculation are referred to as burnable isotopes. An isotope is considered burnable in region j if it is included in both the HFN and CLERKC data for region j. Non-burnable isotopes may appear in the HFN region data, since only the isotopes that are found in CLERKC will be considered by REFIRE when preparing the concentrations and resonance parameters for the next orbit. An orbit is a term pertinent only to the burnup or WITTLE modes. A calculation in the burnup (or WITTLE) mode that proceeds from the first segment of ZODIAC-G used and passes through all the necessary segments until it reaches the beginning segment again, is called an orbit. Thus n passes through this sequence would be denoted as n orbits.

REFIRE makes up a new input file from the information on the REFIRE Data file (tape or drum) and the input file, NUDATA. By entering IDUM=1, in the FIREUP input, REFIRE will print the updated input before returning to the control routines. Then the starting code for the next orbit is called or else the case is terminated if no further calculation is to be performed.

A. Burnup Mode

A ZODIAC-G burnup case comprises all the data necessary to make a burnup calculation for one case. This is at least one HRG and

THERMOS case followed by one HFN case, which in turn is followed by a CLERKC case for each HFN region subject to burnup. For each CLERKC case there is an ALCHEMY calculation, where input is prepared for REFIRE. Note that return to HRG and THERMOS is not required on every orbit. After one full orbit, selected or all subsequent orbits may start with HFN in order to save machine time. The user must judge the advisability of the shortcut in terms of the sensitivity of the particular case being run.

B. Non-Burnup Mode

The non-burnup mode allows individual segments of ZODIAC-G to be utilized in a non-linked fashion. It is possible to run a series of HRG cases or a series of THERMOS cases, or a series of HFN cases. The control routine, NOBURN, can direct the flow only to HRG, THERMOS, or HFN. It is not possible to run CLERKC or ALCHEMY by themselves since they require input generated internally in the other segments.

C. HTH Mode

The HTH mode allows one to do a one-dimensional reactivity survey study where the generation of cross sections and determination of multigroup fluxes and reactivity can be accomplished in one pass. Like the input for the burnup mode, the HTH input data is comprised of at least one HRG and THERMOS case followed by one HFN case. As in the burnup mode, the coupling of the epithermal and thermal cross sections occurs in THERMOS where they are prepared for HFN input.

D. WITTLE Mode

The fast reactor burnup mode allows one to do a burnup analysis

in which no recalculation of multigroup cross section is done. This mode is similar to the burnup mode without the cross section generation segments. The HFN case is followed by a CLERKC case for each HFN region subject to burnup. The CLERKC case(s) are followed by ALCHEMY which performs the actual burnup calculation.

ZODIAC-G FLOW DIAGRAMBURNUP MODE

FIGURE I

ZODIAC-G FLOW DIAGRAMNO-BURN MODE FIGURE II

ZODIAC-G FLOW DIAGRAMHTH MODE

Note: NUDATA is used as input into HRG, THERMOS and HFN.

FIGURE III

ZODIAC-G FLOW DIAGRAMWITTLE MODE FIGURE IV

III. CARD DECK SETUP AND OPERATING NOTES

Control Cards

The control cards for use with the CSCX operating system on the UNIVAC 1108 are as follows:

∇X ASG,R A = ZODIAC-G PCF, G = ZLT

∇X ASG,W F = HFNDT, H = RDT (optional tapes, see FIREUP Input)

∇ XQT CUR

IN A

TRI A

∇ XQT ZODIAC/GABS

INPUT DATA

∇N XQT CUR

TRI G,F,H

∇FIN

Running Time

Running time can be estimated by adding up the running times of the code segments to be executed, allowing 20 seconds to load and execute plus 15 seconds each orbit for REFIRE. HRG uses between 30 and 45 seconds for an average three group case. THERMOS runs between 90 and 270 seconds for a full transport calculation, depending on the number of space points used. HFN uses 12 seconds, and each CLERKC and ALCHEMY calculation uses 3 seconds. A case with four groups, one burnable region, and twenty space points in THERMOS took 4 minutes for a full orbit.

The test case shown in Appendix B is a sample burnup case. It should take between 1.5 and 2 minutes. The test case uses a fast cosine current calculation in THERMOS to reduce the running time for test purposes.

IV. INPUT INSTRUCTIONS

The input required for a ZODIAC-G case is primarily the input required by the individual codes. A few restrictions or modifications have been added to this input. In addition a small amount of input was necessary to link the various codes together.

A. Limitations

Code Limitations

The code is designed to do cell burnup in an automated manner, but does not include the capability of handling a THERMOS calculation with more than one fuel region. A problem arises in REFIRE at update time because there are no mechanics in the code to place the next orbit concentration for any isotope in more than one mixture.

The code does not have a reduced form of input as did its predecessors. Thus, the total input for each code, for each region must be prepared.

Size Limitations

The following size limitations apply to ZODIAC-G:

1. Maximum number of energy groups = 20 for burnup and WITTLE modes.
= 33 for HRG in non-burnup mode.
= 34 for HTH mode (33 in HRG, and 1 broad group in THERMOS).
2. Maximum number of regions = 20 for HFN in burnup and WITTLE modes, including burnable regions.
= 50 for HFN in non-burnup and HTH modes.
= 20 for THERMOS in any mode (20 space points are allowed in THERMOS).

3. Maximum number of burnable regions = 15
4. Maximum number of burnable isotopes in a burnable region = 20
5. Maximum number of isotopes in = 150 Count the isotope once for all regions each region in which it appears.
6. Other size limitations are imposed by HFN and apply specifically to it. These are given with the HFN input instructions.

Library Limitations

There is some incompatibility between the HRG and THERMOS libraries. The HRG library is the larger of the two and contains cross-section data for over 200 isotopes. Cross section information not found on the THERMOS library can be included as part of the THERMOS input. Thus, a new library does not have to be created before running the code. If isotopes are added please note the comments in the Odd Data Restrictions and THERMOS input instructions concerning isotope input order.

Low cross-section fission products are represented by the Nephew⁽⁹⁾ set of pseudo-fission products. High cross-section isotopes are not included in these pseudo-fission products. Xe-135 and Sm-149 should be included explicitly.

Data Restrictions

The nature of ZODIAC's growth and the fact that it is a combination of codes of widespread origin, make necessary certain odd data restrictions. If these restrictions are violated, the program will either abort or produce cheerfully and unwittingly, a set of erroneous results. While these are mainly logical restrictions if considered

in the light of program flow, they are not at all obvious to the non-programmer. Therefore, they are specifically pointed out here, even though they are also embedded in the text further on.

1. Data for each core region or homogenized pseudo-region comprises a separate case for THERMOS and HRG. Data for each burnable region comprises a separate CLERKC case. One HFN case includes all regions.
2. The nuclide input in an HRG case must be entered in ascending numerical order according to the nuclide identification number. Since there are no cross-reference tables of "ident" numbers between HRG and THERMOS libraries, a restriction is imposed such that THERMOS nuclide input be in the same order as HRG nuclide input. This can pose a problem in the event multiple-temperature isotopes are used in THERMOS, or in the case an isotope is input by cards.
3. Burnable isotopes must precede any non-burnable isotopes within each HFN region.
4. An apparently unreasonable restriction exists regarding CLERKC data. See footnote, page 66.
5. Columns 73-80 are used by REFIRE for locating data for updating purposes. Therefore, certain restrictions exist regarding what may be punched in these columns. They may be used for sequence numbers or other identification as long as the following rules are not violated: Card(s) 3 of the FIREUP input must contain the word HEAD in columns 77-80; the HRG resonance parameter cards must contain the word HRGRES in columns 73-80.

B. LISTV Data

The LISTV package is a generalized input routine which utilizes a standard set of input formats for use with FORTRAN V programs. When this routine is used, the number of written input instructions and the amount of input data can be reduced substantially. Whenever the LISTV routines are accessed, all input cards for one case are read. Each card is listed in the output buffer and data is placed in the COMMON area in a form and location specified on the data card. After an error code is set, control is returned to the calling program.

Utilization of the LISTV input routine has four principal advantages:

1. The programmer is freed from the burden of writing input and format statements for each individual program by simply calling the generalized input routine.
2. Data preparation is simplified and data errors minimized by providing the user with a relatively simple, standardized format for many different codes. The input area may be easily cleared between cases. Repetitive data (such as large blocks of zeros) can be condensed onto a very few cards. Portions of data not applicable to a given case need not be punched.
3. Only input quantities which differ from the previous case need be punched. This overload feature cuts input card volume by a significant amount in the typical physics application.

4. A complete listing of input cards for a given case precedes the output of that case, which simplifies location of input errors. Identifying comments may be intermixed with the data.

LISTV is used only for HFN and CLERKC input data.

Description of LISTV Input Cards

A card type is indicated by the entry in column 1 of each card. LISTV recognizes four types of data-bearing cards, one type of control card, and one type of comment card.

Control Card

A 9 card indicates end of case. Upon reading a card with 9 in column 1, LISTV immediately returns control to the calling program. Columns 2-80 are ignored and may contain comments or identification.

Comment Card

Comments, data identification, additional heading material, or what-have you may be entered on cards having C in column 1. The card is listed as punched, but is otherwise ignored by LISTV.

Data Cards

An entry of 0, 1, 2, or blank in column 1 indicates that data is to be transferred from the card to the COMMON storage area. All data-bearing cards are of the same general format:

<u>COLUMNS</u>	<u>ENTRY</u>
1	Card type; indicates format of columns 11-70.
2-3	N, the number of data words on this card.
4-5	K, repetition control.
6-10	L0C, The COMMON location to which the first data field on this card is addressed (right adjusted).
11-70	Data (format given below).
71-80	Printed, but otherwise ignored.

<u>Card Type (Col. 1)</u>	<u>Format and Field Width</u>	<u>Data Type</u>	<u>NMAX, Number of Fields per Card</u>	<u>Fields Start in Columns</u>
0	E10.0	Real	6	11,21,31,41,51,61
1	15	Integer	12	11,16,21,26,31,36,41,46,51,56,61,66
2	A6	BCD	10	11,17,23,29,35,41,47,53,59,65
Δ*	Same as preceding card.			

*Note: The symbol Δ indicates one blank in the above description.

Restrictions on LISTV Data

Because all input cards must be scanned by REFIRE, certain restrictions must be placed on data of the type read by LISTV/INPUT.

1. Do not leave column 1 blank.
2. Columns 2-3 and column 4-5 may be used in the usual manner.
However, see item 3 below.
3. REFIRE is supposedly coded to cope with any legitimate LISTV card which is non-blank in column 1. However, exotic combinations of the three control integers in columns 2-3, 4-5 and 6-10 may well lead the program onto virgin ground.
4. A blank in column 6-10 means the address of the first data word on the card immediately follows the last address of the previous card. If the input in columns 2-3 and 4-5 of the previous card is blank then every field of that card is presumed to be filled.

4. (Continued)

If the input in columns 2-3 and 4-5 of the previous card is not blank then the number of fields used can be calculated from these entries. A non-blank entry in columns 6-10 is recommended.

For further information about the LISTV input routine and input data see BNWL-41.

C. 9END CARD

The 9END card was added as an input parameter to ZODIAC-G to aid in termination from any segment of the ZODIAC-G code. Its function is to act as a terminator of case input for a particular segment of the code and to signal the over-all control of the code upon completion of the calculation by this segment. The use of this card will be described for each of the pertinent segments and should be regarded as mode dependent.

HRG: Add the 9END card after data of the last case. For the Burnup and HTH mode this would mean after each case of input. For the non-burnup mode this would mean after the last case of input.

THERMOS: Same as for HRG. Never use blank cards or dummies, as in other THERMOS versions, as a replacement for the 9END card.

HFN: Use a 9 card for all cases except the last case. Use a 9END card for the last case instead of a 9 card. See section on LISTV for description of 9 card.

CLERK: Same as for HFN.

The 9END card is read with a (A1,A4) format beginning in column 1, and can be written either 9ENDØ or 9ØEND, where Ø denotes a blank (no punch).

BEGIN CARD INPUT

D. FIREUP - TYPE I CARDS

Note: FIREUP requires 2 cards of format (24I3); heading cards (Cards No. 3) are optional.

<u>Card No.</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 1</u>	1-3	IFBURN	Mode of operation = 0 for burnup = 1 for non-burnup = 2 for HTH = 3 for WITTLE (FAST REACTOR BURNUP)
	4-6	NORBIT	Starting orbit number for this run. Negative NORBIT indicates startup without an RDT* at orbit >1, (all data must be updated by hand).
	7-9	ITRLIM	Orbit limit for burnup and WITTLE modes (≤ 20). For non-burnup mode, ITRLIM is the number of times a link is called (see Card 2). For HTH mode, ITRLIM is not used, enter 0.
	10-12	IDUM	= 0 no effect = 1 to obtain listing of input cards
	13-15	IRDT***	= 0 RDT on Tape H or unused = 1 RDT on drum
	16-18	IHFNDT***	= 0 HFNDT** on Tape F (Unit 12) or unused = 1 HFNDT on drum
	19-21	IZLT	= 0 ZLT, Tape G or unused = 1 ZLT on drum (not available)
	22-24	NCYCLE	Number of pairs of HRG-THERMOS cases when IFBURN = 0 or 2. Not used when IFBURN = 1 or 3. If negative NCYCLE do not go to HFN in HTH mode.

*RDT = REFIRE Data Tape

**HFNDT = HFN Data Tape

*** Recommend usage of tapes for restart purposes in burnup and WITTLE modes.

<u>Card No.</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
Card 1 (contd.)	25-27	XHFN	HFN cross-section input type from THERMOS = 0, none produced = 1, micro, region average = 2, micro, cell average = 3, macro cell average = 4, 1 and 3 = 5, 2 and 3
	28-30	NHPUN	= 0, No HFN output punched = 1, HFN output punched
	31-33	IFQDT	= 0, No PACTOLUS output punched = 1, PACTOLUS output written to tape.
	34-36	IFUDGE	= 0, HRG-HFN concentrations match = 1, THERMOS-HFN concentrations match
	37-39	IFBAH	= 0, Normal, no effect = 1, Add the HFN cross-section input from this run to an existing HFNDT
	40-72		Not used
<u>Card 2</u>	1-3	LINK(1)	Contains link numbers for the section of code to be initiated, (LINK(L),L=1,ITRLIM).
	4-6	LINK(2)	
	.	.	
	.	.	

For burnup mode or WITTLE mode; (IFBURN=0 or 3), LINK(L) is the first link to be executed in orbit L.

For non-burnup mode; (IFBURN = 1), the code specified by LINK(1) will be executed for 1 or more cases until it finds a 9END card; then the code specified by LINK(2) for its kind of data, etc.

For HTH mode; (IFBURN = 2), Card 2 must be present but it may be blank since it is not used.

Link Numbers: 04 HRG
05 HFN
20 CLERK *
23 ALCHMY *
30 THERMOS

- * It is not legal to start with CLERK or ALCHMY because they require internally generated input data.

Card 3: Optional HEAD cards

This data is used to describe the run being made. The first 72 columns of the first card appear at the top of each printed page of output. The total set of HEAD card input appears on page 2 of the printed output. There may be any number of cards of this type, but they must all be identified by having the word HEAD punched in columns (77-80).

