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GYMEA — A NUCLIDE DEPLETION, SPACE INDEPENDENT, MULTIGROUP NEUTRON DIFFUSION, DATA PREPARATION CODE

by

J.P. POLLARD
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ABSTRACT

GYMEA is a multi-purpose neutronics code used extensively in the H.T.G.C.R. project of the A.A.E.C. The code has three main functions:

(i) running of burnup surveys of near–homogeneous reactor systems,

(ii) running of neutron diffusion calculations in nuclear data library correlations with measurements made in near–homogeneous subcritical assemblies carried out at the A.A.E.C., and

(iii) preparation of suitably averaged cross section data from the code's 120–group (with resonance parameters), 70–nuclide main data library for direct input to space–dependent codes such as CRAM, 4–ZOOM (9–ZOOM translated to the IBM 7040), DSN and TDC (Carlson's FLOCO versions translated to the IBM 7040), and WDSN.

Because free input is used and a toy compiler is provided, new applications of the code can be developed by code users to extend its function. The source language is FORTRAN IV (95 per cent.) and MAP (5 per cent.) for the IBM 7040 (and later an IBM 360). 32K words of core storage are required together with 4–6 magnetic tapes and an on–line 1401 including reader, punch, and printer. Typical runs for data preparation take 3 minutes, diffusion calculations 10 minutes and burnup calculations 15 minutes.

A few illustrative examples are included in the report.

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1. INTRODUCTION

The maintenance of a nuclear data file, and its ready transformation to group data for neutronics codes, is essential for a reactor project such as the H.T.G.C.R. (High Temperature Gas-Cooled Reactor) project under study at the A.A.E.C. Research Establishment. The file should be processed with groups collapsed over a reasonable spectrum. For a homogeneous core the flux obtained from a space-independent, or space-averaged, calculation of neutron balance provides a reasonable spectrum for group collapsing. In a reactor study extending beyond clean core conditions the calculation of burnt-up core nuclide concentrations is a valuable asset for determining group data at different stages of reactor life. In addition no reactor study is satisfactory unless the data file correlates satisfactorily with selected experiments carried out on macroscopic properties of materials to be used in the reactor project. Out of these needs came the codes GIBBA (Pollard and Clancy 1964) and MULGA (Clancy et al. 1963); and out of experience obtained with these codes came GYMEA.

GYMEA is essentially three codes in one: it is (i) a zero dimensional multigroup ($\leq$ 120) neutron diffusion code, (ii) a multinuclide ($\leq$ 100) burnup code, and (iii) a data preparation code. It is written in FORTRAN IV (95%) and MAP (5%) for the IBM 7040 computer system. The programme computes neutron spectrum (optionally) and nuclide concentrations to enable spectrum-weighted, group-averaged cross section data and scattering transfer matrix data to be prepared for direct input to a variety of neutronics codes (CRAM,4-ZOOM,DSN,WDSN, and GYMEA).

Although the code has essentially the three main functions mentioned previously, these functions are by no means independent and experience with the code has shown the advantages to be gained from having all three aspects in the one programme. Features of the code include:

(1) criticality on concentration or group-dependent buckling;

(2) output of reaction rates, microscopic and/or macroscopic cross sections collapsed over the spectrum for mixtures defined by the user;

(3) saving up of the previously mentioned information, which may be processed further using the toy-FORTRAN provided as part of the code;

(4) detailed resonance theory using an extension of the Hill and Schaefer method (McKay et al. 1965);

(5) allowance for resonance overlap following Keane's (1966) observations on the work of Rowlands (1963), including gross flux corrections suggested by Keane and Pollard (1966);

(6) allowance for resonance screening of small particles of fuel separated from the main bulk of core material, following Keane (1964a);

(7) production of resonance shielding factors to save time when using the code for a burnup survey;

(8) burnup calculated analytically- permitting large time steps;

(9) parallel searching of a tape for a chosen scattering matrix using the IBM 1401 while the IBM 7040 is engaged in calculation (Richardson 1965).

The code uses two completely binary libraries- one a cross section (and resonance parameter) tape, the other a scattering matrix tape- and needs a scratch tape for intermediate storage of information. Input is read from the card reader and output is produced on the printer and punch (CRAM data, etc.). A condensed and/or mixed GYMEA library can also be produced on one or two other tape units.

The cross section library contains information for six neutron reactions:

(1) (n,γ), (n,α), or (n,p), depending on the nuclide,

(2) (n,f),

(3) (n, absorption),

(4) (n,ν-f) or (n,n) for moderator nuclides,

(5) (n, transport), and

(6) (n,2n) or other reaction, depending on the nuclide.

In burnup calculations reactions (1) and (6) are used to produce other nuclides and reaction (2) is used to produce fission products for fuel of one of four different types. A general table is given at the beginning of this library which states the burnup mechanism of each nuclide. This feature adds considerably to the flexibility of the programme as burnup mechanisms are not built into the programme. Such a table may contain an entry that reads

U235,2,NO0,U236,NO0,0.,0.,0.,0.

which states that U^{235} yields fission products based on the 2nd yield entry for each fission product nuclide, that decay is not be considered. (NO0), that reaction (1) of the library produces U^{236}, that reaction (6) of the library is not to be considered as far as producing another nuclide is concerned, and that the decay constant is zero, as are also the four possible yields from fuels designated as fuels of type 1,2,3, or 4. A restriction does apply however to the ordering of the library nuclides. Further details are given in Section *18*.

The scattering matrix library contains scattering transfer matrices for materials such as BeO at a variety of temperatures. In addition, the theory used in the preparation of the scattering matrix can be selected, for example BeO crystal scattering. Since the cross section library usually contains data for individual nuclides, the user must provide the mixing rules as part of the card input to the programme.

Such a rule can be punched in free format (*22*)

'BEO' = 1.BE9, 1.O16, DENSITY 1.8' '

After the appearance of this card the user can refer to BeO as though data for it were given as part of the cross section library information. The density is used only if nuclide ratios are to be normalized to unit volume or if the effect of dispersed fuel particles is to be included (*5.3*).

Further GYMEA libraries can be created during running of the programme. These libraries can have resonance parameters turned into shielding coefficients, or simply cross sections, and the groups can be collapsed and nuclides mixed to form a new library oriented to the particular needs of the user.

2. CODE PHILOSOPHY

The structure of an input deck for GYMEA is not unlike a set of source decks for compilation and execution under the FORTRAN monitor. The reason for this is that particular users will bias the running of GYMEA to suit their needs, which may include minor extensions of the code using the toy-FORTRAN compiler. A run may thus consist of a set of subroutines and perhaps a set of jobs. The jobs may well be carried out for different people, with completely independent jobs being run to take advantage of time-saving resulting from loading and unloading tapes.

Each GYMEA user deserves to be protected from a previous 'foul-up' just as each job of a monitor run is guaranteed this protection. In fact the philosophy of GYMEA on detecting an error is to call standard error routines which essentially call in the next job. It is possible however for any user to write his own version of error routines using the toy-FORTRAN provided as part of the input facility. This type of variable extent input is possible as the code has a standard state, and entry of data simply overwrites, or extends, this state to suit the needs of the user. It is felt that the structure and philosophy of this code with its free input, variable extent data will find wider application in scientific computing in the near future.

Those using computer programmes must surely be amazed at hardware development of computers over the past decade and must surely be disappointed with software developments over the same period. Perhaps writers of codes have available many more powerful tools now than ten years ago, but we should seriously ask, how have the code users fared? Most scientific computing in the field of nuclear reactor development is now initiated by persons other than code authors. Code authors, and machine manufacturers, must therefore seriously look at this sadly neglected area of computing. It is pleasing to read reports of a compiler language being developed by IBM (1965) which promises to FORGO (perhaps a suitable name) the old tradition in computing of terminating a user's run without his permission.

3. CODE MECHANISM

3.0 Summary

The code is a chain programme and consists of six links. Common subroutines form the bulk of the main programme and common data consumes a large fraction of the available storage. One array WH (10000) is used for storing different quantities at different stages of the calculation and an understanding of how this array is used throws some light on the structure of GYMEA.

3.1 Chain 1– Compiler and Error Routines

All data up to and including a CEASE card is read into the array WH. Since cards are originally read with FORMAT (12A6), 800 cards can be entered. These cards are then inspected, using a free FORMAT input subroutine (*22*), and certain cards are compiled, that is, overwritten by direct linkages to internal subroutines; for example

$$Z(8) = Z(10)*0.8234E-2$$

is compiled into a card with a $ in column 1 followed by numbers which provide the necessary direct calculation of Z(8). The cards are then written at the beginning of tape 4 as a complete file.

In addition, errors call this chain, which rewinds all libraries and prints self–explanatory messages.

3.2 Chain 2– Input Data

The cards previously written on tape 4 are read into WH and the cards are inspected. Data is then entered into COMMON to enable the neutronics part of the programme to function. Control is transferred to chain 3 when a time card is detected; such a card may read

T = 0. DAYS, 20 MAX.FLUX IT., 0 CRIT. IT.

3.3 Chain 3– Burnup

Should burnup be required, a 100 x 100 (maximum) nuclide balance array is stored in WH. As the array must be nearly triangular (6) the original information is stored in the lower half of the array and the solution is produced in the upper half of the array. In practice the use of this array and the flexible burnup mechanism table mentioned in Section *1* makes analytic solution feasible and worthwhile.

3.4 Chain 4– Group Flux Calculation, Condensing and Mixing Functions

When group flux is required to be calculated from neutron balance, WH is used to store information as an array 83 x 120 (maximum).

Scattering from one group to another is thus restricted to 80 groups, as the first two entries in each column are 'length of scattering vector' and 'position of self–scatter term'.

Condensed and mixed cross section data is then generated inWH for six reactions per group per mixture. Generated data is thus restricted by the requirement:

$$6x(\text{number of condensed groups})x(\text{number of specified materials}) \leq 10000$$

Should the user wish to delay output of this information it may be written on tape 4 as a further file.

3.5 Chain 5– Output for Most Neutronics Codes and Printed Output

The array WH is not disturbed by this chain, which uses the information for output either

as cards for a variety of codes or as printed output. Scattering matrix information is stored in full in an array WSS (3000), hence the following restriction applies:

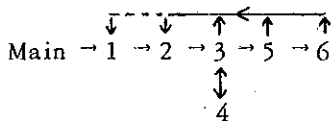
(number of condensed groups)^2 x (number of specified materials with scattering matrices) ≤ 3000

3.6 Chain 6– Output for GYMEA Library

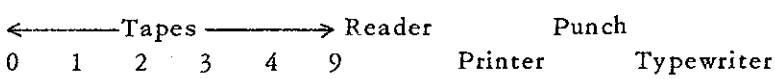
Again the array WH is left undisturbed as some of the information is needed for creating a new GYMEA library. Information not given in this array, such as resonance parameters or shielding coefficients, is obtained from the cross section library. Scattering matrices given as part of the scattering matrix library are simply condensed– mixing is ignored for this application. By repeated calling to this chain, it is possible to collapse the scattering matrices over different spectra for different temperatures and so build up a tape with the same layout as the original.

3.7 Programme Flow

Essentially each chain is called as follows:



3.8 IBM 7040 Operating System



Tape 0 = a possible library tape either used or created,

Tape 1 = " " " " " " " " ,

Tape 2 = scattering matrix tape attached through on–line 1401,

Tape 3 = a possible library tape either used or created,

Tape 4 = scratch tape,

Tape 9 = normal system tape using $EXECUTE GYMEA to call in programme (an ordinary chain tape may be used alternatively).

Reader = card data input unit,

Printer = printed output unit,

Punch = punched card output unit for CRAM data, etc,

Typewriter = unit used for operator messages.

3.9 Proposed IBM 360 Version

At the time of writing this report details have not been settled for the IBM 360 version of GYMEA. Magnetic disk storage will be used for the libraries, otherwise the programme will not be changed a great deal initially. In addition the output medium for other neutronics codes (CRAM, etc.) will be disk rather than the cards used for the present version. The programme should be operational in September, 1966.

Extensions of the code will follow after September 1966 which will enable more detailed treatment to be given to heterogeneous effects. In addition code-to-code communication will be improved using magnetic disk as a common data pool between programmes so that GYMEA may be readily used in a loop embracing other neutronics codes.

4. A SIMPLE JOB AS ILLUSTRATION

```
$IBSYS              ...hints are given thus
$ID
$JOB                2210 J.POLLARD    'GYMEA'
$*                  LOAD TAPES AS INDICATED
$PAUSE              295 ON 1, 260 ON 2(VIA 1401),SCRATCH ON 4
$EXECUTE            GYMEA
                    ...the above are normal 7040 monitor cards
*GYMEA              ...this card must be first data card
                    ...an * in col.1 indicates a comment card
      ,JOB1         A SIMPLE JOB AS ILLUSTRATION
                    ...the first card of a job (here called JOB1)
                    ...the input data is punched anywhere on a card
      CALL STAN     ...restores data to the standard state
      USE LIB X-S=1 OF 100 NUCLIDES AND SCAT =2
                    ...normally the first 3 characters identify the
                    ... card and numbers are extracted from the
                    ... remaining data.
      'BEO'=1.BE9,1.O16,DENSITY =1.8' '
                    ...the mixture BeO is defined in terms of
                    ...constituents of the X-S library:' ' means end of
                    ...definition
      SCAT 900.     'BEO' CRY    ' '
                    ...900.K scattering matrix of BeO crystal is
                    ...required
      N(1,100)=0.,'BEO'=4.-2,U233=4.-5' '
                    ...the nuclide concentrations are set
      OUTPUT 3  PRINTX  PRINTS  CRAM
                    ...the type of output required is set
      MATS 'BEO', U233, PU239' '
                    ...the resonance data of Pu239 will of course be
                    ...obtained for infinite dilution
      GROUPS 5  1   40   50   71   90   120
      T=0.DAYS,  20 MAX FLUX ITERATIONS, 0 CRITICALITY
                    ...this sends control to chain 3
      END           ...the last card of a job
      CEASE         ...the last card of a set of jobs (a load)
$IBSYS              ...note:the order of the data may be varied
                    ...provided the quantities defined by the user precede use
```

5. CHAIN 2– INPUT DATA

5.0 Alphabetic List of Card Input Types

An example of each card input type is included in the alphabetic list below. Only the underlined characters are necessary to determine the type of the card. Most of the data is punched in free format (22) – the exceptions are double underlined and b(=blank) is used in these cases to indicate the setting out. Normally the data is punched as for FORTRAN coding. Data, other than FORTRAN-like cards, can be extended beyond one card (column 1 to 72); continuation cards must then be punched in column 1 with a non-descending integer, which is tested but not read as part of the data. Brief comments, which are not to be punched, are given thus:

...comments, page(s) giving details, main page
...first.

bbbbb7bbbb13bbb...comment card (in column 1), 15

=

/ 99 ...numbered card to assist logic (any card except END or
= ...CEASE), 59

=GYMEA NDXD NDSC ...library check card, 15

,GR01 ...beginning of a job, 14

,DATA GR01 ...beginning of data read by user's programme, 61

,DISCARD ...beginning of other than the first load, 14

,RETAIN ...alternative to above, 14

'H2O'=2.H1,1.O16,1.' ' ...a mixing rule, 19

ACCURACY = 1.E-5 ...group flux accuracy parameter, 32 , 45

ALL N = 2*.04,68*0 ...concentrations for all nuclides, 21

AVX LIMIT=0. ...sets exit limit for B2AV, 33

BURN 2*-1,1,97*0 ...modifies burnup mechanism, 33

CALL NS1 ...call to subroutine,62 ,14 ;NS1 shielding
...subroutine, 23

CEASE ...terminating card of a load, 14

CONTINUE ...end of DO loop, 60

COPY 3 NDS1 1 5*0 4*1 ...sets parameters which determine
...structure of a scattering matrix
...library to be copied, 17

CREATE 3 NDX1 6*-1 64*0 ...sets parameters which determine
...structure of a cross section
...library to be created, 16

DO 2 -1=1,5,1 ...start of a DO loop, 60

DT= 100.,20,0,2 ...forces neutronics calculation, 28 , 35

END ...final card of a job or subroutine, 14,60

```
ERROR 1,16150,0,0    ...permits voluminous dump of programme common on
                     ...detection of an error, 72

FIFA PU239 PU241 ' '    ...distinguishing card for a burnup user, 24, 36

FLUX = 1.+14    ...sets required flux level, 30

FORMAT(1X1P10E12.3)    ...user's required format for output, 61

GB2 = 120*0.003    ...sets group-dependent buckling, 32

GFLUX = 1, 1.5, 2, 2.1, 3, 3, 4, 3.8, 5, 6.1, 6.2, 6.18,
1 6.2, 6.29, 8.1, 7, 80*7.2, 10, 11, 12, 12.2, 18*2, 0.1,
1 1.-2    ...sets flux spectrum (not level)- note continuation cards, 32

GO TO 3    ...control is transferred to statement numbered 3, 60

GROUPS 3 1 10 72 120    ...required condensed groups, 26

GSOURCE 1. 119*0.    ...overwrites library fission source, 32

HEADb1 SAMPLE JOB    ...user's choice of heading information, 17

IF (X(0)) 1,2,2    ...logical test, 60

ITERATE 5, .05    ...sets outer iteration control for equilibrium search, 71

J(1)=2    ...arithmetic card, 59

KEFF LIMIT = 1.    ...sets exit limit for k_eff, 33

KINF LIMIT = 1.05    ...sets exit limit for k_∞, 33

MATS 'BEO' U233 (23,70)' '    ...required materials for output, 26

N 'BEO'=.04,(23,70)=1.-10' '    ...required concentrations, 21

OUTPUT 1 PRINTX    ...printed group cross sections sought, 25

PART .01 'PU' ' '    ...particle size (for resonance theory), 22

PAUSE    ...used with tape changing, 60

POWER = 11. WATTS/CC    ...only a burnup user may use this, 30

PUNCHbOUTPUT NO 1    ...columns 13-72 punched as a card 1-60, 61

PUT 3 30X1 3 30S1    ...used with GYMEA library preparation, 17, 55

PX 51,121,1    ...punches output from X array, 61

REQD 10    ...required overlap and transport cross section, 27

RETURN    ...returns from a user's subroutine, 62, 14

RX 671,790,1    ...reads data cards after CEASE, 61

SAVE 4 6*1 3*1    ...condensed data is saved in core, 27

SCAT 900. 'BEO' CRYbbb' '    ...scattering temperature and matrices, 17
```

SEARCH B10 .1, 1.2, 10., 1., 0.001 ...sets criticality search conditions, 29

SHUT DOWN ...burnup option, 31

START UP ...burnup option, 31

SUBROUTINE DAT ...first card of a subroutine, 62

TEMP=850 ...temperature used in resonance theory (if different from SCAT ...card temperature), 18

TYPEbbLOAD TAPE 260 ON 2 ...operator messages, 61

T= 0., 20, 0 ...forces neutronics calculation, 28, 35

UNLOAD 2 ...physical tape unload, 61

USE 1,70,2 ...libraries to be used, 15

VOID .4 ...rescales nuclide concentrations by .6, 22

WRITE10 TYPICAL BEO SYSTEM ...writes this message on the printer, 61

WX 551,670,1 ...outputs X variables on the printer with FORMAT specified, 61

X(9)=4.9 ...arithmetic card, 59

Z(0)=1.0 ...arithmetic card, 59

$IBSYS ...7040 monitor card, example, 9

5.1 Layout of a Run

Some entities which help to describe the structure of a data deck must first be defined. In Section *4* a simple job was given as illustration. A job consists of all data cards for a problem, which starts with the problem identification

,NAME AND ANY COMMENTS

which has other control cards to force burnup calculations (detailed later), and which terminates

END

These cards are typical of input data which is punched in free format (*22*) anywhere on a card or set of cards. The job name is given by the 4 characters immediately following the comma of the leading card. This name is used to label output and serves to identify a job. A job must retain an identity since, if errors arise in a job, the job is terminated (see Section *10* however) and the next job is called. If the next job is dependent on the first, then it will also be terminated following an error in the first job, unless the standard data state (*11*) is restored thus

CALL STAN

before a neutronics calculation is attempted. Since data generated in one job is available in subsequent jobs the choice of boundary between jobs is somewhat arbitrary.

In addition to jobs, which are carried out in the order of loading, subroutines may be written by the user. These subroutines are common to all the jobs making up a load. A load thus consists of initial subroutines, jobs, and perhaps subroutines interspersed between jobs, loaded into the core for all data given prior to a card which is punched

CEASE

The selection of initial subroutines is based on the fact that the subroutines can be retained or discarded for the next load. Subsequent loads must be started with one of the cards

,DISCARD

,RETAIN

Between loads, data is always restored to the standard state as the compiler uses the COMMON data area for its own needs.

The compiler and subroutines are discussed in Section *10*, but suffice it to say here that subroutines start with

SUBROUTINE EG1

they usually contain

RETURN

and they must conclude

END

Subroutines may call other subroutines, either written in the same fashion or provided internally, and the manner of calling is simply

CALL EG1

Unlike FORTRAN subroutines, arguments may not be appended to the calling statement.

The choice of a load is also somewhat arbitrary, although it should be borne in mind that a load may not contain more than 800 data cards and may not consist of more than 10 jobs.

It is possible for the user to test whether a previous job has been terminated owing to an error condition, even if the job is not in the same load, as one variable available to the user (*12*) is set thus:

X(0) = –ve if an error exit,

or X(0) = 0. otherwise. A typical test at the beginning of a job might be

IF(X(0)) 1,2,2

etc. Section *10* contains further details of the compiler language.

A full set of data for GYMEA is termed a run. A run starts with the necessary monitor cards, as given in the simple example of Section *4*, and terminates with the monitor card

$IBSYS

The first data card of a run is overwritten by the SEARCH routine (Richardson 1965) when this routine is transferred from 7040 core to the 1401 core. For this reason a spurious first card should be provided, punched say

*GYMEA

In general cards punched with an * in column 1 are comment cards designed to assist data checking as they are ignored by GYMEA.

5.2 Library Information

5.2.1 Library request

Before any reference is made to data in a library, a library tape or tapes must be specified thus

USE X–S 1 , 21 NUCLIDES, SCAT 2

Only the underlined are the important indicatives. The first number is the unit on which the cross section library is mounted (LIB), the second number (NN) is the number of the last nuclide beyond which the cross section nuclear data is ignored, and the third number is the unit on which the scattering transfer matrix library is mounted (LIBC). A cross section library must always be provided before a neutronics calculation is attempted; on the other hand a scattering matrix library is only necessary if group flux is to be calculated from neutron balance of a homogeneous system (*7.2*), and the actual unit must be 2, connected through the on–line 1401. Since this card forces the programme to check that the specified tapes are in fact GYMEA libraries LIBC should be punched as a negative number if a scattering matrix tape is not required. The number NN is mainly of interest to burnup users as they may save machine time by eliminating consideration of the nuclides at the end of the library. Other users may just as well use NN =100 (this is equivalent to the full nuclide set if the library does not contain 100 nuclides) as no time–saving results from using a smaller number.

If the libraries referenced in a previous USE card, not necessarily immediately before, are required to be checked to make sure they are specific libraries then the following type of card should be used

=GYMEA NDXD NDSC

The labels NDXD and NDSC must agree with the libraries mounted, cross section library first, otherwise the subroutine LIB is called. The user may write this subroutine himself if required (*10*). If LIBC < 0 then any non–blank label can be used for the second item. In addition to this checking feature, the =GYMEA card prints the library heading record of each library to provide the user with a record for later reference.

5.2.2 Library copies

During the loading of information for chain 4 flux calculation, the user can create an additional library for each entry to this part of the programme. This created tape is then used in calculating reaction rates and collapsed and mixed cross section data rather than the original library– this need for reading the cross section library twice is explained more fully in Section 7. The saving of machine time that may result depends on the problem being undertaken and the actual original library. An example is given in JOB2, Section *15*. For a problem not requiring burnup (*5.3.9*), only those nuclides specified for output (*5.4.2*) are created on the specified tape. The library may thus be considerably reduced in bulk with a consequent saving of machine time during later calculation of collapsed and mixed cross section data. This created library is a complete library in every detail, and may be used later in a run following a new USE card, or may be dismounted and saved for later use. The card that sets this option is, for example,

CREATE TAPE 3 NDX9 THUS 100*0

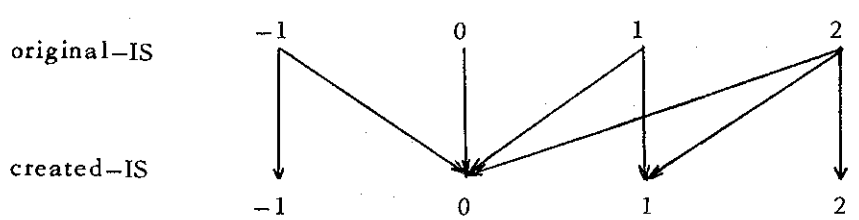
Again the underlined are the important indicatives and the example illustrates the use of repeated entry of a data word, 100*0 (*22*). The significant entries on the card have the following meanings:

(i) the tape unit on which the additional library is to be created, or a negative number if create mode is no longer required,

(ii) the identification label to be given to the library,

(iii) the numbers (IS) that identify the type of nuclear data to be created, given for each nuclide of the original library (actually NN data words); –1 = light scatterer (scattering cross section is given rather than $\nu\sigma_f$), 0 = nuclide with only cross sections given, 1 = nuclide with shielding coefficients given (*5.3.8*) for the library-designated resonance groups (*18.1.1*), and ⩾2 = nuclide with resonance parameters given for the resonance groups. If any entry is less than –1 then the data is created with the same structure as the original library.

A restriction obviously applies to the type of data that may be created, depending on the type of data given in the original library...



The additional information required for the production of shielding coefficients (*7.4.3*) is detailed later (*5.3.8*). It is important to note that data may be punched on more than one card following each control word, for example CREATE. To prevent the free input routine from reading through control words when insufficient data is given by the user, all continuation cards must be punched with a non–descending integer in column 1, which is tested, but otherwise ignored. This feature must be used with all data extending beyond one card; see however Section *10.1.4*.

All libraries produced by GYMEA, and all printed output, are labelled with heading information which may be set by the user thus

HEAD SAMPLE RUN FOR J.P. AND G.R.

The alphabetic information punched in columns 13 to 54 is used as heading. The character given in column 12 is used as page control for printed output produced by chain 5 (*8.3*). In addition to the heading information given above, the date held in the 7040 core is always used as part of the heading record.

It has been shown that machine time may be saved by creating a reduced bulk copy of an original cross section library. It is not envisaged that machine time will be seriously affected by the bulk of a scattering matrix library, as the first required scattering matrix for a specific temperature is located by the 1401 working in parallel operation with the 7040 (Richardson 1965). Nevertheless a feature is available which permits the bulk of a library to be reduced. As shown later in this section, it is possible to group-collapse a scattering matrix library, and the newly-created scattering matrix tape must have the same structure as the original. This forms a strong motive for having available a feature for deleting information from an original library.

The card used to cause this copy to be made is, for example,

COPY TAPE 2 NDS8 THUS 1, 5*0, 1, 3*0

The underlined items have similar meanings to the items on the CREATE card with the exception that the fixed point numbers that follow the label have the following meaning

0 = don't copy

1 = copy

and numbers must be given first for the material set of the original scattering matrix library (*18*), 6 in the example, and then for the temperature set (*18*), 4 in the example. This may be understood if it is noted that the structure of the scattering matrix library is such that data for all materials is given for every temperature of the library temperature set.

Again the information on the HEAD card and the date is used to form a heading record. A point that was not previously emphasized is that a scattering matrix may be mounted or created on any unit, but if the tape is to be used in neutronics calculations it must be mounted as unit 2 and must be connected through the on-line 1401. Unlike the CREATE feature, which is delayed until the neutronics calculation is under way, COPY is carried out on detecting the data card.

5.2.3 Condensed and mixed GYMEA library

Most of the comments relating to preparation of condensed and mixed rather than simply copied or data-deleted libraries are better discussed in the section dealing with this type of preparation (*9*).

A card that sets the cross section library unit and prepared library name, and the scattering matrix unit and prepared library name, may be punched, for example:

PUT X-S 3 XS01 SCAT 0 SC01

The programme includes provision for the preparation of both libraries on the same unit; the cross section library precedes the scattering matrix library.

5.2.4 Scattering matrices request

As discussed earlier in this section, it is generally necessary to nominate a tape unit for the scattering matrix library (USE), and the programme can be made to check that the correct library is mounted (=GYMEA). As it is possible to have available scattering matrices for one material for different thermal scattering models, each scattering material to be included in the study must be nominated, as well as its method of preparation. The card used for this may read, for example:

SCAT 900., 'BEO' CRY ' '

It is necessary of course to know the temperatures, materials, and mode of preparation of available scatterers in the scattering matrix library. In the example above the first item is the required temperature in degrees Kelvin, which must agree with an entry in the library temperature set table to within one degree. The given temperature also sets the temperature to be used in resonance theory (*7.4*); this may, however, be changed as indicated below. The next entries are alternately material and mode of preparation, given for all scatterers of interest in the problem in hand, terminating with inverted commas ' '. In general, chemical names enclosed in commas, for example 'BEO', describe a material that is not necessarily given in the cross section library (*5.3*). The correspondence is determined by data cards which specify the mixing rules. The mode of preparation must always be given as 6 characters, for example,

CRYbbb (b = blank)

Abbreviations such as CRYbbb for crystal scattering and GASbbb for monatomic gas scattering are convenient for indicating the required scattering law; these conventions are, however, the conventions of authors of the scattering matrix library and have no explicit meaning to the code GYMEA.

As a rule the materials given in the scattering matrix library set are materials which must be defined by the user to obtain the correspondence with nuclides in the cross section library (*19*). This layout of scattering matrix library is not essential, but it does provide the user with the means of adding proportions of scattering matrices to allow for, say, the scattering of neutrons in O^{16} associated with heavy nuclides when they are present in a matrix of a dominant scatterer, say BeO. In Section *5.3.1* such an application is given as an example. The complication associated with materials stems from the fact that fundamentally the code, since it is a burnup code, must deal only with nuclides. The code never has available concentrations of materials, and these are always produced when required from the nest of mixing rules given by the user and the nuclide concentrations.

5.2.5 Resonance temperature

It is possible to change the temperature specified on the SCAT card as far as it determines the temperature used in resonance theory. A data card that will cause this change may be punched, for example:

TEMP 850. K

5.3 Nuclide Information

5.3.1 Material specifications

Three possible representations of material specifications are given below:

(i) Nuclide labels, for example BE9 (or BE 9), are used to identify specific nuclides available in the cross section library.

(ii) Material labels, for example 'BEO' (note the inverted commas enclosing at most four characters), are used to identify specific materials either available in the cross section library or defined using mixing rules detailed below.

(iii) Nuclide sets, for example (1,5) (note the brackets), are used to identify nuclides of the cross section library, 1 to 5 in the example cited.

In addition, the blank material label ' ' is used to indicate the end of nuclide information, and commas or blanks may be used to separate nuclide information and assist readability. The distinction between nuclides and materials which are given in the library is unimportant except to authors of cross section libraries, who must be able to describe burnup mechanisms adequately (*18*). The distinction between materials which are given in the library and materials defined by the user is only important if an application required by the user requires material densities. Such densities are available only for defined materials (*5.3.5* and *5.3.7*).

5.3.2 Mixing rules

A mixing rule is given by the general statement:

material = weighted sum of nuclides or materials, either given in the library or defined previously, with density (g/cm^3) given immediately before the terminating blank material label' '.

For example,

'BEO' = 1.BE9, 1.O16, 1.8' '

is read as 'for every one molecule of BeO we have 1 atom of Be^9 and 1 atom of O^{16}, the density of BeO being 1.8 g/cm^3'. Alternatively this can be written

'BEO' = 1.BE9, 1.O16, DENSITY 1.8' '

or 'BEO' = 1.(1,2), 1.8' ' IF BE AND O 1 AND 2 OF LIB

In the second example DENSITY is not interpreted by the free input routine as it is seeking a number. This possibility of insertion of check words is typical of the application of the free input routine to GYMEA. However, check words used to assist data checking should be avoided when the routine is seeking alphabetic information. Further details are given in Section *22*. For those people not familiar with the inverted comma, it is punched $\frac{4}{8}$ in the one card column (lower case =) and is frequently written as @ for punching detail to avoid confusion with other characters.

It is shown in Section *10* that elements of a Z array can be calculated or set. This feature can be used with mixing rules, since a negative weight is replaced by the implied indirectly referenced element of the Z array. For example,

Z(20) = 0.76
Z(21) = 0.17
Z(22) = 0.07

'PU' = −20 PU239, −21 PU240, −22 PU241, 0' '

defines 'PU' to consist of 0.76 parts of Pu^{239}, 0.17 parts of Pu^{240}, 0.07 parts of Pu^{241}; the density is zero, which is satisfactory for applications not requiring material density. The elements of the Z array may be defined later than the appearance of the card defining 'PU', as the interpretation is not made until immediately before actual use of the information given on the card, for example, to define a material concentration of 'PU'. Density may also be specified in this indirect fashion by giving a negative value. Again a feature of the free input routine has been used, namely, the decimal point was not punched for the floating point data, as the routine provides an imagined decimal point to the extreme right of the number (*22*). The material 'PU' may be used, if required, in mixing rules that follow, for example

'PUO2' = 1.'PU',2.O16,11.' '

Normally mixing rules must be associated with materials given in the scattering matrix library and selected using a SCAT card (*5.2.4*), for example,

'BE9' = 1.BE9, 0' '
'O16' = 1.O16, 0' '

As a more involved application, indicating the reason why the scattering matrices are usually given as materials which must be defined by the user (*19*), consider an example in which

$N_{BeO} = 4 \times 10^{-2}$ nuclides/10^{-24} cm^3

$N_{U^{235}O_2} = 1 \times 10^{-4}$ nuclides/10^{-24} cm^3

and the following SCAT card is used:

SCAT 900, 'BEO' CRY 'O16' GAS ' '

Care must be taken to ensure that scattering by oxygen is not accounted for twice. In the example, for every 1 atom of O^{16} associated with U^{235} there are 201 atoms of O^{16} in the mixture. The definitions

'BEO' = 1.BE9,1.O16,0' '

'O16' = 201. O16,-1 O16,0' ' THE LAST O16 is Z(1) WEIGHTED

Z(1) = -200.

are therefore used to obtain an allowance for the O^{16} not present in BeO using 'O16' GAS scattering. Two entries of weighted amounts of O^{16}, which give in all a weight of unity are required because the material concentration of 'O16' is obtained from the first entry on the definition card as the nuclide concentration of O^{16} divided by 201 (see Section *5.3.3*). The concentration of 'O16' calculated in this manner is used with the 'O16' microscopic scattering matrix data to give the required macroscopic data which makes allowance for scattering of neutrons with oxygen in $U^{235}O_2$. On the other hand the cross sections of 'O16' are obtained from the complete mixing rule. A more general example is given as part of JOB4, section *15*.

The other remaining odd value for a fraction of a material, zero, is also given an interpretation which is useful for defining a single material which has the macroscopic properties of its constituents, for example,

'MIX' = 0. (1,100), 0.' '

The microscopic cross sections of the component nuclides are weighted by the nuclide concentration defined immediately before actual use of the card, say to prepare data for CRAM. For people intent on burnup studies, it should be pointed out that three sets of nuclide concentration exist at the end of a time step – called by printed output AFT.N, AVE.N and BEF.N (17). The actual concentrations used for this weighting purpose depend on Z(0) in the following fashion:

$$Z(0) = \begin{cases} +ve & \text{AFT.N,} \\ 0 & \text{AVE.N,} \\ -ve & \text{BEF.N.} \end{cases}$$

For a user not involved in burnup studies, provided Z(0) is not negative, this point may be ignored, since

AVE.N = AFT.N

From computer storage considerations no more than 40 materials may be defined, and no more than 200 entries may appear in a compacted table, based on storage of information 2 words per nuclide or material, or 4 words per material set plus 1 word for each density.

