CCC-371
ORIGEN 2.2

OAK RIDGE NATIONAL LABORATORY

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U.S. DEPARTMENT OF ENERGY

RSICC COMPUTER CODE COLLECTION

ORIGEN 2.2

Isotope Generation and Depletion Code

Matrix Exponential Method

Contributed by:

Oak Ridge National Laboratory
Oak Ridge, Tennessee

RADIATION SAFETY INFORMATION COMPUTATIONAL CENTER

Documentation for CCC-371/ORIGEN 2.2 Code Package

(June 2002)

RSICC COMPUTER CODE CCC-371

1. NAME AND TITLE

ORIGEN2 V2.2: Isotope Generation and Depletion Code) Matrix Exponential Method. New ORIGEN users are advised to consider requesting CCC-702/ORIGEN-ARP.

2. CONTRIBUTOR

Oak Ridge National Laboratory, Oak Ridge, Tennessee.

3. CODING LANGUAGE AND COMPUTER

Fortran; Pentium PC (Windows and Linux), DEC Alpha, Sun (C00371ALLCP03).

4. NATURE OF PROBLEM SOLVED

ORIGEN is a computer code system for calculating the buildup, decay, and processing of radioactive materials. ORIGEN2 is a revised version of ORIGEN and incorporates updates of the reactor models, cross sections, fission product yields, decay data, and decay photon data, as well as the source code. ORIGEN2.1 replaces ORIGEN2 and includes additional libraries for standard and extended-burnup PWR and BWR calculations, which are documented in ORNL/TM-11018.

ORIGEN2.1 was first released in August 1991 and was replaced with ORIGEN2 Version 2.2 in June 2002. Version 2.2 was the first update to ORIGEN2 in over 10 years and was stimulated by a user discovering a discrepancy in the mass of fission products calculated using ORIGEN2 V2.1. Code modifications, as well as reducing the irradiation time step to no more than 100 days/step reduced the discrepancy from ~10% to 0.16%. The bug does not noticeably affect the fission product mass in typical ORIGEN2 calculations involving reactor fuels because essentially all of the fissions come from actinides that have explicit fission product yield libraries. Thus, most previous ORIGEN2 calculations that were otherwise set up properly should not be affected.

No new development is planned for ORIGEN2. New ORIGEN users are advised to consider requesting the CCC-702/ORIGEN-ARP package, which is a PC code system for Windows 95/NT or later and includes a GUI and a graphics program.

5. METHOD OF SOLUTION

ORIGEN uses a matrix exponential method to solve a large system of coupled, linear, first-order ordinary differential equations with constant coefficients.

ORIGEN2 has been variably dimensioned to allow the user to tailor the size of the executable module to the problem size and/or the available computer space. Dimensioned arrays have been set large enough to handle almost any size problem, using virtual memory capabilities available on most mainframe and 386/486 based PCS. The user is provided with much of the framework necessary to put some of the arrays to several different uses, call for the subroutines that perform the desired operations, and provide a mechanism to execute multiple ORIGEN2 problems with a single job.

6. RESTRICTIONS OR LIMITATIONS

No detailed documentation for guiding a novice user is provided.

7. TYPICAL RUNNING TIME

All five sample problems ran in about 1 minute on a Pentium IV 1.6GHZ.

8. COMPUTER HARDWARE REQUIREMENTS

Version 2.2 runs on Pentium PCs, Sun, and DEC Alpha workstations.

9. COMPUTER SOFTWARE REQUIREMENTS

Executables are included for Windows and Linux PCs. All other systems require a Fortran compiler. The Windows executables were created on a Pentium IV in a DOS window of Windows2000 with the Lahey/Fujitsu Fortran 95 Compiler Release 5.50d compiler. They were also tested under WindowsXP. The code was tested on a Pentium III running RedHat Linux 6.1 with The Portland Group, Inc. (PGI) F77 compiler 3.1-3 & gcc. The PGI executables are included in the Linux distribution. ORIGEN22 was also tested on DEC 500 AU under Digital Unix 4.0D with the DEC Fortran 5.1-8 compiler and on a Sun SparcStation under SunOS 5.6 using f77 5.0. Unix users may need to modify date and time subroutine calls.

10. REFERENCES

a) Included in documentation:

A. G. Croff, "ORIGEN2 Code Package CCC-371," Informal Notes (October 1981).

A. G. Croff, "A User's Manual for the ORIGEN2 Computer Code," ORNL/TM-7175 (July 1980).

A. G. Croff, "ORIGEN2: A Versatile Computer Code for Calculating the Nuclide Compositions and Characteristics of Nuclear Materials," *Nucl. Technol.*, 62, p 335 (September 1983).

Scott Ludwig, Correction to *Nucl. Technol.* (September 1983) article.

Scott Ludwig, "ORIGEN2, Version 2.1 (August 1, 1991) Release Notes."(Revised May 1999).

Scott Ludwig, “Revision to ORIGEN2 - Version 2.2,” transmittal memo (May 23, 2002).

b) Background information:

S. B. Ludwig, J. P. Renier, "Standard- and Extended-Burnup PWR and BWR Reactor Models for the ORIGEN2 Computer Code," ORNL/TM-11018 (December 1989).

11. CONTENTS OF CODE PACKAGE

Included are the referenced documents in (10.a) and a CD which contains a self-extracting, compressed Windows file and a GNU compressed tar file. The distribution files include source code, executables for Windows and Linux PCs, libraries, batch files, information files, and sample problem input, plus output from the sample problem.

12. DATE OF ABSTRACT

February 1982; revised December 1982, January 1985, July 1985, August 1985, January 1986, January 1987, October 1987, January 1989, September 1989, September 1990, May 1991, August 1991, July 1995, February 1996, August 1996, May 1999, June 2002.

KEYWORDS: ISOTOPE INVENTORY; FISSION PRODUCT INVENTORY; MICROCOMPUTER; MULTIGROUP; NEUTRON; GAMMA-RAY SOURCE

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

October 5, 1981

To: RSIC Codes Coordinator

From: A. G. Croff AGC

Subject: ORIGEN2 Code Package CCC-371 (INFORMAL NOTES)

As a result of user feedback and internal examination of the uses of ORIGEN2, a number of corrections and minor modifications have been made to ORIGEN2. Attachment 1 to this memo describes the corrections that have been made to rectify errors discovered in the ORIGEN2 code, its data bases, and the original sources of input data. I believe that all of the changes, except the second item, can be made by users that already have ORIGEN2 operating.

Attachment 2 to this memo lists a series of minor modifications that have been made to the code to enhance the usefulness of ORIGEN2. Although many of these changes could be made by an ambitious user, they are probably best accommodated by having the user reacquire the ORIGEN2 code package.

As noted in Attachment 2, the pages of the user's manual affected by the corrections and modifications have been changed in a corresponding manner. A copy of the altered pages has been included as Attachment 3 to this memo. You should note that the pages on both sides of a physical sheet in the user's manual have been included in Attachment 3 to facilitate two-sided copying even though only one of the pages actually was changed.

As a result of the corrections and changes given in Attachments 1 and 2, plus the addition of cross section libraries for thorium-cycle LMFBRs, it was necessary to recreate the tape containing the ORIGEN2 code package. This has been completed and the new code package is on X20742, which is an 800 BPI standard label tape. All files have DSN=ORIGEN2. The first 63 files have DCB=(RECFM=FB,LRECL=80,BLKSIZE=2000) and the last seven files have DCB=(RECFM=FB,LRECL=133,BLKSIZE=2660). As noted in Attachment 2, the sample problem output has been redone to reflect the corrections and modifications described herein. I have enclosed as Attachment 4 a listing of file 1 of the new ORIGEN2 tape, which is a table of contents for the tape.

Finally, it would aid users significantly if you would include Appendix A of the ORIGEN2 user's manual (ORNL/TM-7175), which is the sample problem listing as corrected by Attachment 3 to this memo, in the documentation for CCC-371.

AGC:il

4 attachments

cc: K. J. Notz
AGC File

UCN-430

CORRECTIONS MADE IN ORIGEN2 AS OF SEPTEMBER 1981

1. An erroneous recoverable heat value (0.2 MeV/disintegration) was included in the distributed decay library for Cm-242. The correct value is 6.2158 MeV/disintegration.

2. Two different types of errors have been discovered in the bremsstrahlung contribution to the ORIGEN2 photon libraries.

   a. The following nuclides had the bremsstrahlung for metastable states added to the ground state: As-82, Nb-98, Rh-110, Cd-120, In-122, Sb-128, Sb-132, I-136, and Np-236.

   b. The following nuclides had duplicate bremsstrahlung data included in the photon library: Mn-58, Pm-148m, Pm-148, Ir-194, Pb-214, Bi-214, Th-234, Pa-234m, Pa-234, Np-238, Np-240, U-240, Pu-241, Pu-243, Sr-90, Y-90, Tc-99, Ru-106, and Cs-135.

   It should be noted that only the bremsstrahlung data were affected and thus the gamma-ray data are correct. This problem can only be corrected by obtaining new libraries from RSIC.

3. It was discovered that subroutine FUDGE was not assigning the burnup-dependent cross sections properly in cases where DEC commands were interspersed in relatively few IRP or IRF commands during and irradiation calculation. The following changes in subroutine FUDGE will correct this:

   a. Insert the following statement as the first executable statement:

   ```
   KIRR = MIRR + 1 .
   ```

   b. Change the first statement following statement label 199 from

   ```
   IF(MIRR.GT.0)VECT(MIRR) = VECTOT
   ```

   to

   ```
   VECT(KIRR) = VECTOT .
   ```

   c. Change the third card (second executable statement) after statement label 300 from

   ```
   IF(VECT(MIRR).GT.ERR)XAN=POWER*DELT/(86400.0*VECT(MIRR))
   ```

   to

   ```
   IF(VECT(KIRR).GT.ERR)XAN=POWER*DELT/(86400.0*VECT(KIRR)) .
   ```

4. At the beginning portion of the executable statements in subroutine NUDAT1, move the statement LPUN=1 down so that it follows the card reading DO 1 LITYP=2,4 instead of preceding it.

5. It was pointed out that an erroneous water density was used in calculating the activation ratios for the endpieces of a BWR (see ORNL/TM-6055). It is estimated that the ratios should be reduced by a factor of three.

6. In subroutine PHOLIB, the use of 18-energy-group photon libraries results in ORIGEN2 attempting to write beyond the bottom of a page when the library is being listed. This can be remedied by changing the card following statement label 103 from

```
IF(MOD(IP,50).NE.0)GO TO 106
```

to

```
IF(MOD(IP,25).NE.0)GO TO 106 .
```

7. The sample output deck included in the ORIGEN2 package and the listing in the user's manual (ORNL/TM-7175) were inconsistent and required the following corrections:

   a. In both the listing and the sample deck on the ORIGEN2 tape, card 239 should read

      ```
      PRO    10 4 -2 -2    PUT HLW IN -2 .
      ```

   b. In the sample deck card 245 should read

      ```
      HED    1    *    HLW .
      ```

   c. In both the listing and sample deck cards 296 through 300 should be changed so that the library numbers are 204, 205, and 206 instead of 21, 41, and 61, respectively.

   d. In both the listing and sample deck cards 303 and 305 should have the rightmost 0.0 deleted.

   e. In both the listing and sample deck cards 304 and 306 should have the nuclide identifier (380900 or 551370) replaced by 0.0.

8. The switching between output units provided by the OUT command was found to work incorrectly in the case where photon libraries were not employed. This can be corrected in subroutine MAIN3 by the following changes:

   a. Alter the fifth card following statement label 513 from

      IF(NSIZE(20).LT.1)GO TO 511

      to

      IF(NSIZE(20).LT.1)GO TO 515 .

   b. Insert the following new statement immediately following the call to subroutine GAMMA (i.e., make this the ninth card following statement label 513):

      515 CONTINUE .

9. Although there are conflicting data, it appears that the decay branching for Zr-98 is in error in the decay library. The fraction of Zr-98 decaying to the metastable state of Nb-98 (parameter FBX in Table 5.1 of the user's manual) should be changed to 0.0 from its current value of 1.0.

11. Two users with a penchant for following the details of very complex subroutines have discovered errors in subroutines DECAY and TERM. Based on this, the following changes are recommended:

   a. The parameter DJ should be changed to DK on cards DECA 750 and TER 1110.

   b. Card TER 1770 should be changed from

      AJ=AJ+AP(N)

      to

      AJ=AJ+AP(N)*T .

   c. Card TER 1840 should be changed from

      NLARGE = 3.5*ASUM + 5.0

      to

      NLARGE = 3.5*ASUM + 6.0 .

The net effect of these changes is to make these subroutines technically correct. However, we have been unable to find any effect of the changes on ORIGEN2 results.

12. It was noted that the initialization of arrays IS and STTFPB in subroutine MAIN3 could potentially destroy information that should be retained. This can be corrected by the following:

    a. Change the first executable statement in MAIN3 from

    ```
    IF(NSTP.GT.0.AND.NSTP.LT.4)GO TO 11
    ```

    to

    ```
    IF(NREC.GE.0)GO TO 11 .
    ```

    b. Inserting the statement DATA NREC/-1/ in the BLOCK DATA subroutine.

13. In subroutine OUT2 statement label 290, which currently reads

```
290 IF(DIS(I).LE.2.1965E-08)
     $XA(M)=XNEW(M,I)*DIS(I)*1.6283E+13*FFA(I-ILITE)*
```

should be changed to read

```
290 IF(DIS(I).LE.2.1965E-08)
     $XA(M)=XNEW(M,I)*DIS(I)*1.6283E+13*FFA(I-ILITE)*XSAV(M) .
```

The erroneous statement would not have produced the correct values in the fractional alpha curies table.

MODIFICATIONS MADE TO ORIGEN2 AS OF SEPTEMBER 1981

1. The following modifications were made to facilitate the further processing of ORIGEN2 output:

   a. The title printed at the top of each output page now begins with an asterisk.

   b. The definition of the ORIGEN2 output table type and units now begins with an integer corresponding to the appropriate "table number" in Table 4.3.

   c. The element tables now output all elements which have at least one isotope in a given segment (e.g., activation products, actinides) instead of only those that have at least one non-zero value.

   d. The very small, negative values (on the order of -1.0×10^{-25}) have been set equal to zero in subroutine EQUIL. These values result from small, cumulative roundoff errors and are of no consequence. An error message will be printed if the absolute magnitude of a negative value exceeds 10^{-15}.

2. The principal ORIGEN2 output unit, which is indicated by a positive value for parameter NOUT(1) on the OUT command, has been changed from unit 6 to unit 8. This change is to permit messages from the computer (generally errors) to be directed to unit 6 and thus to hard copy even though the bulk of ORIGEN2 output is being written on units 8 and/or 11.

3. The following modifications have been made to the irradiation commands IRF and IRP:

   a. The IRP option to input specific power and have ORIGEN2 normalize the concentrations to a metric ton, as indicated by a negative RIRP(2), on the IRP instruction, has been eliminated due to a lack of interest. In its place a "referback" option identical to that used by the IRF command has been installed (see item 3.b immediately following for details).

b. The referback option for both the IRF and IRP commands has been changed from that described for IRF in the user's manual. Previously, the referback specified the fraction the previous flux was to be multiplied by to get the flux for the current step. A disadvantage of this was that the referback fractions were cumulative. This restriction has been alleviated by modifying ORIGEN2 so that the referbacks (flux or power) operate on the last set of irradiation commands where RIRF(2) and/or RIRP(2) were positive.