The following subsections describe the input for each of the code segments of ZODIAC-G. Depending on the mode selected, certain ones of these subsections may be skipped when preparing your input.

If IFBURN = 0 or 2, for burnup or HTH mode respectively, then you should proceed to the next subsection (E) which is instruction for the input of HRG.

If IFBURN = 1, for non-burnup mode, then you should go to the appropriate subsection; either HRG, THERMOS, or HFN.

If IFBURN = 3, for WITTLE mode, then you may skip the subsections E and F which are instructions for the input of HRG and THERMOS.

E. HRG (LINK 04) - TYPE II CARDS

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
Card 0	16	1-6	NOID	HRG library tape identification number.
Note: Sufficient cards 1-11 are needed with each case for a complete specification Card 0 is input only once.				
<u>Card 1</u>	12A6	1-72	BXCX(I)	Case title card This information is printed as heading on each page of output.
<u>Card 2</u>	E12	1-12	WTP (MTP)	Type of problem: 1.0 - P1 calculation 2.0 - B1 calculation 3.0 - Fine group fluxes to be read in; fine group currents zeroed internally. 4.0 - Fine group fluxes and currents and P1 leakage terms to be read in. 5.0 - Fine group fluxes and currents and B1 transform parameter to be read in.
	E12	13-24	WSTU (MSTU)	Source: 0.0 - Unit source in one fine group 1.0 - U ²³³ fission spectrum 2.0 - U ²³⁵ fission spectrum 3.0 - Pu ²³⁹ fission spectrum 4.0 - Pu ²⁴¹ fission spectrum 5.0 - Cf ²⁵² fission spectrum 6.0 - Po-Be (Whitmore-Baker) 7.0 - Po-Be (Cochrane-Henry) 8.0 - Ra-Be (Hill)

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 2</u> (contd.)	E12	25-36	WGHUS (MGHUS)	Unit source specification: (needed only if 0.0 in cols. 13-24) Group number of fine group having the unit source. NOT USED.
<u>Card 3</u>	E12	1-12	POI (NOI)	Number of nuclides
	E12	13-24	PNOAG (NOAG)	Number of broad groups (≤ 33.0)
	E12	25-36	PMAGE (MAGE)	Age Calculation option: 0.0 - No 1.0 - Yes
	E12	37-48	PMICR (MICR)	Microscopic cross section to be averaged over broad groups: 0.0 - No 1.0 - Yes (required when IFBURN = 0, for burnable regions)
	E12	49-60	SJGM (JGM)	Geometry specification for resonance integral calculations: 0.0 - none 1.0 - Slab 2.0 - Cylinder 3.0 - Sphere
<u>Card 4</u>	6E12	1-72	CEG(I)	Broad group energy boundaries: Lower energy boundary, in electron volts and in decreasing magnitude, 6 values per card for as many broad groups as given by PNOAG, Cols. 13- 24 of Card 3. (See energy group structure for fine groups in the Appendix A).

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 5A</u>	6E12	1-72	AJ(I)	Fine group currents: (Needed only if WTP = 4.0 or 5.0 in cols. 1-12 of Card 2). Fine group currents to be read in, 6 per card, 68 total.
<u>Card 5B</u>	6E12	1-72	APHI(I)	Fine group fluxes: (Needed only if WTP = 3.0, 4.0, or 5.0 in cols. 1-12 of Card 2). Fine group fluxes to be read in, 6 per card, 68 total.

Nuclide Data Cards: A set of cards 6-8 must be supplied in order, as needed, for each nuclide. The sets must be arranged in ascending order of nuclide identification number. See Appendix A for a list of nuclide identification numbers.

<u>Card 6</u>	E12	1-12	PMANU (MANU)	Nuclide identification number
	E12	13-24	ADEN	Nuclide density per barn-cm
	E12	25-36	SSON	Self-shielding factor input specification 0.0 - No (self-shielding is not allowed in burnup mode). 1.0 - Yes (self-shielding is allowed in non-burnup and HTH mode).
	E12	37-48	HATSS	Self-shielding factor type specification (needed if 1.0 in cols. 25-36). 0.0 - Broad group 1.0 - Fine group

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 6</u> (contd.)	E12	49-60	AMOD	Admixed moderator mass (neutron mass units). If this entry is included, the admixed moderator is to be treated in intermediate resonance calculation. Not used if the nuclide does not require Card 8 data.
<u>Card 7</u>	6E12	1-72	PSFS(I)	Self-shielding factors: Needed only if SS0N = 1.0, (cols. 25-36 of Card 6). The number of self-shielding factors to be read in, 6 per card, is determined by the entry HATSS (cols. 37-48 of Card 6). If self-shielding is by broad group, HATSS = 0.0, then PNOAG values (cols. 13-24 of Card 3) are needed. If self-shielding is by fine group, HATSS = 1.0, then 68 factors must be read in.
<u>Card 8</u>	Resonance integral data: (Needed only if nuclide requires a resonance integral calculation. Such nuclides are indicated by an asterisk in the list of identification numbers; see Appendix A).			
	E12	1-12	SIG(1,1)	σ_m , admixed moderator scattering cross section in barns per atom of this nuclide ($\sigma_m = 0.0$ for pure metal), used in the IM approximation.
	E12	13-24	SIG(2,1)	σ_p , total off-resonance scattering cross sections in barns per atom of this nuclide, used in NR approximations.

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 8</u>				
(contd.)	E12	25-36	SIGU(1)	σ_{meff} , effective total off-resonance scattering cross section in barns per absorber atom of this nuclide, based on Wigner's rational approximation, used in unresolved resonance calculation.
	E12	37-48	AR(1)	Nuclide density of resonance absorber in single equivalent "fuel burnup," per barn-cm.
	E12	49-60	RBAR	Mean chord length, $\bar{\ell}$ of single equivalent "fuel lump," in cm.
	E12	61-72	T(1)	Temperature of "fuel lump" in $^{\circ}\text{K}$.
	A8	73-80	A	The name HRGRES, which is a flag to locate the resonance parameter card at REFIRE update time, must be entered here.

Note: Resonance data cards are updated by REFIRE at the end of each orbit in the following manner:

$$\begin{aligned}
 \text{AR}(\text{new}) &= \left[\text{AR}(\text{old}) / \text{ADEN}(\text{old}) \right] \left[\text{ADEN}(\text{new}) \right] \\
 \sigma_{\text{m}}(\text{new}) &= \left[\text{AR}(\text{old}) / \text{AR}(\text{new}) \right] \left[\sigma_{\text{m}}(\text{old}) \right] \\
 \sigma_{\text{p}}(\text{new}) &= \left[\text{AR}(\text{old}) / \text{AR}(\text{new}) \right] \left[\sigma_{\text{p}}(\text{old}) \right] \\
 \sigma_{\text{meff}}(\text{new}) &= \left[\text{AR}(\text{old}) / \text{AR}(\text{new}) \right] \left[\sigma_{\text{meff}}(\text{old}) \right]
 \end{aligned}$$

where "old" denotes values of the orbit just completed and "new" refers to the orbit for which data is being prepared; ADEN is the nuclide density and AR is the nuclide density of the resonance absorber.

P1 Calculation (Cards 9 and 10 are needed only if columns 1-12 of Card 2 contain 1.0 or 4.0).

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 9</u>	E12	1-12	HATLT	Input control, leakage factors: 0.0 - Broad group 1.0 - Fine group
<u>Card 10</u>	6E12	1-72	AL1(I)	Leakage factors: Leakage factors to be read in, 6 per card, for a total of: PNOAG values (cols. 13-24 in Card 3) If 0.0 in cols. 1-12 of Card 9; 68 values if 1.0 in cols. 1-12 of Card 9.

B1 Calculation (Card 11 is needed only if cols. 1-12 of Card 2 contain 2.0 or 5.0)

<u>Card 11</u>	E12	1-12	TKN	Fourier transform parameter, k, the square root of the buckling.
	E12	13-24	WAG	Control parameter: 0.0 - B1 method 1.0 - P1 Fourier transform method (α_n set to 1.0)

Note: If another HRG case is to be run in non-burnup mode, return to input Card 1.

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 12</u>	A6	1-6	9END	To signify the end of HRG input data, enter either 9END or 9 END. In burnup mode and HTH mode, each case of HRG input will be terminated by a 9END card. In the event multiple HRG cases are to be input in the non-burnup mode, it is necessary to have a 9END card only after the last HRG case.

If IFBURN = 0 or 2, for burnup or HTH mode respectively, then you should proceed to the next subsection (F) which is instruction for the input of THERMOS.

If IFBURN = 1, for non-burnup mode, then you should go to the appropriate subsection; either HRG, THERMOS or HFN, or terminate if there is no more input.

F. THERMOS (LINK 30)- TYPE III CARDS
PROBLEM IDENTIFICATION AND BYPASS

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 1</u>	72H	1-72	----	72 Hollerith character identification with a one in column 1 for program control of printer.
<u>Card 2</u>	2I5	1-5	IDENT	Identification number. If negative or zero, program exits.
		6-10	IBY	Bypass, normally zero. If >0, the cross sections used for the last case will be used again. If < 0, the edit from the last case will be repeated with new parameters.

Note: If IBY > 0, go to Card 19. If IBY < 0, go to Card 23.

PROBLEM SIZE AND CONTROL

<u>Card 3</u>	9I5	1-5	NX	Number of space points ≤ 20
		6-10	IX	Number of speed groups ≤ 30
		11-15	MX	Number of mixtures ≤ 5
		16-20	ISOX	Number of isotopes used in cell from library*
		21-25	ISOXE	Number of isotopes used in edit from library*
		26-30	ICX	Number of isotopes used in cell not from library*
		31-35	ICXE	Number of isotopes used in edit not from library*

* The only restriction on this is that $ISOX + ICX + ISOXE + ICXE \leq 30$.

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 3</u> (contd.)		36-40	NANI	=1 for anisotropy correction to the scattering kernel =0 for isotropic scattering kernel
		31-35	ICONEX	For burnup mode, enter the mix number containing the fuel isotopes to be updated by REFIRE. Not used in the other modes.
<u>Card 4</u>	2011	1-20	MTBL(N) N=1,NX	Mixture number (1-5) assigned to each space point N.

DESCRIPTION OF ISOTOPES USED IN CELL FROM LIBRARY

(IGNORE IF ISOX = 0)

<u>Card 5*</u>	2F5.0	1-5	WSTBA(J)	First ident of J th isotope used in cell.
		6-10	WSTBB(J)	Second ident of J th isotope used in cell.
	MXE10.5	11-20 21-30 etc.	CONCTA(J,M) M=1,MX	Concentration of the J th isotope used in the cell in the M th mixture.
	1E10.5		AMAS(J)	Isotope mass used in mubar calculation if first moment kernel is not available. Repeat Card 5 for J=1, ISOX.

* Note: For the HTH and burnup modes, the isotopes must be input in the same order as HRG.

DESCRIPTION OF ISOTOPES USED IN EDIT FROM LIBRARY

(IGNORE IF ISOXE =0)

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 6</u>	2F5.0	1-5	WSTBE(J)	First ident of J th isotope used in edit.
		6-10	WSTBG(J)	Second ident of J th isotope used in edit.
	1E10.5	11-20	CONCTE(J)	Concentration of J th isotope used in edit.
				Repeat Card 6 for J = 1, ISOXE.

SPEED MESH

(IGNORE IF ISOX + ISOXE ≠ 0)

<u>Card 7</u>	7E10.5	1-10	V(I), I=1, IX	Speed mesh points, v_j , in increasing order.
		11-20		
		etc.		Repeat Card 7 as many times as necessary.
<u>Card 8</u>	7E10.5	1-10	DV(I), I=1, IX	Integration weights for speed mesh.
		11-20		
		etc.		Repeat Card 8 as many times as necessary.

DESCRIPTION OF ISOTOPES USED IN CELL NOT FROM LIBRARY

(IGNORE IF ICX = 0)

Note: Anisotropy correction to the scattering kernel is not made for these isotopes.

<u>Card 9*</u>	2F5.0	1-5	WSTBA(LP)	First ident of the LP th isotope used in cell.
		6-10	WSTBB(LP)	Second ident of the LP th isotope used in cell.
	MXE10.5	11-20	CONCTA(LP,M),	Concentration of the LP th isotope used in mixture M.
		21-30	M=1, MX	
		etc.		
	1E10.5		AMAS(LP)	Mass of the LP th isotope.

* NOTE: For the HTH and burnup modes, the isotopes must be input in the same order as HRG.

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 10</u>	2I5	1-5	NXAT,	= 0, Cross-section input is tabular. $\neq 0$, σ_a and σ_f are $1/v$, and σ_s is constant.
		6-10	NKERT	= 1, Both scattering kernel and cross-section will be computed. = 0, Tabular scatter is used for kernel diagonal term. < 0 , and NXAT = 0, the scattering kernel will be input also.
	E10.5	11-20	TP	Temperature for L^{pth} isotope kernel. (Ignore if NKERT ≤ 1)

IF NXAT $\neq 0$, Cross Sections are input here.

Card 11

11a.	7E10.5	1-10	VALXA	$\sigma_a = \text{VALXA} / V(I)$, $I=1, IX$
		11-20	VALXF	$\sigma_f = \text{VALXF} / V(I)$, $I=1, IX$
		21-30	VNU	v
		31-40	VALXS	$\sigma_s = \text{VALXS}$, $I=1, IX$. (Ignore if NKERT = 1)

IF NXAT = 0, Cross sections are input here.

11b.	7E10.5		XA(I), $I=1, IX$	Tabular absorption cross-sections.
11c.	7E10.5		XF(I), $I=1, IX$	Tabular fission cross-sections.
11d.	E10.5	1-10	VNU	Nu value for thermal fission

IF NKERT < 0 , Scattering kernel is input here.

11e.	7E10.5	1-10	PP(I,J)	Tabular scattering kernel values.
		11-20	$I=1, IX, J=1, IX$	
		etc.		

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
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IF $NKERT \leq 0$, Scattering cross-section is input here.

11f.	7E10.5	1-10 etc.	XS(I), I=1, IX	Tabular scattering cross-section values.
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IF $NKERT = 1$, Scatter kernel and cross-section is computed here.

<u>Card 12</u>	3E10.5	1-10	AT(N)	Cross-Section σ_r used in the n^{th} term of LP^{th} isotope scattering kernel.
		11-20	AMT(N)	Mass used in n^{th} term of LP^{th} isotope scattering kernel.
		21-30	AKT(N)	Value X_n used in n^{th} term of LP^{th} isotope scattering kernel.
				Repeat Card 12 for $N = 1, NKERT$

Cards 9 - 12 are repeated ICX times.

DESCRIPTION OF ISOTOPES USED IN EDIT NOT FROM LIBRARY
(IGNORE IF ICXE = 0)

<u>Card 13</u>	2F5.0	1-5	WSTBE(LP)	First ident of LP^{th} isotope used in edit.
		6-10	WSTBG(LP)	Second ident of LP^{th} isotope used in edit.
	1E10.5	11-20	CONCTE(LP)	Concentration of LP^{th} isotope used in edit.
<u>Card 14</u>	I5	1-5	NXAT	If zero, σ_a for the LP^{th} isotope is tabular. If non-zero, σ_a is $1/v$.
<u>Card 15</u>	7E10.5	1-10 11-20 etc.	VALXA(I)	Microscopic absorption cross section for LP^{th} isotope.
			I=1, IX	If $NXAT \neq 0$, only one number, $\sigma_a(KT_0)$, is read. Repeat Card 15 as many times as necessary.