5.3.3 Dominant nuclide

The first library nuclide or material of a specification is termed the dominant nuclide. If the first item of a definition is a defined material, then the first library nuclide or material of this defined material is the dominant nuclide; this procedure may have to be taken to further depth, but eventually a library nuclide or material will be located. Given the concentration of say 'BEO', it is then a simple matter to calculate the additional amount of Be^9 and O^{16} this contributes to a homogeneous mixture. The reverse is not so simple, however, unless the concentration of the dominant nuclide Be^9 is used to calculate the concentration of 'BEO'. Essentially, every defined material should have a unique dominant nuclide if the concentration of defined materials is to have a sensible meaning, say, for printed output (*8.3*). In addition, when mixing is carried out for preparing a new GYMEA library (*9*) entries in the burnup table that describe the next nuclide of a burnup chain are based solely on the dominant nuclide. On the other hand the mixture decay constant and mixture yields from fission are an aggregate for the whole mixture.

This interpretation may not be of universal application, but it is a simple matter to change the table using the library edit programme, EDITOR (Ford 1966- see brief details Section 19).

5.3.4 Concentration definition

Nuclide or material concentrations may be given simply as ratios (5.3.5), or as nuclides/10^{-24} cm^3. Normally these concentrations are entered using a card which starts N and which terminates ' ', although it is possible to calculate concentrations and have the result available to GYMEA through the user's COMMON data area (12). An example of the latter method is

```
X(51) = 1.E-4
```

and an example of the former method is

```
N'BEO' = 1.-4' '
```

Note that the condensed exponent notation is available for floating point data (E absent) using the free input routine (22). Remembering that only concentrations of library nuclides are stored by the code (5.2.4), one essential difference exists between the two methods – the first enters 1.E-4 as the concentration of Be^9, provided it is the first library nuclide, and the second adds 1.E-4 to the previous concentrations of Be^9 and O^{16}. This last feature is a result of the requirement, for defined materials, of adding say O^{16} from BeO to O^{16} from ThO_2 to give the correct O^{16} content of a mixture of BeO and ThO_2. To avoid confusion with materials possibly available as part of the library data, this feature of adding concentrations is extended to cover all single nuclides and materials. When the concentration of a set of library nuclides is given, however, the concentration specified over-writes the previous data. This, plus the fact that more than one concentration may be specified on a card, enables concentrations to be easily set; for example,

```
N(1,100)=0., 'BEO' = 1.-4 'THO2'= 1.-6' '
```

will set

$$N_{Be^9} = 1. \times 10^{-4}$$

$$N_{O^{16}} = 1.02 \times 10^{-4}$$

and $$N_{Th^{232}} = 1. \times 10^{-6}$$

provided the materials 'BEO' and 'THO2' have been defined prior to the use of this card.

To enable nuclide concentrations to be readily punched using a computer programme, including GYMEA itself, concentrations of all nuclides (NN) may be given in library order following the control word ALL N, for example,

```
ALL N 1.00E-04 1.02E-04  ...ETC...
```

5.3.5 Normalization of concentrations to unit volume

A subroutine NUC is available which transforms nuclide or material ratios to nuclides/10^{-24} cm^3. Only defined materials should be used in detailing material ratios, as the density of each material is used to calculate nuclide concentrations assuming that there is no change of volume on mixing. The concentration of any other nuclides specified will be set zero without an error condition resulting. An example of the use of this feature is

```
'BEO' = 1.BE9, 1.O16, 1.8' '

'THO2'= 1.TH232, 2.O16, -5' ' I.E.Z(5) = DENSITY

N(1,100)= 0., 'BEO' = 100, 'THO2' = 1' '
CALL NUC
```

On entry to the subroutine the array AFT.N (X(51)–X(150)) contains nuclide ratios derived from the material ratios given on the data card, and on exit the array AFT.N contains these concentrations normalized to nuclides/10^{-24} cm^3.

It is important for this application that only materials required in the calculation should have (non–zero) densities given and that the materials with non–zero densities should each contain a unique dominant nuclide (*5.3.3*). Materials with zero densities given are ignored. The sample calculation, JOB2 of Section *15*, illustrates these remarks.

5.3.6 Renormalization of concentrations to allow for void

When a data card, punched, for example,

VOID 0.05 I.E. 5 PERCENT

is detected in the input, the concentrations held in the array AFT.N are renormalized by the factor (1–VOID).

5.3.7 Effect of resonance self shielding of separated fuel particles

The procedure given by Keane (1964a) for modifying the potential scattering cross section of moderator nuclides, σ_s, when fuel particles are separated from the bulk of moderator, gives

$$\sigma_s^* = \sigma_s /(1 + \bar{\ell}\,\Sigma_p\, V_m /V_p)$$

which is applied in resonance theory as

$$\sigma_p^* = N_{mod}\ \sigma_s^*/N_{res},$$

for all library moderator nuclides (*18*), where

$\bar{\ell}$ = modified mean chord length for the fuel particles volume V, surface S

$= \frac{3a}{2}(\frac{4V}{S})$

= aD of Keane and he recommends using a $=\frac{1}{2}$,

D = mean diameter of particles in cm, and

V_m /V_p = ratio volume of homogeneous mixture to volume of separated particles.

The potential scattering cross sections for moderator nuclides, originally extracted from the specified cross section library tape, are adjusted automatically when a card such as

PART 0.01 'TH' ' '

is detected. In this example $\bar{\ell}$=0.01 cm is required (200 micron particles) for separated fuel particles composed of all the Th originally given as a homogeneous mixture, that is, the concentrations for the homogeneous system must be given before this card. The materials given on the PART card must be defined by the user as the densities are required in this application. A further feature which helps if $\bar{\ell}$ is to be calculated using the compiler, is that a negative data entry refers to an element of the Z array (*12*); for example if $\bar{\ell}$ = –1, then Z(1) is used instead. New PART cards may be used as frequently as required – note that a card must be used if the initial composition is changed.

The total potential scattering cross section, σ_{pt}, used in GYMEA resonance theory (*7.4.2*) then amounts to the following:

$$\sigma_{pt} = \sigma_{sr} + \text{sum}(\sigma_p^*)$$

where σ_{sr} = the potential scattering cross section of the resonance nuclide being studied, and the sum is taken over all moderating nuclides. The expression for σ_{pt} given above is of the same form as the expression used in calculating heterogeneous effects of a more general nature than dispersed fuel particles. In such applications, a = 2/3 is generally used, and then $\bar{\ell}$ = 4V/S.

The user may wish to adjust the potential scattering cross sections of the nuclides himself using the compiler and the fact that the cross sections are held in the user's COMMON (*12*) as X(351) – X(450) for nuclides 1–100. It should be noted that the resonance theory requires the identity of each nuclide to be retained as the theory determines a factor λ for each potential scattering cross section. The feature mentioned should prove useful although it must be used with some care.

5.3.8 Concentration definition for shielding theory

It is shown in Section 7.4.3 that a shielded cross section at one temperature is given by

$$\sigma_x = \sigma_\infty / \left(1 + \frac{A}{\sigma_p} + \frac{B}{\sigma_p^2}\right)^{1/2} \qquad (x = \gamma, f, \text{ and } \nu f),$$

where

σ_p = total moderator potential scattering cross section per absorber atom, and

σ_∞ , A, and B are the shielding parameters to be determined for each reaction type x.

The three parameters are determined from three forced calculations of the shielded resonance cross section using resonance theory (7.4.2). The forced calculations are carried out for three different specified nuclide concentrations contained in three arrays designated $\underset{\sim}{N}_1$, $\underset{\sim}{N}_2$, and $\underset{\sim}{N}_3$. The nuclide concentrations may be entered into these arrays using three subroutines. These subroutines require the concentrations to be defined using the nuclide concentration card (that is stored in the array called AFT.N), for example,

```
N(1,100) = 0., BE9 = 4.-2, TH232 = 4.-4' '
```

The subroutine

```
CALL NS1
```

then transfers selected elements of AFT.N to the array $\underset{\sim}{N}_1$. Two rules are observed in this selection:

(i) if the library does not contain any shielding factors (IS≠1) then all concentrations stored in AFT.N are transferred to $\underset{\sim}{N}_1$, or

(ii) if the library contains at least one shielded nuclide (IS=1) then only the concentrations of those nuclides that have resonance parameters given (IS≥2) are transferred to $\underset{\sim}{N}_1$.

The subroutines

```
CALL NS2
```

```
CALL NS3
```

play a similar role but relate to the arrays $\underset{\sim}{N}_2$ and $\underset{\sim}{N}_3$ respectively. The reason for the selection rules cited above is that entry of data for the calculation of shielding parameters for a specified nuclide should not destroy previous data possibly read from the library tape (*18*).

A library containing shielding parameters for selected nuclides may be created during normal running of the programme. The feature is set with the CREATE card (*5.2.2*). The concentrations $\underset{\sim}{N}_1$, $\underset{\sim}{N}_2$, and $\underset{\sim}{N}_3$, besides providing sample points for calculating resonance cross sections, are used to regenerate these cross sections before the shielding parameters are group collapsed (9).

5.3.9 Distinguishing card for a burnup user– FIFA

When GYMEA is run as a neutronics code for clean core conditions, only data requested for output (*5.4*) is used to give reaction rates and condensed and mixed cross sections. When burnup is required, however, data for all nuclides is used, up to and including data for the nuclide specified on the USE card (NN). Since this latter manner of operating GYMEA probably involves a greater bulk of calculation, it should be avoided by all except users intent on burnup studies. The type of card that distinguishes a burnup user from a neutronics user is punched, for example,

FIFA PU239, PU241 ' '

where the nuclide or material labels identify nuclides to be included in the definition of initial fissile atom concentration used in the calculation of FIFA (fissions/initial fissile atom). The concentration of Pu^{239} and Pu^{241} defined prior to this card will be set in COMMON storage (as FIFC or X(39)) for later use. FIFC should be non–zero, otherwise a burnup job will be terminated for T≠0 (*5.5*). In addition all nuclide concentrations defined prior to the use of this card are copied from the array AFT.N to BEF.N (*12.3*).

A burnup user may return to the alternative status using a FIFA card punched

FIFA ' '

5.4 Information Obtained on Output

5.4.1 Type of output

The code has provision for output of information for a variety of neutronics codes, as well as information which may be printed.

Printed output is created in two chains– chains 3 and 5. Output from the burnup and neutronics chain (3) is illustrated in Section *17*, but it should be noted that single nuclide information, as distinct from information for defined mixtures, may be printed as 1–group collapsed cross sections, reaction rates/source neutron (standard option), etc. The type of normalized output obtained is determined by a control word X(9) (=0. for the standard state). Starting at the first digit of X(9) immediately preceeding the decimal point and moving to the right, each digit is inspected in turn to enable more than one output table to be produced for each neutronics calculation. The digits have the following interpretation:

0 $N\sigma\phi/S$

1 $N\sigma\phi$

2 $N\sigma$

3 $\sigma\phi$

4 σ

5 $N*\sigma\phi/S$

6 $N*\sigma\phi$

8 new page (only)

9 end of output

where

N = nuclide concentration AFT.N

σ = collapsed cross section (6 reactions given)

ϕ = flux

S = source strength, hence $N\sigma\phi/S$ is a reaction rate per source neutron

N* = nuclide concentration AVE.N

(N and N* are the same for a non–burnup user)

If two successive digits are the same, the output terminates on the second digit of the pair. Using the compiler (*10*), X(9) can be set as part of the input data; thus

X(9) = 4.809

would result in two tables being produced, the first for σ and the second for $N\sigma\phi/S$, with the latter starting on a fresh page. The table for σ would follow a standard table, starting on a new page, which lists k_{eff}, k_{∞}, etc. (6.5). Only the first 7 digits may be used for this application.

If X(9) is negative, no output is produced unless $X(9) \leqslant -10$. in which case the complete set of condensed and mixed cross sections is produced as a further file (the first file is the compiled input data) on tape 4. The user may wish to prevent, or save up, output during an iterative procedure carried out under control of the compiler. When output is saved up on tape 4, it can be used later with the aid of the subroutine OUTPUT which is obtained thus:

CALL OUTPUT

Of course it is not possible to change the number of groups or number of materials between generating the information and using it (see also Section *13.3*).

Output from chains 5 and 6 is requested using a card

OUTPUT 2 CRAM PRINTX

which informs the programme that 2 types of output are required, namely CRAMbb (b=blank) and PRINTX. The types of output that may be requested are:

PRINTX	(printed cross section data given one material at a time)
CRAM	(FORTRAN version of Hassit's code (1962))
4–ZOOM	(FORTRAN version of 9–ZOOM (Stone et al. 1959))
DSN	(FORTRAN version of Carlson's code (Carlson et al. 1960))
WDSN	(WINFRITH DSN code (Francescon (1963))
PRINTS	(printed scattering matrix data)
GYMEA	(a PUT card must also be used (*5.2.3*); Section *9* gives details of preparation of new condensed and mixed cross section and scattering matrix libraries for GYMEA).

From time to time other codes will be added to this list as they become available on the computer used at the A.A.E.C. For the user wishing to extend the source code, Section *20* contains brief details of the programme source structure.

In addition to the name, for example PRINTX, each item of the above list may be followed by a fixed point number if required (not compulsory). If PRINTX is followed by a 1, then the cross section output is printed one group at a time for all materials required. The meaning associated with this feature for other items of the list is given in Sections 8 and 9.

The variable X(6) is used in conjunction with PRINTX and PRINTS in much the same manner as X(9) is used for burnup and neutronics chain output except that the digit 8 has no interpretation – instead, page control of output, other than the first page of a calculation, is set with a character in column 12 of the HEAD card (5.2.2).

5.4.2 Content of output

The content of output information is determined by three cards which set the materials required for output, the condensed group structure, and the required resonance overlap procedure and transport cross section averaging procedure. An example of the first type is

MATS U233, 'BEO', (3,8) ' '

which specifies output for eight materials – U^{233}, BeO (presumably a defined material), and the library nuclides 3 to 8 inclusive. Again ' ' is used as a terminator of material labels. The collapsed group structure is given in terms of the library groups thus

GROUPS 2 1 48 120

which specifies that the condensed groups have the following structure:

group 1 condensed = original groups 1 to 48

group 2 condensed = original groups 49 to 120.

The condensed groups need not embrace the full library set, but scattering matrices may be truncated if the full set is not used. Note that if the number of groups defined is NGD then (NGD+1) fixed point numbers must be given to specify the condensed group boundaries. Should these numbers run beyond one data card then subsequent continuation cards must have a non-descending integer punched in column 1. This integer is tested by the free input routine (22), but otherwise ignored. This feature of continuation cards is available with all data except FORTRAN-like cards.

The programme includes optional provision to allow for cross section change due to overlap of resonances (7.4.5) and optional averaging of transport cross sections when condensing groups (7.3) thus

$$\text{(i)}\quad \bar{\sigma}_{tr} = \sum_i \sigma_{tr,i}\,\phi_i \Big/ \sum_i \phi_i$$

or

$$\text{(ii)}\quad \bar{\sigma}_{tr} = \sum_i \sigma_{tr,i}\,D_i\,B_i^2\,\phi_i \Big/ \sum_i D_i\,B_i^2\,\phi_i \quad ,$$

where $\bar{\sigma}_{tr}$ is the collapsed transport cross section for a particular nuclide,

$\sigma_{tr,i}$ is the library i^{th} group transport cross section for a particular nuclide,

D_i is the i^{th} group transport cross section based on $\Sigma_{tr,i}$, the transport cross section of the mixture specified by the user (5.3.4), and is given by

$$D_i = \frac{1}{3}\,\Sigma_{tr,i}$$

B_i^2 is the group dependent buckling specified by the user (5.7) or the number 10^{-15} if the buckling is zero,

ϕ_i is the group dependent flux (5.5),

and the summation on i extends over all groups to be collapsed to one.

A single fixed point number is given on a card, for example,

REQD 11

where the tens digit has the interpretation

0 = no overlap

1 = overlap

and the units digit has the interpretation

0 = method (i)

1 = method (ii), normal diffusion code requirement.

The standard state of the code (*11*) sets this variable to 11. During print out the variable is referenced

XS-OT= 11

and, if the option required cannot be accommodated by the current calculation of the code (*7.4.5*), the option used instead is printed with a minus added as a warning indication.

Entries on the MATS card are restricted to not more than 40 words of indicative information, based on a nuclide or material producing 1 such word or a material set producing 3 words for each data item on the card.

5.4.3 Output for later computation

The user can set the condensed and mixed cross section subroutine to save selected, weighted, condensed and mixed cross sections in the user's COMMON (*12*). Using this feature it is possible to calculate quantities by manipulation with the compiler (*10*). Entries given on the appropriate SAVE card relate to a previously used, although not necessarily immediately preceding, MATS cards, for example,

MATS U233, 'BEO', (3,8) ' '

SAVE AS 4 2*1, 4*0, 100 0 -1

The fixed point numbers supply the following information:

(i) The first number is a digit 0 to 7 which has the same interpretation as digits of X(9) and X(6) (*5.4.1*), that is σ is to be saved for the example.

(ii) The second to seventh numbers are six digits 0 or 1 which relate in order to individual neutron reactions to be saved or not;

0 = do not save

1 = save,

and reaction 1 = (n,γ) usually

2 = (n,f)

3 = (n,abs)

4 = (n,νf) or (n,n) for moderator nuclides

5 = (n,transport)

6 = (n,2n) usually ,

(see library details, Section *18.1*). Thus σ_γ^1 and σ_f are required for the example given.

(iii) The remaining numbers, comprising one for every entry on the MATS card– (3,8) is one entry– have an interpretation which is best explained in terms of the example:

100 = save first entry for U^{233} in Z(100), second entry in Z(101), etc.,

0 = do not save information for BeO

−1 = use index register J(1) (see Section *10*) and save first entry for nuclide 3 in Z(J(1)), second entry for nuclide 3 in Z(J(1) + 1), etc.

If 3 condensed groups were requested with a previous card, then entries saved for U^{233} in the example would result in the Z array containing the following information:

Z(100) = σ_γ (group 1),

Z(101) = σ_γ (group 2),

Z(102) = σ_γ (group 3),

Z(103) = σ_f (group 1),

Z(104) = σ_f (group 2),

and Z(105) = σ_f (group 3).

If X(8)≠0. then, instead of information being directly stored in the Z array as indicated above, X(8) weighted entries would be added to existing Z elements thus:

Z(100) = Z(100) + X(8) *σ_γ (group 1), etc.

Using this feature it is possible to obtain time-averaged quantities, for example.

5.5 Forcing a Neutronics Calculation

5.5.1 Flux from neutron balance

Two types of time card cause the programme to call the neutronics and burnup chain, chain 3. These cards are discussed at length in Section *6.1*. However, a user not intent on burnup, but requiring group flux to be calculated from neutron balance of a homogeneous mixture of materials with specified concentrations (7), will probably use a card punched

T = 0., 20, 0

or DT = 0., 20, 0, 1

which simply sets reactor time to zero, that is, clean core status, sets an upper limit to the number of iterations required in the flux calculation, and sets the maximum number of criticality iterations to zero. This latter number is only positive when a parameter is to be adjusted to achieve a specified state of criticality.

5.5.2 Criticality

If a parameter is required to be adjusted to achieve criticality, then, before a time card punched, say,

T = 0., 20, 6

can be used, an eigenvalue search card must be given. Such cards may be punched, for example,

SEARCH B10 1.-3, 0.8, 1.+3, 1., 0.001

SEARCH 'CM' .1, 1.1, 10., 1.05,1.-4

SEARCH GB2 1.-2, 0.5, 1.+2, 1., 0.01

The indicative word SEARCH should be followed by a library or defined material name (brackets are not permitted), or by GB2, which indicates group buckling is to be adjusted to achieve criticality. When the latter option is required, only the level of a previously defined group-dependent buckling (*5.7*) is adjusted. To understand the other entries on the card, it should be noted that the programme finds an eigenvalue which multiplies the original guess given by the user; in the first example this would be the concentration of B^{10}, set perhaps using a card

N B10 = 1.E-7 ' '

The five floating point numbers given on the SEARCH card (and available as X(33) to X(37) of the user's COMMON –Section *12*) have the following meaning for each number, in order of punching:

(i) a lower limit for the eigenvalue, λ,

(ii) a second guess at the eigenvalue (remember λ=1 is the first guess),

(iii) an upper limit for the eigenvalue,

(iv) the required multiplication constant, k_{eff}, and

(v) the required accuracy in k_{eff} .

If the search proceeds outside the specified limits an error will result. The method used is based on linear interpolation or extrapolation.

Criticality is not restricted to T=0 but may be used after any burnup step.

5.5.3 Other flux options

The user may prefer to group collapse data with either

(i) a flux of his choice given for all groups, or

(ii) a flux appropriate to the Westcott (1957) convention (*13.2*).

Section *5.7* shows that a group flux can be defined as part of the input data, and the only point which needs to be emphasised here is that if resonance overlap and/or diffusion type transport cross sections (*5.4.2*) are required, the programme must be forced to enter the subroutine that normally calculates flux from neutron balance. This is because these features require data based on the whole library, and a first reading of the library is carried out in the subroutine mentioned (see also the CREATE feature (*5.2.1*)). If the maximum number of flux iterations is set to 1, the actual routine that calculates flux from neutron balance is bypassed. Thus a card punched, say,

T=0., 1, 0

can be used.

However, if the options mentioned are not required, or if the user's COMMON has been set to the required data (*12*), then one reading of the library can be bypassed with two cards punched, for example,

FLUX = 1.+13 – SEE END OF SECTION

T = 0., –1, 0

A card punched with a negative number of iterations sends control to the subroutine that calculates reaction rates and condensed and mixed cross section data (7.3) without first entering the flux balance subroutine. Zero iterations also has an interpretation, which is that both the subroutines mentioned are bypassed. Of course a calculation of the type mentioned above must have previously been carried out– this feature is really only of interest to a burnup user with non–changing reaction rates.

Westcott flux (13.2) with a specified r value (ratio of epithermal to thermal flux) is obtained using three cards punched, for example,

```
FLUX = 1.+13

X(0) = 0.02

CALL WEST
```

The first sets the flux level (5.6), the second gives the r value, and the third forces the calculation to proceed. The neutronics calculation can then be carried out using a time card as the subroutine WEST will have generated the required elements of group flux.

The reader may wonder at this stage why a FLUX card is not always required. The reason is that the programme sets the flux level appropriate to neutron balance from unit source if no flux (or FLUX=0.) is given (5.6). If the flux is to be calculated in this fashion using WEST, data may be punched thus:

```
FLUX = 1.

X(0) = 0.08

CALL WEST

FLUX = 0.

T = 0., 1, 0
```

It should be noted that group flux is set to the level given on the FLUX card not when this card is used, but rather when WEST, or the subroutine that calculates reaction rates and mixed and condensed cross section data, is called.

5.6 Reactor Control Information

It was shown above that the total flux level can be set with a card

```
FLUX = 1.+13  N/CM**2/SEC
```

and it was noted that this does not immediately set the group-dependent flux to the specified level. Other possible data of this section may only be used by burnup users, that is, those users who have indicated their intention with a FIFA card (5.3.9). Firstly it should be noted that the use of a FLUX card also tells the programme that during burnup the FLUX level is to remain at the level specified. If in addition the group-dependent flux does not change, then the one analytic solution of the burnup equations (6.2) holds for all time, and advantage may be taken of this feature by using time steps chosen simply to provide output information. However, if the group-dependent flux, the spectrum, does change, time steps must be chosen consistent with this, using, say,

```
DT = 100., 20, 0, 1
```

(see also Section 6.1).

Burnup users may set the power level thus:

```
POWER = 10.  WATTS/CM**3
```

which tells the programme to adjust the level of previously calculated reaction rates (*7.3.1*) to this level before proceeding with burnup. The status of constant flux level burnup can be retained using two cards, for example,

POWER = 10.

FLUX = 0.

which will overwrite zero FLUX with that calculated to give the specified power. From then on this calculated flux level will be retained. Similarly the status of step–wise constant power level burnup can be retained using

FLUX = 1.+14

POWER = 0.

If the flux is to be calculated at a level consistent with unit source then the feature previously indicated in Section *5.5.3* can be used, namely,

POWER = 0.

FLUX = 0.

The last mentioned cards appear to have shut the reactor down, but this is not the interpretation of the programme. Instead the SHUT DOWN option is set using a card punched

SHUT DOWN

When this card is used the previously defined status is retained, so that later the option for START UP can be set using a card punched

START UP

Since the SHUT DOWN card sets reaction rates to zero, a calculation of fresh reaction rates must be forced before proceeding. This can be done using, for example,

DT=0.,20,0,1

These features are of use to those interested in, say, the reactivity saving resulting from allowing certain nuclides, for example Pa^{233}, time to decay, and are best clarified with an example.

Example

An infinite homogeneous reactor composed initially of Be^{9}(4×10^{-2} nuc./10^{-24} cm^3), U^{233}(1×10^{-5} nuc./10^{-24} cm^3), and Th^{232} (1×10^{-4} nuc./10^{-24} cm^3) is to be burnt for 500 days at a constant power level of 0.1 watt/cm^3 and a temperature of 300 °K. It is then to be shut down for 10 days and started up again. What is k_{eff} after a further 90 days burnup?

Excluding monitor cards and cards associated with voluminous neutronics output (*5.4*), the data for this problem may read:

```
*GYMEA
      ,EX1      ILLUSTRATES BURN UP
      USE   1,61,2
      SCAT  300. BE9 GAS  ' '
      N(1,100)=0., BE9=4.-2, U233=1.-5, TH232=1.-4 ' '
      POWER = 0.1
      FIFA   U233  ' '
      T = 0.,20,0
      DT = 125.,20,0,4
      SHUT DOWN
      DT = 10.,0,0,1
*NOTE...NO FLUX ITERATIONS
      START UP
      DT=0.,20,0,1
      T=600.,20,0
      END
      CEASE
```

5.7 Group Information

Three types of group information may be entered as data, using cards punched, for example,

GFLUX = 1. 1.5 1.8 2. 5. 6.

1 8. 10. , ETC...

GSOURCE = 0.54, 0.46, 118*0

GB2 = 120*1.-4 1/CM**2

Data must be given for the library number of groups (NG) and since this data frequently extends beyond one card a non-descending integer must be punched in column 1 of continuation cards as explained in Section *5.4.2.*

The first type illustrated above defines the spectrum of group flux but not the level (5.6). The second defines the spectrum of group source, which will be used rather than the library spectrum. The level is adjusted to a total source of 1 n/cm³.sec. The third defines a group-dependent buckling, which is normally defined with all elements the same. However it is possible roughly to simulate a reflected core for a burnup study, using a typical calculation carried out with a space-dependent code which calculates

$$B^2 = - \left[\int \nabla^2 \phi \, dV / \int \phi \, dV\right]_{core}$$

for each neutron energy group.

All of the above quantities may also be entered via the X array of the user's COMMON (*12*).

5.8 Flux Accuracy and Burnup Mechanism Information

The user may change the accuracy parameter used as a convergence test in the calculation of group flux from neutron balance (7.*2*). For example

ACCURACY = 1.-5

will set a parameter which will stop further iterations of group flux when roughly speaking the total absorption and leakage rate from unit source changes by less than 10^{-5} from one iteration to the next.

The standard state (*11*) consists of an ACCURACY parameter of 10^{-4}. It is not anticipated that this feature will be used except by people studying the effect of small changes on a system.

Frequently it is difficult to assess the relative importance of an individual nuclide on the burnup mechanism. It is possible for the user to change the burnup mechanism slightly with a card punched, for example,

BURN 2*-1, 1, 97*0

which should contain entries for each nuclide being USED (NN nuclides in all). Each entry of a fixed point number sets an option for each library nuclide in turn. The options are:

(i) -1 do not burn up (still produced however)

(ii) 0 follow library rules

(iii) 1 burn up (does not produce further library nuclides however).

The example given in Section *6.2* better explains the function of this type of card.

5.9 Other Data

It is possible for the user to specify lower limits for k_{eff}, k_{∞}, B2AV (*6*) using the cards

KEFF LIMIT = 1.

KINF LIMIT = 1.1

AVX LIMIT = 1.-4

When a quantity falls below a level set in this manner the next job is called (SEND). The standard state (*11*) for each of these limits is 0., 0., and -1. respectively.

The user may make changes to data that is set by the subroutine STAN (*11*), or that is read from the heading file of the library (*18*), using the compiler discussed at length in Section *10*. For example it may be desired to change the potential scattering cross section of the first library nuclide to 5.4 barns. This would be achieved thus:

X(351) = 5.4

CHAIN 3 - PULLEY 6

6. CHAIN 3- BURNUP

6.0 Summary

This chain controls the neutronics calculation and burnup. Burnup is carried out analytically based on the burnup mechanisms given as part of the cross section library. Time-dependent quantities, such as FIFA, are also calculated analytically using average concentrations for a time step. The analytic solution procedure requires the 1-group microscopic reaction rates to remain constant, hence it may still be necessary for the user to specify 'integration' time steps consistent with the needs of his problem - say, 100 days. Chain 4 (7) carries out the calculation of group flux and cross sections and chain 3 uses the results to calculate k_{eff}, etc. The concentration of any nuclide, mixture, or level of group-dependent buckling may be adjusted to achieve a specified value of k_{eff} if required.

6.1 Data Options

Control is transferred to chain 3 from the input chain 2 when a 'time' card is detected. The data supplied with the card controls the functioning of the chain. Two types of 'time' cards are permitted, for example,

T=0.,20,0

DT=100.,20,0,1

but both determine the same quantities. The data entries given in order have the following meanings:

(1) determines the time (in days) after first start up (T=0.,...) at which output is required for the behaviour of the reactor system being studied (if the specified time is negative then X(41) is used instead),

(2) determines the option required with the flux spectrum calculation (LSID),

(3) determines a limit to the number of permitted iterations to achieve criticality on, say, buckling (*5.5.2*), and

(4) which is only used with the DT card, is the number of such time steps required at one entry to chain 3 - control is not passed to chain 5 until the number of repeats is satisfied, hence CRAM output, for example, would not be produced for the intermediate steps.

The manner in which the chain works can best be understood by referring to the flow diagram which follows.

burnup (1) if T = 0. or DT = 0. bypass burnup,

(2) normalize reaction rates consistent with specified power or flux,

(3) analytically calculate nuclide concentrations at end of time step, average for time step, and use the average concentrations to calculate time integrals (FIFA, etc.),

neutronics (4) if LSID ≠ 0 call chain 4 for calculation of flux spectrum and/or reaction rates and condensed, mixed cross sections,

(5) calculate multiplication constant, k_{eff}, etc.,

(6) if criticality required, adjust eigenvalue on concentration of a nuclide or mixture or level of group-dependent buckling and return to (4),

output (7) output burnup results– nuclide concentrations, 1–group reaction rates, etc.

(8) if all repeats have not been satisfied, return to (1),

finish (9) call chain 5 if output required,

(10) call chain 6 if output required,

(11) return control to chain 2 otherwise.

Note that burnup is carried out before the group flux calculation. This is necessary to give quantities such as multiplication constant, k_{eff}, a precise meaning. Of course the user must make sure that burnup is possible by forcing a calculation of reaction rates at T = 0.(LSID ≠ 0) or after START UP following a period of SHUT DOWN (5.6). The user requiring burnup should force a calculation of reaction rates for all nuclides rather than for just those specified on the MATS card. As discussed in Section 5.3.9 this is achieved by the use of a card which indicates also the nuclides, or materials, to be included in the definition of initial fissile atom to be used later in the calculation of FIFA (fissions/initial fissile atom). Such a card may be

FIFA PU239 PU241 ' '

and when chain 2 detects this card the concentration of Pu^{239} and Pu^{243} previously defined are added together and set aside in COMMON storage. This concentration should be non–zero, or an error will result for T ≠ 0. In addition all nuclide concentrations defined before the use of this card are copied from the array AFT.N to BEF.N (*12*).

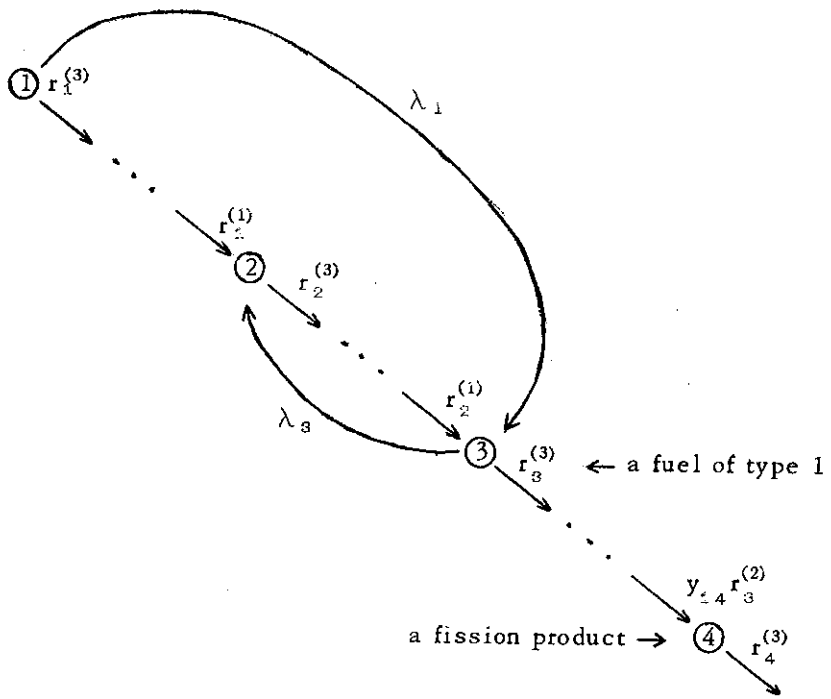
6.2 Analytic Solution of Burnup Equations

The set of equations for production and burnup of each nuclide are a set of coupled first order differential equations. In GYMEA these equations are solved all at once for all nuclides up to the nuclide specified on the USE card. For example, with the card

USE 1 , 55, 2

the user has stated that he is only interested in the first 55 nuclides of the library. To save machine time, and to simplify greatly the solution of the equations, the nuclides must be ordered in the GYMEA cross section library so that except for a few isolated instances a nuclide can only burn or decay to a nuclide further down the library set. For the few isolated instances a nuclide can burn or decay to the nuclide immediately preceding it in the library set provided that the preceding nuclide itself does not do the same thing.

The simple burnup chain below highlights features of the analytic solution technique. A circle denotes a nuclide, and lines leading to and from the circle indicate the burnup mechanism described by the burnup table given as part of the cross section library for this illustrative problem (*18*).



Here $r_\ell^{(k)} = \sum_{i=1}^{NG} \sigma_{\ell i}^{(k)} \phi_i$ for nuclide ℓ ,

where subscript i indicates the neutron energy group ,

superscript (k) indicates reaction (k) of the library,

namely (1) = reaction (1), usually (n,γ),

(2) = fission,

(3) = absorption (7.3),

and λ_ℓ is the decay constant (10^{-24}/sec) of nuclide ℓ .

Section 7 and Section 18 elaborate further on the quantities introduced here.