4. A new command, GTO, has been installed in ORIGEN2. The command allows the user to jump to a defined set of instructions in the ORIGEN2 input, execute these instructions, and then return to the next command following the GTO. This feature eliminates difficulties experienced with heading vectors appropriately when using the DOL command in certain situations.

5. The output unit for error messages generated by ORIGEN2 has been changed from unit 6 to unit 15. Unit 15 has been used previously for some debugging and other internal information, and this modification simply consolidates the ORIGEN2-generated messges. The subroutines where changes occurred are FLUXO, NUDAT1, NUDAT2, NUDAT3, PHOLIB, DECAY, TERM, and EQUIL.

6. Subroutine QQREAD, which was left over from a preliminary version of ORIGEN2, has been eliminated since it was not used in the current version.

7. Array NUCL, containing the list of nuclides being considered in the calculation, has been passed to subroutines DECAY, TERM, and EQUIL to facilitate debugging.

8. Extensive numbers of comment cards have been installed in subroutine DECAY to facilitate understanding of this extremely complex routine. Comment cards have also been inserted in subroutine TERM, many of which refer to those in the very-similar subroutine DECAY.

9. The (n,2n) and (n,3n) fission product cross sections for the LWR models, which were not included in the original libraries, have now been included. The cross sections were taken from ENDF/B-IV, and there are relatively few of these. The inclusion of these reactions reqoired the inclusion of several more nuclides in the ORIGEN2 decay libraries.

10. In subroutine SIGRED, the statement reading

```
IF(YESNO.LT.1.0)RETURN
```

has been changed to

```
IF(YESNO.LT.0.0)RETURN
```

to make it consistent with the user's manual.

11. Subroutine MAIN2 was modified to initialize the cutoff values for the summary tables and parameter ERR without having to use a CUT command. The previously-existing ORIGEN2 default values (see Sect. 4.9.E of the user's manual) are used in this initialization.

12. The sixteen different MAIN routines, which provide the different dimensions for ORIGEN2, have been modified in the following manner:

    a. The dimensions have been altered slightly to accommodate the changes in the decay library noted above, errors in the photon library described in the corrections list, and recognition of the necessity for handling a wider variety of cases. In general, the changes are very small.

    b. Arrays A, LOCA, and NFUDFP were moved into COMMON/BIG/ to facilitate the use of large-core memory on CDC computers. The change is transparent to other computers.

    c. Comment cards were installed in the MAINs to facilitate use and understanding of the routines.

13. ORIGEN2 has been reworked by a polishing code which has cleaned up the code internally, renumbered all of the statement labels, and numbered each card in columns 73-80. It should be noted that all statement and card numbers herein refer to the previously-existing numbers.

14. The sample problem for the RSIC tape has been redone to reflect both these changes as well as those in the corrections list.

15. Updated pages for the ORIGEN2 user's manual have been included for distribution with the new code package.

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CHEMICAL TECHNOLOGY DIVISION

NUCLEAR FUEL AND WASTE PROGRAMS

Waste Management Analysis for Nuclear Fuel Cycles
(Activity No. AP 05 25 10 0; FTP/A No. ONL-WH01)

A USER'S MANUAL FOR THE ORIGEN2 COMPUTER CODE

A. G. Croff

Date Published: July 1980

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

CONTENTS

A USER'S MANUAL FOR THE ORIGEN2 COMPUTER CODE

A. G. Croff

ABSTRACT

This report describes how to use a revised version of the ORIGEN computer code, designated ORIGEN2. Included are a description of the input data, input deck organization, and sample input and output. ORIGEN2 can be obtained from the Radiation Shielding Information Center at ORNL.

1. INTRODUCTION

ORIGEN is a widely used computer code for calculating the buildup, decay, and processing of radioactive materials. During the past few years, a sustained effort was undertaken by ORNL to update the original ORIGEN code[1] and its associated data bases. The results of this effort were updates of the reactor models, cross sections, fission product yields, decay data, decay photon data, and the ORIGEN computer code itself.[2-5] The object of interest in this report is the revised version of the ORIGEN computer code, which is called ORIGEN2. Specifically, this report constitutes a detailed user's manual for ORIGEN2.

Section 2 of this report describes several general considerations that differentiate ORIGEN2 from the original version of ORIGEN. These general considerations are very important since (1) their effect is to give ORIGEN2 an outward appearance which is radically different from the original version, and (2) they must be fully understood if the user is to comprehend the rest of the user's manual.

Section 3 describes the nature of several types of data that are initialized before any irradiation or decay calculations are performed. The methods for altering these data are also described in this section.

Section 4, which is the heart of the user's manual, describes the instructions whereby the user directs ORIGEN2 to perform the calculations required to achieve the desired results. It is at this point that the increased flexibility and the more voluminous input requirements of ORIGEN2 become most evident.

Section 5 describes the contents and formats of the decay, cross section/fission product yield, and photon libraries used by ORIGEN2. For most users, the required libraries have been supplied along with ORIGEN2, and Sect. 5 will be of little concern. However, these descriptions are vital for those users who create their own libraries or wish to override certain values in the existing libraries.

Section 6, which is relevant to all users, describes how the initial material compositions used in ORIGEN2 are specified. The format of these data is somewhat, although not radically, different from that of the original ORIGEN.

Section 7 describes the organization of ORIGEN2 input decks for two cases: one with the data libraries on cards, and the other with the data libraries on tape or a direct-access device. This section is important because of the large number of different types of input data required by ORIGEN2 and because of the variability of the input that is required, depending on the options the user elects to invoke.

Finally, Section 8 describes a sample ORIGEN2 input deck (listed in Appendix A), generic ORIGEN2 output, and sample ORIGEN2 output (listed in Appendix B). This type of description is necessary because of the large number of isotopes and table types that can be output by ORIGEN2.

A code package containing ORIGEN2 and its data libraries can be obtained at the following address:

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

(615) 574-6176

2. GENERAL CONSIDERATIONS

2.1 ORIGEN2 MAIN

The MAIN routine of ORIGEN2 performs four major functions:

1. provides a mechanism to variably dimension ORIGEN2 to accommodate different problem sizes,
2. provides much of the framework necessary to put some of the arrays to several different uses,
3. calls for the subroutines that perform the desired operations, and
4. provides a mechanism to execute multiple ORIGEN2 problems with a single job.

The third function is handled automatically and will not be discussed. The fourth function is discussed in Sect. 4.29.

ORIGEN2 has been variably dimensioned to allow the user to tailor the size of the executable module to the problem size and/or the available computer space. The size of the ORIGEN2 executable module ranges from about 175K (1K = 1024 bytes = 256 single precision words) to about 600K, principally depending on the number of nuclides being considered.

Figure 2.1 gives a listing of ORIGEN2 MAIN with alphabetic character strings (e.g., CCCC) substituted for numerical array dimensions. A description of each of these array dimensions is given in Table 2.1. The required size of these dimensions principally depends on the number of nuclides being considered in a given case. These nuclides are grouped into three segments as follows:

1. Activation products, which consist of nearly all naturally occurring nuclides, their neutron absorption products, and the decay daughters of these products. This segment is principally used to handle structural materials (e.g., Zircaloy) and fuel impurities.
2. Actinides, which contain the isotopes of the elements thorium (atomic number 90) through einsteinium (atomic number 99) that appear in significant amounts in discharged reactor fuels plus their decay daughters.

```
      LOGICAL   LONG
      INTEGER*2 LOCA,NONO,KD,LOC,NGF,NGM,NGR,NYIELD,NONP,NQ,MMAX,KAP,
     $LOCP,NFUDFP
      DOUBLE PRECISION CIEN,CSUM
      DIMENSION XNEW(AAAA,BBBB),COEFF(CCCC,BBBB),NPROD(CCCC,BBBB),
     $MMAX(BBBB),KAP(BBBB)
      DIMENSION STTYPB(JJJJ,10),ISTOTI(JJJJ,03),IS(JJJJ),ESTOTI(JJJJ)
      DIMENSION A(DDDD),LOCA(DDDD),NFUDFP(FFFF,OOOO)
      DIMENSION DR(NNNN),ER(NNNN),FR(NNNN)
      DIMENSION YIELD(EEEE),NYIELD(FFFF),RMULT(NNNN,3)
      DIMENSION ALPHN(GGGG),NUCAN(GGGG),NUCSFU(GGGG),NY(GGGG),YY(GGGG),
     $FFSF(GGGG),FFA(GGGG)
      COMMON /JUNK/ERR,IDB(1),ILITE,IACT,IFP,ITOT,ILMAX,IAMAX,IFMAX,
     $ITMAX,IZMAX,AXN,OXN,FLUX,POWER,INDEX,TYPEAV(4),IPMMAX
      COMMON /MAIN03/NSTP,ANMUL,ANEXP,NABMAX,        ICNMAX,IAPMAX,IFYMAX
C 1766 WORDS ARE NECESSARY IN /NUDSCR/ BEGINNING WITH S
C /NUDSCR/ IS USED FOR MULTIPLE PURPOSES.
      COMMON /NUDSCR/DUM1(CCCC,BBBB),DUM2(MMMM,BBBB),S(2),CIEN(BBBB),
     $ CSUM(BBBB),NONP(BBBB),NQ(BBBB),XP(BBBB),XPAR(BBBB),XTEMP(BBBB),
     $ D(BBBB),AP(IIII),LOCP(IIII),LONG(BBBB)
      COMMON /BIG/NUCL(BBBB),Q(BBBB),FG(0004),TOCAP(BBBB),GENNEU(GGGG),
     $ALPHAN(GGGG),SPONF(GGGG),SPNU(GGGG),FISS(GGGG),NUCAB(BBBB),
     $AMPC(BBBB),NMPC(BBBB),XSTORE(JJJJ,BBBB),DIS(BBBB),B(BBBB),
     $ABUND(KKKK),NONO(BBBB),KD(BBBB),LOC(DDDD),NGF(BBBB),NGM(BBBB),
     $NGR(LLLL),GGR(LLLL)
C DR,ER, AND FR PROVIDE A CONVENIENT MECHANISM FOR INITIALIZING VARIABLE
C MULTIPLIER ARRAY RMULT.
      EQUIVALENCE (DR(1),RMULT(1,1)),(ER(1),RMULT(1,2)),
     $(FR(1),RMULT(1,3))
      EQUIVALENCE (DUM1(1,1),COEFF(1,1)),(DUM2(1,1),NPROD(1,1)),
     $(NONP(1),MMAX(1)),(KAP(1),NQ(1)),(XNEW(1,1),DUM1(1,1))
      EQUIVALENCE (XP(1),ALPHN(1)),(ALPHN(GGGG),NUCAN(1)),(NUCAN(GGGG),
     $NUCSFU(1)),(NUCSFU(GGGG),NY(1)),(NY(GGGG),YY(1)),(YY(GGGG),
     $FFSF(1)),(FFSF(GGGG),YIELD(1)),(YIELD(EEEE),NYIELD(1))
      CALL Q105F(6)
C INITIALIZE PAGE COUNTER
      NPAGE=IPAGE(0)
      LX= JJJJ
      NX= AAAA
      LC= CCCC
      ILMAX= MMMM
      IAMAX= GGGG
      IFMAX= FFFF
      ITMAX= BBBB
      IZMAX= DDDD
      IPMMAX=LLLL
      IAPMAX=IIII
      IFYMAX=EEEE
      NABMAX=KKKK
      ICNMAX=OOOO
      IFC= FFFF
      LAB=NNNN
C NEUTRONS PER NEUTRON-INDUCED FISSION: 0=THERMAL SPECTRUM; 1=FAST SPECTRUM
      NYTP=1
      NYTP=0
C CALL SUBROUTINE TO READ CARD INPUT FROM UNIT 5, PRINT IT ON UNIT 6, AND
C WRITE IT ON UNIT 50.  UNIT 50 IS THEN REWOUND AND ORIGEN2 READS THE DATA
C FROM UNIT 50.
      CALL LISTIT(5,6,50)
      REWIND 50
C MAIN1 HANDLES THE MISCELLANEOUS INITIALIZATION DATA
    1 CALL MAIN1(NYTP,SPNU,ALPHN,NUCAN,NUCSFU,NY,YY,ANMUL,ANEXP)
C MAIN2 READS THE ORIGEN2 COMMANDS
    2 CALL MAIN2(NSTP)
C MAIN3 EXECUTES THE ORIGEN2 COMMANDS
    3 CALL MAIN3(
     $ LONG,STTYPB,ISTOTI,IS,ESTOTI,  LX, NX, LC,IFD,
     $NUCAB,NONO,KD,LOC,NGF,NGM,NGR,NYIELD,NONP,NQ,LOCP,MMAX,KAP,
     $LOCA,NFUDFP,     CIEN,CSUM,                 S,
     $NUCL,Q,FG,TOCAP,GENNEU,ALPHAN,SPONF,SPNU,FISS,AMPC,NMPC,XSTORE,
     $DIS,B,GGR,YIELD,A      ,XP,XPAR,XTEMP,D,AP,COEFF,NPROD,    XNEW,
     $ALPHN,NUCAN,NUCSFU,NY,YY,FFSF,FFA,ABUND,RMULT,LAB)
C THIS "GO TO" PROVIDES THE MECHANISM FOR EXECUTING MULTIPLE PROBLEMS WITHIN
C A SINGLE JOB.
      GO TO (1,2,3,4),NSTP
    4 CONTINUE
      CALL Q105F(6)
      STOP 100
      END
```

Fig. 2.1. Generic ORIGEN2 MAIN subprogram.

Table 2.1. Description of alphabetic array dimensions in Fig. 2.1

Alphabetic character string in Fig. 2.1	Description
AAAA	Number of output vectors, i.e., MN in XNEW (MX,ITMAX)
BBBB	Maximum number of nuclides = ITMAX
CCCC	Maximum number of non-zero cross-section and decay reactions per nuclide = LC in COEFF(LC,ITMAX)
DDDD	Total number of non-zero matrix elements (Array A)
EEEE	Number of non-zero fission product yields
FFFF	Maximum number of fission products = IFMAX
GGGG	Maximum number of actinides + 1 = IAMAX
HHHH	13 - LC (See C above)
IIII	Maximum number of non-zero elements for long-lived nuclides (Array AP)
JJJJ	Number of storage vectors = LMX in XSTORE(MX,ITMAX)
KKKK	Number of non-zero natural abundances
LLLL	Number of non-zero photon yields
MMMM	Maximum number of light nuclides = ILMAX
NNNN	Maximum number of variable multipliers in RMULV
OOOO	Number of actinides with both direct fission product yields and a variable fission cross section (usually 3; can be 4 for plutonium-enriched thorium fuels)

3. Fission products, which consist of nuclides produced by actinide fission plus their decay and capture products.

The meaning of the word "vectors" in Table 2.1 is discussed in Sect. 2.4.

ORIGEN2 keeps track of and prints the minimum required size of most of the variably dimensioned arrays (see Sect. 8.2.2). A summary of the recommended dimensions for several problem sizes is given in Table 2.2. The magnitude of the dimensions is dependent on the number of actinide nuclides having direct fission product yields, which can range from zero to eight (see Sect. 4.18). Dimensions are given in Table 2.2 for cases with 0, 4, 6, and 8 actinides having direct fission product yields.