Cards 13-15 are repeated ICXE times.

SLOWING DOWN SOURCE DATA

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 16</u>	4I5	1-5	NSC	Number of cards (type 18) required for source definition. This entry is normally = 0 since the source for library isotopes is stored on the library tape. If $\neq 0$, these sources are added onto those from tape. Necessary for HRG source computation.
		6-10	NST	If ≤ 0 , a spatially flat source is used. If > 0 , the source distribution, $S_d(r_i)$ is read.
		11-15	NPRNT	$\neq 0$ will print the source term.
		16-20	NGAM	$\neq 0$ compute source from HRG fluxes (For this option the source term is zeroed before computation).
<u>IGNORE Card 17 if NST ≤ 0.</u>				
<u>Card 17</u>	7E10.5	1-10	SD(N)	Spatial source distribution $S_d(r_i)$.
		11-20	N=1,NX	Repeat Card 17 as many times as necessary.
		etc.		
<u>Card 18</u>	1I5	1-5	M	Mixture number (1-5) in which this source is used.
	4E10.5	6-15	AM	Mass used in the calculation of this source.
		16-25	HXS	Microscopic high energy cross section for the source.
		26-35	HCON	Concentration of isotope for this source.
		36-45	TP	Effective temperature of protons. If this error function correction is not used, TP = 0.

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
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Card 18 is repeated until NSC cards have been read.

GEOMETRY DATA FOR EITHER SLAB OR CYLINDRICAL GEOMETRY

<u>Card 19</u>	515	1-5	LEAKT	<p>< 0, Full slab with vacuum boundaries. = 0, Half slab with symmetry and right vacuum boundary or cylinder with vacuum boundary. = 1, slab or cylinder with reflecting boundaries. = 2, Right hand albedoes will be input. (Available only in fast cosine current routines).</p>
		6-10	NXA	Number of regions.
		11-15	NGEOM	<p>= 1, Regular cylindrical geometry with Argonne corrections. = 2, Fast cosine currents; cylindrical geometry; from SRL. = 3, Regular slab geometry with Argonne corrections. = 4, Fast cosine currents; slab geometry; from SRL.</p>
		16-20	NSMR	<p>> 0 gives punched card output of a smeared cell which can be used for region input to a later case.</p>
		21-25	NCUR	<p>= 0, Current calculation using T matrix. = 1, Current calculation utilizing flux gradient calculation.</p>

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>IGNORE Card 20 if LEAKT $\neq$ 2</u>				
<u>Card 20</u>	7E10.5	1-10	REFL(I)	Right hand boundary albedoes.
		11-20	I=1,IX	Input from low to high
		etc.		velocities; as many cards as necessary.
<u>Card 21</u>	2I5	1-5	NRXA	Region number in increasing order.
		6-10	NP	Number of space points in this region.
	1E10.5	11-20	TH	Thickness of this region.

Card 21 is repeated until NXA cards have been read.

ITERATION PARAMETERS

Note: Values in parentheses are "standard"; see ITMAX.

<u>Card 22</u>	5E10.5	1-10	EPS	Neutron density convergence criterion, $\epsilon_r (= 10^{-5})$.
		11-20	RELC	Initial overrelaxation factor, $\omega_0 (= 1.0)$. (If the anisotropy scattering is made RELC = 1.0).
		21-30	EPSG	Extrapolation criterion, $\epsilon_e (= 0.05)$.
		31-40	OVERX	Maximum extrapolation factor (= 100.).
		41-50	FACTOR	Under extrapolation factor (= 1.00).

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 22</u>				
(Contd)	4I5	51-55	ITBG	Minimum iterations before extrapolation, $\ell_b (= 5)$. (If anisotropy corr. ITBG = ITMAX + 1 shuts off all extrapolation.)
		56-60	LCMX	Number of overrelaxation factors tested, $\ell_e (= 5)$.
		61-65	ITDM	Minimum delay between extrapolations, $\ell_d (= 5)$.
		66-70	ITMAX	Maximum number of iterations allowed (= 100). If ITMAX ≤ 0 , all options on this card are ignored and the variables set to a standard value.
	I2	71-72	IPT	If > 0 , record of each iteration is printed. If ≤ 0 , print is omitted (=0).
<u>Card 23</u>	1I5	1-5	IXPCM	Number of energy intervals J over which edit is desired ≤ 5 . If more edits are desired, see Card 2. If IXPCM = 0, then the code sets IXPCM = 1, NLOW(1) = 0, IXPT(1) = 30; thereby producing one edit over all 30 energies.
	2I5	6-10	NLOW(J)	Index of lower bound for edit integral.
		11-15	IXPT(J)	Index of upper bound for edit integral.

Repeat variables NLOW(J) and IXPT(J) in pairs on card 23 for J=1, IXPCM.

<u>Card No.</u>	<u>Format</u>	<u>Colm.</u>	<u>Variable Entry</u>	<u>Description</u>
<u>Card 24</u>	2011	1-20	NRTBL(N), N=1,NX	An integer (<10) is assigned to each space point. A sequence of the same integer defines an edit region. Spatial averages are done in an edit region.

Note: If more THERMOS cases are to be run in non-burnup mode, then return to Card 1. If this is the last case in the non-burnup mode, go to Card 27. If HTH is to be executed with no HFN information produced, then go to Card 27. For all other cases continue with Card 25.

<u>Card 25</u>	12A6	1-6 7-12 13-18	(NAMES(I,J), I=1,2), J=1,ISOX+ICX etc.	Names (2A6 per isotope) for the HFN microscopic elements. These Names represent the isotopes in the sequence that they appear in the input.
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Note: If the variable XHFN in the FIREUP input is 0 or 3, then Card 25 is eliminated. Card 26 is required only if XHFN = 3,4 or 5.

<u>Card 26</u>	2A6	1-6 7-12	NAMES(I), I=1,2	Name for the macroscopic HFN cell data block.
<u>Card 27</u>	A6	1-6	9END	To signify the end of THERMOS input data, enter 9END or 9 END.

When ZODIAC-G is run in the burnup or HTH mode, the last page of each case of THERMOS output contains a table of material order for check purposes. This allows comparison of HRG, THERMOS and HFN material order as specified in the input data. If a dissimilar order exists and was not expected, then the improper cross sections have been paired for HFN input and this should be corrected. As a special case, you could have a seemingly erroneous order when different temperatures of the same isotope are used in THERMOS. Then dummy HRG isotopes must be used to keep the ordering scheme correct.

If IFBURN = 0 or 2, for burnup or HTH mode respectively, then you should return to subsection (E) for HRG input for another region; or proceed to the next subsection (G) which is the instruction for the input of HFN.

If IFBURN = 1, for non-burnup mode, then you should go to the appropriate subsection; either HRG, THERMOS or HFN, or terminate if there is no more input.

G. HFN(LINK 05) - TYPE IV CARDS

The version of HFN in ZODIAC-G includes all options of standard HFN:⁽⁵⁾ HFN Data Tape (HFNDT) updating, flux gradients, criticality search, etc. It differs from standard HFN in two features: (1) a larger in-core library permits it to handle many more isotopes per case: (2) a single buckling is entered for all groups. HFN data tapes for ZODIAC-G have absorption cross sections in the old buckling slot.

The required cross section library may be in one of two forms: (1) a previously prepared HFNDT; (2) cards of LISTV format, included within the HFN case. The library source is specified by input option.

All HFN input is in LISTV format. Because of the enlarged in-core library, many input locations are different from previous HFN locations. Format is the entry in column 1 of the data card. Loc is the entry in columns 6-10. These input instructions are ordered by topic according to ascending values of Loc, except in some infrequent cases. I have grouped values of Loc that are associated with each other together. For example, if a value of Loc is a switch which determines a further choice of input, then all associated values of Loc are grouped together.

GROUP STRUCTURE

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	
1	1	N_1	Number of energy groups ($1 < N_1 \leq 20$).
1	2	N_2	<p>= 0, Scattering transfer can take neutrons only from a group to the next lower energy (higher indexed) group.</p> <p>$\leq N_1$, Neutrons may be scattered from any group into any lower energy group. In addition, neutrons may be upscattered from any lower energy group into group N, where $N > N_2$; i.e., N_2 is the index of the first thermal group.</p> <p>Example: In a five-group problem with two thermal groups, $N_1 = 5$ and $N_2 = 4$.</p>

EXTERNAL SOURCE SPECIFICATIONS

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
1	3	N_3	<p>= 0, All information on external sources is input, by space points, into locations 15551 through 17650. This option includes the case where no external source is present.</p> <p>= 1, The external source to the right of each space point, SP_i, is input for all points. The program will set the source to the left of the point, SM_i, equal to SP_i unless a non-zero value for SM_i is input.</p> <p>=2, The external source is constant within each region. The regional values of the external source are entered in Locations 17651 through 17700.</p>
0	15551	SP_1	External source to right of HFN mesh point number one.
0	15552	SP_2	External source to right of HFN mesh point number two.
		etc.	

Note: Input to SP array is destroyed if $N_3 = 2$, specifying a region-wise constant source.

0	16601	SM_2	External source to left of HFN mesh point number two.
0	16602	SM_3	External source to left of HFN mesh point number three.
		etc.	

Note: Input to SM array is destroyed if $N_3 = 1$, specifying $SM_i = SP_i$, or if $N_3 = 2$.

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
0	17651	SOURCE ₁	Strength of spatially constant source in region one.
0	17652	SOURCE ₂	
	etc.		

Note: The SOURCE array is ignored unless $N_3 = 2$.

DATA TAPE MANIPULATION

1	4	N_4	<p>= 0, All cross section data is input from cards, and no HFN Data Tape is to be used.</p> <p>> 0, An output HFNDT will be written on unit IT2 (Loc. 6), including all materials presently in the in-core library. If there is an input HFNDT on unit IT1 (Loc. 5), information from the input HFNDT will also be included. In case data for a given material and group structure are found both on the input HFNDT and in the in-core library, the in-core library data will be written and the old tape data omitted. Use Locs. 15551-17550 to enter reference records (10 words/material) which identify the materials on the tape. Reference record for material 1 is entered in Locs. 15551-15560, followed by reference record for material 2 in Locs. 15561-15570, etc.</p> <p>< 0, The input HFNDT on unit IT1 (Loc. 5) will be scanned for materials which are specified as being in the in-core library (by having names in Locs. 15001-15400). Data for a material will be read from the HFNDT and placed in the in-core library if both group structure and two-word name are matched.</p>
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<u>Format</u>	<u>Loc.</u>	<u>Variable Entry</u>	<u>Description</u>
1	5	IT1	<p>= 0, No input HFNDT is mounted.</p> <p>> 0, An input HFNDT is mounted on unit IT1. IT1 = 12 for burnup and WITTLE modes</p> <p><u>Note:</u> If an FCC library is used, FIREUP writes this library to unit 25 (drum) and sets IT1 = 25.</p>
1	6	IT2	<p>= 0, No output HFNDT will be written.</p> <p>> 0, An output HFNDT will be written on unit IT2 (see Loc. 4 for details). Suggest IT2 = 7 (D).</p>
<p><u>Note:</u> After an updating pass has been completed, the contents of Locs. 5 and 6 are interchanged. Thus, in the absence of over-riding input, successive updating passes will result in the latest data tape alternating between the two units.</p>			
1	7	N ₇	<p>This option, indicating that N₇ materials are to be deleted during updating of the HFNDT, is presently inoperative.</p>
1	8	N ₈	<p>= 0, When updating an HFNDT, list the names, group structure, and references for all materials placed on the tape.</p> <p>= 1, List the names, group structure, references, and the cross sections placed on the HFNDT.</p>
1	9	N ₉	<p>This entry, concerned with halts for mounting and dismounting tapes, is inoperative.</p>

CONTROL INFORMATION

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
1	10	N_{10}	<p>= 0, This HFN case will be run, after which Loc. 47 will be interrogated to determine which link to call.</p> <p>> 0, After getting cross sections from the HFNDT, the program will return for more input before running case. In this manner, individual neutron parameters from the HFNDT may be changed before use. N_{10} is reset to zero after testing.</p> <p>< 0, After getting cross sections from the HFNDT, the program will first mix, then return for more card input before running a case. N_{10} is reset to zero after testing.</p>
1	11	N_{11}	<p>= 0, No effect.</p> <p>> 0, Clear all data from core immediately, then return to read more input before running. Any input read in the same case with this entry will also be cleared to zero.</p>
1	12	N_{12}	<p>= 0, Save fluxes and fission densities computed for this case as a starting point for the next case. Fluxes and fission densities are cleared between orbits in burnup and WITTLE modes.</p> <p>= 1, After this case is run, clear fluxes, fission densities, and pointwise external sources. Following cases start from flat (or input) flux guess.</p>

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
1	22	NOKSDT	Burnup over-ride switch, functional for both burn-up and non-burnup cases. NOKSDT = 0 is normal entry (burnup with only 1 HFN case); other situations may require a non-zero entry. See also Loc. 49.
		NOKSDT	<p>= 0, Write cross-sections, fluxes, and concentrations from this HFN case to the drum, whether or not this is a burnup case. Use NOKSDT = 0 only for burnup and only for the HFN case which requires new concentrations from REFIRE.</p> <p>> 0, Do not write burnup information to the drum, whether or not this is a burnup case. Use NOKSDT > 0 for</p> <ol style="list-style-type: none"> 1. All HFN cases of a non-burnup or HTH run solely as a time-saving device. 2. All HFN cases of a burnup run except the HFN case which must receive new concentrations at REFIRE time.
1	47	LINK	<p>= 0, Call CLERK after completion of this HFN case.</p> <p>< 0, After completion of this case, overload another case of HFN input and process it.</p> <p>= 5, After completion of this case, clear core, then read and process a new HFN case.</p>
1	48	NCS	<p>= 0, No FCC Library</p> <p>> 0, FCC Library having NCS cross sections for each group follows 9-card of this case.</p>

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
1	49	N ₄₉	<p>= 0, No effect. This entry is sufficient under any of these conditions</p> <ol style="list-style-type: none"> 1. No burnup 2. Burnup with only one HFN case 3. Burnup with multiple HFN cases, of which the first one is to receive new concentrations at the end of the burnup step. <p>≠ 0, Modify concentrations of this HFN case at end of the burnup step. It is necessary to use this entry only if there are multiple HFN cases and the case to be modified is not the first.</p>

CASE SPECIFICATIONS

1	13	N ₁₃	<p>= 0, Slab geometry</p> <p>= 1, Cylindrical geometry</p> <p>= 2, Spherical geometry</p>
1	14	NR	<p>Number of regions:</p> <p>(0 < NR ≤ 20) for burnup cases.</p> <p>(0 < NR ≤ 50) for non-burnup cases.</p>
1	15	N ₁₅	<p>= 0, Compute direct flux.</p> <p>= 1, Compute adjoint flux.</p> <p>= 2, Compute direct flux, adjoint flux and their gradients at each point. Also, compute volume integrals of the form.</p> $\int \nabla \phi_i^\dagger \nabla \phi_j \, dV \quad \text{and} \quad \int \phi_i^\dagger \phi_j \, dV.$ <p>N₁₅ will be set to zero at the completion of this sequence.</p>

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
1	28	N_{28}	<p>= 0, No effect.</p> <p>= 1, Compute gradients of the converged (direct or adjoint) fluxes. If $N_{15} = 2$, this entry is not needed.</p>
1	35	N_{35}	<p>= 0, A fission neutron production calculation will be performed using $\nu\Sigma_f$. Do not use $N_{35} = 0$ for burnup cases.</p> <p>= 1, This entry should be used for burnup cases. A true power density calculation will be performed using the fission cross sections located where the in-scattering cross sections normally are. HFNDTs have the fission cross sections in the appropriate place, and contain the transfer matrix.</p>

CRITICALITY SEARCH

1	16	N_{16}	<p>= 0, No criticality search; locations 17-21 will be ignored.</p> <p>> 0, Location of parameter to be varied in an attempt to obtain a given multiplication, k. The first calculation of the neutron eigenvalue, k_1, is made with the value of the variable parameter specified by N_{16}. For the calculation of k_2, the variable parameter is modified by a procedure using $(\Delta k)^{-1}(\text{Loc. 21})$. Successive calculations of k_i are made with program-estimated values of the variable parameter. After each calculation, k_i is compared to the desired k_0 in Loc. 19. The criticality search is deemed successful when $k_0 - k_i < dk$ (Loc. 20). The search is terminated after N_{18} calculations if this convergence criterion has not been met.</p>
---	----	----------	--

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
			Each calculation of k involving a new value of variable parameter will produce a new case of output; no input is read between these cases.
1	17	N_{17}	<p>= 0, Variable parameter has no effect on mixtures.</p> <p>≠ 0, Remix all materials each time the parameter is varied.</p>
1	18	N_{18}	> 2, Maximum number of calculations to be performed in the attempt to produce the desired multiplication, k_0 . See Loc. 16.
0	19	k_0	Desired multiplication. See Loc. 16.
0	20	dk	Accuracy in k required for a successful search. See Loc. 16.
0	21	$(\Delta k)^{-1}$	Estimate of parameter change which will <u>increase</u> k by one percent. See Loc. 16.