The quantity $y_{3,4}$ is the yield of nuclide 4 from fission of fuel of type 1– say nuclide 3 was designated as being a fuel of this type. Let $N\ell$ = the nuclide concentration of nuclide ℓ (nuc./10^{-24} cm^3) at time t (10^{24} sec) after the previously considered time step of the reactor system composed of a homogeneous mixture of the nuclides designated 1 to 4. The following nuclide balance then applies for each nuclide;

Time rate of change of $N\ell$

= loss due to decay of nuclide ℓ

+ loss due to n–absorption by nuclide ℓ

+ gain due to decay of nuclides which produce nuclide ℓ

+ gain due to n–capture reactions which produce nuclide ℓ

+ yield from fission of nuclide ℓ from the four possible fuel types.

Using a dot to denote differentiation with respect to the variable t, the set of balance equations may be written:

$$\begin{pmatrix} \dot{N}_1 \\ \dot{N}_2 \\ \dot{N}_3 \\ \dot{N}_4 \end{pmatrix} = \begin{pmatrix} -r_1^{(3)} - \lambda_1 & 0 & 0 & 0 \\ r_1^{(1)} & -r_2^{(3)} & \lambda_3 & 0 \\ \lambda_1 & r_2^{(1)} & -r_3^{(3)} - \lambda_3 & 0 \\ 0 & 0 & y_{14} r_3^{(2)} & -r_4^{(3)} \end{pmatrix} \begin{pmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \end{pmatrix}$$

$$\text{or} \quad \underset{\sim}{\dot{N}} = \underset{\approx}{A}\ \underset{\sim}{N} \ . \qquad -(1)$$

Notice that A is a lower triangular matrix except for the term λ_3 – this form is typical for a complete library set of coupled equations with only a few isolated just off–triangular elements.

Before the solution of Equation 1 is considered, a few additional features will be discussed. In a general set of equations reaction (6) (usually (n,2n)) may produce a nuclide belonging to the library set, hence production terms $r^{(6)}$ would appear in the matrix $\underset{\approx}{A}$.

Use of a card such as

BURN 0 1 0 -1

(5.8) for the example being studied would force nuclide 2 to burn out, rather than to burn to nuclide 3; hence the production term $r_2^{(1)}$ would not appear in $\underset{\approx}{A}$, and, since nuclide 4 would be prevented from burning out, the loss term $-r_4^{(3)}$ would not appear in $\underset{\approx}{A}$. This type of card forms a convenient way to investigate the effect of chosen nuclides on the overall burnup mechanism. It should be borne in mind that the BURN card does not alter decay or yield from fission.

Returning to the solution of the set of equations (1), the first step is to carry out transformations on $\underset{\approx}{A}$ to yield a lower triangular matrix. In the example chosen this may be achieved using the matrix

$$\underset{\approx}{I_3}(x) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & x & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad -(2)$$

Now $\underset{\approx}{I_3}(x)\,\underset{\approx}{I_3}(y) = \underset{\approx}{I_3}(x+y)$,

$\therefore \quad \underset{\approx}{I_3}(x)\,\underset{\approx}{I_3}(-x) = \underset{\approx}{I_3}(0) = \underset{\approx}{I}$

$\therefore \quad \underset{\approx}{I_3}(-x) = \underset{\approx}{I_3}^{-1}(x)$.

Then, from Equation 1,

$$(\underset{\approx}{I_3}(x)\,\underset{\sim}{\dot{N}}) = (\underset{\approx}{I_3}(x)\,\underset{\approx}{A}\,\underset{\approx}{I_3}(-x))\ (\underset{\approx}{I_3}(x)\,\underset{\sim}{N})$$

which is of the same form as the original Equation 1, namely

$$\underset{\sim}{\dot{N}}^* = \underset{\approx}{A}^*\,\underset{\sim}{N}^* , \qquad -(3)$$

except that $\underset{\approx}{A}^*$ may be made lower triangular by a suitable choice of x. If x is chosen so that

$$x^2 a_{32} + x(a_{22} - a_{33}) - a_{23} = 0 \qquad -(4)$$

then the element a^*_{23} is zero in the transformed matrix and no other upper triangular element appears, as any off-triangular elements are always separated from one another by at least one zero element- a requirement of the ordering of the library nuclides. The roots of Equation 4 are always real as the off-diagonal terms are always positive, and the actual choice of root is immaterial as the new diagonal terms a^*_{22} and a^*_{33} simply interchange roles if one root is used rather than the other. For the more general solution of Equation 1 applied to other library nuclide sets, a series of transformations $\underset{\approx}{I}_{i_1}(x_1)\ \underset{\approx}{I}_{i_2}(x_2)\ldots$ may be necessary; however a set of equations (3) is eventually obtained for which $\underset{\approx}{A}^*$ is lower triangular.

Assuming that all leading diagonal elements a^*_{ii} are different from each other, excluding possible zero elements, then the eigenvalues of $\underset{\approx}{A}^*$ are simply the diagonal terms and a solution of the Equations 3 of the form

$$\underset{\sim}{N}^* = \underset{\approx}{B}\,\underset{\sim}{e} \qquad -(5)$$

can be assumed, where $\underset{\approx}{B}$ is the required solution matrix and is lower triangular,

and $\underset{\sim}{e} =$ $\begin{pmatrix} \exp(a^*_{11}t) \\ \exp(a^*_{22}t) \\ \exp(a^*_{33}t) \\ \exp(a^*_{44}t) \end{pmatrix}$.

In practice the requirement that the eigenvalues are distinct is always met and will only be violated if an attempt is made to use a library containing the same nuclide in several different positions. Differentiation of Equations 5 and comparison with Equations 3 then gives

$$b_{ij} = \frac{\sum_{k=j}^{i-1} a^*_{ik}\, b_{kj}}{a^*_{jj} - a^*_{ii}} \quad \text{if} \quad i \neq j \qquad -(6)$$

for the off-diagonal terms, and the initial condition $\underset{\sim}{N}^* = \underset{\sim}{N}^*(t=0)$ leads to the equation

$$b_{ii} = N^*_i(t=0) - \sum_{k=1}^{i-1} b_{ik} \qquad (7)$$

for the diagonal terms. The result for i = 1 may be imagined contained in Equations 6 and 7 if we set backward sums to zero, $\sum_{k=1}^{0} \ldots = 0$. Equations 5 and 6 express a recurrence relation which enables all the elements of the solution matrix $\underset{\approx}{B}$ to be determined provided the indices are ranged as follows:

(1,1); (2,1), (2,2); (3,1), (3,2), (3,3); etc.

The set of nuclide concentrations $\underset{\sim}{N}^*$ may then be obtained from Equation 5 and the original library nuclide set may be obtained from the simple transformation:

$$\underset{\sim}{N} = \underset{\approx}{I}_3(-x)\,\underset{\sim}{N}^* = \begin{pmatrix} N_1^* \\ N_2^* - x N_3^* \\ N_3^* \\ N_4^* \end{pmatrix} . \qquad (8)$$

One objection that may be raised concerning the analytic solution technique is that it appears to be prone to round-off error, especially for the production of He^3 from the Be (n,α) reaction. However the experiences of the authors indicate otherwise. Stated differently, the analytic procedure enables long (say 100-day) time steps to be taken and hence the small (say 1-day) time steps, which would produce the greatest round-off error, are unnecessary.

6.3 Analytic Calculation of Average Nuclide Concentrations

Since the analytic solution of the burnup equations is available in the form of Equations 5 and 8, time integrals of power and FIFA are best given in terms of average nuclide concentrations for the time step. The average concentrations for the time step are simply

$$\hat{\underset{\sim}{N}} = \underset{\approx}{I}_3(-x)\,\underset{\approx}{B}\,\hat{\underset{\sim}{e}} \quad , \qquad -(9)$$

where $\hat{\underset{\sim}{e}}$ contains elements of the form

$$= \frac{1}{t}\int_0^t \exp(a_{ii}^* t')\,dt'$$

$$= \frac{1}{a_{ii}^* t}\left[\exp(a_{ii}^* t) - 1\right] . \qquad -(10)$$

For small argument $a_{ii}^* t$, Equation 10 may be expanded as a series in t and a few terms retained, thus avoiding excessive round-off error.

6.4 Time Integrals

Some clarification is necessary on the statement made early in Section 6.2 , namely that t (10^{24} sec) is the time after the previously considered time step. For a burnup carried out so that power is continually adjusted to the same specified level given on the POWER card, t is simply the time between steps specified explicitly by the user, perhaps using a card DT=... For a burnup carried out so that flux and reaction rates remain fixed (LSID=0), the first entry to chain 3 for a given DT card will force a solution of the burnup equations. However, further repeats, as specified on the card by the user, will use the previous analytic solution, and hence t is the time from the last step of previous entry to chain 3. Since the user has presumably requested intermediate steps only to provide output for his own information, rather than to assist the solution of the problem, this possible point of confusion should be borne in mind.

The various time integrals are given simply by the equations below.

$$\phi\text{-T(t)} = \phi\text{-T(0)} + \phi\, t\,(\text{sec}),$$

$$XX(t) = XX(0) + \left[\sum_\ell \hat{N}_\ell (r_\ell^{(4)} - r_\ell^{(3)})\right] t\,(\text{days})/D\phi(t),$$

$$B2AV(t) = XX(t)/\text{total t (days)}$$

$$P\text{-T(t)} = P\text{-T(0)} + \left(\sum_\ell \hat{N}_\ell\, f_\ell\, r_\ell^{(2)}\right) t\,(\text{days}),$$

$$FIS(t) = FIS(0) + \left(\sum_\ell \hat{N}_\ell\, r_\ell^{(2)}\right) t\,(\text{sec}),$$

FIFA(t) = FIS(t)/ initial fissile atom concentration,

where ϕ-T = flux time in n/cm^2,

B2AV = average estimated buckling to give k_{eff}=1 in cm^{-2},

D = 1-group diffusion coefficient based on $\underset{\sim}{N}$ in cm
$= \sum_{i=1}^{NG} D_i B_i^2 \phi_i / B_1^2 \sum_{i=1}^{NG} \phi_i$

P-T = power-time in watt days/cm^3,

f_ℓ = energy release/fission of nuclide ℓ in joule/fission,

FIS = fissions/cm^3, and

FIFA = fissions/initial fissile atom. -(11)

6.5 Multiplication Constant, etc.

One-group collapsed macroscopic cross sections for fission emission ($\nu\Sigma_f$), total absorption (Σ_a), and specified leakage (DB^2) are all obtained from the following type of rule

$$\nu\Sigma_f = \sum_{i=1}^{NG} (\nu\Sigma_f)_i \phi_i / \sum_{i=1}^{NG} \phi_i \quad . \tag{1}$$

The effective multiplication constant of a homogeneous system is then given by

$$k_{eff} = \nu\Sigma_f / (\Sigma_a + DB^2). \tag{2}$$

In addition the infinite multiplication constant is simply

$$k_\infty = \nu\Sigma_f / \Sigma_a \quad . \tag{3}$$

For a large system an estimate of leakage necessary to make k_{eff}=1 may be made from Equation 2, namely

$$B_\infty^2 = (\nu\Sigma_f - \Sigma_a)/D \tag{4}$$

and the code produces this as output B2 (INF). Similarly Equation 2 can be used to obtain an additional leakage term DB^2_{eff} which makes k_{eff}=1 when leakage DB^2 has already been included based on a specified group-dependent buckling (5.7), that is

$$B^2_{eff} = (\nu\Sigma_f - \Sigma_a - DB^2)/D. \tag{5}$$

Since it is possible to obtain group-collapsed transport cross sections, weighted by DB^2 for each group (5.4.2), then, when buckling has not been specified, the code uses $B_i^2 = 10^{-15}$ (i = 1,2,...,NG) to prevent the weight from being zero.

For a system which is not large, a change in leakage produces a change in the flux which in turn results in a change in the group-collapsed cross sections, hence the buckling obtained from Equation 4, B^2_∞, may not be particularly accurate. The code, however, has provision for adjusting B^2 to achieve criticality (5.5.2). After each adjustment a further flux calculation is carried out until the specified multiplication is achieved.

Two other quantities produced by the code are extrapolation distance, d, and radius of an equivalent critical sphere, R, obtained by applying Equation 4. The equations used are

$$d = 2.13 \sum_{i=1}^{NG} (D_i B_i^2)^2 \phi_i / B_1^2 \sum_{i=1}^{NG} D_i B_i^2 \phi_i \qquad (6)$$

and

$$R = (\pi/B_\infty) - d \quad (B_\infty^2 > 0)$$

$$= 0 \quad (B_\infty^2 \leq 0) \, . \qquad (7)$$

For a system with group-independent buckling B_i^2 (i=1,2,...,NG) adjusted to make $k_{eff} = 1$, then $B_i^2 = B_\infty^2$.

The macroscopic cross sections which are used in the above equations are derived from the cross sections calculated in the first library reading (group flux calculation subroutine, Section 7.2) for a non-burnup user (no FIFA card). For a burnup user the cross sections used are calculated in the second library reading (reaction rates, condensed and mixed cross section calculation subroutine, Section 7.3). The reason is quite simple – a non-burnup user may not want output for all materials that contribute to k_{eff} (5.4.2), hence all the information may not be available from the second library reading. The only possible difference is that the cross sections calculated during the second library reading are corrected for resonance overlap and resonance gross flux correction (7.4.5) whereas the first are not.

A burnup user obtaining output for the full library group structure can obtain an idea of the magnitude of the overlap and gross flux correction from 'total neutron loss rate/source neutron' printed by chain 5 (8), since differences from unity result from the condition that 'total neutron loss rate' is based on the first library reading (no correction) whereas 'source neutron' is based on the second reading (includes correction). When taken together, the two corrections mentioned above to some extent compensate each other as they are corrections of the same form but with different signs.

After burnup, the power density, in watts/cm^3, is given by

$$P = \sum_\ell N_\ell f_\ell r_\ell^{(2)} \qquad (8)$$

using the notation of Section 6.4. Before burnup is calculated an equation similar to (8) above is used to readjust the level of the reaction rates $r_\ell^{(k)}$ if the 'constant' power option is set (5.6). Only a burnup user may specify this 'constant' power option.

CHAIN 4 -- GROUP FLUX CALCULATION,
CONDENSING AND MIXING FUNCTIONS

7. CHAIN 4– GROUP FLUX CALCULATION, CONDENSING AND MIXING FUNCTIONS

7.0 Summary

A group flux calculation may be carried out for a homogeneous system containing a uniformly distributed neutron source emitting 1 neutron per cm^3 per second. The calculation requires a first reading of the cross section library during which stage a smaller bulk library may be prepared for the second reading if required (*5.2.2*). Scattering matrices specified (*5.2.4*) are used in the calculation. Using this group flux, or the flux obtained from other options (*5.5.3*), group-condensed and nuclide mixed cross sections and 1–group microscopic reaction rates are obtained. This also requires a reading of a cross section library.

7.1 Required Option

As discussed in Sections *5.5* and *6.1*, chain 4 is called when the second entry on the time card (LSID) is non–zero, for example,

T=0., 20, 0

If LSID is positive then the main cross section library is read and a copy is created (*5.2.2* and *5.5.3*) if required. If LSID is also greater than 1 the flux balance subroutine is entered. Following this the reaction rate, condensing and mixing subroutine is called. On the other hand if LSID is negative, only the reaction rate, condensing and mixing subroutine is called.

7.2 Group Flux Calculation

The specified cross section library (*5.2*) is read to obtain Σ_a, $\nu\Sigma_f$, Σ_{tr} for each group (1 to NG) for the homogeneous mixture to be studied (*5.3.4*), and the specified scattering matrix library is read to obtain group–to–group transfers $\Sigma_{i\to j}$ based on the chosen scattering matrices. As mentioned in Section *5.2* it is possible to CREATE a cross section library while reading the main library perhaps to change resonance parameters to shielded cross sections for use with the collapsing procedure (*7.3*). This procedure is probably only worthwhile for a person requiring burnup using a cross section library containing many resonance parameters. Resonance theories are discussed in Section *7.4*.

If the group flux is to be determined from neutron conservation (LSID>1), the equation solved is

$$\underset{\approx}{W}\ \underset{\sim}{\phi} = \underset{\sim}{\chi} \ ,$$

where $\underset{\sim}{\chi}$ is the group fission spectrum (*18* and *5.7*) normalized so that

$$\sum_{j=1}^{NG} \chi_j = 1 \ ,$$

$\underset{\sim}{\phi}$ is the group flux , and

$\underset{\approx}{W}$ has elements given by

$$W_{ji} = (AA)_i\ \delta_{ij} - \sum_{\ell} N_\ell\ \sigma_{i\to j}^{\ell}$$

where

$$(AA)_i = \frac{B_i^2}{3(\Sigma_{tr})_i} + (\Sigma_a)_i \ ,$$

$\sigma_{i\to j}^{\ell}$ is the transfer from group i to j for nuclide ℓ , except that

$$\sigma_{i\to i}^{\ell} = -\sum_{j\neq i} \sigma_{i\to j}^{\ell} \ ,$$

and ℓ is summed over nuclides with scattering matrices given on the SCAT card (*5.2.4*).

The method used is based on the Gauss–Seidel iteration technique as given by Ralston and Wilf (1960) but advantage is taken of the main features of the flux equation.

For the K−1 groups into which no neutrons are scattered from lower energies, that is groups j such that

$$W_{ji} = 0 \quad \text{for } i > j \ , \ j = 1,2,\ldots,K-1,$$

the matrix is lower triangular and the solution is immediate. For the remaining groups the equations become

$$\sum_{i=K}^{NG} W_{ji}\ \phi_i = \chi'_j \quad , j = K,\ldots,NG,$$

where $\underset{\sim}{\chi}'$ is now a slowing down source.

The iteration scheme used for the n^{th} time applied to solving the preceding equation for $\phi^{(n)}$ amounts simply to solving the three equations given below for $\phi_j^{(n)}$. The solutions $\phi_{j+1}^{(n)}$ and $\phi_{j+2}^{(n)}$ from the same equations are not obtained, as they are not required at this stage. The three equations are

$$\begin{pmatrix} W_{j,j} & W_{j,j+1} & W_{j,j+2} \\ W_{j+1,j} & W_{j+1,j+1} & W_{j+1,j+2} \\ W_{j+2,j} & W_{j+2,j+1} & W_{j+2,j+2} \end{pmatrix} \begin{pmatrix} \phi_j^{(n)} \\ \phi_{j+1}^{(n)} \\ \phi_{j+2}^{(n)} \end{pmatrix} = \begin{pmatrix} \chi'_j \\ \chi'_{j+1} \\ \chi'_{j+2} \end{pmatrix} -$$

$$- \begin{pmatrix} W_{j,K} & \cdots & W_{j,j-1} \\ W_{j+1,K} & \cdots & W_{j+1,j-1} \\ W_{j+2,K} & \cdots & W_{j+2,j-1} \end{pmatrix} \begin{pmatrix} \phi_K^{(n)} \\ \vdots \\ \phi_{j-1}^{(n)} \end{pmatrix} - \begin{pmatrix} W_{j,j+3} & \cdots & W_{j,NG} \\ W_{j+1,j+3} & \cdots & W_{j+1,NG} \\ W_{j+2,j+3} & \cdots & W_{j+2,NG} \end{pmatrix} \begin{pmatrix} \phi_{j+3}^{(n-1)} \\ \vdots \\ \phi_{NG}^{(n-1)} \end{pmatrix} .$$

A division into 2 regions is made after the first iteration by the requirement that i should be as large as possible, say i = L−1, such that

$$\left| \sum_{j=1}^{i-1} W_{ji} \right| < 0.1\ W_{ii} \ ;$$

that is, the number of upscatters from group L−1 is to be just less than one tenth of the total removals from that group. If NG−L is greater than 5, these groups are collapsed into 3 sections such that

$\sum_i (AA)_i\ \phi_i^{(1)}$ is approximately the same in each section.

Using these three sections, the three equations

$$\sum_k \left(\sum_{i,j}^{(k',k)} W_{ji}\ \phi_i^{(n)} \right) \lambda^{(k)} = \sum_j^{(k')} \chi'_j \quad ,$$

where k and k′ have values from 1 to 3 are solved for $\lambda^{(k)}$ after each major iteration to give

$$\phi_i^{(n')} = \lambda^{(k)} \phi_i^{(n)} .$$

The initial estimate $\underset{\sim}{\phi}^{(0)}$ is either a Westcott flux (13.2) or the group flux from a previous calculation.

The accuracy criterion used for convergence is

$$\sum_{j=1}^{NG} (AA)_j \mid \phi_j^{(n)} - \phi_j^{(n-1)} \mid \leq \epsilon \ ,$$

where ϵ, usually 10^{-4}, may be set in the input data (*5.8*). The number of iterations required depends mainly on the ratio of absorption to scatters in each group, and $\underset{\sim}{\phi}^{(0)}$, and usually ranges between 4 and 7 for the basic 120-group libraries (*19*).

7.3 Condensing and Mixing Functions

7.3.1 Reaction rates

The burnup of a nuclide depends on microscopic reaction rates (*6.2*). For this reason if burnup is required (*5.3.9*), reaction rates for all library nuclides (NN) are calculated. If burnup is not required, only reaction rates of those nuclides requested for output (*5.4.2*) are obtained. The six reactions treated are those obtained from the cross section library (*18*), namely

(1) (n,capture 1)– usually (n,γ)

(2) (n,fission)

(3) (n,absorption)

(4) (n, ν fission emission)

(5) (n, transport)

(6) (n,capture 2)– usually (n,2n).

Using a superscript to indicate the particular reaction and subscripts to indicate in order nuclide and group, we have

$$r_\ell^{(k)} = \sum_{i=1}^{NG} \sigma_{\ell i}^{(k)} \phi_i \ (k = 1,2,3,4,6), \tag{1}$$

$$r_\ell^{(5)} = \left(\sum_{i=1}^{NG} \sigma_{\ell i}^{(5)} D_i B_i^2 \phi_i\right) \left(\sum_{i=1}^{NG} \phi_i \Big/ \sum_{i=1}^{NG} D_i B_i^2 \phi_i\right) , \tag{2}$$

$I = 1$, standard option,

or $$r_\ell^{(5)} = \sum_{i=1}^{NG} \sigma_{\ell i}^{(5)} \phi_i \ , \qquad I = 0 \ ,$$

where ϕ_i is the group flux, which is calculated from neutron balance (*7.2*), read into the programme (*5.7*), or calculated from a Westcott flux (*13.2*),

D_i is the group diffusion coefficient $= 1/3 \ (\Sigma_{tr})_i$,

$(\Sigma_{tr})_i$ is the group transport cross section for the specified mixture,

B_i^2 is the group buckling specified by the user (*5.7*), and

I is the option required with transport averaging – the second digit on REQD card (*5.4.2*).

7.3.2 Condensing

The user may specify the groups required for the condensed cross sections available for output (*8* and *9*). The specification is given on a card punched, for example,

GRØUPS 5 1,40,60,80,100,120

where the entries relate to the main library groups (*5.4.2*). The condensing is then carried out with equations analogous to Equations 1 and 2 of section *7.3.1*, for example,

$$\bar{\sigma}^{(3)}_{12} = \sum_{i=41}^{60} \sigma^{(3)}_{1i} \phi_i / \sum_{i=41}^{60} \phi_i$$

Reaction (4) for light nuclides of the library set (*18*), unlike the corresponding entries for r (microscopic reaction rates), relate to neutron elastic scattering.

7.3.3 Mixing

Mixing is carried out according to rules set by the user, say,

'BEO' = 1.BE9,1.O16,1.8 ' '

for materials specified for output (*5.3.2* and *5.4.2*). For example

MATS U233, 'BEO' ' '

will produce, in the order specified, data for the library nuclide U^{233} and the defined material BeO. Since Be^9 and O^{16} would presumably be designated as light nuclides (*18*) reaction (4) would be (n,n). The rule used is that all components of the mixture must be light for a defined material to be considered to be light.

7.4 Resonance Theories

7.4.1 Resonance information

The resonance information supplied by the library consists of parameters for single-level Breit–Wigner resonance contours and resonance-removed cross sections. The so–called resonance-removed cross section is the residual cross section left over when the resonance contour, which is considered to be symmetric, is subtracted from the cross section of interest. This idea has been used for some time at the A.A.E.C. and is based on the usually accepted idea in resonance studies of adding a correction to calculations to allow for the '1/v tail' neglected in the analysis. This tail is not always '1/v', as single-level Breit–Wigner resonance contours do not account for features such as fission interference. In addition the cross sections for the region normally considered to consist of unresolved resonances is treated as part of the resonance-removed cross section. Using resonance parameters, and the resonance-removed cross sections, it is possible not only to reconstruct a cross section at say 300°K, but also to produce a cross section at other temperatures. The error introduced by neglecting the temperature dependence of the resonance-removed cross section should not be of great significance except possibly for the calculation of temperature coefficients of reactivity. For these calculations, the resonance region contribution, the Doppler coefficient, should be checked with a code which takes account of features neglected by GYMEA. LUBRA (Kletzmayr 1966) is such a code.

7.4.2 Cross sections from resonance parameters

The method used to calculate cross sections from resonance parameters for different temperatures and different shielding resulting from flux variation through resonances is the method of McKay et al. (1965), which is an extension of the Hill–Schaefer method (1962). The justification of the chosen relationship of group cross sections to quantities calculated by resonance theory is given by Keane and Pollard (1966). Following the notation of the first mentioned paper, we have for one resonance

$$\sigma_a = (1-p)\ \bar{\xi}\,\sigma_p / p\,\delta u \quad \text{(group resonance cross section)}, \tag{1}$$

where δu = width of resonance group in lethargy units,

$$p = e^{-\rho I/\bar{\xi}\sigma_p} \quad \text{(resonance escape probability)}, \tag{2}$$

$$\rho = 2/(1+p), \tag{3}$$

$$I = \frac{\Gamma_a \sigma_o}{E_r}\, a_\lambda\, J(\theta, a_\lambda) \quad \text{(resonance integral)}, \tag{4}$$

$$\lambda_\ell = 1 - \alpha_\ell \frac{(C_1 + C_\lambda)}{x_\ell} \arctan\left(\frac{x_\ell}{C_1 + \alpha_\ell C_\lambda}\right), \tag{5}$$

$$x_\ell = 2E_r (1-\alpha_\ell)/\Gamma, \tag{6}$$

$$\sigma_{p\lambda} = \sum_{\ell=1}^{k} \lambda_\ell \sigma_{p\ell} \qquad \left(\begin{array}{l} k = \text{resonance nuclide} \\ \ell = 1 \text{ to } k-1 = \text{light nuclides} \end{array}\right) \tag{7}$$

$$\sigma_{p\ell} = N_\ell \sigma_{s\ell} / N_k \tag{8}$$

$$a_\lambda = \frac{\sigma_{p\lambda}}{\sigma_o} \frac{\Gamma}{\Gamma_a + \lambda_k \Gamma_n}, \tag{9}$$

and

$$C_\lambda = (1 + 1/a_\lambda)^{1/2}. \tag{10}$$

The function $J(\theta,\beta)$ used in GYMEA is an approximation proposed by Doherty (1963).

Equations 5 to 10 and 4 and 3 are simply solved using one iteration, and numerical accuracy is retained in Equation 1 using an expanded form based on Equation 2 for $(1-p) < 10^{-4}$. Other cross sections are obtained from σ_a of Equation 1 using ratios of resonance widths, for example,

$$\sigma_{n,\gamma} = \frac{\Gamma_\gamma \sigma_a}{\Gamma_a} + \sigma^*_{n,\gamma} \text{ resonance removed}.$$

The entry held in the library (*18*) as cross section (3)– normally absorption – is not used in the resonance region for nuclides with resonance parameters or shielding coefficients given, as cross sections (1) and (2) are summed to give the required cross section (3).

7.4.3 Cross sections from shielding coefficients

Following Keane (1964b) it can be seen that for zero temperature the equations of Section 7.4.2 give approximately (for one resonance)

$$\sigma_a = \sigma_I / (1 + \sigma_o/\sigma_p)^{1/2}, \tag{1}$$

where

$$\sigma_I = \pi \Gamma_a \sigma_o / 2E_r\, \delta u \tag{2}$$

= infinitely dilute cross section.

Values of the concentration variation (σ_p variation) of a cross section can therefore be anticipated for several resonances in a group, and not necessarily at zero temperature, using

$$\sigma_x = \sigma_\infty / (1 + \frac{A}{\sigma_p} + \frac{B}{\sigma_p^2})^{1/2} \quad (x = \gamma, f, \text{ and } \nu f). \tag{3}$$

Three parameters σ_∞, A, and B have been introduced in Equation 3 and these are determined from three calculations of σ_x for three different σ_p. In all, nine parameters are determined for three reactions.

Within this context σ_∞ need not agree with σ_I, summed over resonances of the group. The three σ_p chosen in calculating σ_∞, A, and B would be based on the anticipated range of concentration variation of the nuclide under study for either a burnup study or a survey. For variation over a range of σ_p, typically, 10^4, 5×10^4, 5×10^5, Equation 3 has been found by the authors to be remarkably satisfactory. This point needs further verification however. It should be remembered from Section *5.3.8* that resonance parameters can be automatically turned into shielding coefficients using the CREATE feature (*5.2.2*).

The σ_p used in Equation 3, unlike its counterpart in resonance theory (*7.4.2*), does not include the potential scattering cross section of the resonance nuclide– this convention is used throughout shielding theory.

When using shielding coefficients the temperature is fixed to the value chosen when preparing these parameters.

7.4.4 Particle self shielding

Section *5.3.7* introduced a basis for allowing for particle self shielding following Keane (1964a). This method modifies the potential scattering cross section of light nuclides thus

$$\sigma_s^* = \sigma_s / (1 + \bar{\ell}\, \Sigma_p V_m / V_p) .$$

The modified potential scattering cross sections, σ_s^*, are used both in resonance theory (*7.4.2*) and shielding theory (*7.4.3*).

7.4.5 Resonance overlap

Following the option set with a REQD card (*5.4.2*), it is possible to allow for overlap of resonances using the method of Rowlands (1963) investigated by Keane (1966). In addition the resonance gross flux correction factors investigated by Keane and Pollard (1966) are combined with the overlap corrections, assuming these two factors to be independent. In GYMEA the method amounts to correcting cross sections (1) to (4) for all nuclides for the resonance groups using the factor

$$C_{\ell i} = 1 - \left((\Sigma_a)_i - \Sigma_{\ell i}^{(3)} \right) h / \Sigma_p , \qquad (1)$$

then

$$\sigma_{\ell i}^{(k)*} = \sigma_{\ell i}^{(k)}\, C_{\ell i} \quad (k = 1,2,3,4), \qquad (2)$$

where

$$(\Sigma_a)_i = \sum_{\ell=1}^{NN} \Sigma_{\ell i}^{(3)} \qquad (3)$$

$= $ total absorption cross section for the i^{th} group,

$\Sigma_{\ell i}^{(3)}$ = absorption cross section for the ℓ^{th} nuclide,

Σ_p = total potential scattering cross section, and

$h = 1 - \delta u / 2\bar{\xi}$.

Allowance for overlap and gross flux correction is only possible if the vector $(\Sigma_a)_i$ is available from a first reading of the library, or is set by the user in COMMON (*12*), otherwise the programme will change the option. Normally this means that

REQD 01

should precede

T=0.,-1,0

In addition, the storage assigned to $(\Sigma_a)_i$ is shared with information used in the burnup calculation; hence after a burnup calculation, $(\Sigma_a)_i$ should be regenerated if overlap and gross flux correction is required, using, say

DT=100., 20 (NOTE-POSITIVE), 0

CHAIN 5 – OUTPUT FOR MOST NEUTRONICS CODES AND PRINTED OUTPUT

8. CHAIN 5 – OUTPUT FOR MOST NEUTRONICS CODES AND PRINTED OUTPUT

8.0 Summary

Chain 5 produces output on cards suitable for input to the codes CRAM, 4–ZOOM, DSN, WDSN, as well as printed multigroup cross–section and scattering matrix data (PRINTX and PRINTS respectively). The required options are set by use of the card

ØUTPUT ...

Each of the code names in format (A6) appearing on this card, for example CRAMbb(b=blank), may be followed by a fixed point number. These numbers are used for PRINTX, CRAM, and DSN. The specific meaning of each is given below.

8.1 Condensing and Mixing

The condensed and mixed cross sections calculated in Chain 4 and stored in the array WH are used here. However the condensing and mixing of scattering matrices occur in this chain. The method of condensing the scattering matrices is given by the equation

$$\sigma_{m\to n} = \sum_i \sum_j \phi_i \sigma_{i\to j} / \sum_i \phi_i$$

where i is summed over the m^{th} set of groups and j over the n^{th} set of groups as defined by the GROUPS card.

For example the following equation applies for the 2 groups 1 to 70, 71 to 120:

$$\sigma_{1\to 2} = \sum_{i=1}^{70} \sum_{j=71}^{120} \phi_i \sigma_{i\to j} / \sum_{i=1}^{70} \phi_i$$

The mixing of scattering matrices follows the rules specified by the user. However, one point needs to be stressed regarding the use of a compound library scattering matrix. For example, if

SCAT 900. 'BEO' CRY bbb' '

is used with 'BEO' = 1.BE9, 1.O16, 0.' '

then neither BE9 nor O16 has a scattering matrix associated with it. The same is true of the usual macroscopic material given by

'MIX' = 0. (1,70) 0.' '

The type of card which should be used in this case is

'MIX' = 0. 'BEO', 0. 'O16', 0. (3,70) 0.' '

where 'O16' is defined as some portion of O16 not included in 'BEO' – see Section *5.3.2* for further details.

8.2 Special Materials

So that different output materials may be produced for different codes during the one calculation, the four material labels 'CRAM', 'ZOOM', 'DSN', and 'WDSN' are given a special meaning. Thus, if a material for output is labelled 'CRAM', it will not be produced as output for the other codes, and output for CRAM will consist only of this material.

8.3 Printed Output

Printed output of both PRINTX and PRINTS is weighted according to the value of X(6) as described in Section *5.4.1*. The title given by the HEAD card (*5.2.2*) is printed at the beginning

of each block of data, so that it usually heads the data for each material. The character in column 12 of the HEAD card is used as the carriage control character when the heading is printed. The use of this feature may considerably improve the layout of the data.

8.3.1 PRINTX

PRINTX output consists of weighted multigroup cross sections for the output materials printed in a readable form. Normally the data is printed as group information for each nuclide, but, if the digit 1 follows PRINTX on the MATS card, material information for each group is produced. The output is always terminated by a table of group summary information.

8.3.2 PRINTS

PRINTS output consists of a print-out of the condensed scattering matrices. The matrices are printed as all outscatters from each group with the self-scatter term equal to the negative sum of the outscatters.

8.4 Data for Other Computer Codes

Condensed cross section data following the user's requirement (*5.4.2*) is produced on cards for the 4 computer codes CRAM, 4-ZOOM, DSN, and WDSN. To delimit a set of data for a code, 3 title cards are punched at the beginning and a distinctive card is punched at the end. Labelling of cards in columns 73 to 80 is used to a variable extent. No action is taken to bring the data into line with the particular restrictions of the code versions used at the A.A.E.C. For example, no truncation of scattering matrices for DSN is carried out. Only for 4-ZOOM was it found necessary to modify the data for the code.

8.4.1 CRAM

Output for CRAM consists of:

(1) The fission spectrum for each group.