The variable NYTF in MAIN (see Fig. 2.1) indicates whether thermal reactor (NYTF = 0) or fast reactor (NYTF = 1) neutron yields per neutron-induced fission are to be used (see also Sect. 3.1).

The variables RMULV, DR, ER, FR, and LAM are related to a multiplier used by the MOV (Sect. 4.12) and ADD (Sect. 4.13) commands. LAM is the number of possible multipliers (presently four) in a given set of multipliers. These are specified by initializing variables DR (first set), ER (second set), and FR (third set) using DATA statements in MAIN. Variables DR, ER, and FR are equivalenced to the appropriate portion of RMULV. The variable LAM is passed in subroutine parameter lists for variable dimensioning purposes.

2.2 ORIGEN2 Free-Format Input

With few exceptions, all of the input data to ORIGEN2 can be specified in free format. The free-format read routines are modifications of those written by L. M. Petrie.[6] The restrictions on free-format input are as follows:

1. All data must appear in the correct order.
2. All data must be of the correct type (e.g., integer or real) and may be in I, F, E, or D format.
3. Each datum must be separated from the next by a comma and/or at least one space.

Table 2.2 Dimensions for various ORIGEN2 case sizes

Parameter	Case 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Segments considered[a]	AP+A+FP	AP+A+FP	AP+A+FP	A+FP	A+FP	A+FP	AP+A	A	AP	AP+A+FP	A	AP	FP	A+FP or A+AP	AP+A+FP	AP+A+FP
Type of calculation[b]	Any	Any	Any	Any	Any	Any	Any	Any	Any	Decay	Decay	Decay	Decay	Any	Any	Any
Number of actinides with direct fission product yields	4	6	8	4	6	8	0	0	0	0	0	0	0	4	6	4
Alphabetic array dimensions[c]																
AAAA	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
BBBB[d]	1676	1676	1676	1000	1000	1000	820	132	700	1676	132	700	880	1000	1676	1676
CCCC	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
DDDD[d]	6400	7900	9600	5000	6600	8200	1800	400	1500	1700	280	600	1000	5000	8000	9996
EEEE[d]	3300	5000	6600	3300	5000	6600	4	4	4	4	4	4	4	3300	5000	6600
FFFF[d]	800	880	880	880	880	880	4	4	4	800	4	4	880	880	880	800
GGGG[d]	132	132	132	132	132	132	132	132	4	132	132	4	4	132	132	132
HHHH	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
IIII[d,e]	3500	4200	5000	2500	3100	3800	1700	500	1300	600	500	250	250	2500	4500	4500
JJJJ	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
KKKK[d]	450	450	450	160	160	160	300	12	300	450	12	300	160	300	450	450
LLLL[d]	8000	8000	8000	4700	4700	4700	4700	1500	3300	8000	1500	3300	3300	4700	8000	8000
MMMM[d]	700	700	700	4	4	4	700	4	700	700	4	700	4	700	700	700
NNNN[d]	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
OOOO[f]	3	4	4	4	4	4	3	3	3	3	3	3	3	3	4	6
Approximate amount of core required for execution (bytes)[g]	546	560	576	396K	412K	420K	332K	182K	290K	494	182K	286K	324K	396K	560K	576K

[a]AP = activation products; A = actinides and daughters; FP = fission products.

[b]Any = either irradiation (i.e., IRP or IRF commands) or decay (i.e., DEC command) can be used. Decay = no irradiation; decay only.

[c]See Table 2.1 and Fig. 2.1 for details on the description and use of these dimensions.

[d]Array dimension should be evenly divisible by 4 to ensure word boundary alignment.

[e]Larger dimensions may be required for small irradiation or decay time step. In the limit of zero time, IIII = DDDD.

[f]Depends on reactor being considered; see Table 2.1, item OOOO.

[g]Can vary, depending on the number of input/output units and buffer sizes.

4. Zero data values must appear explicitly (i.e., a blank is not equivalent to a zero).
5. In general, data may be continued onto multiple records when desired.
6. Certain data must appear as the first datum on a new record. These instances are described later.
7. The maximum record length is 80 bytes.
8. If an end of file is read, control is returned to the calling subroutine.

Thus, in general, the data being read must be in the correct order, must begin on a new card when required, and must be separated by a comma or blank. Other than this, the data may appear anyplace on an input record. In the special case of numbers in E or D format (e.g., 3.8E 01), the space after the E is acceptable and is not considered as the end of the number.

2.3 The ORIGEN2 "Command" Concept

The use of "commands" is one of the principal differences between ORIGEN2 and previous versions of ORIGEN. An ORIGEN2 command directs the computer code to execute a single function, such as a single irradiation step. A series of interrelated commands is generally required to obtain a meaningful result. The series of commands typically ranges from 25 to 200 in number and is similar in logic to a program written in a computer language such as FORTRAN. Thus, the series of commands very much resembles a program which is read and executed by ORIGEN2. The implementation of the command concept in ORIGEN2 is advantageous in that it allows a user to simulate a wide variety of nuclear fuel cycle scenarios in detail, including recycle calculations. The accompanying disadvantage is that the required input is more detailed and more specific than in previous versions of ORIGEN. The currently available ORIGEN2 commands are defined and discussed in Sect. 4.

2.4 The Concept of an ORIGEN2 "Vector"

Before attempting to describe the operational details of ORIGEN2, it is important that the user understand the concept of an ORIGEN2 "vector." An ORIGEN2 vector is a one-dimensional array that specifies the amount of each nuclide being considered in an ORIGEN2 case; it is printed as a single column of numbers in ORIGEN2 output. For example, in Case 1 in Table 2.2, which includes actinide, activation product, and fission product nuclides, a vector might specify the amounts of all these nuclides in a spent PWR fuel assembly after 150 days post-irradiation decay time. In this case, the amounts of about 1676 nuclides (dimension BBBB in Tables 2.1 and 2.2) corresponding to these conditions would be specified in the vector. A schematic diagram of the conceptual vector organization in ORIGEN2 is shown in Fig. 2.2. Two basic types of vectors are accessible to the user: output vectors, and storage vectors.

Twelve output vectors are contained in ORIGEN2. These vectors are written when ORIGEN2 output is produced. Each of the vectors is designated by using positive integers corresponding to the relative location of the vector, with the leftmost vector on the output page being vector 1 and the rightmost vector 12. The information in the output vectors is retained under all conditions except one. This exception occurs when a new set of ORIGEN2 commands is read during a single run using the STP command (Sect. 4.29) and the new set of commands includes a LIB command (Sect. 4.18), which reads new ORIGEN2 decay and cross-section data libraries. In this case, the array containing the output vectors is used as scratch space to read the new libraries and the nuclide mass data are lost.

There are a variable number (LX) of storage vectors in ORIGEN2, depending on the variable dimensions employed (see variable JJJJ in Table 2.1). These vectors are used to store intermediate ORIGEN2 results and cannot be output. The vectors are designated by using negative integers from -1 to -LX. The information in the storage vectors is retained under all circumstances, including those where the output vectors are overwritten.

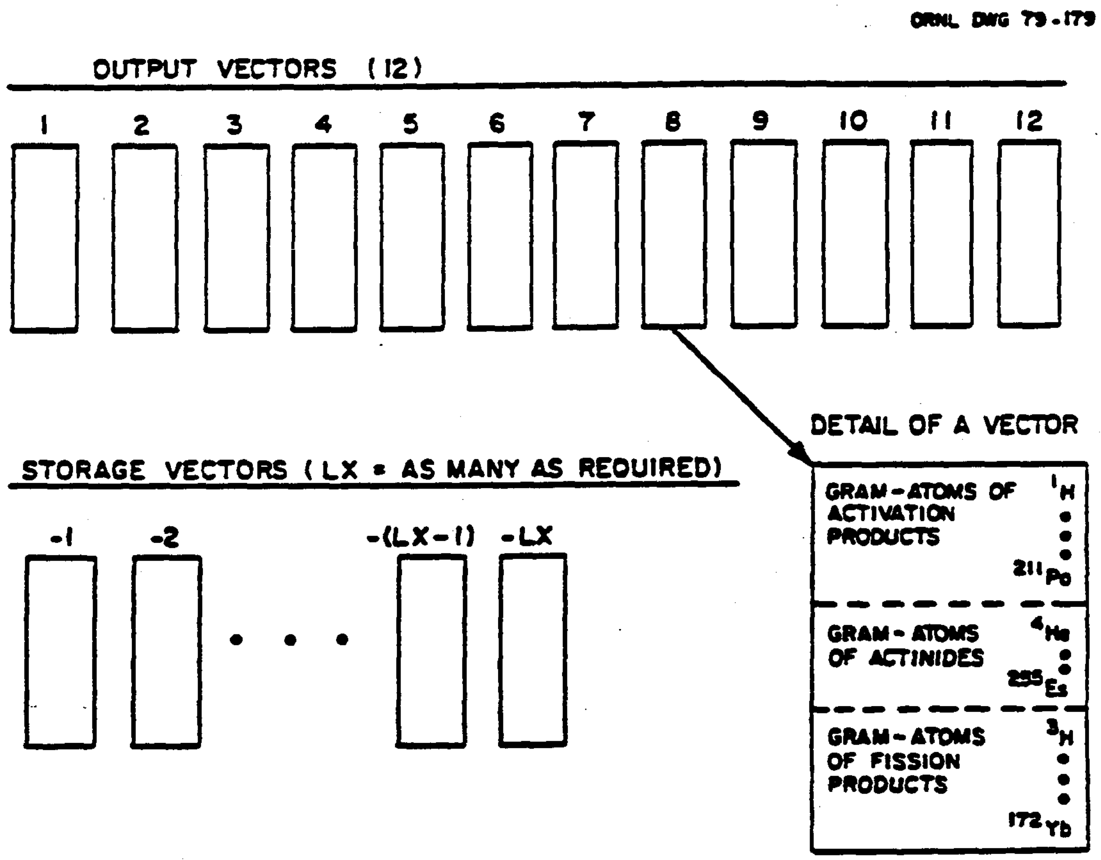

Fig. 2.2. Organization of ORIGEN2 vectors.

2.5 Description of ORIGEN2 Input/Output Units

ORIGEN2 uses several input and output units to facilitate orderly and flexible code operation. These units and their functions are given in Table 2.3. For a basic ORIGEN2 calculation, units 5, 6, 12, and 50 would be necessary, and the rest of the units could be dummied or omitted. The units not used in the basic calculation are required to execute certain ORIGEN2 commands or to provide useful auxiliary information.

2.6 Card Input Echo

ORIGEN2 has included in it a SUBROUTINE LISTIT, which has the function of providing a card input echo. The cards are read on unit 5, printed on unit 6, and written to unit 50, which is a temporary file. Cards that have a dollar sign ($) in the first column of the card are printed (on unit 6) but not written (on unit 50), thus allowing for the inclusion of comments in the input stream that will not interfere with the operation of ORIGEN2. Unit 50 is then rewound, and the rest of ORIGEN2 reads this information from unit 50. The units 5, 6, and 50 appear explicitly in the call to LISTIT, which occurs in MAIN. Thus, if the unit numbers given in Table 2.3 are altered, the unit definitions in the LISTIT parameter list in MAIN must also be changed correspondingly.

2.7 ORIGEN2 Nuclide Identifier

The ORIGEN2 nuclide identifier is a six-digit integer that uniquely defines a particular nuclide. This identifier, which is identical with that in the original ORIGEN, is defined as follows:

NUCLID = 10000*Z + 10*A + IS,

where

NUCLID = six-digit nuclide identifier

Z = atomic number of nuclide

Table 2.3. Description of ORIGEN2 input/output units

Unit number	Description	Remarks
3	Substitute data for decay and cross-section libraries	Specified by LIB command, Sect. 4.18
4	Alternate unit for reading material compositions	See Sect. 4.6
5	Card reader	Specified in MAIN in call to LISTIT
6	Principal output unit; usually directed to line printer	Specified in BLOCK DATA, variables = IOUT, JOUT, KOUT; see Sect. 4.6
7	Unit to write an output vector	Used by PCH command, Sect. 4.15
9	Decay and cross-section library	Specified by LIB command, Sect. 4.18
10	Photon library	Specified by PHO command, Sect. 4.19
11	Alternate output unit; usually directed to line printer	See Sect. 4.5
12	Table of contents for unit 6 above; usually directed to the line printer	Specified in BLOCK DATA, variable = NTOCA
13	Table of contents for unit 11; usually directed to line printer	Specified in BLOCK DATA, variable = NTOCB
15	Print debugging information	
16	Print variable cross-section information	
50	Data set used to temporarily store input read on unit 5	Specified in BLOCK DATA, variable = IUNIT

A = atomic mass of nuclide
IS = isomeric state indicator
0 = ground state
1 = excited state
2 or greater not permitted

Thus, the nuclide identifier for ^{137}Cs (Z = 55, A = 137) would be 551370. The trailing zero (or one) is always required. A leading zero, such as for tritium (NUCLID = 010030), is not required. The six-digit identifier for an element is given by

$$ELEMID = 10000*Z,$$

where ELEMID is the element identifier and Z is defined as above. Thus, the ELEMID for cesium would be 550000.

2.8 Machine Compatibility Considerations

ORIGEN2 has been designed to be as machine-compatible as is possible by using only the FORTRAN computer language, using only standard FORTRAN functions (e.g., SQRT, etc.), using H format specifications for literal data in FORMAT and DATA statements, and minimizing the number of partial-word (i.e., one-byte and two-byte word) arrays. However, in the interest of minimizing space and coding complexity, some features were used that may not be acceptable on non-IBM computers. Specifically, some partial-word arrays are used.

Aspects of ORIGEN2 that are likely to require modification before implementation on other machines are as follows:

1. All partial-length word specifications must be removed for those computers where they are not permitted. These specifications are given by cards at the beginning of each subprogram, and the first characters are INTEGER*2.
2. For those computers with a word length at least twice that of the IBM computers (32 bits), the DOUBLE PRECISION declarations become optional.

3. In two places (subroutines LISTIT and QQREAD), ORIGEN2 is designed to read until an end-of-file is encountered and then branch to another operation. Accommodation of this branch is accomplished differently on different computers, and the user should check this to ensure compatibility.
4. INTEGER FUNCTION QQPACK reads input data, character by character, and constructs words from the characters. As a result of the widely varying word structure on various computers, this routine must be totally changed for each different type of computer. Versions of this subroutine are currently available for IBM and CDC computers.
5. Many non-IBM computers have relatively small core regions for the executing program and a large, directly associated memory for storing the large arrays as opposed to the IBM procedure of placing the entire executing job in core. Thus, for these computers, cards that assign the desired arrays to the directly accessed memory must be included. At the time this report is being issued, this has been accomplished for a CDC 7600 computer.[7]
6. For computers where the use of uninitialized "garbage" in assignment statements will result in errors, the core should be preset to zero.

3. MISCELLANEOUS INITIALIZATION DATA

Because the data discussed in this section are widely varied and are only related by their invariance from case to case, they are categorized as "miscellaneous initialization data." The types of data falling into this category, and the section in which each is discussed, can be summarized as follows:

Section	Data description
3.1	Fission neutron yields per neutron-induced fission
3.2	(α,n) neutron production rates
3.3	Neutron yield per spontaneous fission
3.4	Fractional reprocessing recoveries for individual elements
3.5	Fractional reprocessing recoveries for element groups
3.6	Assignment of individual elements to fractional reprocessing recovery groups
3.7	Elemental chemical toxicities

All of these data are initialized in a BLOCK DATA statement using the types of information described in the appropriate subsection below.