BOUNDARY CONDITIONS

1	27	N_{27}	<p>= 0, Normal entry. See Loc. 15401-15440.</p> <p>= 1, The "albedo" is interpreted as being a fixed extrapolation distance, in cm.</p>
---	----	----------	---

$$\nabla \phi_0 = \frac{\phi_0}{A^-} + \frac{J_{in}^-}{D_0}$$

Refer to equation (13) of HW-71545 for further explanation.

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
			=-1, Cohen's formula for the extrapolation distance from a curved surface is used to compute the <u>right exterior</u> boundary (only) condition:
			$\lambda = \frac{A^+}{1 + 1.065669 \frac{D_{NR}}{R_{NR}}}$
			where the right "albedo" is the extrapolation distance, in transport mean free paths, from a plane boundary (equals 2/3 according to diffusion theory).
0	15401	ALFT ₁	Left exterior boundary albedo for groups 1 through N ₁ .
	15402	ALFT ₂	
	.	.	
	.	.	
	15420	etc.	
0	15421	ARGT ₁	Right exterior boundary albedo for groups 1 through N ₁ .
	15422	ARGT ₂	
	.	.	
	.	.	
	15440	etc.	
Note: An albedo of 1.0 denotes a center of symmetry. A zero albedo is used at the physical boundary of a reactor. An albedo of -1.0 is used when the dimensions given are extrapolated dimensions.			
0	15441	SURSL ₁	Left exterior boundary surface source for groups 1 to N ₁ .
	15442	SURSL ₂	
	.	.	
	.	.	
	15460	etc.	

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
0	15461	SURSR ₁	Right exterior boundary surface source for groups 1 to N ₁ .
	15462	SURSR ₂	
	.	.	
	.	.	
	15480	etc.	

DETECTOR TRAVERSE

1	29	N ₂₉	<p>= 0, Do not normalize computed activities.</p> <p>> 0, Normalize each traverse to 1.0 at HFN mesh point number N₂₉.</p> <p>< 0, Normalize all traverses so that the activity for traverse number one is unity at mesh point number N₂₉. The same normalizing factor will be used on all traverses.</p>
1	30	Not used.	
1	31	N ₃₁	<p>> 0, Number of traverses N₃₁ ≤ 10; also N₃₁ * (No. groups) ≤ 100.</p>
1	32	N ₃₂	<p>= 0, Traverse ratios, for first traverse, will not be computed.</p> <p>> 0, At each mesh point, compute the activity ratio for traverse one:</p>

$$\frac{A_1}{A_{N_{32}}} \quad (\text{before normalization})$$

< 0, At each mesh point, compute the activity fraction for traverse one;

$$\frac{A_1}{A_{N_{32}}} - 1 (\text{before normalization})$$

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
1	33	N_{33}	Same logic as location 32, except pertains to traverse number two.
1	34-41		etc.
2	19901	DETECT ₁	12 Hollerith name for first detector material.
2	19903	DETECT ₂	12 Hollerith name for second detector material.
	.		
	.		
	19920		etc.
0	19801	ACTCRS _{1,1}	Group one activation cross section for detector type one.
0	19802	ACTCRS _{1,2}	Group two activation cross section for detector type one.
	.		
	.		
	.		
	etc.		
0	19801 + (no. grps)	ACTCRS _{2,1}	Group one activation cross section for detector type two. Continue for all groups for each detector.

FLUX AND POWER NORMALIZATION

0	42	A	<p>= 0.0, Normalize "power" (fission neutron production rate) so that average over core region(s) is 1.0, for output.</p> <p>> 0.0, Normalize core power to total output of A megawatts (for purpose of converting to neutrons to Mw, HFN assumes $\nu = 2.46$, with 200 Mev/fission). This entry does not influence the burnup calculation.</p>
1	43	N_{43}	= 0, Normalize fluxes, for output, to be consistent with power.

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
		N_{43}	> 0 , Normalize flux, group N_{43} , to unity at spatial mesh point number N_{44} .
1	44	N_{44}	Mesh point number for flux normalization.
<u>GROUP BUCKLING</u>			
0	45	HFNBCK	Buckling, B^2 , for all groups. Group independent buckling is also possible if B^2 is input as a change case in the second position of the cross-section array for each energy group.

ITERATION CONTROLS

1	53	LMAX	Maximum number of iterations permissible in eigenvalue search. If omitted, LMAX will be set to 100.
	54-56		Unused for input.
0	57	EPSK	Convergence criterion for eigenvalue search. The problem is assumed to have converged if the fractional difference between system eigenvalues on two successive iterations is less than EPSK. If omitted, EPSK will be set to 1.0×10^{-7} .
0	58	EPSPHI	Convergence criterion for eigenvalue search. The maximum fractional change in flux at any point, in any group, on two successive iterations must be less than EPSPHI for convergence. If omitted, EPSPHI will be set to 1.0×10^{-4} .

OUTPUT CONTROL

Suppress Selected Portions of Output by Entering a Non-zero Number in Locations Indicated.

<u>Format</u>	<u>Loc.</u>	<u>Description</u>
1	62	Transfer matrices.
1	63	Few group parameters.
1	64	Pointwise flux and fission density.
1	65	Calculated reactivity as a function of iteration, except final iteration (neg. entry suppresses all reactivities).
1	66	Average fluxes, fission densities, and leakage cross sections computed therefrom.
1	67	Pointwise gradient.
1	68	Perturbation integrals.
1	69	Direct-adjoint flux gradient product (point-and group-wise).
1	70	Direct-adjoint flux product (point- and group-wise).
1	71	All traverse output.
1	72	Flux adjoint product traverse only.
1	73	Average traverse activity.
1	74	Unnormalized traverse activity.
1	75	Normalized traverse activity.
1	76	Traverse ratio data.
1	77	Albedoes, region radii, calculation description.

JOB IDENTIFICATION

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
2	101	ENG	User's name, in 18 or less characters (will appear in output headings).
2	104	DATE	Date, in 18 or less characters (will appear in output headings).
2	107	CASE	Case identification, in 24 or less characters (will appear in output headings).

REGION SPECIFICATIONS

2	111-112	REG ₁	Name of the material in each region, two words per region. If region j is to be mixed ($N47_j \neq 0$), a unique name should be given here; this is the usual circumstance for burnup cases. If region j is not to be mixed ($N47_j = 0$), the name must already be present in the in-core library. The name will be in the in-core library if it is (1) identical to a two-word entry in the COMP array or (2) identical to the two-word name of a previously-mixed material.
	113-114	REG ₂	
	115-116	REG ₃	
	.	.	
	.	.	
	209-210	etc.	
0	211	EN ₁	Number of mesh intervals in region j. This does not include the extra mesh interval inserted near the left boundary. Entering a negative EN _j indicates that region j is a portion of the core (for core power calculation purposes), in which case, the number of mesh intervals in region j is taken to be $ EN_j $.
	212	EN ₂	
	.	.	
	.	.	
	.	.	
	260	etc.	
0	261	R ₀	Inside radius of region 1 (inner region).
	262	R ₁	Outside radius of region 1.

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
0	263	R ₂	Outside radius of region 2.
.	.	.	.
.	.	.	.
.	.	.	.
.	311	.	Etc.
1	351	N47 _j	Mixing code for region j:
.	352	N47 ₂	If N47 _j = 0, a material by the two-word name entered in REG _j (Locations 111-210) is already in the in-core library. It has been placed there by one of three possible means: (1) the cross sections were called in from an HFN Data Tape by an entry of identical name somewhere in the COMP array (Locations 15001-15400); or (2)
.	.	.	the cross sections were read in on cards and a corresponding entry made in the COMP array; or
.	.	.	(3) a material by this name was previously mixed.
.	.	.	If N47 _j > 0, the material in region J is to be manufactured (mixed) from a mixture of N47 _j
.	.	.	materials, the names and proportions of which are specified by the PART and VOL arrays. In-
.	.	.	core library storage will be set aside immediately following the materials read in from cards or the HFNDT, and cleared for a material of the name given in REG _j .
.	.	.	The cross sections for the mixture are computed by:
.	.	.	$\Sigma_{\text{mixture}} = \sum_{k=m+1}^{k=m+N47_j} (\text{VOL}_k)(\Sigma_k)$

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
	.	.	If $N47_j = 0$, then enter the material name
	.	.	for REG_j in the PART array and leave a blank
	.	.	space in the VOL array in the comparable
	.	.	position. This is necessary because of the
	.	.	pseudo-mix which is used to get the buckling.
	799-800	etc.	See description of N47 (locations 351-400).
0	801	VOL_1	Volume fractions (or nuclide densities) of
	802	VOL_2	mixture components. VOL_k is the fraction of
	.	.	the mixture which is composed of material
	.	.	$PART_k$.
	.	.	
	1000	etc.	

Note: In burnup cases, any isotope which appears in the CLERKC case for region j must be a mixture component of region j in HFN. Therefore, it must have a name, $PART_k$, and a concentration, VOL_k , and must be counted in computing $N47_j$. Enter a small number (suggested: 1.0×10^{-10} to 1.0×10^{-20}) as VOL_k for isotopes whose initial concentration should be zero. If VOL_k is entered as 0.0 for any burnable isotope, that isotope will be ignored in the CLERKC and ALCHEMY calculations.

CROSS-SECTION LIBRARY-DATA

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
0	1001-14000	D	In-core library. A definitive description of in-core library requirements is not necessary if an HFN data tape is used. If cross section input is on cards, then the following words of wisdom should be read.

In order to save storage, the cross sections used by HFN are stored in a "packed" array. This means that data for material one is entered in consecutive locations (starting with location 1001) until all data for that material has been entered. Data for the second material follows immediately, regardless of the number of groups being used. Thirteen thousand (13000) memory locations have been set aside for cross section storage, with space available for 200 material names. Using this packing scheme, many materials may be used in few-group calculations, without suffering from the severe limitations imposed when a complex group structure is used. Assuming a full scattering matrix, the following numbers of materials are allowed for various numbers of groups.

<u>Number of Groups</u>	<u>Maximum Number of Materials</u>
4	200
6	200
10	112
14	68
20	40

There are seven parameters, for each group, which are herein referred to as the "few group" parameters. They are listed in the order in which they are stored in the in-core library for each material and group.

- (1) Diffusion coefficient, D^i
- (2) Absorption cross section, σ_a^i
- (3) Removal cross section, σ_r^i

- (4) Nu times fission cross section, $\nu\sigma_f^i$
- (5) Fraction of fission neutrons born into the group, χ^i
- (6) Fission cross section, σ_f^i
- (7) Fraction of fixed external source neutrons born into group, χ_{ext}^i

Items 2 and 6 are different than the entries of the normal version of HFN.

The second parameter was the perpendicular buckling entry and the sixth parameter was the in-scattering cross section (for slowing from next higher energy group when transfer matrix is not used). The current entries for 2 and 6 are necessary for the burnup calculation but they are stored in temporary arrays. This allows the older few-group ordering to be used by entering its input data as change cases. For example, energy dependent B^2 can be entered as a change case, to be used in the diffusion calculation instead of a constant B^2 over all broad group energies.

The few group parameters for each group, starting with group 1, are entered into successive locations starting with location 1001. If the single group slowing-down option ($N_2 = 0$) has been selected, the group 1 few group parameters for material two immediately follow the lowest energy group parameters for material one.

If a multi-group ($N_2 > 0$) scattering model has been specified, the scattering transfer matrix must follow the few group parameters for the lowest energy group. The data for material two will immediately follow the transfer matrix for material one.

The first "row" of the transfer matrix consists of all possible cross sections which can account for scattering into group one, including self-scattering (from one to one). The second row is similarly defined. The lengths of the various rows are determined by the entries in locations one and two. The row for epithermal group i ($1 \leq i < N_2$) has i entries, $(\Sigma_{1 \rightarrow i}) \Sigma_{2 \rightarrow i}) \dots, \Sigma_{i \rightarrow i})$ which give the probabilities for transfer from higher, or the same, energies. The row for thermal group i , on the other hand, consists of one entry for each energy group, representing the fact that, using the present definition of "thermal" group i ,

a neutron may be scattered from any group into group i , so that ($N_2 \leq i \leq N_1$) the i -th transfer now consists of $\Sigma_1 \rightarrow i$, $\Sigma_2 \rightarrow i$, ..., $\Sigma_{N_1} \rightarrow i$. The first element of each row, $\Sigma_1 \rightarrow i + 1$ immediately follows the last element of the previous row, $\Sigma_{N_1} \rightarrow i$, or $\Sigma_i \rightarrow i$. For example, if five groups, of which three are thermal, have been specified, the transfer matrix for material number one would be:

<u>Row No.</u>	<u>Location of 1st Element of Row</u>	<u>Entries</u>
1	1036	$\Sigma_1 \rightarrow 1$
2	1037	$\Sigma_1 \rightarrow 2$, $\Sigma_2 \rightarrow 2$
3	1039	$\Sigma_1 \rightarrow 3$, $\Sigma_2 \rightarrow 3$, $\Sigma_3 \rightarrow 3$, $\Sigma_4 \rightarrow 3$, $\Sigma_5 \rightarrow 3$
4	1044	$\Sigma_1 \rightarrow 4$, $\Sigma_2 \rightarrow 4$, $\Sigma_3 \rightarrow 4$, $\Sigma_4 \rightarrow 4$, $\Sigma_5 \rightarrow 4$
5	1049	$\Sigma_1 \rightarrow 5$, $\Sigma_2 \rightarrow 5$, $\Sigma_3 \rightarrow 5$, $\Sigma_4 \rightarrow 5$, $\Sigma_5 \rightarrow 5$

(D^1 for material two would be in location 1054.)