(2) The following information for each material, where each cross section is given as a block for all groups i:

σ_{tr} , σ_r , $\nu\sigma_f$, ($\sigma_{i\to j}$, j = 1,NGD)

and the optional information

σ_c, σ_f, $\sigma_{n,2n}$.

Here

$\sigma_{i\to i}$ is set to zero

and $\sigma_r^i = \sigma_a^i + \sum_{j=1}^{NGD} \sigma_{i\to j}$.

Normally none of the optional cross sections are produced, but if the name CRAM is followed by a fixed point number ℓ, then extra cross sections are produced. Thus, if $\ell = 1$, only σ_c is produced, if $\ell = 2$, σ_c and σ_f are produced, etc. The format used is (1P5E13.5).

8.4.2 4-ZOOM

For a 4-ZOOM, ($\sigma_a - \nu\sigma_f$) and $\nu\sigma_f$ are produced to be used with a ν value of 1.

Output for 4–ZOOM consists of:

(1) The fission spectrum for each group

(2) The average energy of each group

(3) The following information for each material as in Section *8.4.1*:

$$(\sigma_a - \nu\sigma_f),\ \nu\sigma_f,\ \sigma_{tr},\ (\sigma_{tr} - \sigma_a),\ (\mu_{j\to i},\ j = 1,NGD)$$

where

$$\mu_{j\to i} = \begin{cases} \sigma_{j\to i}/\sigma_{ss}^{j} & i \neq j \\ \left(\sigma_{ss}^{j} - \sum_{k\neq j} \sigma_{j\to k}\right)/\sigma_{ss}^{j} & i = j \end{cases}$$

and

$$\sigma_{ss}^{j} = \sigma_{tr}^{j} - \sigma_{a}^{j} .$$

The format used is (1P6E12.4) except for the scattering matrices of heavy materials where the 4–ZOOM repeat notation is used.

8.4.3 DSN

For DSN a fixed point number of the form llkkn may follow the label DSN. Here ll is the table length for output, kk is the position of the self–scatter term in the table and n is the number of optional cross sections required. If ll,kk are not given, the programme calculates the minimum required values. n is set to zero if no value is given. The programme checks to see if the data will fit into the required table.

The output for DSN consists of the G00, K7, K6, V1, C0 vectors, with the K7 vector containing the fission spectrum, the velocities in V1 (cm/10^{-8} sec) condensed inversely, and the K6 vector containing the group flux. The C0 vector contains for each material the following table for each group i :

$$\sigma_c^i,\ \sigma_f^i,\ \sigma_{n,2n}^i,\ \nu\sigma_f^i,\ \sigma_{tr}^i,\ \sigma_{i+k\to i},\ \cdots,\sigma_{i\to i},\cdots\sigma_{(i-\ell)\to i}$$

where k and ℓ have the maximum values required and

$$\sigma_{i\to i} = \sigma_{tr}^i - \sigma_a^i - \sum_{j\neq i} \sigma_{i\to j} .$$

The first three cross sections are optional and are deleted in the order $\sigma_{n,2n}$, σ_f, σ_c. The format used is (1P6E12.5).

8.4.4 WDSN

The output for WDSN must be specified by the user to be macroscopic and, for each material, consists of the table indicated below, with entries for each group i .

$$\text{LV, PSS, 1., } \nu\sigma_f^i,\ \sigma_a^i,\ (\sigma_{i\to j},\ j = \ell, k)$$

where LV is the length of the table excluding the first 4 entries; PSS is the position of self scatter, ℓ and k are the appropriate numbers for group i to give all non–zero values of $\sigma_{i\to j}$, and $\sigma_{i\to i}$ is as in *8.4.3*. The format used is (2I6,1P2E12.4/(6E12.4)).

9. CHAIN 6 – OUTPUT FOR GYMEA LIBRARY

9.0 Summary

The preparation of libraries with smaller bulk than the main libraries (*19*) is frequently desirable to save machine time when a burnup survey of several systems is being carried out. The bulk may be reduced by mixing fission products and condensing the cross section data. For this reason the code GYMEA has available facilities for preparing its own smaller bulk libraries. The cross section library application of deleting nuclides, with perhaps resonance mode changed, is best carried out using the CREATE feature (*5.2.2*). Additions to the libraries can be carried out using the library editing programmes (*19.4*).

9.1 Required Data

Two data cards which must be specified for the preparation of condensed and possibly mixed cross section GYMEA libraries are, for example,

```
PUT  3   XS01  0  SC01

OUTPUT  3  PRINTX  CRAM  GYMEA
```

The first specifies that tape 3 is to be created as a cross section library to be called XS01 and tape 0 is to be created as a scattering matrix library to be called SC01 (*5.2.3*). In addition to these cards, data must be given for

```
MATS    ...

GROUPS  ...

HEAD    ...
```

as with any other output request. Either entry for tape specification on the PUT card may be negative if only one library is to be prepared. Should both entries be the same, then, between preparation of the cross section library and the scattering matrix library, the first tape will be unloaded and a message typed advising the operator to mount a tape for creation of a GYMEA scattering matrix library. The user should type a message before chain 6 is called, using a compiler feature (*10*) to nominate the required tape, for example,

```
TYPE      WHEN ADVISED MOUNT TAPE 300 ON 3

T=0.,20,0
```

A fixed point number may follow GYMEA on the OUTPUT card. This number sets options detailed in Section 9.2, for example,

```
OUTPUT  1  GYMEA  1
```

9.2 Cross Section Library

9.2.1 Library structure

A condensed and/or mixed cross section library is prepared for nuclides in the order specified on the MATS card. Since this order is important in burnup studies (*6.2*) care should be used when preparing the MATS card. The data created is the same type as that given in the specified library, that is, if a nuclide on the main library has resonance parameters given then the created tape also has resonance parameters for the nuclide under discussion.

For the off–resonance region (*18*) condensed data produced by chain 3 (*7.3*) is used, whereas for the resonance region, resonance parameters or shielding coefficients are extracted from the specified library. For this reason mixing is not permitted in the preparation of a GYMEA library

except for nuclides which do not have resonance information as part of the main library (IS $\leq$ 0 Section *5.2.2*). Resonance parameters are simply stored (λ 100 resonances) for a group (unless the group is not collapsed) and then created on tape. On the other hand shielding parameters are used to reconstruct three cross sections, using the arrays $\underset{\sim}{N}_1$, $\underset{\sim}{N}_2$, $\underset{\sim}{N}_3$(*5.3.8*), which are collapsed in the usual fashion (*7.3.2*) and then reconverted to shielding parameters. In both cases the entries held in the library (resonance-removed cross sections) are also collapsed in the standard way.

Using the optional data that may be given after GYMEA on the output card it is possible to select different resonance group boundaries, provided they are 'inside' boundaries which would result using the specified library resonance groups, and to select a library resulting from CREATE (*5.2.2*) rather than the main library. Hence if the main library contains resonance parameters for a nuclide we can CREATE a library with shielding parameters, and this structure can be used in the condensed library preparation. The optional fixed point data word has the form

SLLLUUUB

the digits of which have the interpretation:

S = sign – if negative no resonance information is created,

LLL = lower resonance group boundary in terms of condensed group structure,

UUU = upper resonance group boundary in terms of condensed group structure unless

UUU = 0, in which case the structure of the main library determines the resonance group boundaries,

B = 0 – the main library is used,

B = 1 – the created library is used.

As an example, suppose the main library consists of 12 groups, of which 3 to 10 are designated in the library heading information as being resonance groups (*18*), and the card used (*5.7*) is:

GROUPS 6,1,3,4,6,8,9,12

that is R R R R R R R R

1 1 2 3 4 5 6 7 8 9 10 11 12

1 1 2 3 4 5 6

Then, in terms of the condensed group structure, groups 2 to 5 would be considered to be resonance groups since groups 1 and 6 contain only partial resonance information for the full range. If then

(i) SLLLUUUB=0 (this is implied if the data word is not specified), the resonance groups would be 2 to 5,

(ii) SLLLUUUB=30040
the resonance groups would be 3 to 4

or (iii) SLLLUUUB=10051
an error condition would result as the first group is not a full resonance group.

9.2.2 Burnup table

The burnup table for the mixed nuclide library is obtained from the main library burnup table as follows.

(i) For a library nuclide the table is simply copied.

(ii) For a defined material the burnup and decay scheme of the dominant nuclide (the first nuclide of a definition – Section *5.3.3*) are used except that the decay constant and fission yields are each calculated as an aggregate for all component materials.

The aggregate for decay constant is based on the mixing rules used in the preparation of cross sections for the material (*5.3.2*) whereas the aggregate for fission yields may be weighted in the same fashion or weighted differently using the following feature. If the mixing rule for a material is given in terms of elements of the Z array, for example,

'F2A' = –1 MO95, –3 TC99, –5 RU101, 0' '

then in the preparation of 'F2A' cross sections and decay constant a weight Z (1) would be associated with Mo^{95}, Z(3) with Tc^{99}, and Z(5) with Ru^{101}, whereas in the preparation of fission yields a weight Z(2) would be associated with Mo^{95}, Z(4) with Tc^{99}, and Z(6) with Ru^{101}.

For this application a mixing rule containing a zero coefficient, for example,

'MIX' = 0. (1,55), 0.' '

is not given a special meaning as it is for cross section mixing (*5.3.2*), but is taken to mean zero proportion of the specified nuclides. In general it may be necessary to prepare a burnup table beyond the scope of these features, in which case the library may be corrected later using the library edit programme, EDITOR (Ford 1966 – Section *19.4*).

9.3 Scattering Matrix Library

Mixing rules are ignored in this application as a full main library complement (*18*) is always involved. Each matrix of the library for the specified temperature is condensed to the required groups (*5.4.2*) and the condensed library is copied to the specified tape (*9.1*). If the specified temperature is the first of the library set, not necessarily the smallest temperature, then the tape is rewound and a heading record is created. For other than the first temperature, the tape is not rewound and the condensed scattering matrices are created on the tape without a further heading record. Using these features it is possible to create a condensed scattering matrix library with scattering matrices for each temperature averaged over an appropriate flux spectrum. If the full set of scattering matrices or full set of temperatures is not required, a scattering matrix COPY should first be produced (*5.2.2*).

10. CHAIN 1 – COMPILER AND ERROR ROUTINES

10.0 Summary

The ability to calculate quantities of direct interest in-situ in GYMEA is a useful feature which enables people not necessarily involved in writing the code to extend the code to carry out many different calculations. It has been found that the mixing of macro-data and compiler instructions greatly adds to the versatility of GYMEA.

10.1 The Compiler

This routine is used to read data cards into core, to 'compile' some of them, to write them out on unit 4 as one binary file for execution in CHAIN 2, and finally to set the core to standard state (*11*).

The process of compilation consists of:

(1) All transfer points are set to absolute form.

(2) Most of the FORTRAN-like cards are interpreted and changed into a set of words describing the function of the statement. These words are stored in place of the original card for later execution. For completeness a description of all the FORTRAN-like cards (GYMEA code) follows.

GYMEA code cards are all executable and may be mixed with the other input cards as desired. The data may be punched anywhere on a card but on one card only. Statement numbers are indicated by a slash (/) and are the first characters on a card. They may appear on any of the input cards except END and CEASE, for example,

```
/ 2  T = 0., 20, 0
```

10.1.1 Constants and variables

Any integer or floating point constant acceptable to FREE input may be used (*22*). There are only three variables available, all subscripted, namely, X(n), Z(n), J(n), dimensioned 2000, 860, and 9 respectively. As well there are the special variables X(o), Z(o), and J(o). X and Z are floating point variables and J is a fixed point variable. The subscript n may be any integer, positive or negative. A negative subscript has the meaning X(–n) ≡X(J(n)). Thus J(n) is referred to as –n when used as a subscript or a DO loop index.

10.1.2 Arithmetic statements

An expression consists of one or two variables or constants separated by one of the four operators: +, –, *, /. However an operation on two constants is invalid. An expression is either of fixed or floating point mode; mixed mode expressions are not allowed. A negative sign may precede an expression.

A statement is then of the form

```
a = b
```

where a is a variable and b is an expression. a and b may be of different mode, the expression being evaluated in its mode and converted to the other if required.

Examples are:

```
X(2) = Z(1) * 1.3
Z(10)= -J(9) + J(-2)
J(5) = 7
Z(-5)= -Z(0)
```

10.1.3 Control statements

The main control statements are:

GO TO — The statement GO TO n, where n is a statement number, transfers control to the card with statement number n. The statement GO TO J(0) means: transfer to the card which has the card number of the present card plus J(0). This provides a feature equivalent to a computed GO TO statement.

IF — The statement IF (V) n_1, n_2, n_3 transfers control to the statement number n_1, n_2, or n_3, depending on whether the fixed or floating point variable V is negative, zero, or positive.

DO — The statement DO n $-i_1 = i_2, i_3, i_4$ where n is a statement number and $i_1,\ldots,i_4$ are positive integers, executes repeatedly the statements up to that numbered n, with $J(i_1)$ having the value i_2 incremented in steps of i_4 until i_3 is reached. The integer i_4 must always be given and each DO loop must end with a separate CONTINUE statement.

Other control statements are:

CONTINUE — a dummy statement used mainly to end a DO loop,

PAUSE — causes the machine to halt for operator action,

END — must be the last physical statement of each job or subroutine. Also terminates a job.

The following example is a sample portion of a programme illustrating control statements.

```
      IF (X(-1) ) 1,2,2
/ 1   DO 3 -2 = 1,10,1
      DO 4 -3 = 1,5,1
      J (4)    = J(2) + J(3)
      Z (-4)   = Z(-2) * X(-1)
/ 4   CONTINUE
/ 3   CONTINUE
      GO TO 5
/ 2   X(-1)    = -X(-1) + Z(10)
      GO TO 1
/ 5   CONTINUE
```

10.1.4 Input–output statements

Input–output of numeric (floating point only) data differs more from FORTRAN than other statements do. The first 2 or 3 characters indicate the type of statement and only the numeric information following is relevant. Here W,P,R stand for print, punch, and read respectively.

Where only 2 letters are given the statement is of DO loop form, for example,

```
WX      (X(I), I = 1, 10, 1)

RZ        1 100  2
```

Where the third letter is S, the first number is the number of single variables following, for example,

```
WZS   3   ONLY  Z(0), Z(5), Z(-3)

PXS   5   -1, -2, -3, -4, -5
```

A maximum of 9 variables can be processed this way. If the first number is zero, input–output of a card image columns 1–72 is achieved. Two card images can be read and written this way: one by using X, the other by using Z. Thus

```
RXS  0

WXS  0
```

would be used to read and print a card.

The standard FORMAT for output is (1P5E14.5). This can be changed by using a format card

```
FORMAT(          )
```

where the left bracket must be in column 13. The FORTRAN variable-format feature is used to effect this. The given FORMAT is then the one used until replaced.

When a read card is used, data is read from the card reader under the standard form of free input (*22*); no continuation integer is required in column 1 for this application. This data for any job must begin with the card

```
,DATA JOBN
```

(when JOBN is the job name) which follows the CEASE card. The read feature is useful to enter blocks of data for which no macro–card exists.

There are also four cards for writing messages:

```
WRITE1          comments

PUNCH             ''

TYPE              ''

WRITE2            ''
```

The first 3 output columns 13–72 of the card on the specified device in columns 1–60 and the fourth writes columns 13–72 of the card and columns 1–72 of the next card on the printer in columns 1–132. Note that column 13 of these cards is used for printer control.

The statement UNLOAD n causes the tape on unit n to be physically unloaded.

10.1.5 Subroutines

For the purpose of GYMEA, there are three types of subroutine:

(1) Internal– written in FORTRAN or MAP originally and part of the system.

(2) External– written in GYMEA code by the user as input.

(3) Replaceable– internal versions are available, but if the user enters his own version that will be used for the run.

An external subroutine is a non–argumented subroutine which may include any of the input cards of the code except another SUBROUTINE card. The return from a subroutine, provided by a RETURN card, is to the next input card after that being executed when the subroutine was called. The indices J(1),..., J(9) are saved on entry and restored on return. The last physical statement of a subroutine must be END.

External subroutines are normally loaded first, but they may be loaded between or after the jobs. If two subroutines of the same name are loaded, the last one is used. Subroutines may be nested up to ten deep.

Subroutines are called by

CALL NAME

where only the first 3 letters of NAME are significant. Subroutines which are part of the system and may be called are:

EXP	sets Z(0) = EXP (X(0)),
LOG	sets Z(0) = ALOG (X(0)), that is $\log_e$,
SEND	terminates a job,
SCEASE	terminates all jobs in a load,
EXIT	returns control to the system monitor,
CLOCK	sets Z(0) equal to the running time of the code in minutes,
DAT	called when a data error occurs, calls SEND
LIB	called when a library error occurs, calls SEND
FINISH	called on internal timer overflow, calls DUMP, then calls EXIT,
STAN	sets storage to standard state (*11*),
DUMP	prints out all non–zero J, X, Z variables,
EQU	carries out equilibrium search (*13.1*),
WEST	computes a Westcott group flux (*13.2*),
NS1	transfers data to shielding array 1 (*5.3.8*),
NS2	transfers data to shielding array 2,
NS3	transfers data to shielding array 3,
NUC	normalizes defined material concentrations (*5.3.5*),

OUTPUT writes out the output set up previously, if this was retained prior to this card using X(9) ≤ −10.(*5.4.1*).

DAT, LIB, FINISH, and SEND are the subroutines used by the code that may be replaced.

Examples:

1. To set $Z(59) = e^{5.5}$:

```
X(0) = 5.5
CALL EXP
Z(59) = Z(0)
```

2. To print the machine time used:

```
SUBROUTINE TIME
CALL CLOCK
FORMAT (15 H0TIME TAKEN WAS F6.2,5H MINS)
WZS 1 Z(0)
RETURN
END
```

CALL TIME may then appear anywhere in a job or subroutine.

3. To obtain a dump before termination when the programme detects a data error:

```
SUBROUTINE DAT
CALL DUMP
CALL SEND
END
```

4. To check the tape on a library error:

```
SUBROUTINE LIB
TYPEbbbCHECK TAPE ON 1, MUST BE GYMEA NDXD
PAUSE
USE 1, 70, -1
RETURN
END
```

10.2 Errors

This chain is called when any error is detected by the programme. All libraries are rewound and the input cards read back into storage, and a self-explanatory message is then printed. The bulk of the 68 different error messages is one of the main reasons for the inclusion of all errors in this small chain.

If an ERROR card has been given as data (*13*) the appropriate sections of common storage are dumped out in G format (interpreted as E mode for numbers with a non-zero exponent and I mode otherwise). This should only be used for programme debugging. The programme next calls CHAIN 2 for termination or error recovery.

Errors detected during compilation are treated differently. Instead of the procedure described above, a message is written and the card is not compiled. It is not until an attempt is made to execute the card that the job is terminated.

In relation to termination, it should be remembered that by having subroutines DAT or LIB as input the user can obtain his own termination or recovery procedures. For instance, a check can be made on all the cards of a large job without performing the calculations if an error occurs by using

```
SUBROUTINE DAT

RETURN

END
```

11. STANDARD STATE (STAN)

The common area of storage is set to its standard state after each load is compiled, and whenever requested, by the card

CALL STAN

This should always be the first card of a job that is independent of previous jobs to give protection from an error in the previous jobs. It should also always precede a USE card if the requested libraries have a different structure from libraries used previously.

In the standard state the data areas (apart from WH, which contains the input cards, and a few variables given below) are set to zero. No information pertaining to any library, or any information previously calculated, is retained.

The variables not set to zero and the values they are given are:

LIB = −1)
LIBC = −1) no libraries have been specified,
LIBS = −1)
LXG = −1)
LSG = −1)

KTR = 11 overlap and transport options each set to 1,

STR = 1.E −4 accuracy of absorption required in group flux calculation,

SXA = −1. terminate the job if B2AV falls below −1,

IFP = −1 the programme is set to normalize the group flux to unit source when it is calculated,

IWT = −1 reaction rates must be calculated before burnup is attempted,

X(0) is unchanged so that the user can test for previous errors,

FORMAT for GYMEA code output is set to (1P5E14.5)

and HEAD for neutronics output is set to blanks.

12. USER'S COMMON

12.0 Summary

It is possible for the user of GYMEA to use or modify certain variables held in COMMON storage in areas readily accessible using the compiler variables J(0)–J(9), X(0)–X(2000), Z(0)–Z(860) (*10.1.1*). For example, we may modify the potential scattering cross section of the first library nuclide thus

```
X(351) = 3.0
```

A list follows which gives entries in the user's COMMON in terms of variables of the source language programme (*21*) and names associated with printed output.

12.1 Index Registers J(0) – J(9)

The variables J(0) to J(9) are not used in the source programme. These variables enable data to be processed using ordered arrays; for example, to set Z(1) to Z(100) to zero we may use

```
      DO9  -1 = 1,100,1
      Z(-1)   = 0.
     / 9 CONTINUE
```

Here Z(–1) is interpreted as Z(J(1)).

12.2 Special Registers X(0) – X(10)

The variables X(0) to X(10) are used as subroutine arguments and they obey the same rules as do variables appended to a normal FORTRAN function or subroutine-calling statement, for example to calculate e^t (t=X(11)) we may write

```
      X(0) = X(11)
      CALL EXP
```

The result of the calculation is then available using the variable Z(0). In addition to this function these variables are used to control certain aspects of the programme indicated below.

X(0) =1. on error exit from a job, 0. normal exit,

X(1) to X(4) not used at present,

X(5) =1. programme uses average concentrations (AVE.N) in determining k_{eff}, etc.,

0. programme uses final concentrations (AFT.N),

X(6) sets type of printed multigroup condensed output (*5.4.1*),

X(7) used in conjunction with CALL EQU (*13.1*),

X(8) used as a weighted coefficient for data accumulated with SAVE (*5.4.3*),

X(9) sets type of printed one–group condensed output (*5.4.1*),

X(10) used by the programme for burnup control.

12.3 Result Registers X(11) – X(1999)

X	Coding	Print Out	Remarks
11	TA	T(DAYS)	time after burnup in days
12	DTD		difference in time between current and previous time step in days
13	AFL	FLUX	flux level in n/cm^2 sec
14	APR	POWER,AFTER	power after burnup in $watts/cm^3$
15	RPR	POWER,SPEC.	specified power used as input
16	VPR	POWER,AVERAGE	average power for the time step
17	BPR	POWER,BEFORE	power at the beginning of the time step
18	FIN	FLUX–T	flux–time integral in n/cm^2
19	PIN	POWER–T	power–time integral in $watt-days/cm^3$
20	VIN		total fissions $/cm^3$
21	XIN		X–time integral in $days/cm^2$ with $X = (\nu \Sigma_f - \Sigma_a)/D$
22	FIFA	FIFA	fissions/initial fissile atom = VIN / FIFC
23	AKI	K(INF)	k_∞
24	AKE	K(EFF)	k_{eff}
25	XI	B2(INF)	estimated buckling to give $k_{eff} = 1$ in cm^{-2}
26	XE	B2(EFF)	estimated buckling to give $k_{eff} = 1$ including DB^2 term, from B^2 defined by the user, in cm^{-2}
27	XAV	B2AV	time average buckling in cm^{-2}
28	CNA	A/S	neutrons absorbed/source neutron (should be close to 1. if the group flux is calculated from neutron balance)
29	SKI		KINF LIMIT for job exit (CALL SEND)
30	SKE		KEFF LIMIT for job exit
31	SXA		AVX LIMIT (X(27)) for job exit
32	STR		ACC IN ABS. RATE (5.9)

33	GL	lower eigenvalue limit
34	GG	second guess at eigenvalue
35	GU	upper eigenvalue limit
36	AER	required k_{eff} (or FIFA (*13.1*))
37	ACER	required accuracy in k_{eff} (or FIFA)
38	ACET	outer iteration accuracy in power (*13.1*)
39	FIFC	initial fissile atom concentration
40	TEMP	resonance temperature (degrees Kelvin)
41	TLAST	if T= −1,20,0 is used then X(41) replaces −1
42	BPRS	previous BPR (GYMEA modifies BPR)
43	XY(1)	$\Sigma_a + DB^2$
44	XY(2)	$\nu\Sigma_f$
45	XY(3)	DB^2
46	EPART	$\bar{\ell}$ used in resonance shielding
47	VOID	void used to normalize nuclide concentrations
48	ETC1(1)	B2AV saved from group flux calculation EQU search (*13.1*)
49	ETC1(2)	number of file skips through tape 4 before reading or writing cross section data (*13.3*)
50	ETC1(3)	not used
51 o 150	AN AFT.N	nuclide concentrations at the end of the time step (nuclides/10^{-24} cm^3)
151 o 250	AV AVE.N	average nuclide concentrations for the time step (the numbers printed above AFT.N and BEF.N refer to the extremes of time in days for the average concentrations)
251 o 350	BN BEF.N	for constant power runs this is the N's of the previous step and for constant flux runs this is the initial fuel concentrations
351 o 450	SXS	potential scattering cross sections for each library nuclide
451 o 550	FER	fission energy release for each nuclide (joule/fission)
551 o 670	GFLUX	group flux
671 o 790	GSCE	group source (the programme normalizes this to unit sum)
791 o 910	GB2	group buckling

911 to 1030	WU and AA	$\Sigma_a + DB^2$ for each group, or burnup matrix terms if group flux calculation does not follow burnup
1031 to 1150	WV	$\nu\Sigma_f$ for each group, or burnup matrix terms as mentioned above
1151 to 1270	DB2	DB^2 for each group
1271 to 1370	R(L,1)	microscopic reaction rates for capture 1 reaction for all nuclides ($r_\ell^{(1)}$ Section 7.3.1) in 10^{-24}/sec
1371 to 1470	R(L,2)	fission
1471 to 1570	R(L,3)	absorption
1571 to 1670	R(L,4)	ν–fission
1671 to 1770	R(L,5)	transport
1771 to 1870	R(L,6)	capture 2
1871 to 1970	DC	decay constants for each nuclide in 10^{-24}/sec
1971	ETC2 CRIT.R	radius of critical sphere in cm (extrapolation distance removed) based on B2(INF)
1972	EXTRAP.D	extrapolation distance in cm
1973 to 1999		spares

12.4 Additional Registers Z(0) – Z(860)

Z(0) (≡X(2000)) is used by subroutines as output argument and this variable is used to indicate which set of N's are to be used in forming macroscopic cross section information (*5.3.2*).

Z(1) to Z(500) are available for the user's calculations and are retained.

Z(501) to Z(860) are available for the user's calculations but are destroyed by the programme after a time card, T=0., 20,0, for example. The programme uses the array in terms of three arrays dimensioned WX(120), WY(120), and WZ(120).

12.5 Other Programme Data

It is possible to make available data beyond the user's COMMON by using the fact that the origin of blank COMMON is X(19491), and all programme variables in COMMON are listed relative to this origin in Section *21*. Fixed point data may be changed using the origin J(19501).

13. SPECIAL FEATURES

13.0 Summary

Details are given of (1) a simple model used to represent ultimate performance of a recycling fuel system after reaching equilibrium, (2) a method of obtaining a soft spectrum essentially based on joining a Maxwellian–spectrum to a 1/E–spectrum, (3) a procedure for accumulating cross section data for later processing, and (4) a method used in the original source debugging.

13.1 Equilibrium Search

Following the ideas of Bicevskis (1963), a feature is available which allows the study of a homogeneous recirculating fuel reactor system operating under equilibrium conditions. The model implies infinite recirculation rate of fuel particles and does not fully account for resonance self screening by the fuel. Nevertheless the idea is a useful starting point for survey calculations biased towards calculating ultimate performance of the system after it has been operating for some time. For this model the composition of the core is the average of all states of burnup of a recirculating fuel particle prior to rejection. The required core power density is specified as P watts/cm^3 and this is required to be the average power density of a fuel particle from first entry into the core to final rejection. Since the system is in equilibrium the model is equivalent to a fuel particle burning up under conditions of constant flux level and spectrum, which is a problem which makes full use of the analytic solution technique used in GYMEA (6.2). The problem is to find the equilibrium state core concentrations of component nuclides which (1) determine the spectrum and level through the specified power and (2) represent the average of all states of burnup of one fuel particle burning in this spectrum. An iterative procedure is available in GYMEA which

(i) calculates flux level and spectrum from a guess at the equilibrium concentrations, $\hat{\underset{\sim}{N}}_A$(AFT.N);

(ii) calculates the time of burnup of a fuel particle ($\underset{\sim}{N}_S$–BEF.N) necessary to achieve a specified number of fissions (F, FIFAS)– inner iteration;

(iii) calculates the average composition of the burning fuel particle $\hat{\underset{\sim}{N}}_B$ (AVE.N) and its average power density,

(iv) if the power density is not that specified for the core, repeats the procedure from (i) using $\hat{\underset{\sim}{N}}_B$ in place of $\hat{\underset{\sim}{N}}_A$ – outer iteration.

JOB4 (15) illustrates the manner in which GYMEA is set up to do the problem. For this application it should be noted that the requirement for the inner iteration is specified with a SEARCH card (5.5.2) which must be punched with NO0 followed by the 3 eigenvalue parameters, the required FIFA, and the required accuracy in FIFA. The outer iteration is set to a required accuracy using a card, punched, for example,

ITERATE 9,0.1

which sets the outer iteration to terminate after 9 attempts if the power from one iteration to the next is not within the specified limit of 0.1 watt/cm^3.

On completion of an equilibrium search, the concentrations AFT.N are normally overwritten with the concentrations AVE.N – step (iv) above. This may be prevented by setting

X(7)=–1.

13.2 Westcott Flux

When the subroutine WEST is used thus

CALL WEST

a group flux is calculated based on the Westcott convention with an r value (ratio of epithermal to thermal flux) specified using the variable X(0) (*5.5.3*). In addition to the Maxwellian thermal region (temperature set by SCAT or TEMP card (*5.2.4*)), joining region, and 1/E region, a terminating region is added based on the fission source thus

$$\int_o^u S(u')\,du' .$$

The flux per unit lethargy is then given by (Westcott 1957)

$$\phi(u) \propto (x^2 e^{-x} + \beta\Delta \int_o^u S(u')\,du')$$

where $x = E/kT$,

$\beta = r/(1-1.01r)$,

and $\Delta = (1-0.26(1+(x/16.4)^5)^{-1} + (4.75/x)^7)^{-1}$.

This is integrated to give group flux following Cook (1964).

WEST is also used as a guess for group flux which is to be calculated from neutron balance of a homogeneous system (*7.2*) provided a group flux is not otherwise defined.

13.3 Saving Output on Tape 4

Normally, using the feature mentioned in Section *5.4.1* for saving output on tape 4 ($X(9) \leq -10.$), a file of cross section information is saved as a second file of binary records, maximum 256 words. This file consists of condensed and mixed cross section data given/reaction/group/material. If however X(49) is N. then, not counting the first file, N files will be skipped before information is written or read. With this feature it is possible to use tape 4 as a library in another programme or to list the tape later using the option

```
CALL OUTPUT
```

In this application the additional information such as nuclide concentration, etc., is obtained from the data currently held in core and may therefore not relate to the cross section data.

13.4 Expanded Error Diagnostics

A card is available which sets the 'width' of programme COMMON (*21*) to be printed when an error is detected (normally zero). This feature was designed to assist programme debugging; however it may be of use to people trying to probe the manner in which GYMEA functions. An example of the use of the feature is

```
ERROR  1, 16000, 1,10000
```

which will result in a print out, when an error is detected, of COMMON 1 to 16000, excluding the array WH, and elements 1 to 10000 of the array WH.

14. CHECKOUT

14.0 Summary

Checkout of a code such as GYMEA must, of necessity, be divided into three categories: (1) theory checkout, (2) coding checkout, and (3) library checkout. Brief details are given below of some of the tests which have been carried out. These tests were all completely satisfactory.

14.1 Theory Checkout

(1) Resonance theory checked against PEAS (Pollard 1964) and LUBRA (Kletzmayr 1966).

(2) Analytic burnup theory checked with DEMON (Bennett 1965).

14.2 Coding Checkout

(1) Group data preparation checked against MULGA (Clancy et al. 1963).

(2) Burnup performance compared with FEVER (Todt 1962).

(3) Neutron diffusion calculation of critical buckling for a bare system compared with CRAM (Hassitt 1962).

14.3 Library Checkout

(1) Cross section data for dominant nuclides checked against MULGA data.

(2) Selected cross section data plotted to the same scale as that given by Hughes and Schwartz(1958).

14.4 Maintenance

Maintenance based on these three main aspects will continue for the life of the GYMEA project, which is expected to be at least five years. From time to time further documents will be published to give the GYMEA user confidence in the ability of GYMEA to provide data which will adequately predict neutron behaviour in a reactor system. For example, correlation of A.A.E.C. measurements carried out on exponential assemblies composed of BeO – Pu – Th – U^{233} – U^{235} – U^{238} with predictions based on GYMEA data is at present being prepared.