3.1 Fission Neutron Yield per Neutron-Induced Fission

The BLOCK DATA statement supplies spectrum-weighted single-group fission neutron yields per neutron-induced fission for a thermal reactor (PWR-U) and a fast reactor (advanced-oxide LMFBR). These data are used in calculating the infinite neutron multiplication factor for a mixture of nuclides. These data cannot be altered except by changing the values in the BLOCK DATA routine and recompiling it.

3.2 (α,n) Neutron Production Rate

The BLOCK DATA routine supplies measured (α,n) neutron production rates (units = neutrons g^{-1} sec^{-1}) for nuclides in oxide fuels which override values calculated with an empirical equation in ORIGEN2. The (α,n) neutron production rates for those nuclides not listed explicitly are calculated from an empirical equation. The parameters in the equation and the explicit values cannot be altered except by changing the values in the BLOCK DATA subroutine and recompiling it.

3.3 Fission Neutron Yield per Spontaneous Fission

The BLOCK DATA routine supplies measured neutron yields per spontaneous fission which override values calculated with an empirical equation in ORIGEN2. These neutron yields, denoted as SF yields, are used to calculate the decay neutron activity of nuclide mixtures. The SF neutron yields for those nuclides not given explicitly are calculated from an empirical equation. These initialization data cannot be altered except by changing the values in the BLOCK DATA routine and recompiling it.

3.4 Fractional Reprocessing Recoveries for Individual Elements

3.4.1 Initialization values

The BLOCK DATA subroutine supplies reprocessing fractional recoveries (FRs) for each individual element. The FRs are used to separate a specified elemental composition into two separate streams. The individual element FRs initially present in ORIGEN2 are given in Table 3.1. A single FR set specifies an FR for each of 99 elements. There are ten sets of individual FRs in ORIGEN2.

The individual FR sets also serve another purpose under certain circumstances. If one or more WAC commands (see Sect. 4.17) are used, then at least one individual-element or element-group (see Sect. 3.5) FR set must contain continuous removal rates for the elements in units

Table 3.1. ORIGEN2 default individual-element fractional recoveries

Element	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10
	Fractional recoveries									
H	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.9	1.0
He	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	1.0
Li-B	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
C, N	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	1.0
O	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
F	0.0	0.001	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Ne	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	1.0
Na-S	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Cl	0.0	0.001	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Ar	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	1.0
K-Se	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Br	0.0	0.001	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Kr	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	1.0
Rb-Te	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
I	0.0	0.001	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Xe	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	1.0
Cs-At	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Rn	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	1.0
Fr-Ac	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Th	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
Pa	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	1.0
U	0.995	1.0	0.0005	0.999	1.0	0.2	0.6	1.0	0.0	1.0
Np	0.0	1.0	0.0005	0.0	0.05	0.05	0.0	0.0	0.0	1.0
Pu	0.995	1.0	0.0005	0.9999	1.0	0.02	0.0	0.0	0.0	1.0
Am-Es	0.0	1.0	0.0005	0.0	0.001	0.001	0.0	0.0	0.0	1.0

of sec^{-1}. The continuous removal rates specified in the FR set are those appropriate for a reactor with continuous fuel reprocessing (e.g., an MSBR). The specified continuous removal rates are used by the WAC command to generate equivalent continuous feed rates of waste during waste decay.

In either of the above cases, the initial data can be altered by using the methods described below.

3.4.2 Overriding initial values

The default FRs for individual elements can be overriden by using the following procedure:

A. Function: Overrides individual-element FR supplied in the BLOCK DATA subroutine.

B. Data sequence:

```
NE(1)       NS(1)       FR(1)
  .           .           .
  .           .           .
  .           .           .
NE(M)       NS(M)       FR(M)
  .           .           .
  .           .           .
  .           .           .
NE(MMAX)    NS(MMAX)    FR(MMAX)
-1
```

where

NE(M) = one- or two-digit element atomic number (1-99) for the fractional recovery on the Mth card

NS(M) = set number (1-10) for the individual fractional recovery on the Mth card

FR(M) = fractional recovery replacing the initial value for element NE(N) in set NS(N)

MMAX = number of individual-element fractional recoveries being overriden (can be zero)

C. Number of cards: MMAX+1

D. Terminate reading these data: NE(MMAX+1).LT.0

E. Skip reading these data: One card with NE(1).LT.0

F. Remarks:

1. The FR(M) values also serve to define continuous removal rates for the WAC command (see Sects. 3.4.1 and 4.17). Initial continuous removal rates can be overriden in the same manner as the fractional recoveries.

3.5 Fractional Reprocessing Recoveries for Element Groups

3.5.1 Initialization values

The BLOCK DATA subroutine supplies FR values for a group of elements. These group FRs can be employed in essentially the same manner as the FRs for individual elements (discussed in Sect. 3.4). That is, the group values can be used to separate a single, specified elemental composition into two different streams or to designate continuous removal rates for the WAC command. The FR values for the groups initially present in ORIGEN2 are given in Table 3.2. ORIGEN2 can contain up to 20 groups of elements. There are ten sets of group FR in ORIGEN2, each specifying the FR for all groups.

The initial-element group FR can be altered by using the procedure described in the subsections that follow.

3.5.2 Overriding initial values

The default-element group FR can be overriden by using the procedure described below.

A. Function: Override element group FR supplied by the BLOCK DATA subroutine.

Table 3.2. ORIGEN2 default element-group fractional recoveries

Group	Fractional recoveries: Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10
1	0.0	1.0	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	0.0
2	0.0	1.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	0.0
3	0.0	1.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	0.0
4	0.995	1.0	0.0005	0.999	1.0	0.2	0.6	1.0	0.0	0.0
5	0.0	1.0	0.0005	0.0	0.05	0.05	0.0	0.0	0.0	0.0
6	0.995	1.0	0.0005	0.9999	1.0	0.02	0.0	0.0	0.0	0.0
7	0.0	1.0	0.0005	0.0	0.001	0.001	0.0	0.0	0.0	0.0
8	0.0	1.0	0.0005	0.0	0.001	0.001	0.0	0.0	0.0	0.0
9	0.0	1.0	0.0005	0.0	0.001	0.001	0.0	0.0	0.0	0.0
10	0.0	1.0	0.0005	0.0	0.001	0.001	0.0	0.0	0.0	0.0
11	0.0	1.0	0.0005	0.0	0.001	0.001	0.0	0.0	0.0	0.0
12	0.0	0.001	0.0005	0.0	1.0	1.0	1.0	0.0	0.0	0.0
13	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0005	0.0	1.0	1.0	0.0	0.0	0.9	0.0
15-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

B. Data sequence:

NG(1)	NS(1)	FR(1)
.	.	.
.	.	.
.	.	.
NG(L)	NS(L)	FR(L)
.	.	.
.	.	.
.	.	.
NG(LMAX)	NS(LMAX)	FR(LMAX)
-1		

where

NG(L) = one- or two-digit element group number (1-20) for the fractional recovery on card L

NS(L) = set number (1-10) for the element-group fractional recoveries on the card L

FR(L) = fractional recovery replacing the initial value for group NG(L) in set NS(L)

LMAX = number of group fractional recoveries being overridden (can be zero)

C. Number of cards: LMAX+1

D. Terminate reading these data: NG(LMAX+1).LT.0

E. Skip reading these data: One card with NG(1).LT.0

F. Remarks:

1. The FR(L) also serve to define continuous removal rates for the WAC command (see Sects. 3.4.1, 3.5.1, and 4.27). Initial continuous removal rates can be overridden in the same manner as the group fractional recoveries.

3.6 Assignment of Elements to Fractional Recovery Groups

3.6.1 Initialization values

The BLOCK DATA subroutine also assigns each of the 99 elements to one of the 20-element groups discussed in Sect. 3.5. Any number of elements may be assigned to a given group, but an individual element can be a member of only one group. The initial membership of the ORIGEN2 element group is given in Table 3.3.

The assignment of elements to FR groups can be altered by using the procedure described below.

3.6.2 Overriding initial values

The membership of the default element group can be overriden by using the procedure described below.

A. Function: Override element-group membership assignments supplied by the BLOCK DATA subroutine.

B. Data sequence:

```
NE(1)        NG(1)
  .            .
  .            .
  .            .
NE(I)        NG(I)
  .            .
  .            .
  .            .
NE(IMAX)     NG(IMAX)
-1
```

where

NE(I) = one- or two-digit element atomic number (1-99) on Card 1

NG(I) = one- or two-digit element group number (1-20) where element NE(I) is to be assigned

IMAX = number of element assignments being overridden (can be zero)

Table 3.3. Membership of ORIGEN2 default element group

Group	Elements in group
1	All elements except those in groups 2-14
2	Th
3	Pa
4	U
5	Np
6	Pu
7	Am
8	Cm
9	Bk
10	Cf
11	Es
12	F, Cl, Br, I
13	He, C, N, Ne, Ar, Kr, Xe, Rn
14	H
15-20	None

C. Number of cards: IMAX+1

D. Terminate reading these data: NE(IMAX+1).LT.0

E. Skip reading these data: One card with NG(1).LT.0

3.7 Elemental Chemical Toxicities

The BLOCK DATA subroutine supplies maximum permissible concentrations (MPCs) for each of the chemical elements in water. The MPC is used to calculate the volume of water required to dilute a given amount of an element to a concentration corresponding to its MPC. The volume of water required for each element in a mixture is assumed to yield the total volume of dilution water required and thus a measure of the chemical toxicity of the elemental mixture. These data cannot be altered except by changing the values in the BLOCK DATA subroutine and recompiling it.

4. ORIGEN2 COMMANDS

The instructions defined in this section, called ORIGEN2 commands, enable the user to precisely define the order in which any or all of the ORIGEN2 program functions are executed. This procedure is analogous to writing a FORTRAN program in that the commands define a series of operations which will be performed sequentially, with the sequence being variable at the user's option. The use of the commands to define the ORIGEN2 problem flowsheet allows the use of a "DO loop" command, which executes a set of instructions within the range of the loop a prescribed number of times. Coupled with other options, this gives the user the capability for easily investigating fuel recycle (e.g., plutonium) and nuclear fuel cycle waste production rates as a function of time.

The general format of the ORIGEN2 commands is

COM   PARM(1), PARM(2), . . . PARM(I) ,

where COM is a keyword defining the instruction type and the PARM(I) are parameters supplying various data necessary for the execution of the operational commands. Details on the data format are given in Sect. 2.2. A list of the ORIGEN2 commands and a brief description of their functions are given in Table 4.1.

Before attempting to use ORIGEN2, it should be noted that there are certain restrictions on the order in which the commands must occur. The primary restriction is that the LIB command (Sect. 4.18), which reads the decay and cross-section libraries, must precede most other commands since it defines the list of nuclides being considered. Other restrictions will be noted when the individual commands are discussed.

Each ORIGEN2 command can be present in a single input stream a maximum number of times; the limit depends on the specific command. This limit is given in the section (below) that describes each individual command. The limits can be changed by varying the dimensions of the appropriate array(s) within the ORIGEN2 source deck. The limit on the total number of ORIGEN2 commands that may be used is 300, a number which can also be changed by varying array dimensions within the source deck.

Table 4.1. List of ORIGEN2 commands

Command keyword	Description	Section	Page
ADD	Add two vectors	4.13	40
BAS	Case basis	4.3	28
BUP	Burnup calculation	4.14	42
CON	Continuation	4.28	60
CUT	Cutoff fractions for summary tables	4.9	34
DEC	Decay	4.23	54
DOL	DO loop	4.11	38
END	Terminate execution	4.30	61
FAC	Calculate a multiplication factor	4.4	28
HED	Vector headings	4.7	33
INP	Read input composition, continuous removal rate, and continuous feed rate	4.6	31
IRF	Flux irradiation	4.21	50
IRP	Specific power irradiation	4.22	52
KEQ	Match infinite multiplication factors	4.10	36
LIB	Library print control	4.18	45
LIP	Library print control	4.16	43
LPU	Data library replacement cards	4.20	49
MOV	Move nuclide composition from vector to vector	4.12	38
OPTA	Specify actinide nuclide output table options	4.26	58
OPTF	Specify fission product nuclide output table options	4.27	59
OPTL	Specify activation product output table options	4.25	56
OUT	Print calculated results	4.5	29
PCH	Punch an output vector	4.15	42
PHO	Read photon libraries	4.19	47
PRO	Reprocess fuel	4.24	55
RDA	Read comments regarding case being input	4.1	27
REC	Loop counter	4.8	34
TIT	Case title	4.2	27
WAC	Nuclide accumulation	4.17	44
GTO	GO TO	4.31	61a

4.1 RDA — Read Comments Regarding Case Being Input

A. Function: Prints alphanumeric comments among the listing of the operational commands being input.

B. Data sequence:

RDA COMMENT(S)

where

RDA = command keyword
COMMENT(S) = alphanumeric message

C. Allowable number of RDA commands: Maximum total number of commands.

D. Propagation: None.

E. Remarks: These comments are printed in the listing created when ORIGEN2 is interpreting the commands, which is separate from the card input echo described in Sect. 2.6.

4.2 TIT — Case Title

A. Function: Supplies case title printed in ORIGEN2 output.

B. Data sequence:

TIT A(9), . . . A(80)

where

TIT = command keyword
A(I) = alphanumeric characters in columns 9-80 only

C. Allowable number of TIT commands: 20

D. Propagation: Until changed.

E. Remarks: None.

4.3 BAS — Case Basis

A. Function: Supplies case basis printed in ORIGEN2 output.

B. Data sequence:

BAS A(9), . . . A(80)

where

BAS = command keyword
A(I) = alphanumeric characters in columns 9-80 only

C. Allowable number of BAS commands: 10

D. Propagation: Until changed.

E. Remarks: The BAS command only supplies an alphanumeric message. The user is responsible for the consistency of the basis, the input material masses, specific power, etc.

4.4 FAC — Calculate a Multiplication Factor Based on Total Vector Masses

A. Function: Calculates a multiplication factor, FACTOR[NFAC(1)], based on the total actinide plus fission product masses in one or two vectors for use in MOV (see Sect. 4.12) or ADD (see Sect. 4.13) commands.

B. Data sequence:

FAC NFAC(1), . . . NFAC(4), RFAC(1)

where

FAC = command keyword
NFAC(1) = number of factor calculated by this command (must be greater than zero and less than or equal to the maximum number of FAC commands)
NFAC(2) = vector number

NFAC(3) = vector number

NFAC(4) = method for calculating FACTOR[NFAC(1)]:

= 1 FACTOR[NFAC(1)] = T[NFAC(2)]+T[NFAC(3)]
= 2 FACTOR[NFAC(1)] = T[NFAC(2)]-T[NFAC(3)]
= 3 FACTOR[NFAC(1)] = T[NFAC(2)]*T[NFAC(3)]
= 4 FACTOR[NFAC(1)] = T[NFAC(2)]/T[NFAC(3)]
= 5 FACTOR[NFAC(1)] = T[NFAC(2)]
= 6 FACTOR[NFAC(1)] = T[NFAC(3)]
= 7 FACTOR[NFAC(1)] = 1.0/T[NFAC(2)]
= 8 FACTOR[NFAC(1)] = 1.0/T[NFAC(3)]

where the T[NFAC(I)] are the total fission product plus actinide masses for the indicated vectors, expressed in kilograms.