When data is entered sequentially, it is fairly easy to keep track of what cross sections go into what locations. Sometimes, however, data is not entered sequentially, in which case it is handy to know the amount of storage required by the constants for each material. If single group slowing-down has been specified, this is simply,

$$k = 7 * N_1.$$

If multigroup slowing-down is specified,

$$k = 7 * N_1 + (N_1 - N_2 + 1) * N_1 + \frac{(N_2 - 1 * N_2)}{2}$$

The maximum number of materials which may be stored in the in-core library at one time is

$$L = 200 \text{ if } k \leq 65$$

$$L = (\text{integral part of}) \frac{13000}{k} \text{ if } k > 65$$

MATERIALS IDENTIFICATION

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
2	15001-15002	COMP ₁	Names of materials in the in-core library, two words per material. These names are dealer's choice, but must remain consistent wherever the name is used in the data input. If the cross sections are pulled from an HFNDT made by THERMOS, the form of these names is strictly defined: The first and second words must be identical in spelling and spacing to the name used in the THERMOS input data.
	15003-15004	COMP ₂	
	15005-15006	COMP ₃	
	.	.	
	.	.	
	.	.	
	.	.	
	15399-15400	etc.	

9

To end a case of HFN input, use the control card with 9 in column 1, as described in the description of LISTV input cards. In the last case of HFN input this 9 card is replaced by a card with either 9END or 9 END.

HFN LOCATION RESUME

Given below is a summary of variable locations in the version of HFN in ZODIAC-G that differ from the location index in stand-alone versions of HFN.

<u>Old Loc.</u>	<u>ZODIAC-G Loc</u>	<u>ZODIAC-G Dimens.</u>	<u>ZODIAC-G Variable</u>
10	10	1	LOC 10 = 0, run case. > 0, read input HFNDT and go back for more input before running case. < 0, read input HFNDT, mix, and go back for more input before running.
17380	45	1	LOC 45 is HFN Buckling for all groups.
7	47	1	LOC 47 is link number to call next.
Locations above 100 are changed to allow more materials to be used.			
13872	101	3	ENG
13875	104	3	DATE
13878	107	4	CASE
17581	111	100	REG, two-word region name
17731	211	50	EN, no. of mesh points
17781	261	1	R { inner radius, reg. 1
17782	262	50	outer radius, each reg. } Region specs
20245	351	50	N47, no. mixture components
20295	401	400	PART, 2-word names of mixture mat'ls
20495	801	200	VOL, volume frac's of mixture mat'ls
13881	1001	13000	D, library
17381	15001	400	COMP, 2-word names of lib. mat'ls
20022	15401	20	ALFT
20042	15421	20	ARGT
20062	15441	20	SURF, left
20082	15461	20	SURF, right
17882	15551*	1050	SEXP
18993	16601	1050	SEXM
20195	17651	50	SOURCE, source strength
13752	19801	100	ACTCRS
13852	19901	20	DETECT
			} Traverse data
* Also at 15551 for an update case			
101	15551	2000	REF, material description for use in making up HFNDT

HFN DATA RESUME

Given below is a summary of the locations in common of various types of HFN data.

<u>Subject</u>	<u>Loc.</u>
(1) Group structure	1,2
(2) External Source Specs.	3, 15551-16600, 16601-17650, 17651-17700
(3) Data Tape Manipulation	4, 5, 6, 7, 8, 9
(4) Control Information	10, 11, 12, 22, 47, 48, 49
(5) Case Specifications	13, 14, 15, 28, 35
(6) Criticality Search	16, 17, 18, 19, 20, 21
(7) Boundary Conditions	27, 15401-15420, 15421-15440, 15441-15460, 15461-15480
(8) Detector Traverse	29, 30, 31, 32, 33, 34, 19901-19920, 19801-19900
(9) Flux & Power Normalization	42, 43, 44
(10) Group Buckling	45
(11) Iteration Controls	53, 57, 58
(12) Output Control	62-77
(13) Job Identification	101-110
(14) Region Specifications	111-210, 211-260, 261-311, 351-400 401-800, 801-1000
(15) Cross Section Library	1001-14000
(16) Materials Identification	15001-15400

H. CLERKC (LINK 20) - TYPE V CARDS

Note: All CLERKC input is in LISTV format. Format is the entry in column 1 of the data card. Loc is the location entry in columns 6-10. In addition to the card input described below, region average fluxes and cross sections from HFN are input from drum (LU4).

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
2	1-10	TITLE	Alphanumeric heading information. Appears as heading on CLERKC output and on ALCHEMY output.
0	11	GEOM*	Geometry specification: If slab, GEOM = 1.0 and $V = (D1)(D2)(D3)$ If cylinder, GEOM = 2.0 and $V = (\pi)(D3)(D2^2 - D1^2)$ If sphere, GEOM = 3.0 and $V = (4\pi/3)(D2^3 - D1^3)$
0	12	D1*	Dimension 1
0	13	D2*	Dimension 2
0	14	D3*	Dimension 3
0	15	CPOWER	Total core power level in megawatts. Enter CPOWER only with data of the first burnable region. CPOWER ≥ 0 indicates only one burnable region. CPOWER < 0 indicates that this is the first of more than one burnable region. CPOWER will be used to compute the power split between regions. The results of this calculation will appear at the end of the LU4 input, where the value given in location 15 is the negative of the ALCHEMY flux for that region.

* These data must be entered for all regions, even though the data for region j are identical to that of region j-1. This is necessary because the overload feature of LISTV type input is disabled at the time the power split is being computed.

Note: CLERKC input requires two kinds of time steps:

- (1) ALCHEMY time step: Δt for times at which ALCHEMY is to compute concentrations relative to the time zero.
 - (2) Orbit time step: Δt from one HFN orbit to the next HFN orbit. This time is relative to the first orbit time.
- Both are expressed in the output in terms of time from startup, and neither need be constant. See page 74 for examples.

The following locations are concerned with ALCHEMY time:

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
0	16	STEPS	Number of times at which ALCHEMY is to compute concentrations. If positive, $t(1) = 0.0$, and Δt is entered in Loc. 17. If negative, times are entered in Locs. 1281 through $1280 + \text{STEPS} $.
0	17	DELT	Δt for ALCHEMY (required only if STEPS is positive non-zero).
0	1281-1330	ATIME	Times at which ALCHEMY is to compute concentrations (required only if STEPS is negative).

The following locations are concerned with Orbit Time:

0	18	GBSTEP	Burnup step. If the time interval, Δt , is constant from orbit to orbit, enter Δt here. Orbit 1 will be at $T = 0.0$, and Orbit i at $T = (i-1)\text{GBSTEP}$. If the burnup step is not constant, enter $\text{GBSTEP} = 0.0$ and see Loc. 1331.
0	1331-1350	TSUB0	Burnup time for each orbit. If burnup step is not constant, enter 0.0 at Loc. 18 and the time of Orbit $i+1$ at Loc. $1330+i$. This entry is used in Orbit i to determine which set of concentrations to put on the RDT for input to Orbit $i+1$.

Example (4-orbit case):

Loc. 18	= 0.0	[Orbit 1 always 0.0]
1331	= 10.0	Orbit 2 is at 10.0
1332	= 20.0	Orbit 3 is at 20.0
1333	= 40.0	Orbit 4 is at 40.0
1334	= 60.0	Concentrations from $T=60.0$ will be put on the RDT at the end of Orbit 4.

Note: If the Time of Orbit $i+1$ does not appear in the array of ALCHEMY times for Orbit i , it will be added.

If ALCHEMY times are not the same for all orbits, use Loc. 16 and (17 or 1281) for one orbit. Specify ALCHEMY times for remaining orbits by Locs. 1351-1370 and 1501-1900 in the following manner:

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
1	1351-1370	IWT_i	If $IWT_i = 0$, ALCHEMY times for Orbit i will be as specified by Locs. 16, 17, and 1281-1330. If IWT_i is positive, nonzero, TIMSET(IWT) will be used as the ALCHEMY time set for Orbit i .
0	1501-1520	TIMSET Set 1	An array of ALCHEMY times which may be used for one or more orbits.
0	1521-1540	TIMSET Set 2	
	.	.	
	.	.	
	.	.	
0	1881-1900	TIMSET Set 20	
0	19	ALINK	Number of the link to be called after completion of this CLERKC region. If omitted, ALINK is set to 20.0, and CLERKC looks for more input. Set ALINK = 23.0 in the last CLERKC case input to proceed to ALCHEMY.
0	20	CHAIN	CHAIN will be set to 3.0 internally in CLERKC.
0	21	REG	The HFN region number of this case. Omission or incorrect entry of REG will produce erroneous (and probably obviously erroneous) results.
	22-23		Used for LU4 input.
1	24	IDUMPR	Orbit number. Normally put in by REFIRE. If a restart is necessary without an RDT, then it must be put in by hand.
	25-27		Unused for input.

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
0	28	TIMORB	Real time from time zero for orbit number entered in Loc. 24. Normally put in by REFIRE. If a restart is necessary without an RDT, then it must be put in by hand.
	29-39		Unused for input.
2	40	UNITS	An alphabetic description of the units in which DELT and TIMES are given. If omitted, UNITS will be set to Δ DAYS Δ . Be consistent between selection of time values (HOURS, DAYS, etc.) and UNITS.
	41-440		Used for LU4 input.
2	441-442	ANAME ₁ *	Names of burnable isotopes, two words per name.
	443-444	ANAME ₂	These must be identical in spelling and spacing to the names used in HFN. They need not be in the same order. See Page 73 for a description of the effect of the name FISHIN COUNT.
	.	.	
	.	.	
	.	.	
	479-480	etc.	
0	481	AMASS ₁	Atomic mass of isotopes, in order corresponding to the ANAME array.
	482	AMASS ₂	
	.	.	
	.	.	
	.	.	
	500	etc.	
0	501-520	AMEV*	MeV/fission of isotopes, in order corresponding to the ANAME array.
	521-960		Used for LU4 input. No external input.
1	961	JD(1)	Decay index 1; isotope 1 decays to isotope JD(1).
	962	JD(2)	Decay index 2; isotope 2 decays to isotope JD(2).
	.	.	.
	.	.	.
	.	.	.
	980	JD(20)	Decay index 20; isotope 20 decays to isotope JD(20).

* See footnote, page 66.

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
0	981	YD(1)	Decay constant for isotope 1.
	982	YD(2)	Decay constant for isotope 2.
	.	.	.
	.	.	.
	.	.	.
	1000	YD(20)	Decay constant for isotope 20.

For isotopes having no decay constants, both JD and YD may be omitted; it is not necessary to enter dummy indices or multipliers in any case. The same is true of fission and capture multipliers. See Page 73 for description of the specialized use of fission multipliers.

JF(i,j) is a fission product of isotope j.

1	1001	JF(1,1)	Fission-multiplier index 1 for isotope 1.
	1002	JF(2,1)	Fission-multiplier index 2 for isotope 1.
	1003	JF(3,1)	Fission-multiplier index 3 for isotope 1.
	1004	JF(4,1)	Fission-multiplier index 4 for isotope 1.
	1005	JF(5,1)	Fission-multiplier index 5 for isotope 1.
	1006	JF(1,2)	Fission-multiplier index 1 for isotope 2.
	.	.	.
	.	.	.
	1010	JF(5,2)	Fission-multiplier index 5 for isotope 2.
	1011	JF(1,3)	Fission-multiplier index 1 for isotope 3.
	.	.	.
	.	.	.
	1096	JF(1,20)	Fission-multiplier index 1 for isotope 20.
	1097	JF(2,20)	Fission-multiplier index 2 for isotope 20.
	.	.	.
	.	.	.
	1100	JF(5,20)	Fission-multiplier index 5 for isotope 20.

<u>Format</u>	<u>Loc</u>	<u>Variable Entry</u>	<u>Description</u>
0	1101 -1200	YF(i,j)	Fission yield multiplier i for isotope j. YF(i,j) atoms of isotope JF(i,j) are created for each atom of isotope j which fissions. Enter YF(i,j) exactly 100 locations higher than JF(i,j).
JC(i,j) is the product of a neutron capture by isotope j. Each isotope j can capture neutrons which produce up to two new isotopes.			
1	1201	JC(1,1)	Capture-multiplier index 1 for isotope 1.
	1202	JC(2,1)	Capture-multiplier index 2 for isotope 1.
	1203	JC(1,2)	Capture-multiplier index 1 for isotope 2.
	.	.	.
	.	.	.
	1239	JC(1,20)	Capture-multiplier index 1 for isotope 20.
	1240	JC(2,20)	Capture-multiplier index 2 for isotope 20.
0	1241 -1280	YC(i,j)	Capture yield multiplier i for isotope j. YC(i,j) atoms of isotope JC(i,j) are created for each neutron capture by isotope j. Enter YC(i,j) exactly 40 locations higher than JC(i,j).

To end a case of CLERKC input you use the control card with 9 in column 1, as described in the description of LISTV input cards. In the last case of CLERKC input this 9 card is replaced by a card with either 9END or 9 END.

Input from LU 4 appears on the output at the end of the LU 5 (NUDATA) input. This information is passed to CLERKC from HFNB via drum (LU 10). The locations of these data are given here to assist the user in checking his output.

<u>Location</u>	<u>Input from LU 4</u>
0041	Group 1 σ_a for isotope 1
0042	Group 2 σ_a for isotope 1
.	.
.	.
.	.
0060	Group 20 σ_a for isotope 1
0061	Group 1 σ_a for isotope 2
.	.
0081	Group 1 σ_a for isotope 3
.	.
.	.
.	.
0440	Group 20 σ_a for isotope 20
0521	Group 1 region average flux
0522	Group 2 region average flux
.	.
.	.
.	.
0540	Group 20 region average flux
0541	Group 1 σ_f for isotope 1
0542	Group 2 σ_f for isotope 1
.	.
.	.
.	.
0560	Group 20 σ_f for isotope 1
0561	Group 1 σ_f for isotope 2
.	.

<u>Location</u>	<u>Input from Lu 4 (continued)</u>
0581	Group 1 σ_f for isotope 3
.	.
.	.
.	.
0940	Group 20 σ_f for isotope 20
0941	Concentration of isotope 1 in nuclei/barn-cm.
0942	Concentration of isotope 2 in nuclei/barn-cm.
.	.
.	.
.	.
0960	Concentration of isotope 20 in nuclei/barn-cm.
0022	Number of groups.
0023	Number of isotopes in this CLERKC region.
0015	For multi-region burnup only, the negative of the ALCHEMY flux appears here for each region.