At the time of preparation of this report the code GYMEA has been operational for half a year.

```
$IBSYS
$ID          30073
$JOB            2210 J.POLLARD          'GYMEA'
$*              TAPES REQUIRED.
$PAUSE          295 ON 1, 260 ON 2 (VIA 1401), SCRATCH ON 3 AND 4
$TIME           60
$EXECUTE        GYMEA
*GYMEA
       ,JOB1  A SIMPLE JOB AS ILLUSTRATION.
       CALL STAN
       USE LIB X-S=1 OF 100 NUCLIDES AND SCAT=2
       'BEO'=1.BE9,1.016,DENSITY=1.8''
       SCAT 900. 'BEO' CRY    ''
       N(1,100)=0.,'BEO'=4.-2,U233=4.-5''
       OUTPUT 3 PRINTX PRINTS CRAM
       MATS 'BEO',U233,PU239''
       GROUPS 5 1 40 50 71 90 120
       T=0.DAYS,20 MAX FLUX ITERATIONS,0 CRITICALITY
       END
       CEASE
*
*********************
*
       ,DISCARD SUBROUTINES
       SUBROUTINE PFLUX
*      PRINTS GROUP FLUX
*      NOTE THAT ONLY 3 CHARS OF NAME ARE UNIQUE,PFL..
       FORMAT (6HOGFLUX/ (1X1P10E12.3))
       WX 551,670,1
*      IE WRITE X(551) TO X(670) IN STEPS OF 1
       RETURN
       END
*
*********************
*
       ,JOB2 CRITICALITY
*      CREATION OF A LIB. OF BE9,016, AND U235 TO SAVE TIME
       CALL STAN
       USE 1,70,-1 (A SCAT MATRIX LIB. IS NOT REQD)
       CREATE 3 XDXD  100*-2 I.E. SAME STRUCTURE AS MAIN LIBRARY
*      BE9 AND 016 AS LIGHT NUCS AND U235 AS A RESONANCE NUC
       MATS BE9,016,U235''
```

```
*     ONLY ABOVE MATS ARE CREATED FOR NON-BURN UP USER
      GFLUX=120*1.
      FLUX=1.
      NO16=1.''
*     THE ABOVE ARE REQD TO MAKE A DEFINED PROBLEM
      HEAD   BE9,O16 AND U235 FROM NDXD
      T=0,1(GROUP FLUX IS NOT CALC. HOWEVER),0
*
      CALL STAN
      USE 3,3,2
      =GYMEA XDXD NDSC
      HEAD   CF TABLE 3-98 ANL 5800(2ND ED.)
      'BE9'=1.BE9,0''
      'O16'=1.O16,0''
*     'BE9' AND 'O16' ARE NOT REQD AS SUCH FOR THE MIXTURE BEING STUDIED
*     HENCE A DENSITY OF ZERO IS GIVEN
*     NOTE ALSO THAT THE 2 MATERIALS 'BE9' AND 'BEO' SHOULD NOT HAVE
*     THE SAME DOMINANT NUCLIDE,BE9, IF BOTH ARE REQUIRED FOR VOLUME
*     NORMALIZATION USING     CALL NUC
      SCAT 300. 'BE9' GAS   'O16' GAS   ''
      GB2=120*8.-3
      SEARCH GB2 0.01 0.8 100. 1.000 0.001
*     BUCKLING IS TO BE ADJUSTED TO MAKE K=1.000 + OR - 0.001
      'BEO'=1.BE9,1.O16,1.+10 ''
*     DENSITY OF 'BEO' IS REQD TO BE EFFECTIVELY INFINITE
*     AS 'U5' IS GIVEN FOR THE MIXTURE
      'U5'=1.U235,-1''
*     IE Z(1) CONTAINS DENSITY OF U5 IN MIXTURE (G/CM**3)
      Z(1)=0.0140
      N(1,100)=0.,'U5'=1.,'BEO'=1920.''
      CALL CALC
      Z(1)=0.00702
      N(1,100)=0.,'U5'=1.,'BEO'=3830.''
      CALL CALC
      END
*
**********
*
      SUBROUTINE CALC
*     FORCES CALCULATION OF CRITICALITY AND COMPUTES REQD QUANTITIES
      CALL NUC                          RESCALES NUCLIDE CONC TO UNIT VOL
      T=0.,20,6 MAX CRIT IT
```

```
      Z(3)=X(1971)*X(1971)
      Z(3)=Z(3)*X(1971)
      Z(3)=4.1888*Z(3)                    CRIT VOL
      Z(4)=Z(3)*Z(1)                      MASS OF U5
      Z(4)=Z(4)*1.E-3                     KG-U5
      Z(5)=X(51)/X(53)                    NUCLIDE RATIO
      WRITE10  RATIO       MASS
      WRITE1  BEO/U5      KG-U5
      FORMAT(1H0,F7.0,F10.2)
      WZS 2 5,4
*     IE WRITE 2 Z'S, NAMELY Z(5),Z(4)
      CALL PFLUX
*     PRINT GROUP FLUX
      RETURN
      END
*
**********
*
      ,JOB3    FIRST BURN UP RUN
      CALL STAN
      USE 1,61,2
*     NUCLIDES 62-70 ARE NOT REQD.
      =GYMEA NDXD NDSC
      'BEO'=1.BE9,1.016,1.8''
      'PU'=0.76PU239,0.17PU240,0.07PU241,0''
      'PUO2'=1.'PU',2.016,11.''
      'THO2'=1.TH232,2.016,9.5''
      'FP'=0.(23,61),0''
      Z(0)=1
*     AFT.N WEIGHTED X-S REQD.
      SCAT 900.  'BEO' CRY    ''
      HEAD   FIRST BURN UP RUN
      OUTPUT 1 PRINTX
      MATS 'BEO',TH232,U233,PU239,PU240,PU241,'FP' ''
      GROUPS 2,1,71,120
      X(6)=4.9
      X(9)=4.9
*     OUTPUT IS SET TO PRODUCE MICRO X-S
      N(1,100)=0.,'PUO2'=1.,'THO2'=10.,'BEO'=2000.''
      CALL NUC
      PART 0.01,'PUO2','THO2' ''
*     200 MICRON PARTICLES OF SEPARATED FUEL ('PUO2','THO2')
```

```
      FIFA PU239,PU241''
*     THIS CARD OPENS THE WAY FOR A BURN UP USER AS ITS USE
*     DISTINGUISHES HIM FROM A USER ONLY INTERESTED IN T=0.
      POWER=10. WATTS/CM**3
*     IE BURN UP AT STEP-WISE CONSTANT POWER
      T=0.,20,0
      DT=100.,20,0,2
*     2-GROUP OUTPUT IS NOT PRODUCED AFTER 100 DAYS
      END
      CEASE
*
**********
*
      ,RETAIN SUBROUTINES
      ,JOB4 EQUILIBRIUM SEARCH
      USE 1,61,2
      =GYMEA NDXD NDSC
      'BEO'=1.BE9,1.016,0''
      'O16'=-1 016,-2 016, 0 ''
*     'O16'= O16 ASSOCIATED WITH HEAVY NUCLIDES
*          = Z(1)+Z(2) (=1 LATER) PROPORTION OF O16 FOR CROSS SECTIONS
*     CONCENTRATION OF 'O16' HOWEVER = CONCENTRATION OF O16/Z(1)
*     AND THIS WEIGHTS SCATTERING MATRIX OF 'O16'
*     Z(1) AND Z(2) ARE DEFINED LATER
      SCAT 900. 'BEO' CRY   'O16' GAS   ''
      ITERATE 9,0.1 (WATTS/CM**3)
*     THE MAX. NO. OF (OUTER) ITERATIONS IS SET AND REQD POWER ACCURACY
*     OUTER REFERS TO SPECTRUM DET. FROM EQU. GUESS
      SEARCH NOO .1 .9 10. 1.4 FIFA ACCURATE TO 0.005
*     INNER ITERATION-ADJUSTMENT OF TIME OF BURN UP
*     TO ACHIEVE A SPECIFIED FIFA
      HEAD   EQUILIBRIUM SEARCH
      N(1,100)=0.,BE9=4.-2,O16=4.046-2,TH232=2.-4,PU239=2.34-5,
1     PU240=5.1-6,PU241=1.5-6''
*     NOTE CONTINUATION CARD ABOVE(A NON-DESCENDING INTEGER IN COL 1)
      Z(1)=X(52)-X(51)                    EXCESS O16
      Z(1)=X(52)/Z(1)                     INVERSE FRACTION OF O16
      Z(2)=1.-Z(1)
      FIFA PU239,PU241''
*     AFT.N ARRAY IS ALSO TRANSFERRED TO BEF.N
*     AND THIS MAT IS BURNT FOR THIS MODE OF OPERATION
      N(3,100)=0.,TH232=1.9-4,U233=4.3-6,PU239=2.8-6,PU240=2.-6,
```

```
1       PU241=2.2-6**
*       THIS SET IS AN EQU. GUESS AND DETS FIRST SPECTRUM
        POWER=11.
        CALL EQU
*       A FINAL SPECTRUM DET MUST BE FORCED IF MULTIGROUP OUTPUT
*       IS REQD-USE T=0.,20,0,SAY
        CALL PFLUX
        UNLOAD 1
        UNLOAD 2
        TYPE   TAPES UNLOADED
        END
        CEASE
$IBSYS
```

16. COMMENTS ON OUTPUT

Heading information is widely used to clarify the meaning of output information (see Section *12.3* for the correspondence of printed labels with variables of the theory). The data entries given thus

```
      4    3    5     11
IT-FLUX,EIGEN.XS-0T
```

for the sample output (*17*) in order refer to

(1) the actual number of iterations taken by the subroutine calculating group flux from neutron balance (*7.2*) if its use has been specified (*7.1*) (minus the maximum number of iterations specified if convergence has not been achieved), or the number given on the time card, say T=0,-1,0, otherwise (*5.5.3*),

(2) the number of inner iterations associated with convergence of the SEARCH procedure (*5.5.2*) (negative if not converged),

(3) the number of outer iterations associated with the search for an equilibrium composition (*13.1*) (negative if not converged), and

(4) a number which indicates the overlap and transport averaging method adopted by the code (negative if the specified options cannot be accommodated) (*5.4.2*).

Columns 1 to 60 of the actual user's card which initiates the neutronics calculation are given to help label the output and suitable comments may be appended to this card if required.

The library nuclear data is under continual revision and hence the output given here may not be completely up to date. The source and type of data is shortly to be documented (Cook 1966).

SAMPLE OUTPUT 17

```
     2210 J.POLLARD        'GYMEA'

$ID          30073
$JOB            2210 J.POLLARD          'GYMEA'
$*              TAPES REQUIRED.
$PAUSE          295 ON 1, 260 ON 2 (VIA 1401), SCRATCH ON 3 AND 4
$TIME           60
$EXECUTE        GYMEA
```

GYMEA DATA LIST * 23/12/65 *

```
ISN     SOURCE STATEMENT

  1     ,JOB1  A SIMPLE JOB AS ILLUSTRATION.
  2     CALL STAN
  3     USE LIB X-S=1 OF 100 NUCLIDES AND SCAT=2
  4     'BEO'=1.8E9,1.016,DENSITY=1.8''
  5     SCAT 900. 'BEO' CRY    ''
  6     N(1,100)=0.,'BEO'=4.-2,U233=4.-5''
  7     OUTPUT 3 PRINTX PRINTS CRAM
  8     MATS 'BEO',U233,PU239''
  9     GROUPS 5 1 40 50 71 90 120
 10     T=0.DAYS,20 MAX FLUX ITERATIONS,0 CRITICALITY
 11     END
 12     CEASE
```

GYMEA JOB JOB1 X-SEC LIB. NDXD (120, 70, 0.K) ON 1 * 23/12/65 * OUTPUT NO. 1 RESONANCE TEMP= 900.K
---- SCATT '' NDSC (900.K) '' 2 -------- ISN 10 ---

T=0.DAYS,20 MAX FLUX ITERATIONS,0 CRITICALITY

T(DAYS)	FLUX-T	POWER-T	FIFA	UNIT SCE FLUX	POWER	
0.	0.	0.	0.	2.912E+02	0.	(AFTER)
					0.	(AVERGE)
					0.	(BEFORE)
					0.	(SPEC.)

	K	B2	B2AV	CRIT.R-EXTRAP.D(CM)		A/S
(AFT.N)						1.0000101E+00
(EFF.)	2.2433	4.089E-03				
(INF.)	2.2433	4.089E-03	4.089E-03	4.651E+01	2.623E+00	

4 1 1 11
IT-FLUX,EIGEN.XS-OT

SCAT BY 4.000E-02 'BEO' CRY

OUTPUT NO. 1 JOB1

AFT.N*SIGMA*FLUX/SOURCE NEUTRON

T(RANGE)=	0.	-DAYS-	0.								
NUCLIDE	AFT.N	AVE.N	BEF.N	BURN	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	DECAY	
0 LEAK							3.041E-13					
1 BE9	4.000E-02	4.000E-02	0.	0	3.344E-02	0.	-3.813E-02	0.	5.389E+01	8.280E-02	0.	1
2 O16	4.000E-02	4.000E-02	0.	0	0.	0.	8.119E-03	0.	3.807E+01	0.	0.	2
13 U233	4.000E-05	4.000E-05	0.	0	1.330E-01	8.970E-01	1.030E+00	2.243E+00	9.735E-01	0.	0.	13
18 PU239	0.	0.	0.	0	0.	0.	0.	0.	0.	0.	0.	18

==========

MATERIAL 'BEO' AFT.N= 4.0000E-02 OUTPUT NO 1, JOB1 ,* 23/12/65 *

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT XS-OT= 11 AS AFT.N*SIGMA*FLUX/SOURCE NEUTRON
1		0.	11.75	3.3442E-02	0.	-4.1151E-02	0.	4.9365E+01	8.2799E-02	6.0057E+01
2		11.75	14.00	0.	0.	3.9708E-04	0.	1.1517E+01	0.	1.2270E+01
3		14.00	16.10	0.	0.	9.1839E-04	0.	9.2726E+00	0.	9.8793E+00
4		16.10	18.00	0.	0.	4.3350E-03	0.	1.4481E+01	0.	1.5425E+01
5		18.00	23.00	0.	0.	5.4888E-03	0.	8.7726E+00	0.	9.3411E+00

MATERIAL U233 AFT.N= 4.0000E-05 OUTPUT NO 1, JOB1 ,* 23/12/65 *

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT XS-OT= 11 AS AFT.N*SIGMA*FLUX/SOURCE NEUTRON
1		0.	11.75	1.6346E-02	6.6815E-02	8.3162E-02	1.6784E-01	1.2224E-01	0.	0.
2		11.75	14.00	2.0943E-02	7.3965E-02	9.4908E-02	1.8492E-01	1.0715E-01	0.	0.
3		14.00	16.10	3.1014E-02	1.9827E-01	2.2928E-01	4.9566E-01	2.3532E-01	0.	0.
4		16.10	18.00	3.4436E-02	2.7102E-01	3.0545E-01	6.7750E-01	3.2498E-01	0.	0.
5		18.00	23.00	3.0236E-02	2.8698E-01	3.1717E-01	7.1738E-01	3.2568E-01	0.	0.

MATERIAL PU239 AFT.N= 0. OUTPUT NO 1, JOB1 ,* 23/12/65 *

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT XS-OT= 11 AS AFT.N*SIGMA*FLUX/SOURCE NEUTRON
1		0.	11.75	0.	0.	0.	0.	0.	0.	0.
2		11.75	14.00	0.	0.	0.	0.	0.	0.	0.
3		14.00	16.10	0.	0.	0.	0.	0.	0.	0.
4		16.10	18.00	0.	0.	0.	0.	0.	0.	0.
5		18.00	23.00	0.	0.	0.	0.	0.	0.	0.

SUMMARY INFORMATION,AFT.N NORMALIZED OUTPUT NO 1, JOB1 ,* 23/12/65 *

GROUP	LETH	ENERGY(EV)		E(AVE.LETH)	FLUX/SOURCE	FISS.SPECT	TOT.LOSS	TOT.NU-FISS	TOT.DB**2
1	0.	11.75	1.0000E+07	7.8893E+01	2.8088E+04	1.7142E+02	1.00000	4.2011E-02	1.6784E-01	1.9794E-13
2	11.75	14.00	7.8893E+01	8.3153E+00	2.5613E+01	3.1366E+01	0.	9.5308E-02	1.8492E-01	2.8214E-14
3	14.00	16.10	8.3153E+00	1.0183E+00	2.9098E+00	2.5227E+01	0.	2.3024E-01	4.9570E-01	2.2312E-14
4	16.10	18.00	1.0183E+00	1.5230E-01	3.9380E-01	3.9562E+01	0.	3.0978E-01	6.7750E-01	3.5237E-14
5	18.00	23.00	1.5230E-01	1.0262E-03	1.2502E-02	2.3598E+01	0.	3.2266E-01	7.1738E-01	2.0402E-14
1 - 5						2.9118E+02	1.00000	1.0000E+00	2.2434E+00	3.0410E-13

```
MATERIAL  'BEO'   AFT.N= 4.0000E-02   OUTPUT NO  1, JOB1 ,* 23/12/65 *

OUTSCATTERS FROM GROUP  1
-9.5798E-01  9.5798E-01  0.          0.          0.

OUTSCATTERS FROM GROUP  2
 0.          -8.6402E-01  8.6402E-01  0.          0.

OUTSCATTERS FROM GROUP  3
 0.           1.3525E-03 -7.1344E-01  7.1208E-01  6.0225E-07

OUTSCATTERS FROM GROUP  4
 0.           0.          7.9638E-02 -9.5901E-01  8.7937E-01

OUTSCATTERS FROM GROUP  5
 0.           0.          0.          5.5671E-01 -5.5671E-01
------------------------
------------------------

MATERIAL  U233    AFT.N= 4.0000E-05   OUTPUT NO  1, JOB1 ,* 23/12/65 *

NO SCATTERING MATRIX
------------------------
------------------------

MATERIAL  PU239   AFT.N= 0.           OUTPUT NO  1, JOB1 ,* 23/12/65 *

NO SCATTERING MATRIX
------------------------
------------------------


                    END OF   JOB1
                  TIME TAKEN IN MINS
   TOTAL        JOB        LINKS 1,2   LINKS 3,4     LINK5       LINK6
1.759E+00    1.656E+00    1.708E-01   9.672E-01    4.297E-01    0.

   BURNUP       FLUX         R-RATES      RUREDY       PAUSE
0.           6.167E-01    2.10CE-01    2.194E-02    0.

NEW LOAD CALLED
```