RFAC(1) = constant value to be used in place of the T[NFAC(I)]:

.GT.0 = substitute RFAC(1) for T[NFAC(2)] when calculating FACTOR[NFAC(1)]
.EQ.0 = use the T[NFAC(I)] as defined
.LT.0 = substitute [-RFAC(I)] for T[NFAC(3)] when calculating FACTOR[NFAC(1)]

The units of RFAC(1) are kilograms.

C. Allowed number of FAC commands: 20

D. Propagation: Until another FAC command with the same value of NFAC(1) is executed.

E. Remarks: Some characteristic results from this command are printed on unit 15.

4.5 OUT — Print Calculated Results

A. Function: Calls for the calculated results in some or all of the output vectors to be printed.

B. Data sequence:

OUT NOUT(1), . . . NOUT(4)

where

OUT = command keyword

NOUT(1) = number of vectors to be printed beginning with the first vector:

.GT.0 = output on units IOUT, JOUT, and KOUT (Unit 6)

.LT.0 = output on unit 11

NOUT(2) = frequency of print if instruction is in a loop (Sect. 4.11) [print occurs first time through loop and every NOUT(2)th recycle thereafter]

NOUT(3) = print number of present recycle:

.GT.0 = yes

.LE.0 = no

NOUT(4) = parameter controlling type of summary table printed:

.LT.0 = all vectors tested for inclusion in summary table except vector -NOUT(4)

.EQ.0 = all vectors tested for inclusion in summary table

.GT.0 = only vector NOUT(4) tested to see if a nuclide is included in the summary table

C. Allowable number of OUT commands: 20

D. Propagation: None.

E. Remarks:

1. If NOUT(2).NE.1, a REC command must be employed (Sect. 4.8).

4.6 INP — Read Input Composition, Continuous Removal Rate, and Continuous Feed Rate

A. Function: Calls for nuclide composition, continuous nuclide feed rate, or continuous elemental removal rate to be read.

B. Data sequence:

INP NINP(1), . . . NINP(6)

where

INP = command keyword

NINP(1) = number of vector in which initial compositions are to be stored

NINP(2) = read nuclide composition:

.EQ.0 = no

.EQ.1 = yes; units are g/basis unit (read on unit 5)

.EQ.2 = yes; units are g-atoms/basis unit (read on unit 5)

.EQ.-1 = yes; units are g/basis unit (read on unit 4)

.EQ.-2 = yes; units are g-atoms/basis unit (read on unit 4)

NINP(3) = read continuous nuclide feed rate:

.LE.0 = no

.EQ.1 = yes; units are g/(time)(basis unit)

.EQ.2 = yes; units are g-atoms/(time)(basis unit)

See NINP(5) for specification of time units.

NINP(4) = read element removal rate per unit time:

.LT.0 = no read; no propagation

.EQ.0 = no read, but propagate previously read values

.GT.0 = read NINP(4) data pairs (see Sect. 6.3)

See NINP(6) for specification of time units.

NINP(5) = time units of continuous nuclide feed rate data (see Table 4.2)

NINP(6) = time units of continuous elemental removal rate data (see Table 4.2)

Table 4.2. Time unit designation

1 = seconds
2 = minutes
3 = hours
4 = days
5 = years
6 = stable
7 = 10^3 years (kY)
8 = 10^6 years (MY)
9 = 10^9 years (GY)

C. Allowable number of INP commands: 15

D. Propagation: None.

E. Remarks: User is responsible for the consistency of the calculational basis with the input masses.

4.7 HED — Vector Headings

A. Function: Allows alphanumeric vector headings to be specified.

B. Data sequence:

HED NHED A(1), . . . A(10)

where

HED = command keyword
NHED = number of vector which is to be given heading
A(I) = ten-character alphanumeric heading anyplace on the card to the right of NHED

C. Allowable number of HED commands: 50

D. Propagation: Until the vector is overwritten.

E. Remarks:

1. The heading is moved with the vector when the MOV (Sect. 14.12) and ADD (Sect. 14.13) commands are used.
2. If a HED command is to be used to label either a vector of input concentrations [vector NINP(1), Sect. 4.6] or the vectors resulting from a PRO command [vectors NPRO(2) and NPRO(3), Sect. 4.24], the HED command must follow the INP or PRO command.
3. If A(1) is an apostrophe or asterisk (*), the ten characters immediately following A(1) are taken as the vector heading. This allows for the inclusion of leading blanks.

4.8 REC — Loop Counter

A. Function: Counts the number of times that a loop (DOL command, Sect. 14.11) has been executed.

B. Data sequence:

REC

where

REC = command keyword

C. Allowable number of REC commands: 1

D. Propagation: None.

E. Remarks:

1. This counter is output as the "Recycle #" in ORIGEN2 output.

4.9 CUT — Cutoff Fractions for Summary Tables

A. Function: Override default cutoff fractions for summary output tables.

B. Data sequence:

CUT[NCUT(1), RCUT(1)], . . . [NCUT(NT), RCUT(NT)], -1

where

CUT = operational command

NCUT(I) = number of the output table to which cutoff fraction RCUT(I) is to apply (see Table 4.3 for table numbers and descriptions)

RCUT(I) = new cutoff fraction for table number NCUT(I)

NT = total number of default cutoff values which are being overridden with this CUT command

C. Allowable number of CUT commands: 3

D. Propagation: Until changed.

Table 4.3. Description of ORIGEN2 output table

Table number	Description of table	Units
1	Isotopic composition of each element	atom fraction
2	Isotopic composition of each element	weight fraction
3	Composition	gram-atoms
4	Composition	atom fraction
5	Composition	grams
6	Composition	weight fraction
7	Radioactivity (total)	Ci
8	Radioactivity (total)	fractional
9	Thermal power	watts
10	Thermal power	fractional
add 11	Radioactivity (total)	Bq
12	Radioactivity (total)	fractional add
13	Radioactive inhalation hazard	m^3 air
14	Radioactive inhalation hazard	fractional
15	Radioactive ingestion hazard	m^3 water
16	Radioactive ingestion hazard	fractional
17	Chemical ingestion hazard	m^3 water
18	Chemical ingestion hazard	fractional
19	Neutron absorption rate	neutrons/sec
20	Neutron absorption rate	fractional
21	Neutron-induced fission rate	fissions/sec
22	Neutron-induced fission rate	fractional
23	Radioactivity (alpha)	Ci
24	Radioactivity (alpha)	fractional
25	(alpha,n) neutron production	neutrons/sec
26	Spontaneous fission neutron production	neutrons/sec
27	Photon emission rate	photons/sec
28	Set test parameter ERR	-

E. Remarks:

1. If an output value for a particular nuclide is less than the cutoff fraction multiplied by the total table value for all vectors being tested (see Sect. 4.5 for additional details on which vectors are tested), then that particular nuclide is not printed.
2. Table number 28 can be used to override the default value for ERR, presently set at 1.0E-25. ERR is used in logical IF statements instead of 0.0.
3. An integer -1 must follow RCUT(NT) unless all 28 cutoff fractions are specified.
4. The default cutoff fractions for the first 26 tables (see Table 4.3) are 0.001; for Table 27 the cutoff is 0.01.
5. The [NCUT(I),RCUT(I)] may continue onto subsequent cards. No operational command is used on the additional cards.
6. The application of the cutoff value to photon tables is somewhat different; it is discussed in Sect. 8.2.2.

4.10 KEQ — Match Infinite Multiplication Factors

A. Function: Blend materials in two vectors so that the resulting infinite multiplication factor (IMF) matches that of another vector or an input value.

B. Data sequence:

KEQ NKEQ(1), NKEQ(2), NKEQ(3), NKEQ(4), NKEQ(5), RKEQ(1)

where

KEQ = command keyword

NKEQ(1) = vector whose IMF is to be matched by vector NKEQ(4)

NKEQ(2) = vector whose material is to be wholly included in the final blended material in vector NKEQ(4)

NKEQ(3) = vector whose material is to be apportioned to obtain the proper IMF for vector NKEQ(4)

NKEQ(4) = vector containing all material in vector NKEQ(2) plus part of the material in NKEQ(3) and having the same IMF as either vector NKEQ(1) or RKEQ(1); that is,

NKEQ(4) = NKEQ(2) + f * NKEQ(3)

where f is the factor by which NKEQ(3) must be multiplied to obtain the correct IMF for NKEQ(4).

NKEQ(5) = vector containing the portion of NKEQ(3) not blended into NKEQ(4); that is,

NKEQ(5) = (1-f) * NKEQ(3)

If (1-f) is less than zero, then NKEQ(5) is set to zero.

RKEQ(1) = desired final IMF for vector NKEQ(4) if RKEQ(1).GT.0.0. If RKEQ(1).LT.0.0, the IMF of vector NKEQ(4) is matched to that of vector NKEQ(1). If RKEQ(1).EQ.0.0, the IMF is equal to RMULV(NREC,1). The RMULV values are specified in a data statement in MAIN (see Sect. 2.1); the NREC parameter is described in Sect. 4.8.

C. Allowable number of KEQ commands: 3

D. Propagation: None.

E. Remarks:

1. The equation used to calculate the parameter f, by which vector NKEQ(3) is multiplied before being combined with material in vector NKEQ(2) and being placed in vector NKEQ(4) is given by

$$f = (k_2 - k_1)*D_2/(k_1 - k_3)*D_3$$

where

k_1 = IMF to be matched from vector NKEQ(1) or RKEQ(1)

k_2 = IMF of material in vector NKEQ(2)

k_3 = IMF of material in vector NKEQ(3)

D_2 = neutron absorption rate of material in vector NKEQ(2), neutrons sec^{-1}

D_3 = neutron absorption rate of material in vector NKEQ(3), neutrons sec^{-1}

2. Some characteristic results from this command are printed on unit 15.

4.11 DOL — DO Loop

A. Function: A "DO loop" which executes the commands within its range a prescribed number of times.

B. Data sequence:

DOL NDOL(1), NDOL(2)

where

DOL = command keyword

NDOL(1) = number of the CON command (Sect. 4.28) which defines the range of this DOL. Each DOL must have a unique CON associated with it.

NDOL(2) = the total number of times the instructions within the loop are to be executed

C. Allowable number of DOL commands: 2

D. Propagation: None.

E. Remarks: None.

4.12 MOV — Move Nuclide Composition from Vector to Vector

A. Function: Moves (i.e., copies) the nuclide concentration data in one vector to another vector, nuclide by nuclide.

B. Data sequence:

MOV NMOV(1), NMOV(2), NMOV(3), RMOV(1)

where

MOV = command keyword

NMOV(1) = number of the vector where the concentrations to be moved are presently stored

NMOV(2) = number of the vector where the concentrations in vector NMOV(1) are to be moved. May be the same as NMOV(1).

NMOV(3) = source of additional multiplier

.GT.0 = number of variable multiplier vector that contains the additional factors by which vector NMOV(1) is to be multiplied before being moved to vector NMOV(2). The variable multipliers are in array RMULV and are initialized with a DATA statement in MAIN. The particular element of RMULV used is

RMULV[NREC, NMOV(3)]

where NREC is the recycle number (Sect. 4.8). The total multiplier, RMULT, is given by

RMULT = RMULV[NREC,NMOV(3)]*RMOV(1).

NREC <u>must</u> be defined to use the variable multiplier option.

.EQ.0 = no additional multiplier is used; that is,

RMULT = RMOV(1).

.LT.0 = The additional multiplier to be used was previously calculated by an FAC command (see Sect. 4.4) and designated as FACTOR[NFAC(1)] at that time. To use this factor, set NMOV(3) = -NFAC(1); the total multiplier is then given by

RMULT = FACTOR[-NMOV(3)]*RMOV(1).

RMOV(1) = factor by which vector NMOV(1) is to be multiplied before being stored in vector NMOV(2).

C. Allowable number of MOV commands: 99

D. Propagation: None.

E. Remarks:

1. Vector NMOV(2) can be zeroed by moving another vector to NMOV(2) with RMOV(1) = 0.0.
2. The information in vector NMOV(1) is not destroyed by the MOV command.
3. Vector NMOV(2) will have the same heading as vector NMOV(1) after the MOV command has been executed.

4.13 ADD — Add Two Vectors

A. Function: Adds the nuclide concentration data in one vector to that in another vector, nuclide by nuclide.

B. Data sequence:

ADD NADD(1), NADD(2), NADD(3), RADD(1)

where

ADD = operational command

NADD(1) = number of the vector where the concentrations to be added are presently stored

NADD(2) = number of the vector to which the concentrations in vector NADD(1) are to be added

NADD(3) = source of additional multiplier

.GT.0 = if NADD(3).GT.0, it is the number of the variable multiplier vector which contains the factors by which vector NADD(1) is to be multiplied before being added to vector NADD(2). The variable multipliers are in array RMULV and are initialized with a DATA statement in MAIN. The particular element of RMULV used is

RMULV[NREC, NADD(3)]

where NREC is the recycle number (see Sect. 4.8). The total multiplier, RMULT, is given by

RMULT = RMULV[NREC,NADD(3)]*RADD(1)

NREC must be defined to use this option (see Sect. 4.8).

.EQ.0 = no additional multiplier used; that is,

RMULT = RADD(1).

.LT.0 = the additional multiplier to be used was previously calculated by a FAC command (see Sect. 4.4) and designated as FACTOR[NFAC(1)]. To use this factor, set NADD(3) = -NFAC(1); the total multiplier is then given by

RMULT = FACTOR[-NADD(3)]*RADD(1)

RADD(1) = factor by which vector NADD(1) is to be multiplied before being added to vector NADD(2) or as specified under NADD(3) above.

C. Allowable number of ADD commands: 30

D. Propagation: None.

E. Remarks:

1. Vector NADD(1) may be subtracted from vector NADD(2) by setting RADD(1) = -1.0. (CAUTION: Negative nuclide concentrations can result in fatal errors.)
2. The information in vector RADD(1) is not altered by the ADD command.
3. Vector NADD(2) will have the same headings as vector NADD(1) after the ADD command has been executed.

4.14 BUP — Burnup Calculation

A. Function: Defines the basis and calculates the average burnup, flux, and specific power for an irradiation.

B. Data sequence:

BUP
   Irradiation
BUP

where

BUP = command keyword

Irradiation = the operational commands (generally several IRPs or IRFs) that describe the fuel irradiation upon which the burnup calculation is to be based.

C. Allowable number of BUP commands: 20 (ten pair).

D. Propagation: Until superseded by other BUP commands.

E. Remarks:

1. A BUP command must appear both before and after the statements constituting the fuel irradiation upon which the burnup calculation is to be based. Other commands may be present between the BUP statements.