Fission products are summed by means of a fission multiplier into an isotope named FISHIN COUNT, which may be located anywhere within the ANAME array. FISHIN COUNT is the accumulated number of fissions, of all fissioning isotopes in the region, that have occurred for the selected time interval. The use of this specific name generates one line of ALCHEMY output giving effective full power hours, which is usually slightly different than the requested time interval because constant power is assumed. This line does not appear if no isotope named FISHIN COUNT is entered. To use this feature, appropriate entries must be made at JF(i,j) and YF(i,j). Example: Using fission multiplier 5, it is desired to accumulate fissions from isotopes 3, 4, 5, and 7 into FISHIN COUNT, which in this case is isotope 14. The following entries are made:

JF(3,5) = 14	YF(3,5) = 1.0
JF(4,5) = 14	YF(4,5) = 1.0
JF(5,5) = 14	YF(5,5) = 1.0
JF(7,5) = 14	YF(7,5) = 1.0

It may be of interest to the user to know how CLERKC determines N, the size of the NxN matrix passed to ALCHEMY. N is the index of the last isotope having a non-zero name; blank names are non-zero. Zero names having indices < N are permissible. Isotopes whose names are not on the SAM Data Tape from HFN (such as blank names and FISHIN COUNT) will have their cross sections and volumes set to zero, but will be included in N regardless of their location.

Repeat CLERK input for each burnable region. If a quantity is unchanged between regions, it need not be input again unless it is flagged with an asterisk.

The following examples may be useful references when making up data for the time arrays used in ALCHEMY.

Example 1

```
Input:  0      16  -4.0      0.0      10.0
        0     1281  0.0      10.0     50.00    100.0
```

Above two cards are complete specification of orbits at 0, 10 days, 20 days, etc., to the number of orbits specified on the FIREUP card. At each orbit, ALCHEMY will compute concentrations for t=0, 10, 50, and 100 days.

Example 2

```
Input:  0      16   3.0      100.0      0.0
        0     1331  10.0      20.0      100.0    200.0    500.0
        0     1501   0.0      10.0
        0     1521  10.0      20.0      100.0
        1     1351   0   1   2   2   0
```

The above cards will produce these results:

<u>Orbit</u>	<u>k computed at T =</u>	<u>ALCHEMY concentrations computed at t =</u>	<u>Concentrations to RDT taken from t =</u>
1	0	0, 10, 100, 200	10
2	10	0, 10, 20	20
3	20	10, 20, 100	100
4	100	10, 20, 100, 200	200
5	200	0, 100, 200, 500	500

I. ALCHEMY (LINK 23)

Note: ALCHEMY requires no input cards; all input for this link is created internally by CLERKC.

J. REFIRE

Note: REFIRE requires no input cards; all input for this link is created internally by ALCHEMY.

V. RESTART

The length of a burnup run often needs to be extended. This situation can occur whether the termination was under normal conditions or resulted from some sort of error condition. The ability to restart a burnup calculation is very desirable because the amount of computer time to perform a rerun may be non-trivial. The termination condition determines what particular method of restarting a case will need to be used to accomplish a successful restart.

The ease of restarting a case is enhanced by saving the HFN cross-section input on tape F and the nuclide concentrations from ALCHEMY on tape H. The data on these tapes is over-written whenever new information is generated. It is not stacked on the tape nor is any of the information retained for all orbits. The data on these tapes can be used as input data at the appropriate place in the code to facilitate restarting the run. However, situations can occur where the tape data is invalid. This causes the user a little more work in getting the case restarted.

Restarting in any orbit is possible at the first HRG case or the first HFN case as well as in REFIRE. Some specific methods of restarting a case are described below. They will take care of most situations. Most of the discussion assumes that the data is saved on tapes, but I have included the procedure to be used if no tapes are saved.

A. Restart In The First Orbit

If a case fails before completing ALCHEMY on the first orbit, it may be restarted at the first restart point preceding the failure. If the case has gotten to HFN or beyond, then it can be restarted at the beginning of HFN by changing the variable entry LINK(1) on the second card of FIREUP

input. If the case is still in the HRG-THERMOS section of the calculation, then it should be resubmitted with no changes. In the event that there are multiple HRG-THERMOS cases, the case must still be started at the beginning if it has not gotten to HFN.

B. Restart With REFIRE

Restarting a case is accomplished most simply by restarting with REFIRE after the first orbit. For this type of restart, the RDT is the only data tape required and only the FIREUP input must be changed. If n orbits have been completed, enter the link to be called (either 04 or 05) in LINK($n+1$) on Card 2 of the FIREUP input, and $n+1$ as the starting orbit number, NORBIT. If m additional orbits are desired, ITERLIM will now be $n+m$. REFIRE will update the original data in preparation for the $n+1$ orbit. This method of restarting can be used whether the previous run was terminated after completion of orbit n or was terminated somewhere in orbit $n+1$. This method of restarting is commonly used when m additional orbits are desired after n orbits have already been calculated. (Note: RDT = REFIRE data tape.)

C. Restart With Links Other Than REFIRE

When restarting with a link other than REFIRE after the first orbit, it is not necessary to update the card input by hand. If the necessary tapes (HFNDT and RDT) have been saved, a restart can be made in orbit n with either link 04 or link 05. To restart at one of these points, the following data changes must be made:

1. The first FIREUP input card must specify orbit n as the starting orbit.
2. The second FIREUP input card must specify the link number in the n^{th} field with which to restart.

(Note: HFNDT = HFN data tape.)

D. Restart Without A REFIRE Data Tape

Sometimes it is desirable to restart a case which has no usable RDT because of tape failure, loss of the reel, or termination of a run within the crucial few seconds during which ALCHEMY is remaking the RDT. If no RDT is available, the user must simulate the principal function of REFIRE by updating the input by hand. The "NUDATA" listing at the beginning of the last orbit output should be used. The new concentrations, resonance parameters, orbit number, orbit limit, and exposure time must be inserted by hand into the input deck. It is also necessary that the restart begins with HRG, since certain information created in THERMOS and used in REFIRE is stored on the RDT. This type of restart is essentially the same as beginning a new case with the appropriate data.

E. Restart After The Twenty Orbit Limit

In some cases it may be necessary to burn beyond the twenty orbit limit allowed in ZODIAC-G. The type of restart necessary to continue the burnup is similar to the restart without a REFIRE data tape. The input must be updated by hand and the case must be restarted with HRG. The input to CLERK concerned with ALCHEMY time and orbit time must also be changed, so that the time for the new orbit 1 is what would have been input for orbit 21. In order to get into the automated mode again, a redundant set of HFN, CLERK and ALCHEMY calculations must be done. This is accomplished by using the same value for orbit time at orbit n as was input for the ALCHEMY time for output of orbit n. Thus the input and output of orbits 1' (21) and 2' (22) for HFN and CLERK should be the same except for round-off error. The ALCHEMY output will be different for orbits 1' and 2'. Due to the redundancy you will want orbit 2' to start with HFN certainly not with HRG, to save on running time.

VI. REFERENCES

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5. J. R. Lilley. Computer Code HFN-Multigroup, Multiregion Neutron Diffusion Theory in One Space Dimension. HW-71545. November, 1961.
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8. R. H. Holeman. Battelle Northwest Laboratories. Private Communication.
9. E. A. Nephew. Thermal and Resonance Absorption Cross Sections of The U^{233} , U^{235} , and Pu^{239} Fission Products. ORNL-2869. March 1960.

APPENDIX A

VII. APPENDIX A

This appendix contains a brief description of the ZLT (ZODIAC-G Library Tape), as well as listings of its contents. The ZLT is made up of two files of data. The first file contains the library information needed for the HRG section of ZODIAC-G. The second file contains the library information needed for the THERMOS section of ZODIAC-G. The THERMOS library is in the non-random access form, as ZODIAC-G has not been coded to accept random accessing of its libraries. There is no particular hocus-pocus involved with generating a ZLT. Any set of library information that exists on a tape, that can be read by HRG can be used for the first file of a ZLT. Also, any set of information that exists on a tape in non-random access form, that can be read by THERMOS can be used for the second file of the ZLT. It will be left to the user's discretion to be aware of the library information intended for use with ZODIAC-G. The listings shown in this appendix contain three different sets of information. The first set shows the fine group energy structure and corresponding lethargy points for the HRG library. The second set is the alphabetic and numerical listing of the nuclides contained in the HRG data of the most recent ZLT. The last set of information is a listing of the nuclides in the THERMOS data of this ZLT.

FINE GROUP ENERGIES

The energies and lethargies at the lower energy boundaries of the HRG fine groups are given in the following tabulation. The upper energy boundary of group n is the lower energy boundary of group $n-1$. $E_0 = 1.0 \times 10^7$ eV.

Group	Lethargy	Energy, eV	Group	Lethargy	Energy, eV
1	0.25	7.79×10^6	35	8.75	1585
2	0.50	6.07×10^6	36	9.00	1234
3	0.75	4.72×10^6	37	9.25	961
4	1.00	3.68×10^6	38	9.50	748
5	1.25	2.87×10^6	39	9.75	583
6	1.50	2.23×10^6	40	10.00	454
7	1.75	1.74×10^6	41	10.25	354
8	2.00	1.35×10^6	42	10.50	275
9	2.25	1.05×10^6	43	10.75	215
10	2.50	8.21×10^5	44	11.00	167
11	2.75	6.39×10^5	45	11.25	130
12	3.00	4.98×10^5	46	11.50	101.3
13	3.25	3.88×10^5	47	11.75	78.9
14	3.50	3.02×10^5	48	12.00	61.4
15	3.75	2.35×10^5	49	12.25	47.9
16	4.00	1.83×10^5	50	12.50	37.3
17	4.25	1.43×10^5	51	12.75	29.0
18	4.50	1.11×10^5	52	13.00	22.6
19	4.75	8.65×10^4	53	13.25	17.6
20	5.00	6.74×10^4	54	13.50	13.7
21	5.25	5.25×10^4	55	13.75	10.68
22	5.50	4.09×10^4	56	14.00	8.32
23	5.75	3.18×10^4	57	14.25	6.48
24	6.00	2.48×10^4	58	14.50	5.04
25	6.25	1.93×10^4	59	14.75	3.93
26	6.50	1.50×10^4	60	15.00	3.06
27	6.75	1.17×10^4	61	15.25	2.38
28	7.00	9.12×10^3	62	15.50	1.86
29	7.25	7.10×10^3	63	15.75	1.44
30	7.50	5.53×10^3	64	16.00	1.125
31	7.75	4.31×10^3	65	16.25	0.876
32	8.00	3.36×10^3	66	16.50	0.683
33	8.25	2.61×10^3	67	16.75	0.532
34	8.50	2.04×10^3	68	17.00	0.414

*** ALPHABETIC LISTING OF NUCLIDES ON DATA TAPE HRG 60170 ***

NUMBER	NUCLIDE	NAME	NUMBER	NUCLIDE	NAME	NUMBER	NUCLIDE	NAME
11	304SS	AL011267	248	DY165		144	Hg201	0102
90	AG107*	C 031667	6	D20	A 090367	145	Hg202	101
91	AG109*	C 020869	233	EUROPIUM-151	OR-62	146	Hg204	101
8	AL27	A 051066	234	EUROPIUM-153	OR-62	1	H1	101
81	AM241	C 052869	235	EUROPIUM-154	OR-62	2	H2	0103
82	AM242	C 061968	236	EUROPIUM-155	OR-62	5	H20 w/UPSCAT	A 012469
83	AM243	C 010769	237	EU156		195	INDIUM-115	OR-62
112	AU197*	A 120566	49	FISSION PRODUCT	23 OR-62	92	IN115*	C 062067
211	BARIUM-134	OR-62	48	FISSION PRODUCT	25 OR-62	199	IODINE-127	OR-62
212	BARIUM-136	OR-62	50	FISSION PRODUCT	39 OR-62	200	IODINE-129	OR-62
213	BARIUM-137	OR-62	47	FISSION-PRODUCT	OR-62	124	IRIDIUM	101
214	BARIUM-138	OR-62	117	F19	A 081066	9	IRON	A 072166
18	BE9 0103	L	238	GD152	D 031170	201	I135	
148	BI209 0103		95	GD152*	D 031170	155	KRYPTON-83	OR-62
19	BORON	A 032167	239	GD153	C 031270	156	KRYPTON-84	OR-62
154	BROMINE-81	OR-62	240	GD154	D 032770	157	KRYPTON-85	OR-62
20	B10	A 032167	96	GD154*	D 032770	158	KRYPTON-86	OR-62
21	B11	A 090165	241	GD155	D 031170	215	LANTHANUM-139	OR-62
35	CADMIUM 0102		97	GD155*	D 031170	147	LEAD 0103	
190	CADMIUM-110	OR-62	242	GD156	D 031170	114	LITHIUM	101
191	CADMIUM-111	OR-62	98	GD156*	D 031170	115	LI6	101
192	CADMIUM-112	OR-62	243	GD157	D 031770	116	LI7	101
193	CADMIUM-113	OR-62	99	GD157*	D 031770	102	LU175A	A 030967
194	CADMIUM-114	OR-62	244	GD158	D 031170	103	LU175B	A 031667
122	CALCIUM 101		100	GD158*	D 031170	104	LU176A	A 030967
216	CERIUM-140	OR-62	245	GD160	D 032770	105	LU176B	A 031667
217	CERIUM-142	OR-62	101	GD160*	D 032770	23	MAGNESIUM	0103
208	CESIUM-133	OR-62	113	HE4	101	140	MERCURY 0102	
209	CESIUM-135	OR-62	126	HF174	C 041567	29	MN55	A 032767
210	CESIUM-137	OR-62	106	HF174*	C 041567	87	MN55* (ENDF/B RES)	12/69
120	CHLORINE 0103		127	HF176	C 041567	34	MOLYBDENUM	0102
28	CHROMIUM	A 051366	107	HF176*	C 041567	176	MOLYBDENUM-100	OR-62
121	CL37	A 090165	128	HF177	C 062367	172	MOLYBDENUM-95	OR-62
84	CM242	C 052869	108	HF177*	C 062367	173	MOLYBDENUM-96	OR-62
85	CM243	A 032007	129	HF178	C 041567	174	MOLYBDENUM-97	OR-62
86	CM244	A 101166	109	HF178*	C 041567	175	MOLYBDENUM-98	OR-62
32	COPPER	A 032707	130	HF179	C 062367	7	NA23	A 040766
30	CO59 0102		110	HF179*	C 062367	170	NB93	
123	CU63	AM032767	131	HF180	C 032567	171	NB94	
88	CU63*	C 032067	111	HF180*	C 032567	219	NEODYMIUM-142	OR-62
89	CU65*	CR020469	141	HG196	101	220	NEODYMIUM-143	OR-62
3	C12	AL081066	142	HG199	0102	221	NEODYMIUM-144	OR-62
247	DY164		143	HG200	0102	222	NEODYMIUM-145	OR-62