AS AFT.N*SIGMA*FLUX/SOURCE NEUTRON

... CARD OUTPUT ...

```
=GYMEA JOB  JOB1  CRAM        OUTPUT NO.     1      * 23/12/65 *
=GYMEA X-S  NDXD  * 24/11/65 * MAIN GENERAL PURPOSE LIB. OF 70 NUC.
=GYMEA SCAT NDSC  3/12/65 'BEO''BE9''O16''H2O''C12''C12'300,900,600,1200
SP                                                                    JOB1    1
  1.00000E+00  0.           0.           0.           0.
I 1                                                                   'BEO'
  7.19930E+00  9.17908E+00  9.18896E+00  9.15082E+00  9.29381E+00
  1.33708E-01  6.88975E-01  7.07914E-01  6.08765E-01  5.95600E-01
  0.           0.           0.           0.           0.
  0.           1.39710E-01  0.           0.           0.
  0.           0.           6.88659E-01  0.           0.
  0.           1.34033E-03  0.           7.05663E-01  5.96820E-07
  0.           0.           5.03257E-02  0.           5.55700E-01
  0.           0.           0.           5.89785E-01  0.
I 2                                                                   U233
  1.78271E+01  8.54057E+01  2.33202E+02  2.05363E+02  3.45034E+02
  1.21281E+01  7.56455E+01  2.27215E+02  1.93021E+02  3.36017E+02
  2.44780E+01  1.47389E+02  4.91194E+02  4.28131E+02  7.60000E+02
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
I 3                                                                   PU239
  1.41353E+01  9.44861E+01  4.24192E+01  1.65160E+03  8.15896E+02
  7.15697E+00  8.32656E+01  3.06373E+01  1.63685E+03  8.09863E+02
  1.34275E+01  1.33457E+02  5.37102E+01  2.87482E+03  1.61275E+03
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
  0.           0.           0.           0.           0.
************************************ END OF  CRAM  DATA. FOR JOB1  OUTPUT NO  1
```

```
                GYMEA DATA LIST          * 23/12/65 *
                                         --------
ISN          SOURCE STATEMENT

  1          SUBROUTINE PFLUX
  2     *    PRINTS GROUP FLUX
  2     *    NOTE THAT ONLY 3 CHARS OF NAME ARE UNIQUE,PFL..
  2          FORMAT (6HOGFLUX/ (1X1P10E12.3))
  3          WX 551,670,1
  4     *    IE WRITE X(551) TO X(670) IN STEPS OF 1
  4          RETURN
  5          END
  6     *
  6     ********************
  6     *
  6          ,JOB2 CRITICALITY
  7     *    CREATION OF A LIB. OF BE9,O16, AND U235 TO SAVE TIME
  7          CALL STAN
  8          USE 1,70,-1 (A SCAT MATRIX LIB. IS NOT REQD)
  9          CREATE 3 XDXD  100*-2 I.E. SAME STRUCTURE AS MAIN LIBRARY
 10     *    BE9 AND O16 AS LIGHT NUCS AND U235 AS A RESONANCE NUC
 10          MATS BE9,O16,U235''
 11     *    ONLY ABOVE MATS ARE CREATED FOR NON-BURN UP USER
 11          GFLUX=120*1.
 12          FLUX=1.
 13          NO16=1.''
 14     *    THE ABOVE ARE REQD TO MAKE A DEFINED PROBLEM
 14          HEAD   BE9,O16 AND U235 FROM NDXD
 15          T=0,1(GROUP FLUX IS NOT CALC. HOWEVER),0
 16     *
 16          CALL STAN
 17          USE 3,3,2
 18          =GYMEA XDXD NDSC
 19          HEAD   CF TABLE 3-98 ANL 5800(2ND ED.)
 20          'BE9'=1.BE9,0''
 21          'O16'=1.O16,0''
 22     *    'BE9' AND 'O16' ARE NOT REQD AS SUCH FOR THE MIXTURE BEING STUDIED
 22     *    HENCE A DENSITY OF ZERO IS GIVEN
 22     *    NOTE ALSO THAT THE 2 MATERIALS 'BE9' AND 'BEO' SHOULD NOT HAVE
 22     *    THE SAME DOMINANT NUCLIDE,BE9, IF BOTH ARE REQUIRED FOR VOLUME
 22     *    NORMALIZATION USING     CALL NUC
 22          SCAT 300. 'BE9' GAS   'O16' GAS   ''
 23          GB2=120*8.-3
 24          SEARCH GB2 0.01 0.8 100. 1.000 0.001
 25     *    BUCKLING IS TO BE ADJUSTED TO MAKE K=1.000 + OR - 0.001
 25          'BEO'=1.BE9,1.O16,1.+10 ''
 26     *    DENSITY OF 'BEO' IS REQD TO BE EFFECTIVELY INFINITE
 26     *    AS 'U5' IS GIVEN FOR THE MIXTURE
 26          'U5'=1.U235,-1''
 27     *    IE Z(1) CONTAINS DENSITY OF U5 IN MIXTURE (G/CM**3)
 27          Z(1)=0.0140
 28          N(1,100)=0.,'U5'=1.,'BEO'=1920.''
 29          CALL CALC
 30          Z(1)=0.00702
 31          N(1,100)=0.,'U5'=1.,'BEO'=3830.''
 32          CALL CALC
 33          END
 34     *
```

```
34    ********************
34    *
34          SUBROUTINE CALC
35    *     FORCES CALCULATION OF CRITICALITY AND COMPUTES REQD QUANTITIES
35          CALL NUC                          RESCALES NUCLIDE CONC TO UNIT VOL
36          T=0.,20,6 MAX CRIT IT
37          Z(3)=X(1971)*X(1971)
38          Z(3)=Z(3)*X(1971)
39          Z(3)=4.1888*Z(3)                  CRIT VOL
40          Z(4)=Z(3)*Z(1)                    MASS OF U5
41          Z(4)=Z(4)*1.E-3                   KG-U5
42          Z(5)=X(51)/X(53)                  NUCLIDE RATIO
43          WRITE10  RATIO      MASS
44          WRITE1  BEO/U5     KG-U5
45          FORMAT(1H0,F7.0,F10.2)
46          WZS 2 5,4
47    *     IE WRITE 2 Z'S, NAMELY Z(5),Z(4)
47          CALL PFLUX
48    *     PRINT GROUP FLUX
48          RETURN
49          END
50    *
50    ********************
50    *
50          ,JOB3    FIRST BURN UP RUN
51          CALL STAN
52          USE 1,61,2
53    *     NUCLIDES 62-70 ARE NOT REQD.
53          =GYMEA NDXD NDSC
54          'BEO'=1.8E9,1.016,1.8''
55          'PU'=0.76PU239,0.17PU240,0.07PU241,0''
56          'PUO2'=1.'PU',2.016,11.''
57          'THO2'=1.TH232,2.016,9.5''
58          'FP'=0.(23,61),0''
59          Z(0)=1
60    *     AFT.N WEIGHTED X-S REQD.
60          SCAT 900.  'BEO' CRY    ''
61          HEAD   FIRST BURN UP RUN
62          OUTPUT 1 PRINTX
63          MATS 'BEO',TH232,U233,PU239,PU240,PU241,'FP' ''
64          GROUPS 2,1,71,120
65          X(6)=4.9
66          X(9)=4.9
67    *     OUTPUT IS SET TO PRODUCE MICRO X-S
67          N(1,100)=0.,'PUO2'=1.,'THO2'=10.,'BEO'=2000.''
68          CALL NUC
69          PART 0.01,'PUO2','THO2' ''
70    *     200 MICRON PARTICLES OF SEPARATED FUEL ('PUO2','THO2')
70          FIFA PU239,PU241''
71    *     THIS CARD OPENS THE WAY FOR A BURN UP USER AS ITS USE
71    *     DISTINGUISHES HIM FROM A USER ONLY INTERESTED IN T=0.
71          POWER=10. WATTS/CM**3
72    *     IE BURN UP AT STEP-WISE CONSTANT POWER
72          T=0.,20,0
73          DT=100.,20,0,2
74    *     2-GROUP OUTPUT IS NOT PRODUCED AFTER 100 DAYS
74          END
75          CEASE
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GYMEA JOB JOB2 X-SEC LIB. NDXD (120, 70,    0.K) ON 1   * 23/12/65 *          OUTPUT NO.  1      RESONANCE TEMP=     0.K
          ---- SCATT  ''  00000          (    0.K) ''-1     --------  ISN  15                ---
                                        CONSTANT
 T(DAYS)     FLUX-T     POWER-T     FIFA      FLUX      POWER                      T=0,1(GROUP FLUX IS NOT CALC. HOWEVER),0
     0.      0.          0.          0.      1.000E+00  0.         (AFTER )
                                                        0.         (AVERGE)
                                                        0.         (BEFORE)
                                                        0.         (SPEC. )
 (AFT.N)       K           82         82AV     CRIT.R-EXTRAP.D(CM)    A/S
 (EFF. )     0.         -2.253E-03                                  1.0000001E+00       1   1   1    11.
 (INF. )     0.         -2.253E-03-2.253E-03  0.         2.069E-01                  IT-FLUX,EIGEN.XS-OT

                     SCAT BY       0.          NOO     AT ALL

OUTPUT NO.  1  JOB2    BE9,O16 AND U235 FROM NDXD                          AFT.N*SIGMA*FLUX/SOURCE NEUTRON

 T(RANGE)=       0.      -DAYS-       0.
  NUCLIDE      AFT.N      AVE.N      BEF.N      BURN       CAP1       FISS        ABS       NU-FISS      TRANS      CAP2       DECAY
   0 LEAK                                                                    4.438E-13
   1 BE9      0.         0.         0.           0        0.         0.         0.         0.         0.         0.         0.          1
   2 O16      1.000E+00  1.000E+00  0.           0        0.         0.         1.000E+00  0.         1.704E+04  0.         0.          2
  15 U235     0.         0.         0.           0        0.         0.         0.         0.         0.         0.         0.         15
==========
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          ----------GYMEA----------* 23/12/65 *----------GYMEA----------

ISN   6          ,J082 CRITICALITY

LIB.  3    =GYMEA X-S  XCXD  * 23/12/65 * 8E9,016 AND U235 FROM NDXD

LIB.  2    =GYMEA SCAT NCSC  3/12/65 'BE0''BE9''016''H20''C12''C12'300,900,600,1200

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GYMEA JOB JOB2 X-SEC LIB. XDXD (120,  3,    0.K) ON 3    * 23/12/65 *          OUTPUT NO.  1      RESONANCE TEMP=  300.K
          ---- SCATT  ''  NDSC          (  300.K) '' 2     --------  ISN  36          ---
                                      UNIT SCE
 T(DAYS)     FLUX-T      POWER-T      FIFA       FLUX      POWER                    T=0.,20,6 MAX CRIT IT
     0.      0.          0.           0.       1.326E+02  0.          (AFTER )
                                                          0.          (AVERGE)
                                                          0.          (BEFORE)
                                                          0.          (SPEC. )
 (AFT.N)       K           B2          B2AV     CRIT.R-EXTRAP.D(CM)    A/S
 (EFF. )   1.0007      8.459E-06                                      9.9999224E-01       3   3   1    11
 (INF. )   2.0712      6.341E-03  6.341E-03  3.789E+01  1.559E+00                      IT-FLUX,EIGEN.XS-OT

                    SCAT BY       6.889E-02 'BE9'  GAS          6.889E-02 'O16'  GAS

OUTPUT NO.  1  JOB2    CF TABLE 3-98 ANL 5800(2ND ED.)                    AFT.N*SIGMA*FLUX/SOURCE NEUTRON

 T(RANGE)=      0.      -DAYS-       0.
  NUCLIDE     AFT.N      AVE.N      BEF.N      BURN       CAP1       FISS        ABS       NU-FISS      TRANS       CAP2       DECAY
  0 LEAK                                                                     5.168E-01
==========

  RATIO       MASS
 BEO/U5      KG-U5

  1920.       3.19

GFLUX
   5.631E+00   4.501E+00   2.107E+00   2.565E+00   2.237E+00   1.679E+00   2.183E+00   2.180E+00   2.079E+00   2.087E+00
   2.083E+00   1.888E+00   1.869E+00   1.861E+00   1.843E+00   1.828E+00   1.816E+00   1.802E+00   1.789E+00   1.775E+00
   1.761E+00   1.747E+00   1.733E+00   1.720E+00   1.706E+00   1.693E+00   1.679E+00   1.666E+00   1.652E+00   1.638E+00
   1.624E+00   1.610E+00   1.596E+00   1.582E+00   1.568E+00   1.552E+00   1.537E+00   1.522E+00   1.508E+00   1.493E+00
   1.474E+00   1.458E+00   1.444E+00   1.430E+00   1.414E+00   1.396E+00   1.383E+00   1.353E+00   7.974E-01   5.194E-01
   5.198E-01   5.168E-01   5.119E-01   5.128E-01   5.120E-01   5.081E-01   5.097E-01   5.080E-01   5.039E-01   5.036E-01
   5.032E-01   5.020E-01   5.035E-01   5.001E-01   5.023E-01   4.990E-01   5.011E-01   4.984E-01   5.010E-01   4.944E-01
   4.974E-01   4.964E-01   4.987E-01   5.000E-01   5.003E-01   5.029E-01   5.048E-01   5.062E-01   5.107E-01   5.127E-01
   5.172E-01   5.226E-01   5.267E-01   5.358E-01   5.474E-01   5.657E-01   5.903E-01   6.258E-01   6.679E-01   7.196E-01
   7.813E-01   8.462E-01   9.178E-01   9.772E-01   1.040E+00   1.085E+00   1.117E+00   1.132E+00   1.129E+00   1.108E+00
   1.072E+00   1.024E+00   9.616E-01   8.948E-01   8.234E-01   7.463E-01   6.734E-01   6.003E-01   5.293E-01   4.663E-01
   4.058E-01   3.510E-01   3.040E-01   2.594E-01   2.227E-01   6.912E-01   2.868E-01   1.130E-01   4.313E-02   1.622E-02
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 GYMEA JOB JOB2 X-SEC LIB. XDXD (120,  3,    0.K) ON 3    * 23/12/65 *         OUTPUT NO.  2     RESONANCE TEMP=  300.K
          ---- SCATT  '' NDSC          (  300.K) '' 2     --------  ISN  36          ---
                                      UNIT SCE
 T(DAYS)     FLUX-T     POWER-T     FIFA       FLUX      POWER                  T=0.,20,6 MAX CRIT IT
    0.       0.          0.          0.      1.635E+02  0.         (AFTER )
                                                        0.         (AVERGE)
                                                        0.         (BEFORE)
                                                        0.         (SPEC. )
 (AFT.N)       K          B2         B2AV     CRIT.R-EXTRAP.D(CM)    A/S
 (EFF. )    0.9998    -1.753E-06                                    9.9978166E-01       2   4   1   11
 (INF. )    2.0551     5.241E-03 5.241E-03 4.190E+01 1.493E+00                      IT-FLUX,EIGEN.XS-OT

                    SCAT BY      6.891E-02 'BE9'  GAS        6.891E-02 'O16'  GAS

OUTPUT NO.  2  JOB2    CF TABLE 3-98 ANL 5800(2ND ED.)                AFT.N*SIGMA*FLUX/SOURCE NEUTRON

 T(RANGE)=      0.      -DAYS-       0.
  NUCLIDE     AFT.N      AVE.N      BEF.N      BURN       CAP1       FISS        ABS       NU-FISS     TRANS      CAP2       DECAY
  O LEAK                                                                     5.135E-01
==========

  RATIO       MASS
 BEO/U5      KG-U5

  3830.       2.16

GFLUX
   5.766E+00   4.614E+00   2.158E+00   2.630E+00   2.295E+00   1.723E+00   2.242E+00   2.241E+00   2.141E+00   2.152E+00
   2.151E+00   1.952E+00   1.935E+00   1.929E+00   1.913E+00   1.900E+00   1.890E+00   1.879E+00   1.868E+00   1.856E+00
   1.844E+00   1.832E+00   1.821E+00   1.809E+00   1.798E+00   1.786E+00   1.775E+00   1.763E+00   1.752E+00   1.740E+00
   1.729E+00   1.717E+00   1.705E+00   1.694E+00   1.682E+00   1.669E+00   1.657E+00   1.645E+00   1.633E+00   1.621E+00
   1.607E+00   1.594E+00   1.583E+00   1.571E+00   1.559E+00   1.545E+00   1.535E+00   1.511E+00   8.915E-01   5.855E-01
   5.835E-01   5.814E-01   5.787E-01   5.786E-01   5.782E-01   5.749E-01   5.766E-01   5.750E-01   5.720E-01   5.724E-01
   5.718E-01   5.707E-01   5.729E-01   5.694E-01   5.729E-01   5.692E-01   5.721E-01   5.694E-01   5.729E-01   5.710E-01
   5.719E-01   5.716E-01   5.750E-01   5.774E-01   5.786E-01   5.825E-01   5.857E-01   5.885E-01   5.952E-01   5.993E-01
   6.067E-01   6.161E-01   6.253E-01   6.424E-01   6.653E-01   7.007E-01   7.507E-01   8.243E-01   9.183E-01   1.039E+00
   1.187E+00   1.352E+00   1.538E+00   1.711E+00   1.895E+00   2.047E+00   2.173E+00   2.264E+00   2.312E+00   2.319E+00
   2.287E+00   2.222E+00   2.118E+00   1.998E+00   1.862E+00   1.707E+00   1.556E+00   1.400E+00   1.245E+00   1.106E+00
   9.700E-01   8.447E-01   7.364E-01   6.322E-01   5.457E-01   1.717E+00   7.262E-01   2.901E-01   1.119E-01   4.236E-02


                  END OF   JOB2
                 TIME TAKEN IN MINS
  TOTAL        JOB        LINKS 1,2    LINKS 3,4      LINK5        LINK6
8.011E+00   5.677E+00    1.015E+00    6.099E+00    4.297E-01    0.

  BURNUP       FLUX         R-RATES      RUREDY       PAUSE
0.           4.712E+00    3.211E-01    1.697E-01    0.
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          ----------GYMEA----------* 23/12/65 *----------GYMEA----------

ISN  50          ,JOB3    FIRST BURN UP RUN

LIB.  1    =GYMEA X-S  NDXD  * 24/11/65 * MAIN GENERAL PURPOSE LIB. OF 70 NUC.

LIb.  2    =GYMEA SCAT NDSC  3/12/65 'BE0''BE9''016''H20''C12''C12'300,900,600,1200

          ------------------------------------------------------------------
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GYMEA JOB JOB3 X-SEC LIB. NDXD (120, 61, 0.K) ON 1 * 23/12/65 * OUTPUT NO. 1 RESONANCE TEMP= 900.K
---- SCATT '' NDSC (900.K) '' 2 -------- ISN 72 ---

T(DAYS)	FLUX-T	POWER-T	FIFA	FLUX	CONSTANT POWER		
0.	0.	0.	0.	1.778E+14	1.000E+01	(AFTER)	T=0.,20,0
					1.000E+01	(AVERGE)	
					1.000E+01	(BEFORE)	
					1.000E+01	(SPEC.)	

	K	B2	B2AV	CRIT.R-EXTRAP.D(CM)	A/S				
(AFT.N)					9.9998929E-01	4	1	1	11
(EFF.)	1.2099	8.833E-04				IT-FLUX,EIGEN.XS-OT			
(INF.)	1.2099	8.833E-04	8.833E-04	1.032E+02	2.486E+00				

SCAT BY 4.290E-02 'BEO' CRY

OUTPUT NO. 1 JOB3 FIRST BURN UP RUN

SIGMA

T(RANGE)= 0. -DAYS- 0.

	NUCLIDE	AFT.N	AVE.N	BEF.N	BURN	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	DECAY	
0	LEAK							0.					
1	BE9	4.290E-02	4.290E-02	4.290E-02	0	3.219E-03	0.	-4.158E-03	0.	4.533E+00	7.969E-03	0.	1
2	O16	4.337E-02	4.337E-02	4.337E-02	0	0.	0.	7.721E-04	0.	3.231E+00	0.	0.	2
3	C12	0.	0.	0.	0	1.056E-03	0.	1.056E-03	0.	3.723E+00	0.	0.	3
4	H1	0.	0.	0.	0	2.039E-02	0.	2.039E-02	0.	5.110E+00	0.	0.	4
5	D2	0.	0.	0.	0	3.500E-05	0.	-1.260E-03	0.	2.178E+00	1.295E-03	0.	5
6	AL27	0.	0.	0.	0	1.746E-02	0.	1.782E-02	0.	2.214E+00	0.	0.	6
7	LI6	0.	0.	0.	0	5.694E+01	0.	5.694E+01	0.	4.719E+01	0.	0.	7
8	T3	0.	0.	0.	0	0.	0.	0.	0.	1.000E+00	0.	1.009E+01	8
9	HE3	0.	0.	0.	0	3.353E+02	0.	3.353E+02	0.	2.749E+02	0.	0.	9
10	TH232	2.145E-04	2.145E-04	2.145E-04	0	3.276E+00	7.615E-03	3.282E+00	1.736E-02	1.226E+01	1.017E-03	0.	10
11	PA233	0.	0.	0.	0	5.020E+01	6.370E-02	5.027E+01	1.539E-01	5.221E+01	0.	1.647E+03	11
12	U232	0.	0.	0.	0	1.842E+01	0.	2.333E+01	0.	1.913E+01	0.	0.	12
13	U233	0.	0.	0.	0	9.555E+00	6.009E+01	6.965E+01	1.503E+02	6.717E+01	0.	0.	13
14	U234	0.	0.	0.	0	3.603E+01	1.754E-01	3.620E+01	3.950E-01	3.926E+01	0.	0.	14
15	U235	0.	0.	0.	0	1.091E+01	3.196E+01	4.287E+01	7.802E+01	4.564E+01	0.	0.	15
16	U236	0.	0.	0.	0	1.637E+01	6.370E-02	1.644E+01	1.539E-01	2.215E+01	0.	0.	16
17	U238	0.	0.	0.	0	1.358E+01	3.203E-02	1.361E+01	8.518E-02	2.076E+01	0.	0.	17
18	PU239	1.630E-05	1.630E-05	1.630E-05	0	5.840E+01	9.600E+01	1.544E+02	2.784E+02	1.308E+02	0.	0.	18
19	PU240	3.646E-06	3.646E-06	3.646E-06	0	2.322E+02	3.209E-02	2.322E+02	9.408E-02	1.354E+02	0.	0.	19
20	PU241	1.501E-06	1.501E-06	1.501E-06	0	3.738E+01	9.758E+01	1.349E+02	2.986E+02	1.182E+02	0.	9.506E+00	20
21	PU242	0.	0.	0.	0	2.633E+01	0.	2.633E+01	0.	3.342E+01	0.	0.	21
22	ZZ999	0.	0.	0.	0	6.141E-02	0.	6.141E-02	0.	5.034E-02	0.	0.	22
23	MO95	0.	0.	0.	0	6.366E+00	0.	6.366E+00	0.	1.382E+01	0.	0.	23
24	TC99	0.	0.	0.	0	1.081E+01	0.	1.081E+01	0.	1.523E+01	0.	0.	24
25	RU101	0.	0.	0.	0	1.060E+01	0.	1.060E+01	0.	1.716E+01	0.	0.	25
26	RU102	0.	0.	0.	0	8.995E+00	0.	8.995E+00	0.	1.560E+01	0.	0.	26
27	RH103	0.	0.	0.	0	6.818E+01	0.	6.818E+01	0.	5.514E+01	0.	0.	27
28	RU104	0.	0.	0.	0	1.359E+01	0.	1.359E+01	0.	1.961E+01	0.	0.	28
29	RH105	0.	0.	0.	0	3.408E+03	0.	3.408E+03	0.	1.000E+01	0.	3.008E+04	29
30	PD105	0.	0.	0.	0	4.379E+00	0.	4.379E+00	0.	9.014E+00	0.	0.	30
31	PD106	0.	0.	0.	0	1.828E+00	0.	1.828E+00	0.	6.241E+00	0.	0.	31
32	PD107	0.	0.	0.	0	4.001E+00	0.	4.001E+00	0.	8.743E+00	0.	0.	32
33	PD108	0.	0.	0.	0	1.025E+01	0.	1.025E+01	0.	1.495E+01	0.	0.	33
34	AG109	0.	0.	0.	0	7.189E+01	0.	7.189E+01	0.	7.000E+01	0.	0.	34
35	CD113	0.	0.	0.	0	2.384E+03	0.	2.384E+03	0.	1.940E+03	0.	0.	35
36	I131	0.	0.	0.	0	3.507E+01	0.	3.507E+01	0.	3.806E+01	0.	5.606E+03	36
37	XE131	0.	0.	0.	0	4.428E+01	0.	4.428E+01	0.	4.913E+01	0.	0.	37
38	XE133	0.	0.	0.	0	9.168E+01	0.	9.168E+01	0.	9.298E+01	0.	8.561E+03	38
39	CS133	0.	0.	0.	0	1.979E+01	0.	1.979E+01	0.	2.623E+01	0.	0.	39

40	CS134	0.	0.	0.	0	6.197E+01	0.	6.197E+01	0.	6.520E+01	0.	0.	40
41	I135	0.	0.	0.	0	1.467E-02	0.	1.467E-02	0.	1.000E+01	0.	1.617E+05	41
42	XE135	0.	0.	0.	0	1.251E+05	0.	1.251E+05	0.	1.328E+05	0.	1.177E+05	42
43	CS135	0.	0.	0.	0	3.172E+00	0.	3.172E+00	0.	1.533E+01	0.	0.	43
44	ND143	0.	0.	0.	0	1.562E+01	0.	1.562E+01	0.	2.886E+01	0.	0.	44
45	ND144	0.	0.	0.	0	6.589E-01	0.	6.589E-01	0.	1.000E+01	0.	0.	45
46	ND145	0.	0.	0.	0	2.170E+01	0.	2.170E+01	0.	4.625E+01	0.	0.	46
47	ND146	0.	0.	0.	0	1.677E+00	0.	1.677E+00	0.	1.000E+01	0.	0.	47
48	PM147	0.	0.	0.	0	6.197E+01	0.	1.174E+02	0.	1.345E+02	5.553E+01	0.	48
49	PM148	0.	0.	0.	0	1.417E+03	0.	1.417E+03	0.	2.080E+03	0.	8.370E+03	49
50	'PM8M'	0.	0.	0.	0	5.669E+03	0.	5.669E+03	0.	4.869E+03	0.	1.111E+03	50
51	SM149	0.	0.	0.	0	3.310E+03	0.	3.310E+03	0.	2.744E+03	0.	0.	51
52	SM150	0.	0.	0.	0	4.686E+01	0.	4.686E+01	0.	7.520E+01	0.	0.	52
53	SM151	0.	0.	0.	0	3.218E+02	0.	3.218E+02	0.	3.144E+02	0.	0.	53
54	SM152	0.	0.	0.	0	1.146E+02	0.	1.146E+02	0.	1.281E+02	0.	0.	54
55	EU153	0.	0.	0.	0	9.525E+01	0.	9.525E+01	0.	1.047E+02	0.	0.	55
56	EU154	0.	0.	0.	0	4.849E+02	0.	4.849E+02	0.	4.196E+02	0.	7.723E+00	56
57	EU155	0.	0.	0.	0	1.264E+03	0.	1.264E+03	0.	1.043E+03	0.	3.089E+01	57
58	'PS1'	0.	0.	0.	0	1.708E+00	0.	1.708E+00	0.	1.177E+01	0.	0.	58
59	'PS2'	0.	0.	0.	0	7.224E-01	0.	7.224E-01	0.	9.062E+00	0.	0.	59
60	'PS3'	0.	0.	0.	0	2.606E+00	0.	2.606E+00	0.	3.175E+01	0.	1.144E+00	60
61	'PS4'	0.	0.	0.	0	7.461E-02	0.	7.461E-02	0.	9.595E+00	0.	6.711E+00	61
0- 61						0.	0.	0.	0.	0.	0.	0.	

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MATERIAL 'BEO' AFT.N= 4.2898E-02 OUTPUT NO 1, JOB3 ,* 23/12/65 * FIRST BURN UP RUN

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT AS SIGMA	XS-OT= 11
1	0.	16.10	3.6940E-03	0.	-4.4001E-03	0.	7.5955E+00	9.1459E-03	9.0074E+00	
2	16.10	23.00	0.	0.	3.4780E-03	0.	9.1978E+00	0.	9.7957E+00	

MATERIAL TH232 AFT.N= 2.1449E-04 OUTPUT NO 1, JOB3 ,* 23/12/65 * FIRST BURN UP RUN

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT AS SIGMA	XS-OT= 11
1	0.	16.10	3.4327E+00	8.7396E-03	3.4403E+00	1.9921E-02	1.2114E+01	1.1668E-03	0.	
2	16.10	23.00	2.2121E+00	0.	2.2121E+00	0.	1.3464E+01	0.	0.	

MATERIAL U233 AFT.N= 0. OUTPUT NO 1, JOB3 ,* 23/12/65 * FIRST BURN UP RUN

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT AS SIGMA	XS-OT= 11
1	0.	16.10	7.5525E+00	3.9002E+01	4.6555E+01	9.7595E+01	4.7352E+01	0.	0.	
2	16.10	23.00	2.3115E+01	2.0288E+02	2.2597E+02	5.0715E+02	2.3654E+02	0.	0.	

MATERIAL PU239 AFT.N= 1.6301E-05 OUTPUT NO 1, JOB3 ,* 23/12/65 * FIRST BURN UP RUN

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT AS SIGMA	XS-OT= 11
1	0.	16.10	7.8998E+00	1.1226E+01	1.9125E+01	3.2630E+01	2.4824E+01	0.	0.	
2	16.10	23.00	4.0029E+02	6.6991E+02	1.0702E+03	1.9426E+03	1.0363E+03	0.	0.	

MATERIAL PU240 AFT.N= 3.6464E-06 OUTPUT NO 1, JOB3 ,* 23/12/65 * FIRST BURN UP RUN

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT AS SIGMA	XS-OT= 11
1	0.	16.10	2.5009E+02	3.6828E-02	2.5012E+02	1.0797E-01	1.3703E+02	0.	0.	
2	16.10	23.00	1.1112E+02	0.	1.1112E+02	0.	1.2138E+02	0.	0.	

MATERIAL PU241 AFT.N= 1.5014E-06 OUTPUT NO 1, JOB3 ,* 23/12/65 * FIRST BURN UP RUN

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT AS SIGMA	XS-OT= 11
1	0.	16.10	1.0870E+01	3.3247E+01	4.4117E+01	1.0177E+02	4.5534E+01	0.	0.	
2	16.10	23.00	2.1688E+02	5.3313E+02	7.4990E+02	1.6312E+03	7.3875E+02	0.	0.	

MATERIAL 'FP' AFT.N= 1.0000E+00 OUTPUT NO 1, JOB3 ,* 23/12/65 * FIRST BURN UP RUN

GROUP	******	LETH	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	SCATT AS SIGMA	XS-OT= 11
1	0.	16.10	0.	0.	0.	0.	0.	0.	0.	
2	16.10	23.00	0.	0.	0.	0.	0.	0.	0.	

SUMMARY INFORMATION,AFT.N NORMALIZED OUTPUT NO 1, JOB3 ,* 23/12/65 * FIRST BURN UP RUN

GROUP		LETH	ENERGY(EV)		E(AVE.LETH)	FLUX/SOURCE	FISS.SPECT	TOT.LOSS	TOT.NU-FISS	TOT.DB**2
1	0.	16.10	1.0000E+07	1.0183E+00	3.1910E+03	2.1121E+02	1.00000	3.8943E-01	1.4637E-01	2.1276E-13
2	16.10	23.00	1.0183E+00	1.0262E-03	3.2325E-02	3.1197E+01	0.	6.1146E-01	1.0643E+00	2.4900E-14
1 - 2						2.4241E+02	1.00000	1.0009E+00	1.2107E+00	2.3766E-13

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GYMEA JOB JOB3 X-SEC LIB. NDXD (120, 61,    0.K) ON 1   * 23/12/65 *        OUTPUT NO.  2     RESONANCE TEMP=  900.K
          ---- SCATT  '' NDSC          (  900.K) '' 2    --------  ISN  73            ---
                                        CONSTANT
T(DAYS)     FLUX-T     POWER-T    FIFA       FLUX      POWER                    DT=100.,20,0,2
  100.0   1.536E+21  1.006E+03  0.1487    1.778E+14  9.447E+00 (AFTER )
                                          1.006E+01 (AVERGE)
                                          1.000E+01 (BEFORE)
                                          1.000E+01 (SPEC. )
(AFT.N)       K          B2         B2AV     CRIT.R-EXTRAP.D(CM)     A/S
(EFF. )    1.1511     6.324E-04                                  9.9999911E-01       4   1   1    11
(INF. )    1.1511     6.324E-04 7.835E-04 1.224E+02 2.482E+00                    IT-FLUX,EIGEN.XS-DT

                   SCAT BY      4.290E-02 '8E0'  CRY

OUTPUT NO.  2  JOB3   FIRST BURN UP RUN                                                    SIGMA

T(RANGE)=    100.0     -DAYS-        0.0
 NUCLIDE     AFT.N      AVE.N       BEF.N      BURN      CAP1       FISS       ABS        NU-FISS    TRANS      CAP2       DECAY
 0 LEAK                                                                    0.
 1 BE9    4.290E-02 4.290E-02 4.290E-02     0     3.199E-03 0.       -4.104E-03 0.       4.538E+00 7.921E-03 0.          1
 2 O16    4.337E-02 4.337E-02 4.337E-02     0     0.        0.        7.681E-04 0.       3.233E+00 0.        0.          2
 3 C12    0.        0.        0.            0     1.060E-03 0.        1.060E-03 0.       3.727E+00 0.        0.          3
 4 H1     0.        0.        0.            0     2.128E-02 0.        2.128E-02 0.       5.141E+00 0.        0.          4
 5 D2     0.        0.        0.            0     3.654E-05 0.       -1.251E-03 0.       2.180E+00 1.287E-03 0.          5
 6 AL27   0.        0.        0.            0     1.808E-02 0.        1.844E-02 0.       2.211E+00 0.        0.          6
 7 LI6    2.031E-07 1.030E-07 0.            0     5.943E+01 0.        5.943E+01 0.       4.931E+01 0.        0.          7
 8 T3     8.808E-09 3.252E-09 0.            0     0.        0.        0.        0.       1.000E+00 0.        1.009E+01   8
 9 HE3    4.002E-11 7.221E-12 0.            0     3.500E+02 0.        3.500E+02 0.       2.874E+02 0.        0.          9
10 TH232  2.134E-04 2.140E-04 2.145E-04     0     3.279E+00 7.570E-03 3.285E+00 1.725E-02 1.226E+01 1.011E-03 0.          10
11 PA233  3.821E-07 2.664E-07 0.            0     5.055E+01 6.332E-02 5.062E+01 1.529E-01 5.261E+01 0.        1.647E+03   11
12 U232   3.282E-10 1.652E-10 0.            0     1.923E+01 0.        2.436E+01 0.       2.000E+01 0.        0.          12
13 U233   6.464E-07 2.566E-07 0.            0     9.668E+00 6.113E+01 7.079E+01 1.529E+02 6.820E+01 0.        0.          13
14 U234   2.381E-08 8.968E-09 0.            0     3.575E+01 1.743E-01 3.593E+01 3.926E-01 3.904E+01 0.        0.          14
15 U235   4.879E-10 1.314E-10 0.            0     1.118E+01 3.348E+01 4.466E+01 8.173E+01 4.717E+01 0.        0.          15
16 U236   2.046E-12 1.251E-12 0.            0     1.618E+01 6.332E-02 1.625E+01 1.529E-01 2.201E+01 0.        0.          16
17 U238   0.        0.        0.            0     1.349E+01 3.184E-02 1.352E+01 8.468E-02 2.069E+01 0.        0.          17
18 PU239  1.286E-05 1.451E-05 1.630E-05     0     6.312E+01 1.036E+02 1.667E+02 3.005E+02 1.419E+02 0.        0.          18
19 PU240  3.640E-06 3.668E-06 3.646E-06     0     2.275E+02 3.190E-02 2.276E+02 9.352E-02 1.334E+02 0.        0.          19
20 PU241  2.376E-06 1.955E-06 1.501E-06     0     3.976E+01 1.033E+02 1.430E+02 3.160E+02 1.252E+02 0.        9.506E+00   20
21 PU242  1.102E-07 5.128E-08 0.            0     2.586E+01 0.        2.586E+01 0.       3.301E+01 0.        0.          21
22 ZZ999  0.        0.        0.            0     6.411E-02 0.        6.411E-02 0.       5.264E-02 0.        0.          22
23 MO95   1.196E-07 6.123E-08 0.            0     6.374E+00 0.        6.374E+00 0.       1.382E+01 0.        0.          23
24 TC99   1.486E-07 7.616E-08 0.            0     1.074E+01 0.        1.074E+01 0.       1.517E+01 0.        0.          24
25 RU101  1.445E-07 7.408E-08 0.            0     1.054E+01 0.        1.054E+01 0.       1.712E+01 0.        0.          25
26 RU102  1.454E-07 7.438E-08 0.            0     8.936E+00 0.        8.936E+00 0.       1.555E+01 0.        0.          26
27 RH103  1.322E-07 6.870E-08 0.            0     6.708E+01 0.        6.708E+01 0.       5.373E+01 0.        0.          27
28 RU104  1.425E-07 7.330E-08 0.            0     1.351E+01 0.        1.351E+01 0.       1.953E+01 0.        0.          28
29 RH105  2.498E-09 2.602E-09 0.            0     3.400E+03 0.        3.400E+03 0.       1.000E+01 0.        3.008E+04   29
30 PD105  1.198E-07 6.003E-08 0.            0     4.386E+00 0.        4.386E+00 0.       9.014E+00 0.        0.          30
31 PD106  1.263E-07 6.441E-08 0.            0     1.835E+00 0.        1.835E+00 0.       6.243E+00 0.        0.          31
32 PD107  9.160E-08 4.679E-08 0.            0     4.006E+00 0.        4.006E+00 0.       8.744E+00 0.        0.          32
33 PD108  6.712E-08 3.426E-08 0.            0     1.021E+01 0.        1.021E+01 0.       1.491E+01 0.        0.          33
34 AG109  4.050E-08 2.085E-08 0.            0     7.111E+01 0.        7.111E+01 0.       6.929E+01 0.        0.          34
35 CD113  7.237E-10 5.327E-10 0.            0     2.592E+03 0.        2.592E+03 0.       2.117E+03 0.        0.          35
36 I131   1.010E-08 9.466E-09 0.            0     3.480E+01 0.        3.480E+01 0.       3.783E+01 0.        5.606E+03   36
37 XE131  7.901E-08 3.664E-08 0.            0     4.434E+01 0.        4.434E+01 0.       4.923E+01 0.        0.          37
38 XE133  1.182E-08 1.164E-08 0.            0     9.091E+01 0.        9.091E+01 0.       9.231E+01 0.        8.561E+03   38
39 CS133  1.509E-07 7.214E-08 0.            0     1.961E+01 0.        1.961E+01 0.       2.607E+01 0.        0.          39
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40	CS134	2.128E-09	6.783E-10	0.	0	6.179E+01	0.	6.179E+01	0.	6.508E+01	0.	0.		40
41	I135	6.477E-10	6.904E-10	0.	0	1.503E-02	0.	1.503E-02	0.	1.000E+01	0.	1.617E+05		41
42	XE135	4.483E-10	4.765E-10	0.	0	1.346E+05	0.	1.346E+05	0.	1.429E+05	0.	1.177E+05		42
43	CS135	8.602E-08	4.376E-08	0.	0	3.177E+00	0.	3.177E+00	0.	1.533E+01	0.	0.		43
44	ND143	1.149E-07	5.869E-08	0.	0	1.654E+01	0.	1.654E+01	0.	2.982E+01	0.	0.		44
45	ND144	9.788E-08	4.954E-08	0.	0	6.698E-01	0.	6.698E-01	0.	1.000E+01	0.	0.		45
46	ND145	7.649E-08	3.917E-08	0.	0	2.169E+01	0.	2.169E+01	0.	4.616E+01	0.	0.		46
47	ND146	6.570E-08	3.330E-08	0.	0	1.697E+00	0.	1.697E+00	0.	1.000E+01	0.	0.		47
48	PM147	4.647E-08	2.444E-08	0.	0	6.155E+01	0.	1.166E+02	0.	1.337E+02	5.524E+01	0.		48
49	PM148	2.772E-10	1.363E-10	0.	0	1.399E+03	0.	1.399E+03	0.	2.057E+03	0.	8.370E+03		49
50	'PM8M'	3.485E-10	1.667E-10	0.	0	5.994E+03	0.	5.994E+03	0.	5.146E+03	0.	1.111E+03		50
51	SM149	6.547E-09	5.340E-09	0.	0	3.542E+03	0.	3.542E+03	0.	2.932E+03	0.	0.		51
52	SM150	2.634E-08	1.133E-08	0.	0	4.659E+01	0.	4.659E+01	0.	7.487E+01	0.	0.		52
53	SM151	1.533E-08	8.390E-09	0.	0	3.376E+02	0.	3.376E+02	0.	3.266E+02	0.	0.		53
54	SM152	1.650E-08	8.074E-09	0.	0	1.152E+02	0.	1.152E+02	0.	1.286E+02	0.	0.		54
55	EU153	8.676E-09	4.309E-09	0.	0	9.567E+01	0.	9.567E+01	0.	1.050E+02	0.	0.		55
56	EU154	4.985E-10	1.720E-10	0.	0	4.883E+02	0.	4.883E+02	0.	4.233E+02	0.	7.723E+00		56
57	EU155	1.652E-09	1.103E-09	0.	0	1.361E+03	0.	1.361E+03	0.	1.123E+03	0.	3.089E+01		57
58	'PS1'	2.916E-07	1.487E-07	0.	0	1.743E+00	0.	1.74 E+00	0.	1.178E+01	0.	0.		58
59	'PS2'	6.715E-07	3.432E-07	0.	0	7.202E-01	0.	7.202E-01	0.	9.056E+00	0.	0.		59
60	'PS3'	2.173E-07	1.109E-07	0.	0	2.621E+00	0.	2.621E+00	0.	3.165E+01	0.	1.144E+00		60
61	'PS4'	1.569E-06	8.018E-07	0.	0	7.580E-02	0.	7.580E-02	0.	9.599E+00	0.	6.711E+00		61
0-	61					0.	0.	0.	0.	0.	0.	0.		

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GYMEA JOB JOB3 X-SEC LIB. NDXD (120, 61,    0.K) ON 1   * 23/12/65 *        OUTPUT NO.  3     RESONANCE TEMP=  900.K
          ---- SCATT  '' NDSC         (  900.K) '' 2     --------  ISN  73              ---
                                                CONSTANT
T(DAYS)    FLUX-T    POWER-T    FIFA      FLUX      POWER                    DT=100.,20,0,2
  200.0  3.162E+21 2.051E+03  0.3033  1.882E+14 9.794E+00 (AFTER )
                                                1.045E+01 (AVERGE)
                                                1.000E+01 (BEFORE)
                                                1.000E+01 (SPEC. )
(AFT.N)      K          B2        B2AV     CRIT.R-EXTRAP.D(CM)    A/S
(EFF. )   1.1425    5.896E-04                                  9.9999839E-01      4   1   1    11
(INF. )   1.1425    5.896E-04 7.497E-04 1.269E+02 2.473E+00                  IT-FLUX,EIGEN.XS-DT

                  SCAT BY      4.290E-02 'BEO'  CRY

OUTPUT NO.  3  JOB3    FIRST BURN UP RUN                                                    SIGMA

T(RANGE)=   200.0     -DAYS-      100.0
 NUCLIDE     AFT.N      AVE.N      BEF.N      BURN      CAP1       FISS       ABS        NU-FISS    TRANS      CAP2       DECAY
 0 LEAK                                                                  0.
 1 BE9     4.290E-02 4.290E-02 4.290E-02      0     3.156E-03  0.       -3.984E-03  0.       4.550E+00 7.813E-03  0.          1
 2 O16     4.337E-02 4.337E-02 4.337E-02      0     0.         0.        7.587E-04  0.       3.238E+00 0.         0.          2
 3 C12     0.        0.        0.             0     1.070E-03  0.        1.070E-03  0.       3.736E+00 0.         0.          3
 4 H1      0.        0.        0.             0     2.324E-02  0.        2.324E-02  0.       5.212E+00 0.         0.          4
 5 D2      0.        0.        0.             0     3.990E-05  0.       -1.230E-03  0.       2.185E+00 1.270E-03  0.          5
 6 AL27    0.        0.        0.             0     1.942E-02  0.        1.978E-02  0.       2.203E+00 0.         0.          6
 7 LI6     3.971E-07 3.016E-07 2.031E-07      0     6.488E+01  0.        6.488E+01  0.       5.399E+01 0.         0.          7
 8 T3      3.789E-08 2.175E-08 8.808E-09      0     0.         0.        0.         0.       1.000E+00 0.         9.528E+00   8
 9 HE3     2.947E-10 1.391E-10 4.002E-11      0     3.822E+02  0.        3.822E+02  0.       3.151E+02 0.         0.          9
10 TH232   2.123E-04 2.128E-04 2.134E-04      0     3.282E+00  7.466E-03 3.288E+00  1.702E-02 1.228E+01 9.967E-04  0.         10
11 PA233   4.302E-07 4.160E-07 3.821E-07      0     5.134E+01  6.245E-02 5.140E+01  1.508E-01 5.345E+01 0.         1.556E+03   11
12 U232    6.583E-10 4.945E-10 3.282E-10      0     2.100E+01  0.        2.660E+01  0.       2.193E+01 0.         0.          12
13 U233    1.571E-06 1.109E-06 6.464E-07      0     9.931E+00  6.370E+01 7.363E+01  1.593E+02 7.073E+01 0.         0.          13
14 U234    7.269E-08 4.697E-08 2.381E-08      0     3.555E+01  1.720E-01 3.573E+01  3.872E-01 3.893E+01 0.         0.          14
15 U235    3.104E-09 1.574E-09 4.879E-10      0     1.173E+01  3.670E+01 4.843E+01  8.957E+01 5.048E+01 0.         0.          15
16 U236    3.030E-11 1.285E-11 2.046E-12      0     1.592E+01  6.245E-02 1.598E+01  1.508E-01 2.184E+01 0.         0.          16
17 U238    0.        0.        0.             0     1.330E+01  3.141E-02 1.333E+01  8.352E-02 2.055E+01 0.         0.          17
18 PU239   9.806E-06 1.126E-05 1.286E-05      0     7.071E+01  1.164E+02 1.871E+02  3.375E+02 1.600E+02 0.         0.          18
19 PU240   3.472E-06 3.577E-06 3.640E-06      0     2.277E+02  3.146E-02 2.278E+02  9.223E-02 1.360E+02 0.         0.          19
20 PU241   3.027E-06 2.720E-06 2.376E-06      0     4.409E+01  1.138E+02 1.579E+02  3.482E+02 1.381E+02 0.         8.980E+00   20
21 PU242   2.780E-07 1.912E-07 1.102E-07      0     2.532E+01  0.        2.532E+01  0.       3.254E+01 0.         0.          21
22 ZZ999   0.        0.        0.             0     7.000E-02  0.        7.000E-02  0.       5.771E-02 0.         0.          22
23 MO95    2.376E-07 1.800E-07 1.196E-07      0     6.385E+00  0.        6.385E+00  0.       1.383E+01 0.         0.          23
24 TC99    2.943E-07 2.234E-07 1.486E-07      0     1.069E+01  0.        1.069E+01  0.       1.512E+01 0.         0.          24
25 RU101   2.852E-07 2.168E-07 1.445E-07      0     1.042E+01  0.        1.042E+01  0.       1.703E+01 0.         0.          25
26 RU102   2.891E-07 2.190E-07 1.454E-07      0     8.816E+00  0.        8.816E+00  0.       1.544E+01 0.         0.          26
27 RH103   2.506E-07 1.940E-07 1.322E-07      0     6.649E+01  0.        6.649E+01  0.       5.231E+01 0.         0.          27
28 RU104   2.783E-07 2.126E-07 1.425E-07      0     1.333E+01  0.        1.333E+01  0.       1.938E+01 0.         0.          28
29 RH105   2.465E-09 2.631E-09 2.498E-09      0     3.436E+03  0.        3.436E+03  0.       1.000E+01 0.         2.842E+04   29
30 PD105   2.401E-07 1.813E-07 1.198E-07      0     4.395E+00  0.        4.395E+00  0.       9.010E+00 0.         0.          30
31 PD106   2.523E-07 1.908E-07 1.263E-07      0     1.850E+00  0.        1.850E+00  0.       6.246E+00 0.         0.          31
32 PD107   1.825E-07 1.382E-07 9.160E-08      0     4.017E+00  0.        4.017E+00  0.       8.746E+00 0.         0.          32
33 PD108   1.340E-07 1.014E-07 6.712E-08      0     1.014E+01  0.        1.014E+01  0.       1.483E+01 0.         0.          33
34 AG109   7.882E-08 6.032E-08 4.050E-08      0     7.017E+01  0.        7.017E+01  0.       6.851E+01 0.         0.          34
35 CD113   7.592E-10 7.453E-10 7.237E-10      0     2.992E+03  0.        2.992E+03  0.       2.462E+03 0.         0.          35
36 I131    1.002E-08 1.057E-08 1.010E-08      0     3.448E+01  0.        3.448E+01  0.       3.757E+01 0.         5.296E+03   36
37 XE131   1.613E-07 1.212E-07 7.901E-08      0     4.451E+01  0.        4.451E+01  0.       4.950E+01 0.         0.          37
38 XE133   1.165E-08 1.239E-08 1.182E-08      0     9.031E+01  0.        9.031E+01  0.       9.188E+01 0.         8.087E+03   38
39 CS133   3.066E-07 2.305E-07 1.509E-07      0     1.942E+01  0.        1.942E+01  0.       2.589E+01 0.         0.          39
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40	CS134	8.958E-09	5.185E-09	2.128E-09	0	6.166E+01	0.	6.166E+01	0.	6.503E+01	0.	0.		40
41	I135	6.386E-10	6.850E-10	6.477E-10	0	1.581E-02	0.	1.581E-02	0.	1.000E+01	0.	1.527E+05		41
42	XE135	4.123E-10	4.423E-10	4.483E-10	0	1.570E+05	0.	1.570E+05	0.	1.675E+05	0.	1.112E+05		42
43	CS135	1.658E-07	1.268E-07	8.602E-08	0	3.189E+00	0.	3.189E+00	0.	1.532E+01	0.	0.		43
44	ND143	2.300E-07	1.737E-07	1.149E-07	0	1.850E+01	0.	1.850E+01	0.	3.189E+01	0.	0.		44
45	ND144	2.017E-07	1.504E-07	9.788E-08	0	6.934E-01	0.	6.934E-01	0.	1.000E+01	0.	0.		45
46	ND145	1.518E-07	1.151E-07	7.649E-08	0	2.176E+01	0.	2.176E+01	0.	4.603E+01	0.	0.		46
47	ND146	1.346E-07	1.006E-07	6.570E-08	0	1.740E+00	0.	1.740E+00	0.	1.000E+01	0.	0.		47
48	PM147	8.522E-08	6.696E-08	4.647E-08	0	6.112E+01	0.	1.158E+02	0.	1.328E+02	5.493E+01	0.		48
49	PM148	5.492E-10	4.249E-10	2.772E-10	0	1.376E+03	0.	1.376E+03	0.	2.029E+03	0.	7.907E+03		49
50	'PM8M'	6.454E-10	4.992E-10	3.485E-10	0	6.645E+03	0.	6.645E+03	0.	5.711E+03	0.	1.050E+03		50
51	SM149	6.401E-09	6.490E-09	6.547E-09	0	4.096E+03	0.	4.096E+03	0.	3.405E+03	0.	0.		51
52	SM150	6.041E-08	4.367E-08	2.634E-08	0	4.636E+01	0.	4.636E+01	0.	7.457E+01	0.	0.		52
53	SM151	2.510E-08	2.072E-08	1.533E-08	0	3.773E+02	0.	3.773E+02	0.	3.589E+02	0.	0.		53
54	SM152	3.595E-08	2.629E-08	1.650E-08	0	1.156E+02	0.	1.156E+02	0.	1.290E+02	0.	0.		54
55	EU153	1.894E-08	1.378E-08	8.676E-09	0	9.704E+01	0.	9.704E+01	0.	1.062E+02	0.	0.		55
56	EU154	1.764E-09	1.091E-09	4.985E-10	0	4.985E+02	0.	4.985E+02	0.	4.332E+02	0.	7.296E+00		56
57	EU155	1.926E-09	1.813E-09	1.652E-09	0	1.567E+03	0.	1.567E+03	0.	1.299E+03	0.	2.918E+01		57
58	'PS1'	5.863E-07	4.418E-07	2.916E-07	0	1.817E+00	0.	1.817E+00	0.	1.181E+01	0.	0.		58
59	'PS2'	1.341E-06	1.014E-06	6.715E-07	0	7.151E-01	0.	7.151E-01	0.	9.042E+00	0.	0.		59
60	'PS3'	4.382E-07	3.297E-07	2.173E-07	0	2.661E+00	0.	2.661E+00	0.	3.142E+01	0.	1.080E+00		60
61	'PS4'	3.141E-06	2.371E-06	1.569E-06	0	7.843E-02	0.	7.843E-02	0.	9.607E+00	0.	6.340E+00		61
0-	61					0.	0.	0.	0.	0.	0.	0.		

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MATERIAL  'BEO'    AFT.N= 4.2899E-02   OUTPUT NO  3, JOB3 ,* 23/12/65 * FIRST BURN UP RUN
  GROUP   ******   LETH    CAP1        FISS        ABS          NU-FISS      TRANS        CAP2         SCATT    XS-OT= 11
                                                                                                    AS SIGMA
    1       0.     16.10   3.7022E-03  0.          -4.4123E-03  0.           7.5924E+00   9.1661E-03   9.0056E+00
    2      16.10   23.00   0.          0.           3.6290E-03  0.           9.2003E+00   0.           9.7987E+00
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MATERIAL  TH232    AFT.N= 2.1228E-04   OUTPUT NO  3, JOB3 ,* 23/12/65 * FIRST BURN UP RUN
  GROUP   ******   LETH    CAP1        FISS        ABS          NU-FISS      TRANS        CAP2         SCATT    XS-OT= 11
                                                                                                    AS SIGMA
    1       0.     16.10   3.4445E+00  8.7590E-03  3.4521E+00   1.9966E-02   1.2117E+01   1.1693E-03   0.
    2      16.10   23.00   2.3423E+00  0.          2.3423E+00   0.           1.3464E+01   0.           0.
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-------------------------
MATERIAL  U233     AFT.N= 1.5712E-06   OUTPUT NO  3, JOB3 ,* 23/12/65 * FIRST BURN UP RUN
  GROUP   ******   LETH    CAP1        FISS        ABS          NU-FISS      TRANS        CAP2         SCATT    XS-OT= 11
                                                                                                    AS SIGMA
    1       0.     16.10   7.4901E+00  3.8434E+01  4.5924E+01   9.6174E+01   4.6781E+01   0.           0.
    2      16.10   23.00   2.4026E+01  2.0955E+02  2.3356E+02   5.2383E+02   2.4405E+02   0.           0.
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-------------------------
MATERIAL  PU239    AFT.N= 9.8061E-06   OUTPUT NO  3, JOB3 ,* 23/12/65 * FIRST BURN UP RUN
  GROUP   ******   LETH    CAP1        FISS        ABS          NU-FISS      TRANS        CAP2         SCATT    XS-OT= 11
                                                                                                    AS SIGMA
    1       0.     16.10   7.9583E+00  1.1269E+01  1.9227E+01   3.2755E+01   2.4926E+01   0.           0.
    2      16.10   23.00   4.3298E+02  7.2307E+02  1.1560E+03   2.0967E+03   1.1376E+03   0.           0.
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-------------------------
MATERIAL  PU240    AFT.N= 3.4721E-06   OUTPUT NO  3, JOB3 ,* 23/12/65 * FIRST BURN UP RUN
  GROUP   ******   LETH    CAP1        FISS        ABS          NU-FISS      TRANS        CAP2         SCATT    XS-OT= 11
                                                                                                    AS SIGMA
    1       0.     16.10   2.4802E+02  3.6910E-02  2.4806E+02   1.0821E-01   1.3810E+02   0.           0.
    2      16.10   23.00   1.1055E+02  0.          1.1055E+02   0.           1.2044E+02   0.           0.
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-------------------------
MATERIAL  PU241    AFT.N= 3.0270E-06   OUTPUT NO  3, JOB3 ,* 23/12/65 * FIRST BURN UP RUN
  GROUP   ******   LETH    CAP1        FISS        ABS          NU-FISS      TRANS        CAP2         SCATT    XS-OT= 11
                                                                                                    AS SIGMA
    1       0.     16.10   1.0828E+01  3.3077E+01  4.3906E+01   1.0125E+02   4.5293E+01   0.           0.
    2      16.10   23.00   2.3614E+02  5.7980E+02  8.1582E+02   1.7740E+03   8.0993E+02   0.           0.
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-------------------------
MATERIAL  'FP'     AFT.N= 1.0000E+00   OUTPUT NO  3, JOB3 ,* 23/12/65 * FIRST BURN UP RUN
  GROUP   ******   LETH    CAP1        FISS        ABS          NU-FISS      TRANS        CAP2         SCATT    XS-OT= 11
                                                                                                    AS SIGMA
    1       0.     16.10   8.9311E-05  0.          9.4205E-05   0.           1.7982E-04   4.9240E-06   0.
    2      16.10   23.00   8.4425E-04  0.          8.4753E-04   0.           1.0196E-03   3.2784E-06   0.
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SUMMARY INFORMATION,AFT.N NORMALIZED  OUTPUT NO  3, JOB3 ,* 23/12/65 * FIRST BURN UP RUN
  GROUP          LETH       ENERGY(EV)        E(AVE.LETH) FLUX/SOURCE  FISS.SPECT   TOT.LOSS     TOT.NU-FISS   TOT.D8**2
    1       0.   16.10   1.0000E+07  1.0183E+00  3.1910E+03  2.1088E+02 1.00000     4.0746E-01   1.6622E-01   2.1241E-13
    2      16.10 23.00   1.0183E+00  1.0262E-03  3.2325E-02  3.6527E+01 0.          5.9395E-01   9.7729E-01   2.9347E-14
    1 -  2                                                   2.4740E+02 1.00000     1.0014E+00   1.1435E+00   2.4176E-13
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END OF J083
TIME TAKEN IN MINS

TOTAL	JOB	LINKS 1,2	LINKS 3,4	LINK5	LINK6
1.927E+01	1.125E+01	1.158E+00	1.664E+01	6.239E-01	0.

BURNUP	FLUX	R-RATES	RUREDY	PAUSE
2.719E-01	8.844E+00	5.743E+00	2.025E-01	0.

NEW LOAD CALLED

GYMEA DATA LIST * 23/12/65 *

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ISN       SOURCE STATEMENT

  6       ,JOB4 EQUILIBRIUM SEARCH
  7       USE 1,61,2
  8       =GYMEA NDXD NDSC
  9       'BEO'=1.BE9,1.016,0''
 10       '016'=-1 016,-2 016, 0 ''
 11   *   '016'= 016 ASSOCIATED WITH HEAVY NUCLIDES
 11   *        = Z(1)+Z(2) (=1 LATER) PROPORTION OF 016 FOR CROSS SECTIONS
 11   *   CONCENTRATION OF '016' HOWEVER = CONCENTRATION OF 016/Z(1)
 11   *   AND THIS WEIGHTS SCATTERING MATRIX OF '016'
 11   *   Z(1) AND Z(2) ARE DEFINED LATER
 11       SCAT 900. 'BEO' CRY   '016' GAS   ''
 12       ITERATE 9,0.1 (WATTS/CM**3)
 13   *   THE MAX. NO. OF (OUTER) ITERATIONS IS SET AND REQD POWER ACCURACY
 13   *   OUTER REFERS TO SPECTRUM DET. FROM EQU. GUESS
 13       SEARCH NOO .1 .9 10. 1.4 FIFA ACCURATE TO 0.005
 14   *   INNER ITERATION-ADJUSTMENT OF TIME OF BURN UP
 14   *   TO ACHIEVE A SPECIFIED FIFA
 14       HEAD   EQUILIBRIUM SEARCH
 15       N(1,100)=0.,BE9=4.-2,016=4.046-2,TH232=2.-4,PU239=2.34-5,
 16   1   PU240=5.1-6,PU241=1.5-6''
 17   *   NOTE CONTINUATION CARD ABOVE(A NON-DESCENDING INTEGER IN COL 1)
 17       Z(1)=X(52)-X(51)                    EXCESS 016
 18       Z(1)=X(52)/Z(1)                     INVERSE FRACTION OF 016
 19       Z(2)=1.-Z(1)
 20       FIFA PU239,PU241''
 21   *   AFT.N ARRAY IS ALSO TRANSFERRED TO BEF.N
 21   *   AND THIS MAT IS BURNT FOR THIS MODE OF OPERATION
 21       N(3,100)=0.,TH232=1.9-4,U233=4.3-6,PU239=2.8-6,PU240=2.-6,
 22   1   PU241=2.2-6''
 23   *   THIS SET IS AN EQU. GUESS AND DETS FIRST SPECTRUM
 23       POWER=11.
 24       CALL EQU
 25   *   A FINAL SPECTRUM DET MUST BE FORCED IF MULTIGROUP OUTPUT
 25   *   IS REQD-USE T=0.,20,0,SAY
 25       CALL PFLUX
 26       UNLOAD 1
 27       UNLOAD 2
 28       TYPE   TAPES UNLOADED
 29       END
 30       CEASE
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          ----------GYMEA----------* 23/12/65 *----------GYMEA----------

ISN   6          ,JOB4 EQUILIBRIUM SEARCH

LIB.  1    =GYMEA X-S  NDXD  * 24/11/65 * MAIN GENERAL PURPOSE LIB. OF 70 NUC.

LIB.  2    =GYMEA SCAT NDSC  3/12/65 'BE0''BE9''O16''H2O''C12''C12'300,900,600,1200

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GYMEA JOB JOB4 X-SEC LIB. NDXD (120, 61, 0.K) ON 1 * 23/12/65 * OUTPUT NO. 1 RESONANCE TEMP= 900.K
---- SCATT '' NDSC (900.K) '' 2 -------- ISN 24 ---

T(DAYS)	FLUX-T	POWER-T	CONSTANT FIFA	FLUX	POWER	
1184.2	2.787E+22	1.311E+04	1.3999	2.723E+14	4.747E+00	(AFTER)
					1.107E+01	(AVERGE)
					4.107E+01	(BEFORE)
					1.100E+01	(SPEC.)

CALL EQU

	K	B2	B2AV	CRIT.R-EXTRAP.D(CM)		A/S
(AVE.N)						0.
(EFF.)	1.0145	4.918E-05				
(INF.)	1.0145	4.918E-05	4.918E-05	4.454E+02	2.597E+00	

0 3 5 11
IT-FLUX,EIGEN.XS-OT

SCAT BY 0. NDO AT ALL

OUTPUT NO. 1 JOB4 EQUILIBRIUM SEARCH

AVE.N*SIGMA*FLUX/SOURCE NEUTRON

T(RANGE)= 1184.2 -DAYS- 0.0

	NUCLIDE	AFT.N	AVE.N	BEF.N	BURN	CAP1	FISS	ABS	NU-FISS	TRANS	CAP2	DECAY	
0	LEAK							2.957E-13					
1	BE9	4.000E-02	4.000E-02	4.000E-02	0	3.329E-02	0.	-3.775E-02	0.	5.280E+01	8.243E-02	0.	1
2	O16	4.046E-02	4.046E-02	4.046E-02	0	0.	0.	8.179E-03	0.	3.778E+01	0.	0.	2
3	C12	0.	0.	0.	0	0.	0.	0.	0.	0.	0.	0.	3
4	H1	0.	0.	0.	0	0.	0.	0.	0.	0.	0.	0.	4
5	D2	0.	0.	0.	0	0.	0.	-0.	0.	0.	0.	0.	5
6	AL27	0.	0.	0.	0	0.	0.	0.	0.	0.	0.	0.	6
7	LI6	1.126E-06	7.890E-07	0.	0	2.174E-02	0.	2.174E-02	0.	1.838E-02	0.	0.	7
8	T3	2.096E-06	8.249E-07	0.	0	0.	0.	0.	0.	2.358E-04	0.	1.552E-03	8
9	HE3	2.214E-08	8.160E-09	0.	0	1.325E-03	0.	1.325E-03	0.	1.114E-03	0.	0.	9
10	TH232	1.815E-04	1.906E-04	2.000E-04	0	1.894E-01	3.752E-04	1.898E-01	8.552E-04	6.830E-01	5.010E-05	0.	10
11	PA233	5.600E-07	5.685E-07	0.	0	8.956E-03	9.360E-06	8.966E-03	2.261E-05	9.335E-03	0.	1.747E-01	11
12	U232	2.934E-09	1.770E-09	0.	0	1.580E-05	0.	2.001E-05	0.	1.682E-05	0.	0.	12
13	U233	6.273E-06	4.282E-06	0.	0	1.401E-02	9.638E-02	1.104E-01	2.410E-01	1.049E-01	0.	0.	13
14	U234	1.526E-06	7.278E-07	0.	0	7.272E-03	3.299E-05	7.305E-03	7.429E-05	8.022E-03	0.	0.	14
15	U235	4.191E-07	1.484E-07	0.	0	6.310E-04	2.342E-03	2.973E-03	5.717E-03	2.962E-03	0.	0.	15
16	U236	5.569E-08	1.437E-08	0.	0	5.947E-05	2.366E-07	5.971E-05	5.714E-07	8.544E-05	0.	0.	16
17	U238	0.	0.	0.	0	0.	0.	0.	0.	0.	0.	0.	17
18	PU239	6.097E-09	2.835E-06	2.340E-05	0	9.002E-02	1.500E-01	2.400E-01	4.349E-01	2.095E-01	0.	0.	18
19	PU240	4.189E-08	1.972E-06	5.100E-06	0	1.419E-01	1.636E-05	1.419E-01	4.795E-05	9.613E-02	0.	0.	19
20	PU241	2.003E-07	2.196E-06	1.500E-06	0	4.289E-02	1.085E-01	1.513E-01	3.319E-01	1.331E-01	0.	3.895E-03	20
21	PU242	2.774E-06	2.250E-06	0.	0	1.443E-02	0.	1.443E-02	0.	1.918E-02	0.	0.	21
22	ZZ999	0.	0.	0.	0	0.	0.	0.	0.	0.	0.	0.	22
23	MO95	1.550E-06	1.072E-06	0.	0	1.966E-03	0.	1.966E-03	0.	4.238E-03	0.	0.	23
24	TC99	1.663E-06	1.254E-06	0.	0	3.782E-03	0.	3.782E-03	0.	5.366E-03	0.	0.	24
25	RU101	1.503E-06	1.184E-06	0.	0	3.288E-03	0.	3.288E-03	0.	5.566E-03	0.	0.	25
26	RU102	1.773E-06	1.301E-06	0.	0	3.002E-03	0.	3.002E-03	0.	5.489E-03	0.	0.	26
27	RH103	6.257E-07	7.190E-07	0.	0	1.332E-02	0.	1.332E-02	0.	9.372E-03	0.	0.	27
28	RU104	1.227E-06	1.061E-06	0.	0	3.731E-03	0.	3.731E-03	0.	5.597E-03	0.	0.	28
29	RH105	8.462E-10	2.810E-09	0.	0	2.969E-03	0.	2.969E-03	0.	8.034E-06	0.	1.578E-02	29
30	PD105	1.410E-06	1.034E-06	0.	0	1.310E-03	0.	1.310E-03	0.	2.650E-03	0.	0.	30
31	PD106	1.613E-06	1.206E-06	0.	0	6.684E-04	0.	6.684E-04	0.	2.160E-03	0.	0.	31
32	PD107	1.037E-06	8.090E-07	0.	0	9.428E-04	0.	9.428E-04	0.	2.025E-03	0.	0.	32
33	PD108	7.400E-07	5.910E-07	0.	0	1.639E-03	0.	1.639E-03	0.	2.426E-03	0.	0.	33
34	AG109	2.376E-07	2.648E-07	0.	0	4.923E-03	0.	4.923E-03	0.	4.843E-03	0.	0.	34
35	CD113	4.576E-11	3.698E-10	0.	0	5.570E-04	0.	5.570E-04	0.	4.725E-04	0.	0.	35
36	I131	5.203E-09	1.210E-08	0.	0	1.136E-04	0.	1.136E-04	0.	1.253E-04	0.	1.266E-02	36
37	XE131	5.604E-07	5.345E-07	0.	0	6.912E-03	0.	6.912E-03	0.	7.778E-03	0.	0.	37
38	XE133	5.615E-09	1.383E-08	0.	0	3.452E-04	0.	3.452E-04	0.	3.540E-04	0.	2.210E-02	38
39	CS133	1.523E-06	1.217E-06	0.	0	6.481E-03	0.	6.481E-03	0.	8.733E-03	0.	0.	39

40	CS134	3.381E-07	1.728E-07	0.	0	3.012E-03	0.	3.012E-03	0.	3.196E-03	0.	0.	40
41	I135	3.054E-10	7.684E-10	0.	0	4.472E-09	0.	4.472E-09	0.	2.197E-06	0.	2.318E-02	41
42	XE135	9.169E-11	2.308E-10	0.	0	1.901E-02	0.	1.901E-02	0.	2.074E-02	0.	5.070E-03	42
43	CS135	7.495E-07	4.227E-07	0.	0	3.943E-04	0.	3.943E-04	0.	1.848E-03	0.	0.	43
44	ND143	1.114E-06	8.982E-07	0.	0	7.653E-03	0.	7.653E-03	0.	1.130E-02	0.	0.	44
45	ND144	2.242E-06	1.308E-06	0.	0	3.106E-04	0.	3.106E-04	0.	3.739E-03	0.	0.	45
46	ND145	8.186E-07	6.325E-07	0.	0	4.025E-03	0.	4.025E-03	0.	8.207E-03	0.	0.	46
47	ND146	1.286E-06	7.783E-07	0.	0	4.418E-04	0.	4.418E-04	0.	2.225E-03	0.	0.	47
48	PM147	1.530E-07	1.984E-07	0.	0	3.332E-03	0.	6.310E-03	0.	7.239E-03	3.010E-03	0.	48
49	PM148	1.346E-09	1.732E-09	0.	0	6.127E-04	0.	6.127E-04	0.	9.121E-04	0.	2.706E-03	49
50	'PM8M'	7.309E-10	9.435E-10	0.	0	2.807E-03	0.	2.807E-03	0.	2.433E-03	0.	1.957E-04	50
51	SM149	1.890E-09	3.557E-09	0.	0	7.467E-03	0.	7.467E-03	0.	6.337E-03	0.	0.	51
52	SM150	3.566E-07	2.925E-07	0.	0	3.809E-03	0.	3.809E-03	0.	6.117E-03	0.	0.	52
53	SM151	2.960E-08	3.145E-08	0.	0	5.575E-03	0.	5.575E-03	0.	5.013E-03	0.	0.	53
54	SM152	1.788E-07	1.582E-07	0.	0	5.184E-03	0.	5.184E-03	0.	5.814E-03	0.	0.	54
55	EU153	1.946E-07	1.340E-07	0.	0	4.024E-03	0.	4.024E-03	0.	4.324E-03	0.	0.	55
56	EU154	3.616E-08	2.283E-08	0.	0	3.620E-03	0.	3.620E-03	0.	3.179E-03	0.	3.291E-05	56
57	EU155	7.236E-09	4.916E-09	0.	0	3.876E-03	0.	3.876E-03	0.	3.287E-03	0.	2.833E-05	57
58	'PS1'	4.229E-06	2.841E-06	0.	0	1.826E-03	0.	1.826E-03	0.	9.719E-03	0.	0.	58
59	'PS2'	9.275E-06	6.314E-06	0.	0	1.241E-03	0.	1.241E-03	0.	1.618E-02	0.	0.	59
60	'PS3'	3.564E-06	2.220E-06	0.	0	1.848E-03	0.	1.848E-03	0.	1.915E-02	0.	4.738E-04	60
61	'PS4'	2.290E-05	1.515E-05	0.	0	4.061E-04	0.	4.061E-04	0.	4.182E-02	0.	1.897E-02	61
0- 61						7.024E-01	3.576E-01	1.000E+00	1.015E+00	9.212E+01	8.549E-02	2.814E-01	

==========

GFLUX

1.063E+13	8.506E+12	3.991E+12	4.879E+12	4.274E+12	3.193E+12	4.181E+12	4.206E+12	4.043E+12	4.089E+12
4.114E+12	3.757E+12	3.745E+12	3.755E+12	3.745E+12	3.741E+12	3.742E+12	3.741E+12	3.738E+12	3.735E+12
3.730E+12	3.725E+12	3.719E+12	3.712E+12	3.704E+12	3.695E+12	3.685E+12	3.674E+12	3.662E+12	3.647E+12
3.632E+12	3.613E+12	3.592E+12	3.573E+12	3.545E+12	3.515E+12	3.462E+12	3.459E+12	3.393E+12	3.390E+12
3.313E+12	3.268E+12	3.243E+12	3.215E+12	3.058E+12	2.959E+12	2.964E+12	2.924E+12	1.724E+12	1.143E+12
1.125E+12	1.130E+12	1.131E+12	1.101E+12	1.085E+12	1.104E+12	1.099E+12	1.104E+12	1.102E+12	1.111E+12
1.113E+12	1.076E+12	1.106E+12	1.103E+12	1.113E+12	1.105E+12	1.112E+12	1.116E+12	1.096E+12	1.100E+12
7.557E+11	1.156E+12	1.149E+12	1.285E+12	1.266E+12	1.307E+12	1.377E+12	1.477E+12	1.605E+12	1.741E+12
1.881E+12	2.001E+12	2.077E+12	2.173E+12	2.319E+12	2.477E+12	2.581E+12	2.640E+12	2.639E+12	2.601E+12
2.531E+12	2.412E+12	2.273E+12	2.086E+12	1.912E+12	1.723E+12	1.540E+12	1.367E+12	1.200E+12	1.047E+12
9.077E+11	7.828E+11	6.688E+11	5.711E+11	4.852E+11	4.089E+11	3.452E+11	2.897E+11	2.418E+11	2.026E+11
1.685E+11	1.398E+11	1.167E+11	9.626E+10	8.015E+10	2.313E+11	8.746E+10	3.266E+10	1.210E+10	4.480E+09

END OF JOB4

TIME TAKEN IN MINS

TOTAL	JOB	LINKS 1,2	LINKS 3,4	LINK5	LINK6
3.815E+01	1.859E+01	1.764E+00	3.482E+01	6.239E-01	0.

BURNUP	FLUX	R-RATES	RUREDY	PAUSE
1.077E+00	1.687E+01	1.442E+01	3.569E-01	0.

END OF DATA ENCOUNTERED ON SYSTEM INPUT FILE

18. STRUCTURE OF BINARY LIBRARIES

18.0 Summary

Details are given of the structure of GYMEA libraries which consist of binary magentic tape files. The cards from which the libraries are prepared are discussed elsewhere (*19.4*). For the cross section library, four types of data exist associated with data for nuclides designated as (1) light – σ_s is given rather than $\nu\sigma_f$ and these nuclides are moderators used for background scattering in resonance theory, (2) unshielded – only cross sections given, (3) shielded – shielding parameters given, and (4) resonance – resonance parameters given.

18.1 GYMEA X–S Library (no scattering matrices) (Max. 120 groups 100 nuclides (or materials))

18.1.0 Summary

A library of NN nuclides contains NN+1 files each separated by a file mark. The library consists of blocked binary records only ($\leq$ 256 words/block). From burnup considerations, the nuclides must be ordered in such a way that, except for a few nuclides, all nuclides are derived from nuclides earlier in the library. Nuclides may be derived from the nuclide immediately following provided no two such requirements appear together. Also from resonance absorption calculation considerations the light nuclides must be first in the library. In general this ordering of nuclides is no handicap to the functioning of the programme as an edit programme is available (Ford 1966 – Section *19*). The library may be considered to consist of five parts:

File 1 – (Library identification *18.1.1*
(Burnup data *18.1.2*
(Group and nuclide information *18.1.3*

Files 2–(NN+1) – (Nuclear data (excluding scattering matrices which are available as part of the SCAT library) *18.1.4* and *18.1.5*

File 1

18.1.1 Library identification

1. Heading record of 12 words (ST(I), I = 1, 12))

word 1 = 6H=GYMEA
word 2 = 6HbX–Sbb
word 3 = 6HNAMEbb, where NAME = library identifier
word 4)
word 12) = 9A6 characters used to describe the library.

2. Second heading record of 5 words (ST(I), I = 1, 5))

word 1 = number of groups (NG)
word 2 = number of nuclides (NN)
word 3 = temperature in °K (this is only meaningful for libraries containing shielding parameters rather than resonance parameters)
word 4 = the group at which resonance theory starts
word 5 = the group at which resonance theory terminates.

18.1.2 Burnup data

NN records of 10 words each $\begin{pmatrix} \text{DO 1 I=1,NN} \\ \vdots \\ \text{ST(K),K=1,10} \end{pmatrix}$. The I^{th} record relates to nuclide I in the library (with nuclear data file (I+1)). The words have the following meanings:

word 1 = 6HPA233b = nuclide I, say.
word 2 = 0–4 to indicate fuel type,
word 3 = (6HNO0bbb if no decay
(6HU233bb if decay of nuclide I produces U233b
(6HYS0bbb if decay of nuclide I produces a nuclide not included in the nuclide set (actually any label will do other than NO0bbb or a library nuclide label).
word 4 = as above but for neutron capture via $\sigma^{(1)}\phi$
word 5 = as above but for neutron capture via $\sigma^{(6)}\phi$
word 6 = λ, the decay constant ($1/10^{25}$ sec)
word 7 = yield (1)
word 8 = yield (2)
word 9 = yield (3)
word 10 = yield (4)

18.1.3 Group and nuclide information (ST(K), K=1, NG(+1) or (ST(K), K=1, NN)

1. A record of NG+1 words of the lethargies of the upper boundary of the first group and the lower boundaries of all groups.

2. A record of NG words of the normalized fission spectrum (unit sum).

3. A record of NG words of the group velocities (cm/10^{-8} sec)

4. A record of NN fixed point words (IS) used to identify each nuclide in relation to resonance theory:

   −1 indicates a light nuclide (maximum 10 will be used)

   0 indicates a nuclide not requiring resonance theory

   1 indicates a nuclide with shielding parameters given

   ⩾2 indicates a nuclide with resonance parameters given.

5. A record of NN words of the nuclide masses (for example 9. for Be^9).

6. A record of NN words of the material's potential scattering cross section, σ_s.

7. A record of NN words of the fission energy releases (joule/fission).

8. A record of NN words of N's to reconstruct shielded cross sections (1).

9. A record of NN words of N's to reconstruct shielded cross sections (2).

10. A record of NN words of N's to reconstruct shielded cross sections (3).

END OF FILE

18.1.4 Heading record, I^{th} nuclide (file I+1)

1. A 3-word record to identify the nuclide
   word 1 = label, for example BE9bbb
   word 2 = mass, for example 9.
   word 3 = IS(*18.1.3*), for example −1

2. A record of NG words indicating the number of trailer records associated with data for each group. In the resonance region each entry indicates the number of resonance parameter sets associated with each group.

18.1.5 Nuclear data, I^{th} nuclide, given a group at a time (NG items in all)

1. For non-resonance groups
   Records of 6 words each (ST(K), K = 1,6)

   word 1 = $\sigma^{(1)} = \sigma_{cap\ 1}$ – usually (n,γ)

   word 2 = $\sigma^{(2)} = \sigma_f$

   word 3 = $\sigma^{(3)} = \sigma_a$

   word 4 = $\sigma^{(4)} = \begin{cases} \nu\sigma_f & \text{for non-light nuclides IS} \neq -1 \\ \sigma_s & \text{for light nuclides IS} = -1 \end{cases}$

   word 5 = $\sigma^{(5)} = \sigma_{tr}$

   word 6 = $\sigma^{(6)} = \sigma_{cap\ 2}$ – usually (n,2n).

2. For resonance groups

   (i) light nuclides, IS = −1,
   as for Section *18.1.5* part 1,

   (ii) nuclides not affected by resonance theory, IS = 0
   as for Section *18.1.5* part 1,

   (iii) nuclides with shielding parameters given, IS = 1 :
   Records of 6 words each (ST(K), K = 1, 6),

   word 1 = $(\sigma_{n,\gamma})_\infty$

   word 2 = $(\sigma_f)_\infty$

   word 3 = σ_s, scattering cross section (not used at present)

   word 4 = $(\nu\sigma_f)_\infty$

   word 5 = σ^*_{tr} absorption removed ($\simeq \sigma_s$)

   word 6 = $\sigma^{(6)} = \sigma_{cap\ 2}$;

Trailer records of 6 words each (the trailer record follows the cross section record) (ST(K), K = 1, 6)

word 1 = $A^{(1)}$

word 2 = $A^{(2)}$

word 3 = $A^{(4)}$

word 4 = $B^{(1)}$

word 5 = $B^{(2)}$

word 6 = $B^{(4)}$;

Then

$$\sigma^{(1)} = (\sigma_{n,\gamma})_\infty \Big/ \left(1 + \frac{A^{(1)}}{\sigma_p} + \frac{B^{(1)}}{\sigma_p^2}\right)^{1/2}$$

$$\sigma^{(2)} = (\sigma_f)_\infty \Big/ \left(1 + \frac{A^{(2)}}{\sigma_p} + \frac{B^{(2)}}{\sigma_p^2}\right)^{1/2}$$

$$\sigma^{(3)} = \sigma^{(1)} + \sigma^{(2)}$$

$$\sigma^{(4)} = (\nu\sigma_f)_\infty \Big/ \left(1 + \frac{A^{(4)}}{\sigma_p} + \frac{B^{(4)}}{\sigma_p^3}\right)^{1/2}$$

$\sigma^{(5)} = \sigma^{(3)} + \sigma_{tr}^*$ absorption removed

$\sigma^{(6)}$ = word 6.

(iv) nuclides with resonance parameters given, IS $\geqslant 2$:
Records of 6 words each (ST(K), K=1, 6),

word 1 = $\sigma_{n,\gamma}^*$ resonance removed

word 2 = σ_f^* resonance removed

word 3 = σ_s (not used at present)

word 4 = $(\nu\sigma_f^*)$ resonance removed

word 5 = σ_{tr}^* absorption removed

word 6 = $\sigma^{(6)} = \sigma_{cap\ 2}$;

M trailer records of 6 words each (the trailer records follow the cross sections record) as indicated in the file heading record (Section *18.1.4* part 2),