4.15 PCH — Punch an Output Vector

A. Function: Punch a designated output vector in ORIGEN2-readable format or write it to a disk file.

B. Data sequence:

PCH   NPCH(1), NPCH(2), NPCH(3)

where

PCH = command keyword

NPCH(1) = control character for light nuclide and structural material punch

NPCH(2) = control character for actinide nuclide punch

NPCH(3) = control character for fission product nuclide punch

If NPCH(I) .EQ.0 - no punch

.GT.0 - number of output vector to be punched

.LT.0 - number of storage vector to be punched

C. Allowable number of PCH commands: 54

D. Propagation: None.

E. Remarks:

1. Format of punched output is [2X,I2,4(1X,I6,2X,1PE10.4)]; see Sect. 6.1 for details.

2. Units of punched output are g-atoms.

3. The last record (card) written by each PCH command is

   0 BURNUP FLUX SPECIFIC POWER.

   The burnup, flux, and specific power are average values produced by the BUP command (Sect. 4.14) and must be present for a file read on unit 4 [NINP(2).LT.0; see Sect. 4.6]. These parameters are not necessary for input material compositions read with NINP(2).GT.0.

4.16 LIP — Library Print Control

A. Function: Controls the printing of the input data libraries.

B. Data sequence:

LIP NLIP(1), NLIP(2), NLIP(3)

where

LIP = command keyword

NLIP(1) = control character for decay library print

NLIP(2) = control character for cross-section library print

NLIP(3) = control character for photon library print

If NLIP(I).EQ.0 - no print

.GT.0 - print library

C. Allowable number of LIP commands: 5

D. Propagation: Until superseded.

E. Remarks: None.

4.17 WAC — Nuclide Accumulation

A. Function: Multiplies a concentration vector by a fractional recovery vector and stores the result in vector B, which contains continuous feed rates.

B. Data sequence:

WAC NWAC(1), NWAC(2)

where

WAC = command keyword

NWAC(1) = number of fractional recovery vector (Sects. 3.4 and 3.5) which is to multiply concentration vector NWAC(2). Fractional recovery NWAC(1) should contain the removal rate of each element from the system in units of sec^{-1} (equivalent to the feed rate to the next system being analyzed).

NWAC(2) = number of concentration vector which is to be multiplied by fractional recovery vector NWAC(1)

C. Maximum allowable number of WAC commands: 2

D. Propagation: None.

E. Remarks:

1. This command will enable the continuous accumulation of waste from a reactor with continuous reprocessing (e.g., an MSBR) to be calculated. The steady-state fuel composition in vector NWAC(2) is multiplied by the appropriate continuous removal rates stored in fractional recovery vector NWAC(1); the result is subsequently stored in vector B. Then the waste is decayed,

with vector B representing the continuous feed of waste to the waste decay step from the continuously reprocessed steady-state reactor.

4.18 LIB — Read Decay and Cross-Section Libraries

A. Function: Read decay and cross-section libraries; substitute decay and cross-section cards and cards with non-standard reactions.

B. Data sequence:

LIB NLIB(1), . . . NLIB(11)

where

LIB = command keyword

NLIB(1) = control character for printing matrix of non-zero reaction rates (array A) for the libraries read (see Sect. 8.2.1).
If NLIB(1).GT.0 - print
.LE.0 - no print

NLIB(2) = identification number of light nuclide decay library to be read; see Table 4.4

NLIB(3) = identification number of actinide nuclide decay library to be read; see Table 4.4

NLIB(4) = identification number of fission product nuclide decay library to be read; see Table 4.4

NLIB(5) = identification number of light nuclide cross-section library to be read; see Table 4.4

NLIB(6) = identification number of actinide nuclide cross-section library to be read; see Table 4.4

NLIB(7) = identification number of fission product nuclide yield and cross-section library to be read; see Table 4.4
If NLIB(2-7).EQ.0 - no read
.GT.0 - normal read on unit NLIB(8)

Table 4.4. Numbers of ORIGEN2 data libraries

Type of library	Category of isotope: Activation product [NLIB(2 or 5)][a]	Category of isotope: Actinide [NLIB(3 or 6)][a]	Category of isotope: Fission product [NLIB(4 or 7)][a]	NLIB(12)[a]
Decay	1	2	3	
Photon	101	102	103	
Cross-section libraries				
PWR: ^{235}U-enriched UO_2: 33,000 MWd/metric ton	204	205	206	1
PWR: ^{235}U-enriched UO_2 in a self-generated Pu recycle reactor	207	208	209	2
PWR: Pu-enriched UO_2 in a self-generated Pu recycle reactor	210	211	212	3
BWR: ^{235}U-enriched UO_2	251	252	253	4
BWR: ^{235}U-enriched fuel in a self-generated Pu recycle reactor	254	255	256	5
BWR: Pu-enriched fuel in a self-generated Pu recycle reactor	257	258	259	6
PWR: ThO_2-enriched with denatured ^{233}U	213	214	215	7
PWR: Pu-enriched ThO_2	216	217	218	8
PWR: ^{235}U-enriched UO_2; 50,000 MWd/metric ton	219	220	221	9
PWR: ThO_2-enriched with makeup, denatured ^{235}U	222	223	224	10
PWR: ThO_2 enriched with recycled, denatured ^{233}U	225	226	227	11

Table 4.4 (continued)

Type of library	Category of isotope			
	Activation product [NLIB(2 or 5)][a]	Actinide [NLIB(3 or 6)][a]	Fission product [NLIB(4 or 7)][a]	NLIB(12)[a]
LMFBR: Early oxide, LWR-Pu/U/U/U				
Core	301	302	303	18
Axial blanket	304	305	316	19
Radial blanket	307	308	309	20
LMFBR: Advanced oxide, LWR-Pu/U/U/U				
Core	311	312	313	12
Axial blanket	314	315	316	13
Radial blanket	317	318	319	14
LMFBR: Advanced oxide, recycle-Pu/U/U/U				
Core	321	322	323	15
Axial blanket	324	325	326	16
Radial blanket	327	328	329	17
LMFBR: Advanced oxide, LWR-Pu/U/U/Th				
Core	331	332	333	32
Axial blanket	334	335	336	33
Radial blanket	337	338	339	34
LMFBR: Advanced oxide, LWR-Pu/Th/Th/Th				
Core	341	342	343	29
Axial blanket	344	345	346	30
Radial blanket	347	348	349	31
LMFBR: Advanced oxide, recycle ^{233}U/Th/Th/Th				
Core	351	352	353	35
Axial blanket	354	355	356	36
Radial blanket	357	358	359	37
LMFBR: Advanced oxide, 14% denatured ^{233}U/Th/Th/Th				
Core	361	362	363	23
Axial blanket	364	365	366	24
Radial blanket	367	368	369	25
LMFBR: Advanced oxide, 44% denatured ^{233}U/Th/Th/Th				
Core	371	372	373	26
Axial blanket	374	375	376	27
Radial blanket	377	378	379	28
LMFBR: FFTF Pu/U	381	382	383	0
Thermal: 0.0253-eV cross sections	201	202	203	0

[a]Refer to Sect. 4.18 for the use of these parameters.

00051a

.LT.0 - normal read on unit NLIB(8) and substitute card read on unit NLIB(9)

NLIB(8) = number of input unit for normal reading of the bulk of the libraries

NLIB(9) = number of input unit for reading substitute cards

NLIB(10) = number of non-standard reactions to be read

If NLIB(10).EQ.0 - no read

.GT.0 - non-standard reactions read on unit NLIB(8)

.LT.0 - non-standard reactions read on unit NLIB(9)

NLIB(11) = control character identifying the set of actinides with direct fission product yields; see Table 4.5

NLIB(12) = control character identifying the set of variable actinide cross sections to be used; see Table 4.4

C. Allowable number of LIB commands: 5

D. Propagation: Until another set of decay libraries is read.

E. Remarks:

1. If substitute cards are to be read, the LPU command(s) (Sect. 4.20) must precede the LIB command in which the cards are to be read.
2. See Sect. 5 for library format details.

4.19 PHO — Read Photon Libraries

A. Function: Read the photon production rate per disintegration in 18 energy groups.

Table 4.5. Actinide sets with direct fission product yields

NLIB(11)	Actinides with direct fission product yields
1	^{235,238}U, ^{239,241}Pu
2	^{232}Th, ^{233,235}U, ^{239}Pu
3	^{232}Th, ^{233,235,238}U, ^{239,241}Pu
4	^{232}Th, ^{233,234,238}U, ^{239,241}Pu, ^{245}Cm, ^{252}Cf

B. Data sequence:

PHO NPHO(1), . . . NPHO(4)

where

PHO = command keyword

NPHO(1) = identification number of activation product photon library to be read; see Table 4.4

NPHO(2) = identification number of actinide nuclide photon library to be read; see Table 4.4

NPHO(3) = identification number of fission product nuclide photon library to be read; see Table 4.4

If NPHO(1-3).LE.0 - no read

.GT.0 - read

NPHO(4) = number of input unit on which the photon libraries are to be read

C. Allowable number of PHO commands: 5

D. Propagation: Until another set of photon libraries is read.

E. Remarks: See Sect. 5.5 for library format details.

4.20 LPU — Data Library Replacement Cards

A. Function: Read nuclide identifiers for replacement decay and/or cross-section data cards to be read by LIB command (Sect. 4.18).

B. Data sequence:

LPU NLPU(1), . . . NLPU(MAX), -1

where

LPU = command keyword

NLPU(1-MAX) = nuclide identifiers for replacement data cards in the order in which they occur in the original data library

MAX = number of nuclide identifiers to be read for a given LPU command; must be .LE.100

C. Allowable number of LPU cards: 9

D. Propagation: Until another LIB command is executed.

E. Remarks:

1. If less than 100 nuclide identifiers are specified, a -1 (integer) must appear after the last identifier.
2. As many cards may be used as are required.
3. The LPU command(s) must precede the LIB command in which the replacement data cards will be read.
4. The first LPU command is associated with the first negative control variable in the NLIB(2-7) set of control variables (Sect. 4.18). The second LPU command is associated with the second negative control variable in the NLIB(2-7) set of control variables, etc.
5. See Sects. 5.1 and 5.2 for library format details.

4.21 IRF — Flux Irradiation

A. Function: Irradiation for a single interval with the neutron flux specified.

B. Data sequence:

IRF RIRF(1), RIRF(2), NIRF(1). . . . NIRF(4)

where

IRF = command keyword

RIRF(1) = time at which this irradiation interval ends

RIRF(2) = if RIRF(2).GT.0.0, this is the neutron flux during this irradiation interval in neutrons cm^{-2} sec^{-1}. If RIFR(2).LT.0.0, the neutron flux is given by:

NEWFLUX = OLDFLUX*[-RIRF(2)]

where

NEWFLUX = flux to be used during this interval, neutrons cm^{-2} sec^{-1}

OLDFLUX = flux for the same time period from the previous irradiation, neutrons cm^{-2} sec^{-1}. See remark 2 below.

NIRF(1) = number of the vector where the material composition at the beginning of this irradiation interval is stored

NIRF(2) = number of the vector where the material composition at the end of this irradiation interval is to be stored

NIRF(3) = time units of RIRF(1); see Table 4.2

NIRF(4) = specification of time at which this irradiation interval begins:

0 = starting time is the end of the previous IRF, IRP, or DEC interval. All reactivity and burnup information is retained, and MIRR is not altered. Used for continuing irradiation/decay on the same output page.

1 = starting time is set to zero. All reactivity and burnup information is retained, and MIRR is set to zero. Used for beginning a new irradiation on the same output page.

2 = starting time is set to zero. All reactivity and burnup information and MIRR are set to zero. Used to begin a new irradiation/decay on a new output page.

3 = same as NIRF(4) = 0 except that the first seven lines of the irradiation information are set to zero. Used for continuing irradiation to a new output page.

4 = same as NIRF(4) = 1 except that the first seven lines of the reactivity and burnup information are set to zero. Used to begin the decay following irradiation on a new output page while retaining the average irradiation parameters.

C. Allowable number of IRF commands: See remark 1 below.

D. Propagation: None.

E. Remarks

1. The total number of IRF + IRP + DEC commands must be .LE.150.
2. For this option to be used, the time steps for the current irradiation and decay sequence must correspond exactly to those in the previous sequence. The fluxes from the previous irradiation are not altered if [-RIFF(2)] is less than zero.
3. The "reactivity and burnup information" referred to in NIRF(4) consists of seven lines of data characteristic of an individual vector (e.g., time, infinite multiplication factor, neutron flux) and three lines containing irradiation parameters (e.g., burnup) averaged over the range of the BUP commands (Sect. 4.14). Also, see Sect. 8.2.2.
4. Internal ORIGEN2 parameters related to the flux/specific power calculations are printed on unit 15 (see Sect. 8.2.1).

4.22 IRP — Specific Power Irradiation

A. Function: Irradiation for a single interval with the specific power specified.

B. Data sequence:

IRP RIRP(1), RIRP(2), NIRP(1), . . . NIRP(4)

where

IRP = command keyword

RIRP(1) = time at which this irradiation interval ends

RIRP(2) = power level during this irradiation interval

.GT.0 = MW(t) per unit of fuel input

.LT.0 = the power is given by:

NEWPOWER = OLDPOWER*[-RIRP(2)]

where

NEWPOWER = power to be used during this interval, MW(+).

See remark 2 below.

NIRP(1) = number of the vector where the material composition at the beginning of this irradiation interval is stored

NIRP(2) = number of the vector where the material composition at the end of this irradiation interval is to be stored

NIRP(3) = time units of RIRP(1); see Table 4.2

NIRP(4) = specification of the time at which this irradiation interval begins:

0 = starting time is the end of the previous IRF, IRP, or DEC interval. All reactivity and burnup information is retained, and MIRR is not altered. Used for continuing irradiation/decay on the same output page.

1 = starting time is set to zero. All reactivity and burnup information is retained, and MIRR is set to zero. Used for beginning a new irradiation on the same output page.

2 = starting time is set to zero. All reactivity and burnup information and MIRR are set to zero. Used to begin a new irradiation/decay on a new page.

3 = same as NIRP(4) = 0 except that the first seven lines of the irradiation information are set to zero. Used for continuing irradiation to a new output page.

4 = same as NIRP(4) = 1 except that the first seven lines of the reactivity and burnup information are set to zero. Used to begin the decay following irradiation on a new output page while retaining the average irradiation parameters.

C. Allowable number of IRP commands: See remark 1 below.

D. Propagation: None.

E. Remarks:

1. The total number of IRF + IRP + DEC commands must be .LE.150.
2. For this option to be used, the time steps for the current irradiation and decay sequence must correspond <u>exactly</u> to those in the previous sequence. The powers from the previous irradiation are not altered if [-RIRP(2)] is less than zero.

3. The "reactivity and burnup information" referred to in NIRP(4) consists of seven lines of data characteristic of an individual vector (e.g., time, infinite multiplication factor, neutron flux) and three lines containing irradiation parameters (e.g., burnup) averaged over the range of the BUP commands (Sect. 4.14).
4. Internal ORIGEN2 parameters related to the flux/specific power calculations are printed on unit 15 (see Sect. 8.2.1).

4.23 DEC — Decay

A. Function: Decay for a single interval.

B. Data sequence:

DEC DEC(1), NDEC(1), . . . NDEC(4)

where

DEC = operational command

DEC(1) = time at which this decay interval ends

NDEC(1) = number of the vector where the material composition at the beginning of this decay interval is stored

NDEC(2) = number of the vector where the material composition at the end of this decay interval is stored

NDEC(3) = time units of DEC(1); see Table 4.2

NDEC(4) = specification of the time at which this decay interval begins:

- 0 = starting time is the end of the previous IRF, IRP, or DEC interval. All reactivity and burnup information is retained, and MIRR is not altered. Used for continuing irradiation/decay on the same output page.
- 1 = starting time is set to zero. All reactivity and burnup information is retained, and MIRR is set to zero. Used for beginning a new irradiation on the same output page.
- 2 = starting time is set to zero. All reactivity and burnup information and MIRR are set to zero. Used to begin a new irradiation/decay on a new output page.