AN ASTERISK(*) IN A NUCLIDE NAME INDICATES THAT DATA FOR THE NUCLIDE INCLUDES RESONANCE PARAMETER TABLES

*** ALPHABETIC LISTING OF NUCLIDES ON DATA TAPE HRG 60170 ***

NUMBER	NUCLIDE NAME	OR-G2	NUMBER	NUCLIDE NAME	OR-G2	NUMBER	NUCLIDE NAME	OR-G2
223	NEODYMIUM-146	OR-G2	118	P31 0102		149	UNIT ONE/V	
224	NEODYMIUM-148	OR-G2	182	RHODIUM-103	OR-G2	62	U232	A 042866
225	NEODYMIUM-150	OR-G2	159	RUBIDIUM-85	OR-G2	64	U233(W)	CR030967
31	NICKEL	A 051666	160	RUBIDIUM-87	OR-G2	63	U233(W)*	CR030967
71	NP237	C 053069	178	RUTHENIUM-101	OR-G2	65	U234	A 092766
72	NP238 0103		179	RUTHENIUM-101	OR-G2	66	U235(W)	C 013169
73	NP239 101		180	RUTHENIUM-102	OR-G2	12	U235(W)*	C 013169
22	N14	AL081066	181	RUTHENIUM-104	OR-G2	67	U236	C 053069
4	O16	AL042966	227	SAMARIUM-147	OR-G2	68	U237	C 041367
183	PALLADIUM-104	OR-G2	228	SAMARIUM-148	OR-G2	69	U238	C 010968
184	PALLADIUM-105	OR-G2	94	SAMARIUM-149	OR-G2	13	U238*	C 010968
185	PALLADIUM-106	OR-G2	229	SAMARIUM-150	OR-G2	70	U239 101	
186	PALLADIUM-107	OR-G2	230	SAMARIUM-151	OR-G2	27	V51 0102	
187	PALLADIUM-108	OR-G2	231	SAMARIUM-152	OR-G2	136	W182 0102	
188	PALLADIUM-110	OR-G2	232	SAMARIUM-154	OR-G2	137	W183	A 032067
58	PA231	A 030967	153	SELENIUM-82	OR-G2	138	W184 0102	
59	PA232 101		150	SE77	A 090165	139	W186 0102	
60	PA233	C 042667	151	SE78	A 090165	202	XENON-126	OR-G2
61	PA234 101		152	SE80	A 090165	203	XENON-130	OR-G2
25	POTASSIUM 0103		24	SILICON 0103		204	XENON-131	OR-G2
218	PRASEODYMIUM-141	OR-G2	189	SILVER-109	OR-G2	205	XENON-132	OR-G2
226	PROMETHIUM-147	OR-G2	161	STRONTIUM-88	OR-G2	206	XENON-134	OR-G2
37	PSEUDO FPROD 1 235		162	STRONTIUM-90	OR-G2	93	XENON-135	OR-G2
41	PSEUDO FPROD 1 239		119	SULFUR 0103	L	207	XENON-136	OR-G2
38	PSEUDO FPROD 2 235		132	TA181	A 032567	163	YTRIUM-89	OR-G2
42	PSEUDO FPROD 2 239		133	TA182		33	ZINC 0102	
39	PSEUDO FPROD 3 235		134	TA183		10	ZIRCONIUM 0103	
43	PSEUDO FPROD 3 239		177	TECHNETIUM-99	OR-G2	164	ZIRCONIUM-90	OR-G2
40	PSEUDO FPROD 4 235		196	TELLURIUM-126	OR-G2	165	ZIRCONIUM-91	OR-G2
44	PSEUDO FPROD 4 239		197	TELLURIUM-128	OR-G2	166	ZIRCONIUM-92	OR-G2
45	PSEUDO FPRODS 1-4 235		198	TELLURIUM-130	OR-G2	167	ZIRCONIUM-93	OR-G2
46	PSEUDO FPRODS 1-4 239		246	TERBIUM-159	OR-G2	168	ZIRCONIUM-94	OR-G2
74	PU236	CR052869	51	TH228	C 030367	169	ZIRCONIUM-96	OR-G2
75	PU238	C 053169	52	TH230	A 091366			
76	PU239(W)	CR062067	53	TH231 101				
14	PU239(W)*	CR062067	55	TH232	A 030967			
77	PU240	CR062068	54	TH232*	A 030967			
15	PU240*	CR062068	56	TH233 101				
78	PU241(W)	CR081966	57	TH234	A 031867			
16	PU241(W)*	CR081966	36	TIN	A 090165			
17	PU242	C 052869	26	TITANIUM 0103				
79	PU243	C 092366	125	TM169	A 041067			
80	PU244	C 110166	135	TUNGSTEN 0102				

AN ASTERISK(*) IN A NUCLIDE NAME INDICATES THAT DATA FOR THE NUCLIDE INCLUDES RESONANCE PARAMETER TABLES

*** NUMERICAL LISTING OF NUCLIDES ON DATA TAPE HRG 60170 ***

NUMBER	NUCLIDE NAME	NUMBER	NUCLIDE NAME	NUMBER	NUCLIDE NAME
1	H1 101	44	PSEUDO FPROD 4 239	87	MN55* (ENDF/B RES) 12/69
2	H2 0103	45	PSEUDO FPROD 1-4 235	88	CU63* C 032067
3	Li6 AL081066	46	PSEUDO FPROD 1-4 239	89	CU65* CR020469
4	Li6 AL042966	47	FISSION-PRODUCT OR-G2	90	AG107* C 031667
5	Li20 W/OPSCAT A 012469	48	FISSION PRODUCT 25 OR-G2	91	AG109* C 020869
6	Li20 A 090367	49	FISSION PRODUCT 23 OR-G2	92	IN115* C 062067
7	Li23 A 040766	50	FISSION PRODUCT 39 OR-G2	93	XENON-135 OR-G2
8	Li27 A 051066	51	TH228 C 030367	94	SAMARIUM-149 OR-G2
9	IRON A 072166	52	TH230 A 091366	95	GD152* D 031170
10	ZIRCONIUM 0103	53	TH231 101	96	GD154* D 032770
11	304SS AL011267	54	TH232* A 030967	97	GD155* D 031170
12	Li235(W)* C 013169	55	TH232 A 030967	98	GD156* D 031170
13	Li238* C 010968	56	TH233 101	99	GD157* D 031770
14	PU239(A)* CR062067	57	TH234 A 031867	100	GD158* D 031170
15	PU240* CR062068	58	PA231 A 030967	101	GD160* D 032770
16	PU241(W)* CR081966	59	PA232 101	102	LU175A A 030967
17	PU242 C 052869	60	PA233 C 042667	103	LU175B A 031667
18	SE9 0103	61	PA234 101	104	LU176A A 030967
19	BORON A 032167	62	U232 A 042866	105	LU176B A 031667
20	Li10 A 032167	63	U233(*)* CR030967	106	HF174* C 041567
21	Li11 A 090165	64	U233(W) CR030967	107	HF176* C 041567
22	Li14 AL081066	65	U234 A 092766	108	HF177* C 062367
23	MAGNESIUM 0103	66	U235(W) C 013169	109	HF178* C 041567
24	SILICON 0103	67	U236 C 053069	110	HF179* C 062367
25	POTASSIUM 0103	68	U237 C 041367	111	HF180* C 032567
26	TITANIUM 0103	69	U238 C 010968	112	AU197* A 120566
27	V51 0102	70	U239 101	113	HE4 101
28	CHROMIUM A 051366	71	NP237 C 053069	114	LI7HIUM 101
29	MN55 A 032767	72	NP238 0103	115	LI6 101
30	CO59 0102	73	NP239 101	116	LI7 101
31	NICKEL A 051666	74	PU236 CR052869	117	F19 A 081066
32	COPPER A 032767	75	PU238 C 053169	118	P31 0102
33	ZINC 0102	76	PU239(W) CR062067	119	SULFUR 0103
34	MOLYBDENUM 0102	77	PU240 CR062068	120	CHLORINE 0103
35	CADMIUM 0102	78	PU241(W) CR081966	121	CL37 A 090165
36	TIN A 090165	79	PU243 C 092366	122	CALCIUM 101
37	PSEUDO FPROD 1 235	80	PU244 C 110166	123	CU63 AM032767
38	PSEUDO FPROD 2 235	81	AM241 C 052869	124	IRIDIUM 101
39	PSEUDO FPROD 3 235	82	AM242 C 061968	125	TM169 A 041067
40	PSEUDO FPROD 4 235	83	AM243 C 010769	126	HF174 C 041567
41	PSEUDO FPROD 1 239	84	CM242 C 052869	127	HF176 C 041567
42	PSEUDO FPROD 2 239	85	CM243 A 032067	128	HF177 C 062367
43	PSEUDO FPROD 3 239	86	CM244 A 101166	129	HF178 C 041567

AN ASTERISK(*) IN A NUCLIDE NAME INDICATES THAT DATA FOR THE NUCLIDE INCLUDES RESONANCE PARAMETER TABLES

*** NUMERICAL LISTING OF NUCLIDES ON DATA TAPE HRG 60170 ***

NUMBER	NUCLIDE	NAME	NUMBER	NUCLIDE	NAME	NUMBER	NUCLIDE	NAME
130	HF179	C 062367	173	MOLYBDENUM-96	OR-G2	216	CERIUM-140	OR-G2
131	HF180	C 032567	174	MOLYBDENUM-97	OR-G2	217	CERIUM-142	OR-G2
132	TA181	A 032567	175	MOLYBDENUM-98	OR-G2	218	PRASEODYMIUM-141	OR-G2
133	TA182		176	MOLYBDENUM-100	OR-G2	219	NEODYMIUM-142	OR-G2
134	TA183		177	TECHNETIUM-99	OR-G2	220	NEODYMIUM-143	OR-G2
135	TUNGSTEN	0102	178	RUTHENIUM-100	OR-G2	221	NEODYMIUM-144	OR-G2
136	W182	0102	179	RUTHENIUM-101	OR-G2	222	NEODYMIUM-145	OR-G2
137	W183	A 032067	180	RUTHENIUM-102	OR-G2	223	NEODYMIUM-146	OR-G2
138	W184	0102	181	RUTHENIUM-104	OR-G2	224	NEODYMIUM-148	OR-G2
139	W186	0102	182	RHODIUM-103	OR-G2	225	NEODYMIUM-150	OR-G2
140	MERCURY	0102	183	PALLADIUM-104	OR-G2	226	PROMETHIUM-147	OR-G2
141	HG196	101	184	PALLADIUM-105	OR-G2	227	SAMARIUM-147	OR-G2
142	HG199	0102	185	PALLADIUM-106	OR-G2	228	SAMARIUM-148	OR-G2
143	HG200	0102	186	PALLADIUM-107	OR-G2	229	SAMARIUM-150	OR-G2
144	HG201	0102	187	PALLADIUM-108	OR-G2	230	SAMARIUM-151	OR-G2
145	HG202	101	188	PALLADIUM-110	OR-G2	231	SAMARIUM-152	OR-G2
146	HG204	101	189	SILVER-109	OR-G2	232	SAMARIUM-154	OR-G2
147	LEAD	0103	190	CADMIUM-110	OR-G2	233	EUROPIUM-151	OR-G2
148	BI209	0103	191	CADMIUM-111	OR-G2	234	EUROPIUM-153	OR-G2
149	UNIT ONE/V		192	CADMIUM-112	OR-G2	235	EUROPIUM-154	OR-G2
150	SE77	A 090165	193	CADMIUM-113	OR-G2	236	EUROPIUM-155	OR-G2
151	SE78	A 090165	194	CADMIUM-114	OR-G2	237	GD156	
152	SE80	A 090165	195	INDIUM-115	OR-G2	238	GD152	D 031170
153	SELENIUM-82	OR-G2	196	TELLURIUM-124	OR-G2	239	GD153	C 031270
154	BROMINE-81	OR-G2	197	TELLURIUM-126	OR-G2	240	GD154	D 032770
155	KRYPTON-83	OR-G2	198	TELLURIUM-130	OR-G2	241	GD155	D 031170
156	KRYPTON-84	OR-G2	199	IODINE-127	OR-G2	242	GD156	D 031170
157	KRYPTON-85	OR-G2	200	IODINE-129	OR-G2	243	GD157	D 031770
158	KRYPTON-86	OR-G2	201	I135		244	GD158	D 031170
159	RUBIDIUM-85	OR-G2	202	XENON-128	OR-G2	245	GD160	D 032770
160	RUBIDIUM-87	OR-G2	203	XENON-130	OR-G2	246	TERBIUM-159	OR-G2
161	STRONTIUM-88	OR-G2	204	XENON-131	OR-G2	247	DY164	
162	STRONTIUM-90	OR-G2	205	XENON-132	OR-G2	248	DY165	
163	YTTRIUM-89	OR-G2	206	XENON-134	OR-G2			
164	ZIRCONIUM-90	OR-G2	207	XENON-136	OR-G2			
165	ZIRCONIUM-91	OR-G2	208	CESIUM-133	OR-G2			
166	ZIRCONIUM-92	OR-G2	209	CESIUM-135	OR-G2			
167	ZIRCONIUM-93	OR-G2	210	CESIUM-137	OR-G2			
168	ZIRCONIUM-94	OR-G2	211	BARIUM-134	OR-G2			
169	ZIRCONIUM-96	OR-G2	212	BARIUM-136	OR-G2			
170	LB93		213	BARIUM-137	OR-G2			
171	NB94		214	BARIUM-138	OR-G2			
172	MOLYBDENUM-95	OR-G2	215	LANTHANUM-139	OR-G2			

AN ASTERISK(*) IN A NUCLIDE NAME INDICATES THAT DATA FOR THE NUCLIDE INCLUDES RESONANCE PARAMETER TABLES

LIST OF LIBRARY MATERIALS

THERMS/UR9069
Random Access Library

Isotope/ Element	Date	First Ident	Second Ident	Number of Kernels
BE 9	11-15-66	4009.	1029.	1
C 12	11-15-66	6012.	29.	1
C 12	11-15-66	6012.	1010.	1
C 12	11-15-66	6012.	1029.	1
C 12	10-21-68	6012.	1042.	1
C 12	10-21-68	6012.	1057.	1
C 12	11-15-66	6012.	1069.	1
C 12	11-15-66	6012.	1097.	1
C 12	11-15-66	6012.	1127.	1
C 12	11-15-66	6012.	1150.	1
C 12	11-15-66	6012.	1200.	1
B	11-15-66	5000.	0.	0
B 10	11-15-66	5010.	0.	0
NA	11-15-66	11000.	29.	1
K	11-15-66	19000.	29.	1
CO	11-15-66	27000.	29.	1
AL 27	11-15-66	13000.	29.	1
NI	11-15-66	28000.	29.	1
CU	11-15-66	29000.	0	0
CU 63	11-15-66	29063.	0.	0
CU 65	11-15-66	29065.	0.	0
ZR	11-15-66	40000.	29.	1
LI	11-15-66	3000.	29.	1
N	11-15-66	7000.	29.	1
304SS	11-15-66	304.	29.	1
1/V	11-15-66	1.	0.	0
DY 164	11-15-66	66164.	0.	0
AU	11-15-66	79000.	0.	0
PA 233	11-15-66	91233.	29.	1
U 234	11-15-66	92234.	29.	1
NP 238	11-15-66	93238.	0.	0
CM 243	11-15-66	96243.	0.	0
CM 244	11-15-66	96244.	0.	0
U 233	4- 3-68	92233.	29.	1
U 235	4- 3-68	92235.	29.	1
U 238	4- 3-68	92238.	29.	1
PU 239	4- 3-68	94239.	29.	1
PU 240	4- 3-68	94240.	29.	1
PU 241	4- 3-68	94241.	29.	1
TH 232	4- 3-68	90232.	29.	1