```
DO1J =1,M
  .
  .
. . .  ST (K), K=1, 6
  .
  .
```

word 1 = E_r (eV)

word 2 = Γ_n "

word 3 = Γ_γ "

word 4 = Γ_f "

word 5 = $\nu\Gamma_f$ "

word 6 = g ;

then the cross sections are calculated as for (iii) except that resonance theory is used instead of shielding theory (*7.4.2*).

END OF FILE

18.2 GYMEA SCAT Library (scattering matrices only) (Max. 120 groups, 80 max. length of scatter)

18.2.0 Summary

A library with data for NS materials and given for NT temperatures contains 1+NSxNT files, each separated by a file mark. The library consists of blocked binary records only (≤256 words/block). This library will be positioned by the IBM 1401 while the IBM 7040 is loading up cross section data (using Richardson's SEARCH 1965). As a result of this, machine time will not be wasted with a library containing many different temperatures. The library may be considered to consist of 4 parts:

File 1 – (Library identification (*18.2.1*)
(Scattering matrix identifiers (*18.2.2*)
(Temperature list (*18.2.3*)

Files 2–(1+NSxNT) – Matrices (*18.2.4*)

File 1

18.2.1 Library identification

1. Heading record of 12 words (ST(K), K=1, 12)

   word 1 = 6H=GYMEA

   word 2 = 6HbSCATb

   word 3 = 6HNAMEbb (not necessarily the same as the cross section library)

   word 4)= 9A6 characters used to describe the library.
   word 12)

2. Second heading record of 3 words (ST(K), K=1, 3)

   word 1 = number of groups (NG – must agree with the cross section library)

   word 2 = number of scattering matrices/temperature (NS)

   word 3 = number of temperatures (NT).

(Note – it is assumed that every temperature has a complete set of scattering matrices).

18.2.2 Scattering matrix identifiers

A record of 2 x NS words (ST(K), K=1, 2*NS). Each group of two words identifies the material and its manner of preparation; for example a library may read

word 1 = 'BEO'
word 2 = CRY
word 3 = BE9 (stored as 6HBE9bbb)
word 4 = GAS

18.2.3 Temperature list

A record of NT words (ST(K), K=1,NT). Each word is a temperature in °K and is given in any order. For example the list may read

word 1 = 900.
word 2 = 300.
word 3 = 600.
word 4 = 1200.

END OF FILE

18.2.4 Heading record, I^{th} material J^{th} temperature (file 1+IxJ) (the next file would be for the $(I+1)^{th}$ material at the J^{th} temperature).

A 3-word record which identifies the matrix and which must agree with information given previously (ST(K), K = 1, 3).

word 1 = material, for example 'BEO'
word 2 = preparation, for example CRY
word 3 = temperature, for example 300.

18.2.5 Scattering data, I^{th} material, J^{th} temperature

After the heading record follow NG records of a variable number of words thus