3 = same as NDEC(4) = 0 except that the first seven lines of the reactivity and burnup information are set to zero. Used for continuing irradiation to a new output page.

4 = same as NDEC(4) = 1 except that the first seven lines of the reactivity and burnup information are set to zero. Used to begin the decay following irradiation on a new output page while retaining the average irradiation parameters.

C. Allowable number of DEC commands: See below.

D. Propagation: None.

E. Remarks:

1. The total number of IRF + IRP + DEC commands must be .LE.150.
2. The "reactivity and burnup information" referred to in NDEC(4) consists of seven lines of data characteristic of an individual vector (e.g. time, infinite multiplication factor, neutron flux) and three lines containing irradiation parameters (e.g., burnup) averaged over the range of the BUP commands (Sect. 4.14).

4.24 PRO — Reprocess Fuel

A. Function: Reprocess fuel into two product compositions.

B. Data sequence:

PRO NPRO(1), . . . NPRO(4)

where

NPRO(1) = number of the vector where the material composition that is to be reprocessed is stored

NPRO(2) = number of the vector where the material that is recovered is to be stored. The amount of an isotope of element NE recovered is given by:

[Mass of isotope NE][f(NPRO(4)].

The fraction f[NPRO(4)] is the fractional recovery of element NE specified by variable NRPO(4) below. See also Sects. 3.4 and 3.5.

NPRO(3) = number of the vector where the material not recovered is to be stored. The amount of an isotope of element NE not recovered is given by:

[Mass of isotope NE][1.0 - f(NPRO(4))].

NPRO(4) = number of the set of fractional recoveries which is to be used in this reprocessing operation. If NPRO(4) is greater than zero, individual fractional recoveries (Sect. 3.4) are to be used. If NPRO(4) is less than zero, group fractional recoveries are to be used (Sect. 3.5).

C. Allowable number of PRO commands: 20

D. Propagation: None.

E. Remarks: None.

4.25 OPTL — Specify Activation Product Output Options

A. Function: Specifies which output table types (nuclide, element, or summary) are to be printed for the activation products.

B. Data sequence:

OPTL NOPTL(1), . . . NOPTL(24)

where

OPTL = command keyword

NOPTL(I) = control character indicating which output table types are to be printed for the activation products; see Table 4.6

I = table number; see Table 4.3 for output table description

C. Allowable number of OPTL commands: 20

D. Propagation: Until changed.

Table 4.6. Specification of output table types to be printed

NOPTL(I) NOPTA(I) NOPTF(I)	Table type printed		
	Nuclide	Element	Summary
1	Yes	Yes	Yes
2	Yes	Yes	No
3	Yes	No	Yes
4	No	Yes	Yes
5	Yes	No	No
6	No	Yes	No
7	No	No	Yes
8	No	No	No

E. Remarks:

1. The NOPTL(I) must all be on a single card.
2. If NOPTL(1) is less than 1, only a summary grams table is printed for <u>all</u> nuclides (including actinides and fission products) until new commands (after an STP, Sect. 4.29) are read.
3. Only the first 24 tables in Table 4.3 are controlled by the OPTL command.

4.26 OPTA — Specify Options for Actinide Nuclide Output Table

A. Function: Specifies which output table types (nuclide, element, or summary) are to be printed for the actinide nuclides.

B. Data sequence:

OPTA NOPTA(1), . . . NOPTA(24)

where

OPTA = command keyword

NOPTA(I) = control character indicating which output table types are to be printed for the actinide nuclides; see Table 4.6

I = table number; see Table 4.3 for output table description

C. Allowable number of OPTA commands: 20

D. Propagation: Until changed.

E. Remarks:

1. The NOPTA(I) must all be on a single card.
2. If NOPTA(1) is less than 1, only a summary grams table is printed for <u>all</u> nuclides (including activation and fission products) until new commands (after an STP, Sect. 4.29) are read.
3. Only the first 24 tables in Table 4.3 are controlled by the OPTA command.

4.27 OPTF — Specify Options for Fission Product Nuclide Output Table

A. Function: Specifies which types of output tables (nuclide, element, or summary) are to be printed for fission product nuclide

B. Data sequence:

OPTF   NOPTF(1), . . . NOPTF(24)

where

OPTF = command keyword

NOPTF(I) = control character indicating which output table types are to be printed for the fission product nuclides; see Table 4.6

I = table number; see Table 4.3 for output table description

C. Allowable number of OPTF commands: 20

D. Propagation: Until changed.

E. Remarks:

1. The NOPTF(I) must all appear on a single card.
2. If NOPTF(1) is less than 1, only a summary grams table is printed for all nuclides (including activation products and actinides) until new commands (after an STP, Sect. 4.29) are read.
3. Only the first 24 tables in Table 4.3 are controlled by the OPTF command.

4.28 CON — Continuation

A. Function: Defines the ranges of the DOL command (Sect. 4.11) or GTO command (Sect. 4.31).

B. Data sequence:

CON NCON

where

CON = command keyword

NCON = number of this CON command; must be equal to NDOL(1) for the DOL command which is to be associated with this CON command

C. Allowable number of CON commands: 20

D. Propagation: None.

E. Remarks:

1. There must be one, and only one, CON command for each DOL command.
2. If the DOL command is removed, the corresponding CON command must also be removed.

4.29 STP — Execute Previous Commands and Branch

A. Function: Execute the set of commands preceding the STP command. Then read and execute more commands.

B. Data sequence:

STP NSTP

where

STP = command keyword

NSTP = branching control character:

1 = read new miscellaneous initialization data (Sect. 3) and a new set of commands (Sect. 4), and execute them.

2 = read a new set of commands (Sect. 4) and execute them.

3 = execute the preceding set of commands again. Additional input data (libraries and initial nuclide concentrations) will be required.

4 = terminate execution (same as END).

C. Allowable number of STP commands: Unlimited.

D. Propagation: None.

E. Remarks: None.

4.30 END — Terminate Execution

A. Function: Terminate execution.

B. Data sequence:

END

where

END = command keyword

C. Allowable number of END commands: 1

D. Propagation: None.

E. Remarks: None.

4.31 GTO — Go To a Group of Instructions and Execute

A. Function: Indicates a range of instructions that should be executed and a flux/power multiplier for this range

B. Data Sequence:

GTO NGTO(1) NGTO(2) RGTO

where

GTO = command keywork

NGTO(1) = number of CON command (Sect. 4.28) that immediately precedes the group of instructions to be executed (if GT.0) or that this command is the last to be executed (if LT.0)

NGTO(2) = number of CON command that immediately follows the group of instructions to be executed

RGTO = parameter by which any fluxes or powers in the group of instructions to be executed will be multiplied; RGTO does not alter the value of fluxes/powers stored for future use

C. Allowable number of GTO commands: 10

D. Propagation: None.

E. Remarks:

1. Following the execution of the group of instructions defined by the GTO instruction, control is returned to the instruction immediately following the GTO.

5. DATA LIBRARIES

There are three separate and distinct nuclide lists in ORIGEN2 for which nuclear data may be required: the activation products, the actinides, and the fission products. The activation products include the low-Z impurities and structural materials. The actinides include all of the heavy isotopes (Z.GT.90) plus all of their decay daughters, including the final stable nuclides. The fission products include all nuclides which have a significant fission product yield (either binary or ternary) plus some nuclides resulting from neutron captures of the fission products. For each of these three segments, there are three different libraries that may be read: a decay data library (Sect. 5.1), a cross-section and fission product yield data library (Sect. 5.2), and a photon yield library (Sect. 5.5). The decay data library gives nuclide half-lives, decay modes, recoverable heat energy, natural abundances, and toxicities. The cross-section and fission product yield library gives the cross sections for (n,γ), (n,2n), (n,3n), (n,α), (n,p), and (n,fission) as effective, one-group reaction rates in barns and the fission product yields from ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu, ^{245}Cm, and ^{252}Cf. The photon data library gives the photons per disintegration in twelve energy groups for the activation products and fission products and in eighteen energy groups for the actinides.

In addition to these normal data library input facilities in ORIGEN2, two additional options may be used to extend, update, or correct these libraries. The first of these options (Sect. 5.3) allows the user to input substitute decay data cards and substitute cross-section and fission product yield data cards which override the corresponding data cards present in the main libraries. This option is particularly useful as an alternative to rebuilding entire data libraries simply to change one or two items. The second option (Sect. 5.4) allows the user to input any flux-dependent reaction rate between any two nuclides. While the user can duplicate the reaction types available in ORIGEN2 [i.e., (n,γ), (n,2n), (n,3n), (n,α), (n,p), (n,fission)], the option is principally intended to allow for the inclusion of non-standard reaction types such as (n,d), (n,t), and (n,np).

5.1 Decay Data Library

The first card of each of the three allowable decay data library segments (activation product, actinide, and fission product) is a title card containing the number of the decay library segment and the alpha-numeric title of the segment. Following the title card are the decay data for the nuclides in a particular library segment. The decay data for each nuclide are specified on two sequential cards. A description of the decay library conventions is given in Table 5.1.

The decay data library serves other vitally important functions in the ORIGEN2 code in addition to supplying decay data. The nuclide identifiers supplied by the decay libraries define the total list of all nuclides that will be considered in subsequent ORIGEN2 calculations. Thus, if a nuclide is to be used in a calculation, it must be present in the decay library, even if only the cross-section or photon information is required. The decay library also defines the nuclide membership of each of the three library segments (activation product, fission product, and actinide) considered by the ORIGEN2 code. Finally, the decay library defines the order in which the nuclides will be printed within each library segment during the normal output. As a result of these considerations, the decay library must be input before the photon libraries (PHO, Sect. 4.19) or before the initial compositions (INP, Sect. 4.6). The decay library is automatically read before the cross-section library when when the LIB command (Sect. 4.18) is invoked.

5.2 Cross-Section and Fission Product Yield Data Library

The first card of each of the three allowable cross-section and fission product yield data libraries (activation product, actinide, and fission product) is a title card containing the number and alphanumeric

Table 5.1. Description of decay library

A. Data sequence:

First card of each library segment:

NLB TITLE

First card for each nuclide:

NLB NUCLID IU THALF FBX FPEC FPECX FA FIT

Second card for each nuclide:

NLB FSF FN QREC ABUND ARCG WRCG

where

NLB = the number of this decay library segment

TITLE = a 72-character alphanumeric segment title beginning in column 9

NUCLID = a six-digit nuclide identifier corresponding to the information on these two decay cards (see Sect. 2.7)

IU = time unit designation of the half-life of NUCLID (see Table 4.2 for specification)

THALF = the half-life of nuclide in units given by IU

FBX = the fraction of negatron beta decay transitions that results in the daughter nuclide being in a relatively long-lived excited state

FPEC = the fraction of all decay events which take place by positron emission or electron capture

FPECX = the fraction of positron and/or electron capture decay events that cause the daughter nuclide to be in a relatively long-lived excited state

FA = the fraction of all decay events which take place by alpha decay

FIT = the fraction of all the decay events of an excited nuclear state which result in the production of the ground state of the same nuclide

FSF = the fraction of all decay events which take place by spontaneous fission

FN = the fraction of all decay events that are (beta + neutron) decays (e.g., ^{89}Br decays to ^{88}Kr + beta + neutron)

QREC = the average, total recoverable energy (i.e., does not include neutrinos) released by each decay event, in MeV

Table 5.1 (continued)

ABUND = the naturally occurring isotopic abundance of NUCLID in atom percent

ARCG = the radioactivity concentration guide (RCG) for continuous inhalation of nuclide NUCLID in unrestricted areas as given in Table II, Column I, of Part 10 of Title 20 of the Code of Federal Regulations (the lower of the soluble or insoluble values is used)

WRCG = the radioactivity concentration guide (RCG) for continuous ingestion of nuclide NUCLID in unrestricted areas as given in Table II, Column II of Part 10 of Title 20 of the Code of Federal Regulations (the lower of the soluble or insoluble values is used)

B. Number of cards per nuclide: 2

C. Terminate card scan for nuclide NUCLID: Automatic.

D. Terminate reading this decay library segment: NLB.LT.0, one card.

E. Skip reading a decay library segment: Controlled by LIB command (Sect. 4.18).

F. Remarks:

1. The fraction of all decay events which take place by negatron beta decay to the ground state of the daughter nuclide is given by (1.0 - FBX - FPEC - FA - FIT - FSF - FN) and is calculated internally in ORIGEN2.

title of the library segment. Following the title card are the cross-section and fission product yield data for the nuclides in a particular library segment. The cross-section information for a nuclide is specified on a single card which, if required, is followed by a card containing the fission product yield data. A description of the cross-section and fission product yield data library conventions is given in Table 5.2. The cross sections used by ORIGEN2 are effective one-group cross sections which, when multiplied by the flux calculated by or input to ORIGEN2, result in the correct reaction rate. The fifth and sixth parameters on the cross-section card have a dual meaning, depending on which library segment is being read. If the actinide segment is being read, then the fifth and sixth parameters are the (n,3n) and (n,fission) cross sections respectively. If either the activation product or fission product segments are being read, then the fifth and sixth parameters are the (n,α) and (n,p) cross sections respectively. The fission product yield card, which is present only in the fission product cross-section segment, specifies the yield of each nuclide per fission from each of eight fissioning species: ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu, ^{245}Cm, and ^{252}Cf. The yields are generally from binary fission, although ternary fission yields have been included for certain important low-Z nuclides.

5.3 Substitute Decay, Cross Section, and Fission Product Yield Data

Substitute decay, cross-section, and fission product yield data can be read by invoking the LPU command (Sect. 4.20). This procedure is an alternative to rebuilding an entire data library just to change a few parameters. It may also be used for parametric studies of output sensitivity to input data changes. The rules regarding the order and format of the substitute data cards are given in Table 5.3. This option is intended for use when the data libraries are on a direct-access device or on tape. Substitute data can also be used if the libraries are on cards, providing that two different card input units are defined.