Isotope/ Element	Date	First Ident	Second Ident	Number of Kernels
LU 175	11-15-66	71175.	0	0
LU 176	11-15-66	71176.	0.	0
EU	11-15-66	63000.	0.	0
CD	11-15-66	48000.	29.	1
HF	11-15-66	72000.	0	0
CR	11-15-66	24000.	29.	1
IN 115	11-15-66	49115.	0.	0
RH 103	11-15-66	45103.	0.	0
0 16	11-15-66	8000.	29.	1
0 16	2-15-67	8000.	30.	1
0 16	2- 6-67	8000.	31.	1
0 16	2-15-67	8000.	32.	1
0 16	2- 6-67	8000.	33.	1
0 16	2-15-67	8000.	34.	1
0 16	2-6-67	8000.	35.	1
0 16	12-11-67	8000.	36.	1
0 16	2- 6-67	8000.	37.	1
FE 56	11-15-66	26056.	29.	1
H 2	4- 3-68	1002.	1029.	2
H 2	4- 3-68	1002.	1030.	2
H 2	4- 3-68	1002.	1031.	2
H 2	4- 3-68	1002.	1032.	2
H 2	4- 3-68	1002.	1033.	2
H 2	4- 3-68	1002.	1034.	2
H 2	4- 3-68	1002.	1035.	2
H 2	4- 3-68	1002.	1036.	2
H 2	4- 3-68	1002.	1037.	2
H 1	11-15-66	1001.	1029.	2
H 1	2-15-67	1001.	1030.	2
H 1	2- 6-67	1001.	1031.	2
H 1	2-15-67	1001.	1032.	2
H 1	2- 6-67	1001.	1033.	2
H 1	2-15-67	1001.	1034.	2
H 1	2- 6-67	1001.	1035.	2
H 1	12-11-67	1001.	1036.	2
H 1	2- 6-67	1001.	1037.	2
H 1	4-10-69	1001.	1039.	2
H 1	4-10-69	1001.	1042.	2
H 1	4-10-69	1001.	1044.	2
H 1	4-10-69	1001.	1047.	2
H 1	4-10-69	1001.	1049.	2
H 1	4-10-69	1001.	1052.	2
H 1	4-10-69	1001.	1054.	2
H 1	4-10-69	1001.	1057.	2
H 2	4-10-69	1002.	1039.	2
H 2	4-10-69	1002.	1042.	2
H 2	4-10-69	1002.	1044.	2
H 2	4-10-69	1002.	1047.	2
H 2	4-10-69	1002.	1049.	2
H 2	4-10-69	1002.	1052.	2
H 2	4-10-69	1002.	1054.	2

Isotope/ Element	Date	First Ident	Second Ident	Number of Kernels
H 2	4-10-69	1002.	1057.	2
0 16	4-10-69	8000.	39.	1
0 16	4-10-69	8000.	42.	1
0 16	4-10-69	8000.	44.	1
0 16	4-10-69	8000.	47.	1
0 16	4-10-69	8000.	49.	1
0 16	4-10-69	8000.	52.	1
0 16	4-10-69	8000.	54.	1
0 16	4-10-69	8000.	57.	1
C 12	11-15-66	6012.	1082.	1
GD	7-16-69	64000.	29.	1
U233FPR	7-16-69	14233.	0.	0
U235FPR	7-16-69	14235.	0.	0
PU39FPR	7-16-69	14239.	0.	0
U235FP1	7-16-69	10235.	0.	0
U235FP2	7-16-69	11235.	0.	0
U235FP3	7-16-69	12235.	0.	0
U235FP4	7-16-69	13235.	0.	0
PU39FP1	7-16-69	10239.	0.	0
PU39FP2	7-16-69	11239.	0	0
PU39FP3	7-16-69	12239.	0	0
PU39FP4	7-16-69	13239.	0.	0
NP 237	7-17-69	93237.	0.	0
PU 238	7-17-69	94238.	0.	0
AM 241	7-17-69	95241.	0.	0
AM 243	7-17-69	95243.	0.	0
CM 242	7-17-69	96242.	0.	0
PU 236	7-17-69	94236.	0.	0
PU 242	7-17-69	94242.	29.	1
U 236	7-17-69	92236.	0.	0
AG 107	1-16-70	47107.	0.	0
AG 109	1-16-70	47109.	0.	0
H 1	2-09-70	1001.	2029.	2
XE 135	3-20-70	54135.	0.	0
SM 149	3-20-70	62149.	0.	0
SM 151	3-20-70	62151.	0.	0
GD 152	3-20-70	64152.	0.	0
GD 153	3-20-70	64153.	0.	0
GD 154	3-20-70	64154.	0.	0
GD 155	3-20-70	64155.	0.	0
GD 156	3-20-70	64156.	0.	0
GD 157	3-20-70	64157.	0.	0
GD 158	3-20-70	64158.	0.	0
GD 160	3-20-70	64160.	0.	0

APPENDIX B

VIII. APPENDIX B

This appendix contains a sample problem for the burnup mode. No sample output is intended to be shown as it becomes quite voluminous. However, it is hoped that this input will aid the user in understanding the flow of ZODIAC-G, the variations in input format, and the use of the library information.

0 1 1 1 0 0 0 1 2 0 0 0 0
 4 4 5 5 4 5 5 4 5 5 5 4 5 5 5 4 5 5 4 5

THIS IS A BURNUP RUN OF THE YANKEE CORE I DATA.
 MINOR ISOTOPES HAVE BEEN ADDED FOR THIS RUN.

HEAD
 HEAD

060170

YANKEE (WITH XE135, LBAR = 1.232, T = 981)

HOLEMAN

1.0		2.0																	
20.0		3.0		1.0		1.0		2.0											
1.17	+4	2.38		0.683															
1.0		2.56423	-2																
4.0		2.96420	-2																
9.0		7.19651	-3																
12.0		2.89427	-4					16.0											
218.527		529.209		1598.159		7.59332	-4	1.232		981.0		HRGRES							
13.0		8.11947	-3					16.0											
7.7896		18.864		56.968		2.13020	-2	1.232		981.0		HRGRES							
14.0		1.0	-20					16.0											
6.3247	+18	15.3165	+18	46.2545	+18	2.6236	-20	1.232		981.0		HRGRES							
15.0		1.0	-20					16.0											
6.3247	+18	15.3165	+18	46.2545	+18	2.6236	-20	1.232		981.0		HRGRES							
16.0		1.0	-20					16.0											
6.3247	+18	15.3165	+18	46.2545	+18	2.6236	-20	1.232		981.0		HRGRES							
17.0		1.0	-20																
28.0		2.05615	-3																
31.0		1.02820	-3																
45.0		1.0	-20																
67.0		1.67710	-6																
71.0		1.0	-20																
74.0		1.0	-20																
75.0		1.0	-20																
81.0		1.0	-20																
82.0		1.0	-20																
84.0		1.0	-20																

B-2

93.0		3.29266	-9						
0.0									
-1.0	-10	-1.0	-10	-1.0	-10				
9 END OF HRG									
1THERMOS - YANKEE -				HOLEMAN					
101	0	8							
20	30	3	20	0	0	0	1	1	
11111112223333333333									
1001	1054					5.2313-02	1.008		
8000	54	4.41315-2				2.6156 -2	16.0		
26056	29		5.593	-2			56.0		
92235	29	7.59332-4					235.04		
92238	29	2.13020-2					238.05		
94239	29	2.6236-20					239.05		
94240	29	2.6236-20					240.05		
94241	29	2.6236-20					241.06		
94242	29	2.6236-20					242.06		
24000	29		1.598	-2			52.0		
28000	29		7.991	-3			59.0		
14235	0	2.6236-20					117.0		
92236	0	4.400 -6					236.05		
93237	0	2.6236-20					237.05		
94236	0	2.6236-20					236.05		
94238	0	2.6236-20					238.05		
95241	0	2.6236-20					241.06		
95242	0	2.6236-20					242.06		
96242	0	2.6236-20					242.06		
54135	0	8.63916-9					135.0		
0	0	0	0						
1	3	2	0	0					
1	7	0.375							
2	3	0.0587							
3	10	0.1737							

```

1.0      -5 1.0      0.05      100.0      1.0      101      5      5      100 1
1        0      30
11111112223333333333
HW      CELLO16      CELLFE      CELLU235W*      CELLU238*      CELLPU39W*      CELL
PU240*      CELLPU41W*      CELLPU242      CELLCR      CELLNI      CELLU351-4      CELL
U236      CELLNP237      CELLPU236      CELLPU238      CELLAM241      CELLAM242      CELL
CM242      CELLXE135      CELL
9 END OF THERMOS CASE 101
210      101 HOLEMAN      JULY 26, 1970      YANKEE CORE I CELL
1 6      1      4      4      0      -1      12      0
1 3      12      1      1      1
1 1      35      1
0 1      45 0.0007
2 2      111U-UNIT CELL
0 1      211 -4.0
0 2      261 0.0      1.0
1 1      351      20
210      401U235W*      CELLU236      CELLU238*      CELLNP237      CELLPU236      CELL
210      411PU238      CELLPU39W*      CELLPU240*      CELLPU41W*      CELLPU242      CELL
210      421AM241      CELLAM242      CELLCM242      CELLU351-4      CELLXE135      CELL
210      431HW      CELLO16      CELLFE      CELLCR      CELLNI      CELL
C THESE ARE THE TIME ZERO CONCENTRATIONS
0 6      801 2.89427-4 1.67710-6 8.11947-3 1.0      -20 1.0      -20 1.0      -20
0 6      807 1.0      -20 1.0      -20 1.0      -20 1.0      -20 1.0      -20 1.0      -20
0 6      813 1.0      -20 1.0      -20 3.29266-9 2.56423-2 2.96420-2 7.19651-3
0 2      819 2.05615-3 1.02820-3
210      15001U235W*      CELLU236      CELLU238*      CELLNP237      CELLPU236      CELL
210      15011PU238      CELLPU39W*      CELLPU240*      CELLPU41W*      CELLPU242      CELL
210      15021AM241      CELLAM242      CELLCM242      CELLU351-4      CELLXE135      CELL
210      15031HW      CELLO16      CELLFE      CELLCR      CELLNI      CELL
0 1 415401 1.0
0 1 415421 1.0
9END

```

B-4

210	1 YANKEE UNIT CELL												
0 6	11	2.0	0.0	30.54435	100.0	28.2	3.0						
0 5	17	40.0	0.0	23.0	3.0	1.0							
0 6	1331	40.0	60.0	80.0	100.0	133.0	166.0						
0 6	1337	200.0	250.0	300.0	350.0	400.0	450.0						
0 6	1343	500.0	550.0	600.0	666.0	733.0	800.0						
0 2	1349	900.0	1000.0										
0 3	1501	0.0	40.0	60.0									
0 3	1521	40.0	60.0	80.0									
0 3	1541	60.0	80.0	100.0									
0 3	1561	80.0	100.0	133.0									
0 3	1581	100.0	133.0	166.0									
0 3	1601	133.0	166.0	200.0									
0 3	1621	166.0	200.0	250.0									
0 3	1641	200.0	250.0	300.0									
0 3	1661	250.0	300.0	350.0									
0 3	1681	300.0	350.0	400.0									
0 3	1701	350.0	400.0	450.0									
0 3	1721	400.0	450.0	500.0									
0 3	1741	450.0	500.0	550.0									
0 3	1761	500.0	550.0	600.0									
0 3	1781	550.0	600.0	666.0									
0 3	1801	600.0	666.0	733.0									
0 3	1821	666.0	733.0	800.0									
0 3	1841	733.0	800.0	900.0									
0 3	1861	800.0	900.0	1000.0									
0 3	1881	900.0	1000.0	1100.0									
112	1351	1	2	3	4	5	6	7	8	9	10	11	12
1 8	1363	13	14	15	16	17	18	19	20				
210	441U235W*	CELLU236	CELLU238*	CELLNP237	CELLPU236	CELL							
210	451PU238	CELLPU39W*	CELLPU240*	CELLPU41W*	CELLPU242	CELL							
210	461AM241	CELLAM242	CELLCM242	CELLU351-4	CELLB L A N K								
2 2	471FISHIN	COUNT											

0 6	481	235.04	236.05	238.05	237.05	236.05	238.05
0 6	487	239.05	240.05	241.06	242.06	241.06	242.06
0 2	493	242.06	117.0				
0 6	501	203.0	200.0	201.0			
0 6	507	211.0	200.0	213.0	200.0		
0 1	513						
1 2	965	15	15	DECAY PU236 TO BLANK, PU238 TO BLANK			
1 1	969	11		DECAY PU241 TO AM241			
1 2	972	13	6	DECAY AM242 TO CM242, CM242 TO PU238			
0 2	985	6.66282-4	2.13360-5				
0 1	989	1.33726-4					
0 2	992	4.62067-1	4.25215-3				
1 2	1001	14	16	U235 FP			
1 2	1006	14	16	U236 FP			
1 2	1011	14	16	U238 FP			
1 2	1031	14	16	PU239 FP			
1 2	1036	14	16	PU240 FP			
1 2	1041	14	16	PU241 FP			
1 2	1046	14	16	PU242 FP			
0 2	1101	.4101	1.0	FISS YIELD URAN			
0 2	1106	.4101	1.0	FISS YIELD URAN			
0 2	1111	.4101	1.0	FISS YIELD URAN			
0 2	1131	.4657	1.0	FISS YIELD PU			
0 2	1136	.4657	1.0	FISS YIELD PU			
0 2	1141	.4657	1.0	FISS YIELD PU			
0 2	1146	.4657	1.0	FISS YIELD PU			
C	CAPTURE INDICES						
1 2	1201	2		U235 TO U236			
1 2	1203	4		U236 TO NP237			
1 2	1205	7	4	U238 TO PU239, U238 TO NP237			
1 2	1207	6	5	NP237 TO PU238, NP237 TO PU236			
1 2	1209	15		PU236 TO BLANK			
1 2	1211	15		PU238 TO BLANK			

1 2	1213	8	6	PU239 TO PU240, PU239 TO PU238
1 2	1215	9		PU240 TO PU241
1 2	1217	10		PU241 TO PU242
1 2	1219	15		PU242 TO BLANK
1 2	1221	10	12	AM241 TO PU242, AM241 TO AM242
1 2	1223	15		AM242 TO BLANK
1 2	1225	15		CM242 TO BLANK
C	CAPTURE YIELDS FOR INDICES ENTERED 40 LOCATIONS HIGHER.			
0 2	1241	1.0		0.0
0 2	1243	1.0		0.0
0 2	1245	1.0		5.01444-3
0 2	1247	1.0		1.04156-5
0 2	1249	1.0		0.0
0 2	1251	1.0		0.0
0 2	1253	1.0		7.62510-5
0 2	1255	1.0		0.0
0 2	1257	1.0		0.0
0 2	1259	1.0		0.0
0 2	1261	.16		.84
0 2	1263	1.0		0.0
0 2	1265	1.0		0.0
9	END			

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