```
DO 1 J=1, NG
  .
  .
  .
. . . N, LGG, ST(K), K=1, N
  .
  .
```

where N is the length of scatters (max.81) and LGG is the position of the 'self-scatter' term (actually the negative sum of the outscatters).

END OF FILE

LIBRARIES AND EDIT
PROGRAMMES IN BRIEF

19. LIBRARIES AND EDIT PROGRAMMES IN BRIEF

19.0 Summary

The content of two main libraries used at the A.A.E.C. is given. Other libraries are discussed as well as the programmes used to edit GYMEA libraries.

19.1 GYMEA X-S Library NDXD, (120 groups, 70 nuclides)

19.1.1 Group boundaries

GROUP		LETH	ENERGY(EV)		E(AVE.LETH)
1	0.	1.75	1.0000E+07	1.7377E+06	4.1686E+06
2	1.75	2.25	1.7377E+06	1.0540E+06	1.3534E+06
3	2.25	2.50	1.0540E+06	8.2085E+05	9.3014E+05
4	2.50	2.75	8.2085E+05	6.3928E+05	7.2440E+05
5	2.75	3.00	6.3928E+05	4.9787E+05	5.6416E+05
6	3.00	3.25	4.9787E+05	3.8774E+05	4.3937E+05
7	3.25	3.50	3.8774E+05	3.0197E+05	3.4218E+05
8	3.50	3.75	3.0197E+05	2.3518E+05	2.6649E+05
9	3.75	4.00	2.3518E+05	1.8316E+05	2.0754E+05
10	4.00	4.25	1.8316E+05	1.4264E+05	1.6163E+05
11	4.25	4.50	1.4264E+05	1.1109E+05	1.2588E+05
12	4.50	4.75	1.1109E+05	8.6517E+04	9.8037E+04
13	4.75	5.00	8.6517E+04	6.7379E+04	7.6351E+04
14	5.00	5.25	6.7379E+04	5.2475E+04	5.9462E+04
15	5.25	5.50	5.2475E+04	4.0868E+04	4.6309E+04
16	5.50	5.75	4.0868E+04	3.1828E+04	3.6066E+04
17	5.75	6.00	3.1828E+04	2.4788E+04	2.8088E+04
18	6.00	6.25	2.4788E+04	1.9305E+04	2.1875E+04
19	6.25	6.50	1.9305E+04	1.5034E+04	1.7036E+04
20	6.50	6.75	1.5034E+04	1.1709E+04	1.3268E+04
21	6.75	7.00	1.1709E+04	9.1188E+03	1.0333E+04
22	7.00	7.25	9.1188E+03	7.1017E+03	8.0473E+03
23	7.25	7.50	7.1017E+03	5.5308E+03	6.2673E+03
24	7.50	7.75	5.5308E+03	4.3074E+03	4.8810E+03
25	7.75	8.00	4.3074E+03	3.3546E+03	3.8013E+03
26	8.00	8.25	3.3546E+03	2.6126E+03	2.9604E+03
27	8.25	8.50	2.6126E+03	2.0347E+03	2.3056E+03
28	8.50	8.75	2.0347E+03	1.5846E+03	1.7956E+03
29	8.75	9.00	1.5846E+03	1.2341E+03	1.3984E+03
30	9.00	9.25	1.2341E+03	9.6112E+02	1.0891E+03
31	9.25	9.50	9.6112E+02	7.4852E+02	8.4818E+02
32	9.50	9.75	7.4852E+02	5.8295E+02	6.6057E+02
33	9.75	10.00	5.8295E+02	4.5400E+02	5.1445E+02
start of resonance region 34	10.00	10.25	4.5400E+02	3.5358E+02	4.0065E+02
35	10.25	10.50	3.5358E+02	2.7536E+02	3.1203E+02
36	10.50	10.75	2.7536E+02	2.1445E+02	2.4301E+02
37	10.75	11.00	2.1445E+02	1.6702E+02	1.8926E+02
38	11.00	11.25	1.6702E+02	1.3007E+02	1.4739E+02
39	11.25	11.50	1.3007E+02	1.0130E+02	1.1479E+02
40	11.50	11.75	1.0130E+02	7.8893E+01	8.9398E+01
41	11.75	12.00	7.8893E+01	6.1442E+01	6.9623E+01
42	12.00	12.25	6.1442E+01	4.7851E+01	5.4222E+01
43	12.25	12.50	4.7851E+01	3.7267E+01	4.2229E+01
44	12.50	12.75	3.7267E+01	2.9023E+01	3.2888E+01
45	12.75	13.00	2.9023E+01	2.2603E+01	2.5613E+01
46	13.00	13.25	2.2603E+01	1.7603E+01	1.9947E+01

	47	13.25	13.50	1.7603E+01	1.3710E+01	1.5535E+01
	48	13.50	13.75	1.3710E+01	1.0677E+01	1.2099E+01
	49	13.75	13.90	1.0677E+01	9.1898E+00	9.9056E+00
	50	13.90	14.00	9.1898E+00	8.3153E+00	8.7416E+00
	51	14.00	14.10	8.3153E+00	7.5240E+00	7.9097E+00
	52	14.10	14.20	7.5240E+00	6.8080E+00	7.1570E+00
	53	14.20	14.30	6.8080E+00	6.1601E+00	6.4760E+00
	54	14.30	14.40	6.1601E+00	5.5739E+00	5.8597E+00
	55	14.40	14.50	5.5739E+00	5.0435E+00	5.3021E+00
	56	14.50	14.60	5.0435E+00	4.5635E+00	4.7975E+00
	57	14.60	14.70	4.5635E+00	4.1292E+00	4.3410E+00
	58	14.70	14.80	4.1292E+00	3.7363E+00	3.9279E+00
	59	14.80	14.90	3.7363E+00	3.3807E+00	3.5541E+00
	60	14.90	15.00	3.3807E+00	3.0590E+00	3.2159E+00
	61	15.00	15.10	3.0590E+00	2.7679E+00	2.9098E+00
	62	15.10	15.20	2.7679E+00	2.5045E+00	2.6329E+00
	63	15.20	15.30	2.5045E+00	2.2662E+00	2.3824E+00
	64	15.30	15.40	2.2662E+00	2.0505E+00	2.1557E+00
	65	15.40	15.50	2.0505E+00	1.8554E+00	1.9505E+00
	66	15.50	15.60	1.8554E+00	1.6788E+00	1.7649E+00
	67	15.60	15.70	1.6788E+00	1.5191E+00	1.5970E+00
	68	15.70	15.80	1.5191E+00	1.3745E+00	1.4450E+00
	69	15.80	15.90	1.3745E+00	1.2437E+00	1.3075E+00
end of resonance region	70	15.90	16.00	1.2437E+00	1.1254E+00	1.1830E+00
	71	16.00	16.10	1.1254E+00	1.0183E+00	1.0705E+00
	72	16.10	16.20	1.0183E+00	9.2136E-01	9.6860E-01
	73	16.20	16.30	9.2136E-01	8.3368E-01	8.7643E-01
	74	16.30	16.40	8.3368E-01	7.5435E-01	7.9302E-01
	75	16.40	16.50	7.5435E-01	6.8256E-01	7.1756E-01
	76	16.50	16.60	6.8256E-01	6.1761E-01	6.4927E-01
	77	16.60	16.70	6.1761E-01	5.5883E-01	5.8749E-01
	78	16.70	16.80	5.5883E-01	5.0565E-01	5.3158E-01
	79	16.80	16.90	5.0565E-01	4.5753E-01	4.8099E-01
	80	16.90	17.00	4.5753E-01	4.1399E-01	4.3522E-01
	81	17.00	17.10	4.1399E-01	3.7460E-01	3.9380E-01
	82	17.10	17.20	3.7460E-01	3.3895E-01	3.5633E-01
	83	17.20	17.30	3.3895E-01	3.0669E-01	3.2242E-01
	84	17.30	17.40	3.0669E-01	2.7751E-01	2.9174E-01
	85	17.40	17.50	2.7751E-01	2.5110E-01	2.6397E-01
	86	17.50	17.60	2.5110E-01	2.2720E-01	2.3885E-01
	87	17.60	17.70	2.2720E-01	2.0558E-01	2.1612E-01
	88	17.70	17.80	2.0558E-01	1.8602E-01	1.9556E-01
	89	17.80	17.90	1.8602E-01	1.6832E-01	1.7695E-01
	90	17.90	18.00	1.6832E-01	1.5230E-01	1.6011E-01
	91	18.00	18.10	1.5230E-01	1.3781E-01	1.4487E-01
	92	18.10	18.20	1.3781E-01	1.2469E-01	1.3109E-01
	93	18.20	18.30	1.2469E-01	1.1283E-01	1.1861E-01
	94	18.30	18.40	1.1283E-01	1.0209E-01	1.0732E-01
	95	18.40	18.50	1.0209E-01	9.2375E-02	9.7111E-02
	96	18.50	18.60	9.2375E-02	8.3584E-02	8.7869E-02
	97	18.60	18.70	8.3584E-02	7.5630E-02	7.9507E-02
	98	18.70	18.80	7.5630E-02	6.8433E-02	7.1941E-02
	99	18.80	18.90	6.8433E-02	6.1920E-02	6.5095E-02
	100	18.90	19.00	6.1920E-02	5.6028E-02	5.8901E-02
	101	19.00	19.10	5.6028E-02	5.0696E-02	5.3295E-02
	102	19.10	19.20	5.0696E-02	4.5872E-02	4.8224E-02
	103	19.20	19.30	4.5872E-02	4.1507E-02	4.3635E-02
	104	19.30	19.40	4.1507E-02	3.7557E-02	3.9482E-02

105	19.40	19.50	3.7557E-02	3.3983E-02	3.5725E-02
106	19.50	19.60	3.3983E-02	3.0749E-02	3.2325E-02
107	19.60	19.70	3.0749E-02	2.7823E-02	2.9249E-02
108	19.70	19.80	2.7823E-02	2.5175E-02	2.6466E-02
109	19.80	19.90	2.5175E-02	2.2779E-02	2.3947E-02
110	19.90	20.00	2.2779E-02	2.0612E-02	2.1668E-02
111	20.00	20.10	2.0612E-02	1.8650E-02	1.9606E-02
112	20.10	20.20	1.8650E-02	1.6875E-02	1.7741E-02
113	20.20	20.30	1.6875E-02	1.5269E-02	1.6052E-02
114	20.30	20.40	1.5269E-02	1.3816E-02	1.4525E-02
115	20.40	20.50	1.3816E-02	1.2502E-02	1.3142E-02
116	20.50	21.00	1.2502E-02	7.5826E-03	9.7362E-03
117	21.00	21.50	7.5826E-03	4.5991E-03	5.9053E-03
118	21.50	22.00	4.5991E-03	2.7895E-03	3.5817E-03
119	22.00	22.50	2.7895E-03	1.6919E-03	2.1724E-03
120	22.50	23.00	1.6919E-03	1.0262E-03	1.3177E-03

19.1.2 Nuclides

6 light nuclides, 16 other main nuclides, 35 individual fission products, 4 pseudo fission products, 9 control nuclides, (R = resonance parameters given).

1	Be^{9}		27	Rh^{103}	54	Sm^{152}	
2	O^{16}		28	Ru^{104}	55	Eu^{153}	
3	C^{12}		29	Rh^{105}	56	Eu^{154}	
4	H^{1}		30	Pd^{105}	57	Eu^{155}	
5	D^{2}		31	Pd^{106}			
6	Al^{27}		32	Pd^{107}	58	'PS1'	
7	Li^{6}		33	Pd^{108}	59	'PS2'	
8	T^{3}		34	Ag^{109}	60	'PS3'	
9	He^{2}		35	Cd^{113}	61	'PS4'	
10	Th^{232}	R	36	I^{131}			
11	Pa^{233}	R	37	Xe^{131}	62	B^{10}	
12	U^{232}		38	Xe^{133}	63	Cr^{52}	
13	U^{233}	R	39	Cs^{133}	64	Mn^{55}	R
14	U^{234}	R	40	Cs^{134}	65	Fe^{56}	
15	U^{235}	R	41	I^{135}	66	Ni^{58}	
16	U^{236}	R	42	Xe^{135}	67	Co^{59}	
17	U^{238}	R	43	Cs^{135}	68	Cu^{63}	
18	Pu^{239}	R	44	Nd^{143}	69	W^{186}	R
19	Pu^{240}	R	45	Nd^{144}	70	Au^{197}	R
20	Pu^{241}	R	46	Nd^{145}			
21	Pu^{242}		47	Nd^{146}			
22	ZZ^{999}		48	Pm^{147}			
			49	Pm^{148}			
23	Mo^{95}		50	Pm^{148M}			
24	Tc^{99}		51	Sm^{149}			
25	Ru^{101}		52	Sm^{150}			
26	Ru^{102}		53	Sm^{151}			

19.2 GYMEA SCAT Library NDSC,

120 groups 6 matrices at 4 temperatures

19.2.1 Materials

'BEO'	CRY	crystal scattering
'BE9'	GAS	monatomic gas scattering
'O16'	GAS	" " "
'H2O'	EFF	effective width model scattering
'C12'	CRY	crystal scattering
'C12'	GAS	monatomic gas scattering

19.2.2 Temperatures

300 °K

900 °K

600 °K

1200 °K

19.3 Other Libraries

The cross section library NDXD was prepared from a library consisting of 100 nuclides (NDXC– Cook 1966) by mixing 43 fission product dregs into 4 pseudo fission products. It has been found that little loss of accuracy results from this procedure for long–term reactivity predictions. Other libraries of both fewer nuclides (more mixed fission products) and fewer groups have been prepared from time to time to suit the particular needs of people engaged in reactor assessment.

Additional scattering matrix libraries are available. The data for all scattering libraries was prepared by McGregor (1965a) using the programmes LEAP (McLatchie 1962), PIXSE (Macdougall 1963), and GAM–1 (Joanou and Dudek 1961).

19.4 Edit Programmes in Brief (EDITOR and SCATLD)

Details have been given in the previous sections for the structure of libraries as required by the code GYMEA. However those engaged in library maintenance are necessarily more interested in the structure of BCD cards from which an original library is loaded or which comprise corrections to be made to an existing library. Two library edit programmes are available– EDITOR (Ford 1966) for the cross section library, and SCATLD (McGregor 1965b) for the scattering matrix library. EDITOR has been made very versatile to cope with the detailed needs of those maintaining the cross section library and uses free input. SCATLD does not need this flexibility, as maintenance is normally only required at the level of one complete scattering matrix, and fixed format input is therefore used.

20. PROGRAMME SOURCE STRUCTURE

The structure of the programme is set out by chains below. Each of the subroutines required in a chain is given, with entries in columns of those subroutines which it calls. Subroutines given in inverted commas have more than one entry point and an (M) following a subroutine means that it is included in chain (0).

CHAIN (0)

'CLOCK'
INTVLL
CHAIN (1)
CHAIN (2)

PSLIB

RUREDY
'SEARCH'
SKIP

RUREDY

'SEARCH'
'CLOCK'

SKIP

CHAIN (1)

SEARCH

–

COLLEC

CONC

CONC

–

LOOK

TEST

TEST

–

NUCL

–

CLOCK

–

CHNRTN

–

CHAIN (0)

FPT

–

HOLLRH

–

CHAIN (1)

'CLOCK' (M)
SKIP (M)
SRCH
COMPIL
ERROR
CHAIN (2)

SRCH

–

COMPIL

'FREE'
PACK
DATE
ERROR
STAN

'FREE'

LHFREE
RHFREE
ERFREE

LHFREE

ERROR

RHFREE

ERROR

ERFREE

CHAIN (1)

CALL
HOLLRH (M)

CALL

CHAIN (2)

ERROR

ERROR 3

ERROR 3

–

STAN

HOLLRH (M)

PACK

–

DATE

–

CHAIN (2)

'CLOCK' (M)
SKIP (M)
MAIN
CALL

MAIN

CHAIN (1)
SCEASE
'FREE'
PACK
'CLOCK'
TEST
HOLLRH (M)
ERROR

CHAIN (2) (contd.)

UNDO
SDAT
CALLCH
GETL
MAKET
PUTN
SORTN
TYPE
GNAME
CALL
RETURN
COLLEC (M)
UNLOAD
BUT
SEND
PART
ORDER
PSLIB (M)
'SEARCH' (M)
NUCL (M)
CONC (M)
SKIP (M)
TEST (M)

CALL
ERROR
MAIN
SDAT
SEND
SCEASE
'SEARCH' (M)
'CLOCK' (M)
DAT
LIBER
STAN
DUMP
CALLCH
FINISH
WEST
NUC
NSS

MAKET
GETL
'FREE'
PUTN
ERROR

GETL
ERROR
PACK
LOOK (M)
'FREE'

DUMP
-

STAN
HOLLRH (M)

GNAME
'FREE'
PACK

SORTN
PUTN

PUTN
-

NSS
TEST (M)

RETURN
CALL
MAIN

SDAT
'FREE'
PACK
ERROR

SEND
'CLOCK' (M)
MAIN

SCEASE
'SEARCH'
'FREE'
PACK
MAIN

LIBER
CALL

DAT
CALL

ERROR
CHAIN (1)

FINISH
DUMP

BUT
LOOK
ERROR

PART
ERROR
COLLEC (M)
AETC

NUC
COLLEC (M)
AETC

CHAIN (2) (contd.)

SORTN

AETC

–

WEST

WESTSP

WESTSP

–

CALLCH

CLOCK

CHAIN (3)

ERROR

UNLOAD

–

UNDO

–

TYPE

–

ORDER

–

PACK

–

'FREE'

as for CHAIN (1)

EXTRA2

–

CHAIN (3)

WATCH

GYMEA2

EQU

OUTPUT

SAVE

CHAIN (2)

CHAIN (5)

CHAIN (6)

SKIP (M)

GYMEA2

ERROR

BURNUP

CHAIN (4)

KETC

EIGENV

TGRALS

OUTPUT

EIGENV

ERROR

COLLEC (M)

SORTN

EXPL

ERROR

TGRALS

ERROR

KETC

–

EQU

ERROR

GYMEA2

OUTPUT

BURNUP

WATCH

CODE

CODE

–

OUTPUT

NUCL (M)

ANORM

HOLLRH (M)

WDS

–

ANORM

–

SAVE

COLLEC (M)

ANORM

WDS

WATCH

CLOCK (M)

ERROR

CHAIN (1)

SORTN

PUTN

PUTN

–

CHAIN (4)

FLUXBL
RATES
CHAIN (3)

FLUXBL
PSLIB (M)
ERROR
STOD
WEST
SKIP (M)
FIRSTD
BLOCKD
RUREDY (M)
SCATD
SEDL
WATCH

RATES
WATCH
COLLEC (M)
SKIP
FIRSTD
BLOCKD
VERLAP
CAM
ERROR

SCATD
RUREDY (M)
COLLEC (M)
LOOK (M)
ERROR
SKIP (M)
PSLIB (M)

FIRSTD
ERROR
SAME
WISIT
CAM
NUCL (M)
SKIP (M)

BLOCKD
SHIELD
RES
RESH

SHIELD
-

RESH
-

RES
RESJ

RESJ
-

STOD
MUGN

MUGN
-

CAM
-

WISIT
ERROR

VERLAP
-

SEDL
SIDW

SIDW
-

WEST
WESTSP

WESTSP
-

SAME
-

WATCH
CLOCK (M)

ERROR
CHAIN (1)

CHAIN (5)

CLOCK (M)
COLLEC (M)
PRINTX
PCRAM
PZOOM
PDSN
PWDSN
PGMCM9
PLSCD
CHAIN (2)
CHAIN (6)
'SGG'
PSLIB (M)
RMAT
SORTS
RUREDY (M)
ERROR
HOLLRH (M)

PRINTX

HOLLRH (M)
GCOL
ANORM
COLLEC (M)
RMAT
CONC (M)
NUCL (M)
PRINTS
PRINTN
WDS

PCRAM

CHEAD
GCOL
RMAT
WDS
'SGG'
NUCL (M)

PZOOM

CHEAD
GCOL
HOLLRH (M)
RMAT
NUCL (M)
WDS
'SGG'
CONC (M)

PDSN

CHEAD
HOLLRH (M)
'SGG'
ERROR
GCOL
RMAT
NUCL (M)

PWDSN

CHEAD
RMAT
NUCL (M)
WDS
'SGG'

PGMCM9

CHEAD
RMAT
NUCL (M)
WDS

PRINTS

PRINTN
'SGG'

PRINTN

–

GCOL

–

RMAT

NUCL

SORTS

SLOOK
NUCL
CONC

SLOOK

ERROR

'SGG'

–

PLSCD

–

WDS

–

ERROR

CHAIN (1)

ANORM

–

CHEAD

–

CHAIN (6)

SHIELD

MATS

NUCL (M)

CHAIN (2)

LOT13

WATCH

RESH

SAME

LOT14

PSLIB (M)

RUREDY (M)

SKIP (M)

WDS

ANORM

WRT

MIXEM

BUT

ERROR

UNLOAD

TYPE

ANORM

–

WRT

MIXEM

MATS

MIXEM

–

BUT

LOOK (M)

ERROR

UNLOAD

–

ERROR

CHAIN (1)

WDS

–

TYPE
(not the same as the subroutine used in CHAIN (2))

–

LOT13

–

LOT14

–

MATS

–

SHIELD

–

RESH

–

SAME

–

WATCH

'CLOCK' (M)

21. PROGRAMME COMMON

A list of the locations of all variables in blank common is given below. This is very useful in implementing two features of the programme which the general user should not require.

The first use is in making accessible variables not included in the user's common. Use of the loop–round feature of core storage gives the relationships

// ≡ X (19491)

// ≡ Z (17491)

// ≡ J (19501)

where // is the symbol used in the listing for the beginning of common. Thus any variables in common can be used, but they should be altered only with great caution. As an example, the lethargy boundaries U(1) to U(121) are accessible as X(32277) to X(32397).

The other use is in conjunction with the expanded error dump facility for programme debugging (*13.4*).

```
1                    BEGIN   PLGCT.,*              00000        USE     PRGCT.              00002        USE     SFLCT.
4          00002     USE     DATCT.                00002        USE     STRCT.              00002        LORG
7          00002 LITCT. OCT   000000000000          00003        OCT     201400000000        00004        OCT     000000000001
10                   EVEN                          00005 LTCR2. OCT     000000000000,000000000000
12         00007     OCT     201400000000,146000000000                                                  IENTRY  EQU     //+0
14               ISUB  EQU     //+10                        ISAVE  EQU     //+50                       NXCD    EQU     //+150
17               ISEN  EQU     //+151                       ISCE   EQU     //+152                      IC      EQU     //+153
20               NEX   EQU     //+154                       LCHAIN EQU     //+155                      NOCDS   EQU     //+156
23               NFCD  EQU     //+157                       IDAT   EQU     //+158                      IDA     EQU     //+159
26               TJOB  EQU     //+160                       IA1    EQU     //+161                      IA2     EQU     //+162
29               IA3   EQU     //+163                       IA4    EQU     //+164                      IA5     EQU     //+165
32               IA6   EQU     //+166                       IA7    EQU     //+167                      JA      EQU     //+171
35               JST   EQU     //+177                       XN1    EQU     //+178                      XN2     EQU     //+179
38               XN3   EQU     //+180                       XN4    EQU     //+181                      CON     EQU     //+182
41               FMT   EQU     //+183                       CARD   EQU     //+195                      I       EQU     //+219
44               J     EQU     //+220                       K      EQU     //+221                      L       EQU     //+222
47               I1    EQU     //+223                       I2     EQU     //+224                      I3      EQU     //+225
50               I4    EQU     //+226                       I5     EQU     //+227                      I6      EQU     //+228
53               I7    EQU     //+229                       I8     EQU     //+230                      I9      EQU     //+231
56               I10   EQU     //+232                       I11    EQU     //+233                      I12     EQU     //+234
59               ICHSED EQU    //+235                       IDATE  EQU     //+236                      TOM     EQU     //+238
62               ETC4  EQU     //+248                       NEN    EQU     //+258                      LIBS    EQU     //+259
65               LIB   EQU     //+260                       LIBC   EQU     //+261                      LIBCS   EQU     //+262
68               NST   EQU     //+263                       ITS    EQU     //+264                      IS      EQU     //+265
71               MIS   EQU     //+365                       IFP    EQU     //+405                      IFPS    EQU     //+406
74               IRA   EQU     //+407                       NSID   EQU     //+408                      LIBR    EQU     //+409
77               IRS   EQU     //+410                       IRT    EQU     //+411                      LXSED   EQU     //+412
80               IW1   EQU     //+416                       IN     EQU     //+417                      IOUT    EQU     //+418
83               IOL   EQU     //+419                       IND    EQU     //+420                      NIKE    EQU     //+421
86               JKE   EQU     //+422                       KE     EQU     //+423                      LSID    EQU     //+424
89               ISID  EQU     //+425                       NTM    EQU     //+426                      NN      EQU     //+427
92               NG    EQU     //+428                       NN1    EQU     //+429                      NG1     EQU     //+430
95               NC    EQU     //+431                       IDLIB  EQU     //+432                      J1      EQU     //+433
98               J2    EQU     //+434                       J3     EQU     //+435                      J4      EQU     //+436
101              J5    EQU     //+437                       J6     EQU     //+438                      J7      EQU     //+439
104              J8    EQU     //+440                       J9     EQU     //+441                      J10     EQU     //+442
107              J11   EQU     //+443                       J12    EQU     //+444                      NHS     EQU     //+445
110              LID   EQU     //+446                       IFIFA  EQU     //+447                      NGD     EQU     //+448
113              MAT   EQU     //+449                       MATGD  EQU     //+450                      NMAT    EQU     //+451
116              I99   EQU     //+452                       DTSUM  EQU     //+453                      TB      EQU     //+454
119              TS    EQU     //+455                       DTS    EQU     //+456                      SFL     EQU     //+457
122              SPR   EQU     //+458                       FIND   EQU     //+459                      PIND    EQU     //+460
125              VIND  EQU     //+461                       XIND   EQU     //+462                      XEA     EQU     //+463
128              FIS   EQU     //+464                       IFB2   EQU     //+465                      BFL     EQU     //+466
131              AE1   EQU     //+467                       AE2    EQU     //+468                      WA      EQU     //+469
134              WB    EQU     //+470                       WC     EQU     //+471                      WD      EQU     //+472
137              WE    EQU     //+473                       WF     EQU     //+474                      WG      EQU     //+475
140              WP    EQU     //+476                       WQ     EQU     //+477                      WR      EQU     //+478
143              WS    EQU     //+479                       WT     EQU     //+480                      RESAL   EQU     //+481
146              RESXI EQU     //+492                       P      EQU     //+503                      PS      EQU     //+514
149              PST   EQU     //+547                       PT     EQU     //+550                      XPINV   EQU     //+551
152              SWN   EQU     //+552                       IP     EQU     //+852                      YD      EQU     //+1252
155              NIF   EQU     //+1652                      XS     EQU     //+1752                     AS      EQU     //+1758
158              BS    EQU     //+1761                      WW     EQU     //+1764                     ESED    EQU     //+11724
```

```
161   SED     EQU     //+11739
164   NSED    EQU     //+11752
167   JSED    EQU     //+11755
170   JSED1   EQU     //+11758
173   ETC3    EQU     //+11761
176   ITRAN   EQU     //+11906
179   KTR     EQU     //+11909
182   NMD     EQU     //+11912
185   NR      EQU     //+11915
188   NPART   EQU     //+11918
191   ICRT    EQU     //+11921
194   PTEMP   EQU     //+11924
197   NSCAT   EQU     //+11927
200   TEV     EQU     //+11930
203   LXGL    EQU     //+11933
206   PMIC    EQU     //+11936
209   IHEAD   EQU     //+11948
212   LMAT    EQU     //+12195
215   KSCATL  EQU     //+12365
218   ISCR    EQU     //+12425
221   XAN     EQU     //+12746
224   SETP    EQU     //+13027
227   MSAVE   EQU     //+13143
230   ITLE1   EQU     //+13223
233   KG2     EQU     //+13251
236   ITSA    EQU     //+13254
239   X9      EQU     //+13257
242   G2      EQU     //+13260
245   NGDC    EQU     //+13263
248   NTEMPC  EQU     //+13266
251   XO      EQU     //+13277
254   DTD     EQU     //+13289
257   RPR     EQU     //+13292
260   FIN     EQU     //+13295
263   XIN     EQU     //+13298
266   AKE     EQU     //+13301
269   XAV     EQU     //+13304
272   SKE     EQU     //+13307
275   GL      EQU     //+13310
278   AER     EQU     //+13313
281   FIFC    EQU     //+13316
284   BPRS    EQU     //+13319
287   VOID    EQU     //+13324
290   AV      EQU     //+13428
293   FER     EQU     //+13728
296   GB2     EQU     //+14068
299   DB2     EQU     //+14428
302   DSED    EQU     //+14787
305   ISED3   EQU     //+15146
308   ETC2    EQU     //+15248
311   IA      EQU     //+161
314   WH      EQU     //+1764
317   CRIT    EQU     //+13310
320   WX      EQU     //+15778
323   JW      EQU     //+15898

      BSED    EQU     //+11742
      ISED    EQU     //+11753
      LSED    EQU     //+11756
      JSED2   EQU     //+11759
      NUCLA   EQU     //+11764
      RPART1  EQU     //+11907
      NOT     EQU     //+11910
      NY      EQU     //+11913
      NS      EQU     //+11916
      NYS     EQU     //+11919
      IPAG    EQU     //+11922
      RTEMP   EQU     //+11925
      NTLIB   EQU     //+11928
      LGL     EQU     //+11931
      LSG     EQU     //+11934
      IWT     EQU     //+11937
      DEFN    EQU     //+11955
      NYN     EQU     //+12245
      KSCATP  EQU     //+12385
      IBURN   EQU     //+12525
      U       EQU     //+12786
      AW      EQU     //+13037
      LOT     EQU     //+13193
      ITLE2   EQU     //+13235
      IOLA    EQU     //+13252
      IFPA    EQU     //+13255
      SAV     EQU     //+13258
      G       EQU     //+13261
      NSC     EQU     //+13264
      JINO    EQU     //+13267
      X       EQU     //+13278
      AFL     EQU     //+13290
      VPR     EQU     //+13293
      PIN     EQU     //+13296
      FIFA    EQU     //+13299
      XI      EQU     //+13302
      CNA     EQU     //+13305
      SXA     EQU     //+13308
      GG      EQU     //+13311
      ACER    EQU     //+13314
      TEMP    EQU     //+13317
      XY      EQU     //+13320
      ETC1    EQU     //+13325
      BN      EQU     //+13528
      GFLUX   EQU     //+13828
      WU      EQU     //+14188
      SIDC    EQU     //+14548
      SEDAC   EQU     //+15144
      INSED   EQU     //+15147
      ZO      EQU     //+15277
      W       EQU     //+1764
      IST     EQU     //+1764
      SIDF    EQU     //+13828
      IW      EQU     //+15778
      SPA     EQU     //+15898

      SIDAC   EQU     //+11751
      KSED    EQU     //+11754
      ICSED   EQU     //+11757
      SED1    EQU     //+11760
      LIBX    EQU     //+11905
      LL      EQU     //+11908
      ICH2    EQU     //+11911
      NGD2    EQU     //+11914
      NT      EQU     //+11917
      LCR     EQU     //+11920
      STEMP   EQU     //+11923
      NTEMP   EQU     //+11926
      NSLIB   EQU     //+11929
      LXG     EQU     //+11932
      LSGL    EQU     //+11935
      TCARD   EQU     //+11938
      NWIS    EQU     //+12155
      LPART   EQU     //+12345
      LSCAT   EQU     //+12405
      NGS     EQU     //+12625
      V1      EQU     //+12907
      JSAVE   EQU     //+13137
      MOT     EQU     //+13208
      ETC5    EQU     //+13247
      ACETA   EQU     //+13253
      X7      EQU     //+13256
      G1      EQU     //+13259
      LSGC    EQU     //+13262
      NTC     EQU     //+13265
      JIN     EQU     //+13268
      TA      EQU     //+13288
      APR     EQU     //+13291
      BPR     EQU     //+13294
      VIN     EQU     //+13297
      AKI     EQU     //+13300
      XE      EQU     //+13303
      SKI     EQU     //+13306
      STR     EQU     //+13309
      GU      EQU     //+13312
      ACET    EQU     //+13315
      TLAST   EQU     //+13318
      EPART   EQU     //+13323
      AN      EQU     //+13328
      SXS     EQU     //+13628
      GSCE    EQU     //+13948
      WV      EQU     //+14308
      SEDET   EQU     //+14668
      ISED1   EQU     //+15145
      DC      EQU     //+15148
      Z       EQU     //+15278
      NW      EQU     //+1764
      AST     EQU     //+1764
      R       EQU     //+14548
      WY      EQU     //+15898
      WZ      EQU     //+16018
```

```
326             NSTA    EQU     //+13278
329             IDEFN   EQU     //+11955
332             LCODE   EQU     CONST+30
335             IDIS    EQU     CONST+86
338             ILC     EQU     CONST+89
341             ILF     EQU     CONST+92
344             ILJ     EQU     CONST+95
347             ILP     EQU     CONST+98
350             ILT     EQU     CONST+101
353             ILZ     EQU     CONST+104
356             ILAST   EQU     CONST+107
359             IBRAK   EQU     CONST+110
362             ILDADA  EQU     CONST+113
365             IGYMEA  EQU     CONST+116
368             SFMT    EQU     CONST+119
371                     EVEN
374             //      CONTRL  //
377     00000           USE     PRGCT.
380             *       PROLOGUE
383                     EXTERN  SETFP.
386                     BEGIN   SFLCT.,*

                        $DKEND COMMON

                NO MESSAGES FOR ABOVE ASSEMBLY
```

```
                        Q       EQU     //+258
                        AA      EQU     //+14188
                        IY      EQU     CONST+45
                        IDOL    EQU     CONST+87
                        ILD     EQU     CONST+90
                        ILG     EQU     CONST+93
                        ILN     EQU     CONST+96
                        ILR     EQU     CONST+99
                        ILW     EQU     CONST+102
                        ILEQ    EQU     CONST+105
                        ILSLH   EQU     CONST+108
                        ILBL    EQU     CONST+111
                        IRBRAK  EQU     CONST+114
                        ILXS    EQU     CONST+117
                        NDIFF   EQU     CONST+121
    00011       CONST   BSS     122
    00203       //      BSS     16138
    00000               TSL     SETFP.
    00000               USE     PLGCT.
                        BEGIN   PRGCT.,*
    00002               USE     SFLCT.

                        END
```

```
                        MSID    EQU     //+428
                        JSUB    EQU     CONST+0
                        ICEA    EQU     CONST+85
                        KSUB    EQU     CONST+88
                        ILE     EQU     CONST+91
                        ILI     EQU     CONST+94
                        ILO     EQU     CONST+97
                        ILS     EQU     CONST+100
                        ILX     EQU     CONST+103
                        ILDOL   EQU     CONST+106
                        ICOM    EQU     CONST+109
                        ILDA    EQU     CONST+112
                        ILGB2   EQU     CONST+115
                        ILSCAT  EQU     CONST+118
                        CONST   CONTRL  CONST,CONST+122
    00203               USE     //
    00203               USE     STRCT.
    00001       P.0010  TRA     S.JXIT
                        EXTERN  S.JXIT
    00002               USE     PRGCT.
                        BEGIN   STRCT.,*
```

22. FREE INPUT SUBROUTINE

22.0 Summary

The routine used has four main features:

(1) numeric data may be in any form readable by eye and alphabetic data may be ignored,

(2) a limited alphabetic mode is available in which blanks only are ignored,

(3) as much control of the reading and interpretation process as possible is left under programmer control,

(4) data can be read from any input device (up to column 72 of a record) or from storage.

For the reading of floating point data, exponents may be simplified by omitting either the 'E' or the sign; blanks may be present in the exponent. Thus .01, 1.E−b2, 1.−2, 2.E2, 2.E+02 are all acceptable. If no decimal point is present, one is assumed after the number.

For any numeric data, the repeat notation, for example 5*.1 meaning a set of five .1's may be used. No blanks are allowed between the numbers here. Thus 5* and *.1 are both completely ignored. A card with an * in column one is ignored.

When alphameric data is read, each character from the first non−blank one is stored in the given vector in the lower part of each word. Thus on the IBM 7040 the character A is equivalent to 21 octal, that is 17 decimal, and if 3 characters are requested the string AbB becomes 17,48,18.

22.1 Use

The routine consists of two MAP subroutines. The first has the 3 normal entry points and the second has the auxiliary routines used, which may be replaced.

The three entry points to the routine for reading floating point, fixed point, and alphameric data respectively are:

```
CALL   EFREE  (IT,IC,A,N)

CALL   IFREE  (IT,IC,IA,N)

CALL   AFREE  (IT,IC,IA,N).
```

In each of these calling sequences IT is the FORTRAN unit number (if negative this implies reading from storage; see later), IC is the column from which interpretation is to begin, A or IA is the variable or vector to be read, and N is the number of elements to be read. The column count may be set as desired and the routine then continues to update it. IC must be greater than 72 for a new record to be read, in which case the (IC/72) card is read and IC is used mod 72 for the column count. If when column 72 is reached a request is not satisfied, a new record is read and IC set back to 1. Thus if no control is required, IC is set to 73 at the beginning and then left for the routine to use.

When data is being read from storage, records are assumed to be stored in blank common under format 12A6. Then if IT is negative the next record used is the M^{th} stored card where M = −IT. Thus IT is updated by the routine when each new card is read if this feature is used. The routine PACK (IA,N) can be used to pack the right hand character of the N($\leq$ 6) elements of the vector IA into the first element of IA in normal A format form.

To provide further control of the routine by the programmer, any of the routines ERFREE, LHFREE, and RHFREE may be rewritten by him.

When an error is detected,

ERFREE (IT,IND,I,ICC,BUF)

is called. Here IT is the unit number; IND is one of the alphameric words bb.E , bbIM, bbIS, bEND, for an exponent or decimal error, a mode error, a scaling error, or a '$' control card respectively; I is the number of elements of the vector already filled; ICC is the present column count; and BUF contains the card image (format 12A6). From this information an appropriate message is printed.

When column 72 of a card is reached,

RHFREE (IT, IMODE, I, N)

is called. Here IMODE $= \left\{ \begin{matrix} 1 \\ 0 \\ -1 \end{matrix} \right\}$ for a call from $\left\{ \begin{matrix} \text{EFREE} \\ \text{IFREE} \\ \text{AFREE} \end{matrix} \right\}$,

and IT, N, I are as above.

When a new record is placed in the working buffer for FREE,

LHFREE (IT, BR, BUF)

is called, where RR is negative for a carry over from a previous record.

In the standard version these last two do nothing. The working buffer, which consists of the 72 characters stored in the right hand end of the words 2 – 73 of the labelled common area /FR/ of length 76, is accessible as long as the area in FREE is actually used.

22.2 Adaptations for GYMEA

This routine is used to give input to the code the following features:

(1) All data may be punched anywhere on a card except in the few cases noted.

(2) On FORTRAN–like cards the repeat notation is discarded (as * means multiplication), and the data for each statement must be on one card only.

(3) For all other cards, repeat notation may be used, and a set of data may be continued over many cards by having a non–descending integer in column 1 for cards other than the first of a set.

(4) Input cards are stored and read from storage as a programme

(5) Cards with an '*' in column one are simply listed.

(6) Where the input cards RX etc.(*10*) are included, the standard version of FREE is used for reading.

23. ACKNOWLEDGEMENTS

The code GYMEA forms part of a larger entity now called the GYMEA PROJECT. This project is to maintain and extend a reliable nuclear data file for reactor calculations to be carried out at the A.A.E.C. Research Establishment. To this end, the talents, inspirations, and hard work of many people have gone into the project. Work of this project has been carried out over a period of several years, although the code GYMEA is of more recent origin. The authors therefore thank the following people for contributions to the project.

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Mr. J. Cook – nuclear data, particularly fission product data,

Mr. B. McGregor – scattering matrix preparation and editing programme SCATLD,

Mr. K. Maher – data transcription and preliminary correlation with experiment,

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Mrs. L. Wall – comparison of GYMEA data with the data of Hughes and Schwartz (1958),

Miss J. Robertson – organization of computer runs;

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