Table 5.2. Description of cross-section and fission product yield data library

A. Data sequence:

First card of each library segment:

NLB TITLE

First card for each nuclide:

NLB NUCLID SNG SN2N SN3N or SNA SNF or SNP SNGX SN2NX YYN

Second card for each nuclide (fission product segment only):

NLB Y(1), . . . Y(8)

where

NLB = the number of this cross-section and fission product yield library segment

TITLE = a 72-character alphanumeric cross-section and fission product yield library segment title beginning in Column 11

NUCLID = a six-digit nuclide identifier corresponding to the data on these one or two cards (see Sect. 2.7)

SNG = the effective, one-group (n,γ) cross section of nuclide NUCLID leading to a ground state

SN2N = the effective, one-group (n,2n) cross section of nuclide NUCLID leading to a ground state

SN3N = the effective, one-group (n,3n) cross section of nuclide NUCLID leading to a ground state; actinide segment only

SNA = the effective, one-group (n,α) cross section of nuclide NUCLID leading to a ground state; activation product and fission product segments only

SNF = the effective, one-group (n,fission) cross section of nuclide NUCLID; actinide segment only

SNP = the effective, one-group (n,p) cross section of nuclide NUCLID leading to a ground state; activation product and fission product segments only

SNGX = the effective, one-group (n,γ) cross section of nuclide NUCLID leading to an excited state of the daughter

SN2NX = the effective, one-group (n,2n) cross section of nuclide NUCLID leading to an excited state of the daughter

YYN = a control character indicating whether or not a fission yield card follows:

YYN.GT.0.0 = fission yield card follows
YYN.LT.0.0 = no fission yield card follows

Table 5.2 (continued)

Y(I) = fission yield of nuclide NUCLID from various fissile species, in percent

I	Fissile species
1	Th-232
2	U-233
3	U-235
4	U-238
5	Pu-239
6	Pu-241
7	Cm-245
8	Cf-249

B. Number of cards per nuclide: 2

C. Terminate card scan for nuclide NUCLID: Automatic.

D. Terminate reading this cross-section and fission product yield library segment: NLB.LT.0, one card.

E. Skip reading this cross-section and fission product yield library segment: Controlled by LIB command (Sect. 4.18).

F. Remarks: None.

Table 5.3. Description of substitute decay, cross-section, and fission product yield data

Data sequence

1. Substitute activation product decay data
2. Substitute actinide decay data
3. Substitute fission product decay data
4. Substitute activation product cross-section data
5. Substitute actinide cross-section data
6. Substitute fission product cross-section and yield data

Format

The substitute data cards are free format, and the order of the data is as described in Tables 5.1 and 5.2.

Remarks

1. The LPU command (Sect. 4.20) used to identify the nuclides for which substitute data are to be read must appear before the LIB command (Sect. 4.18) in which the bulk of the library is read.
2. The nuclides in each of substitute card groups 1 through 6 above must be present in the input stream in the same order in which they are encountered while reading the original decay libraries.
3. A fission product yield card can never appear alone and must always follow a cross-section card for the same nuclide.

5.4 Specification of Non-Standard, Flux-Dependent Reactions

This option allows the user to specify flux-dependent (i.e., cross-section) reactions that cannot be accounted for by using one of the standard ORIGEN2 reaction types [viz., (n,γ), (n,p), (n,α), (n,2n), (n,3n), (n,fission)]. The format of these non-standard, flux-dependent reactions is described in Table 5.4. The number of non-standard, flux-dependent reactions to be read and the input unit number on which they are to be read are defined by the LIB command in Sect. 4.18.

5.5 Photon Data Libraries

The first card of each of the three possible photon library segments is a title card containing the number and alphanumeric title of the photon library segment. Following the title card are cards containing the photon production rates per disintegration in a predetermined energy group structure for each nuclide. A description of the photon library format is given in Table 5.5. The predetermined energy group structure is given in Table 5.6. The input of the photon libraries is controlled by the PHO operational command (Sect. 4.19).

Table 5.4. Description of non-standard, flux-dependent reaction data

Data sequence

NPAR NDAUG RATE

where

NPAR = the six-digit nuclide identifier (see Sect. 2.7) of the parent or precursor nuclide

NDAUG = the six-digit nuclide identifier (see Sect. 2.7) of the daughter nuclide

RATE = the cross section for the formation of nucldie NDAUG from nuclide NPAR in units of barns

Formats

One reaction per card.

Remarks

1. The number of non-standard, flux-dependent reaction cards to be input and the unit number upon which they are to be read are specified using the LIB command (Sect. 4.18).

Table 5.5. Description of photon library

A. Data sequence:

First card of each library segment:

NLB TITLE

First card for each nuclide:

NLB NUCLID NGP(1), RPH(1), . . . NGP(I), RPH(I)

Subsequent card(s) for each nuclide:

NGP(I+1), RPH(I+1), . . . NGP(IMAX), RPH(IMAX), -1

where

NLB = the number of this photon library segment

TITLE = a 72-character alphanumeric photon library segment title beginning in Column 9

NUCLID = a six-digit nuclide identifier for the photon information on the following card(s) (see Sect. 2.7)

NGP(I) = the number of a photon energy group. Eighteen groups are allowed for all segments. The energy group structure is given in Table 5.6.

RPH(I) = photon intensity for energy group NGP(I) in photons per disintegration

IMAX = the number of NGP(I)/RPH(I) pairs specified must be .LE.18

B. Number of cards per nuclide: One "first card" plus as many "subsequent card(s)" as required for those nuclides with non-zero NGP(I)/RPH(I) data.

C. Terminate card scan for nuclide NUCLID: NGP(IMAX+1).LT.0 if IMAX is less than 18; automatic otherwise.

D. Terminate reading this photon library segment: NLB.LT.0.

E. Skip reading this photon library segment: Controlled by PHO command (Sect. 4.19).

F. Remarks:

1. Only those NGP(I)/RPH(I) pairs for which RPH(I) is non-zero need be specified.

Table 5.6. Photon energy group structures for activation products, actinides, and fission products

Group	Group energy (MeV) Lower boundary	Upper boundary	Average
1	0.0	2.0000E-02	1.0000E-02
2	2.0000E-02	3.0000E-02	2.5000E-02
3	3.0000E-02	4.5000E-02	3.7500E-02
4	4.5000E-02	7.0000E-02	5.7500E-02
5	7.0000E-02	1.0000E-01	8.5000E-02
6	1.0000E-01	1.5000E-01	1.2500E-01
7	1.5000E-01	3.0000E-01	2.2500E-01
8	3.0000E-01	4.5000E-01	3.7500E-01
9	4.5000E-01	7.0000E-01	5.7500E-01
10	7.0000E-01	1.0000E 00	8.5000E-01
11	1.0000E 00	1.5000E 00	1.2500E 00
12	1.5000E 00	2.0000E 00	1.7500E 00
13	2.0000E 00	2.5000E 00	2.2500E 00
14	2.5000E 00	3.0000E 00	2.7500E 00
15	3.0000E 00	4.0000E 00	3.5000E 00
16	4.0000E 00	6.0000E 00	5.0000E 00
17	6.0000E 00	8.0000E 00	7.0000E 00
18	8.0000E 00	1.1000E 01	9.5000E 00

6. SPECIFICATION OF INITIAL MATERIAL COMPOSITIONS, CONTINUOUS NUCLIDE FEED RATES, AND CONTINUOUS ELEMENT REMOVAL RATES

This section describes the options available to the user relative to the specification of the initial material compositions, the continuous nuclide feed rates, and the continuous element removal (reprocessing) rates. The most often used option by far is the specification of the initial composition of some material (Sect. 6.1). The initial composition can be specified on either a nuclide-by-nuclide basis or as the amount of a naturally occurring element which is present. The amount of a naturally occurring element is converted to a nuclide-by-nuclide basis internally using the natural isotopic abundances input with the decay library (Sect. 5.1). The amounts of individual nuclides or naturally occurring elements may be specified as g-atoms or g, depending on the control characters of the INP command (Sect. 4.6).

The continuous nuclide feed rate option (Sect. 6.2) allows the user to specify the continuous feed rate of individual nuclides or naturally occurring elements in units of g/(time unit)(basis unit) or g-atoms/(time unit)(basis unit). Both the mass units and the time units are specified by using the INP command (Sect. 4.6). This option is useful in simulating the continuous feed of nuclides to a fluid-fuel reactor (e.g., a MSBR) or to a radioactive waste tank.

The continuous element removal option (Sect. 6.3) allows the user to specify the continuous removal rates of elements during irradiation in units of fraction/time unit. The time units are specified using the INP command (Sect. 4.6). This option is most useful when simulating the continuous reprocessing which would be expected to occur during the operation of a fluid-fuel reactor such as an MSBR. If this option is to be used to calculate continuous element removal in a situation where irradiation is not taking place, then a very small neutron flux must still be specified to allow the continuous element removal option to be used.

6.1 Specification of Initial Material Composition

A. Function: Specify initial amounts of individual nuclides or naturally occurring elements.

B. Data sequence:

NEXT, NUCLID(1), RCOMP(1), . . . NUCLID(IMAX), RCOMP(IMAX)

where

NEXT = a control character indicating for which segment the information is intended and the type of information: (i.e., nuclides or elements)

- 1 = individual activation product nuclides
- 2 = individual actinide nuclides
- 3 = individual fission product nuclides
- 4 = naturally occurring activation product elements
- 5 = naturally occurring actinide elements
- 6 = naturally occurring fission product elements

NUCLID(I) = the six-digit identifier for nuclide or element I (see Sect. 2.7)

RCOMP(I) = amount of nuclide or element NUCLID(I) initially present. The units of RCOMP(I) are specified with the INP operational command (Sect. 4.6).

IMAX = maximum number of NULCID(I)/RCOMP(I) pairs specified on each card must be .LE.4

C. Terminate card scan: NUCLID(IMAX + 1) = 0 if IMAX.LT.4

D. Terminate reading initial composition: Card with NEXT = 0

E. Skip reading initial composition: Alter control characters of pertinent INP command or a card with NEXT = 0.

F. Remarks:

1. If a given nuclide is specified more than once for a single value of NEXT, all of the RCOMP(I) values for that nuclide on cards having that next value are added together to form the initial amount of that nuclide in a particular segment.

2. Initial composition cards with different NEXT values may occur in any order as long as the NUCLID(I) and RCOMP(I) values on any given card correspond to the NEXT value on that card.

6.2 Specification of Continuous Feed Rates

A. Function: Read feed rates of individual nuclides or naturally occurring elements.

B. Data sequence:

NEXT, NUCLID(I), RRATE(1), . . . NUCLID(IMAX), RRATE(IMAX)

where

NEXT = a control character indicating for which segment the information is intended and the type of information:
- 1 = individual activation product nuclides
- 2 = individual actinide nuclides
- 3 = individual fission product nuclides
- 4 = naturally occurring activation product elements
- 5 = naturally occurring actinide elements
- 6 = naturally occurring fission product elements

NUCLID(I) = the six-digit nuclide identifier for nuclide or element I (see Sect. 2.7)

RRATE(I) = the feed rate of nuclide or element NUCLID(I). The units of RRATE(I) are specified with the INP command (Sect. 4.6).

IMAX = maximum number of NUCLID(I)/RRATE(I) pairs specified on each card; IMAX must be .LE.4

C. Terminate card scan: NUCLID(IMAX + 1) = 0 if IMAX.LT.4

D. Terminate reading continuous feed rates: Card with NEXT = 0

E. Skip reading continuous feed rates: Alter control characters of pertinent INP command or a card with NEXT = 0.

F. Remarks:

1. If the feed rate of a given nuclide is specified more than once for a single value of NEXT, all of the RRATE(I) values for that nuclide on cards having that particular NEXT value are added together to form the total feed rate for nuclide NUCLID(I).
2. Continuous feed rate cards with different NEXT values may occur in any order as long as the NUCLID(I) and RRATE(I) values on any given card correspond to the NEXT value on that card.

6.3 Specification of Continuous Reprocessing Rates

A. Function: Read continuous element removal rates during irradiation.

B. Data sequence:

Group 1 (one card set)

RREM(1), NPROS(1), . . . RREM(M), NPROS(M), . . .
RREM(MMAX), NPROS(MMAX)

Group 2 [MMAX card sets (M = 1 to MMAX)]

NZ(M,1), . . . NZ(M,N), . . . NZ[M,NPROS(M)]

where

RREM(M) = the first-order removal rate of elements NZ(M,1) through NZ[M,NPROS(M)]. The units of RREM(M) are specified with the INP command (Sect. 4.6).

NPROS(M) = the number of elements in card set M of Group 2; that is, the number of elements which have a continuous removal rate equal to RREM(M).

MMAX = the number of continuous reprocessing rates to be read. Also, the number of card sets in Group 2. MMAX is specified as NINP(4) using the INP command (Sect. 4.6).

NZ(M,N) = the two-digit (e.g., He = 02) atomic number of an element with removal rate RREM(M).

C. Terminate card scan: Implicit in input information.

D. Terminate reading continuous reprocessing rates: Implicit in input information.

E. Skip reading continuous reprocessing rates: Alter control character of pertinent INP command.

F. Remarks:

1. Continuous element removal will occur only during irradiation. If continuous removal is desired in a situation where no neutron flux is present, use the IRF command (Sect. 4.21) with a very small flux.

7. ORIGEN2 INPUT DECK ORGANIZATION

Sections 7.1 through 7.3 describe the order in which the data discussed in Sects. 2 through 6 are organized in the card input deck. Section 7.1 describes the organization of the source and object card decks that comprise the ORIGEN2 code. Section 7.2 describes the organization of the ORIGEN2 card data input deck, assuming that the nuclide data libraries (Sects. 5.1 through 5.3) are on cards. Section 7.3 is similar to Sect. 7.2, except that the nuclide data libraries are assumed to be on tape or direct-access-device files.

7.1 Source and Object Deck Organization

This section describes the organization of the ORIGEN2 source and object card decks. The general form of the ORIGEN2 code card deck is given in Table 7.1.

The recommended mode of operation, which is reflected in Table 7.1, is to place object decks of all ORIGEN2 subroutines, except MAIN, on either a tape or a direct-access device. During normal operation of ORIGEN2, MAIN would be recompiled each time the code is used and would be the only [FORTRAN subroutines] present in the Table 7.1 input deck scheme. MAIN is recompiled to facilitate use of the variable dimensioning option. No [object deck(s)] would normally be present, and only the INCLUDE HEX card and the overlay cards would be used. The [OVERLAY statements] are not required. They do, however, considerably reduce the size of the final executable module.

A somewhat less common situation occurs when the user wishes to make changes in selected object subroutines that have previously been stored on tape or a direct-access device. In this case, the revised FORTRAN and/or object subroutines are also included in the card deck in the appropriate place, as indicated in Table 7.1. The subroutines on cards will automatically be substituted for those on the tape or direct-access device.

Table 7.1. Source and object deck organization

Input deck	Comments	Section where described
	FORTRAN step	
//FORT.SYSIN DD *		
[FORTRAN Subroutine(s)]	MAIN plus FORTRAN subroutine(s) to be substituted for similarly named subroutines in a previously compiled version of ORIGEN2 that is stored on a direct-access device or tape.	2.1
/*		
	Link-edit step	
//LKED.HEX DD DSN=ORIGEN2.OBJECT,DISP=SHR	JCL to call previously compiled version of ORIGEN2 from direct-access device or tape; not used if the entire ORIGEN2 code is present on cards.	None
//LKED.SYSIN DD * [OBJECT Deck(s)] INCLUDE HEX [OVERLAY Statements] /*	Read OBJECT subroutine(s) to be substituted for those in the previously compiled version of ORIGEN2; substitute FORTRAN subroutines compiled above and OBJECT subroutines for those in object deck on direct-access device or tape; read OVERLAY statements to arrange subroutines in a space-minimizing order. If the entire ORIGEN2 code is present on cards, the INCLUDE HEX card is omitted.	None

In the hopefully uncommon situation where the entire ORIGEN2 code is on cards, the //LKED.HEX . . . and INCLUDE HEX cards are omitted.

7.2 ORIGEN2 Input Deck Organization — Nuclide Data Libraries on Cards

The organization of the ORIGEN2 input deck, assuming that the decay, cross-section, fission-product yield and photon data libraries are on cards, is given in Table 7.2. A summary of the input deck order is as follows:

- control cards defining input/output units;
- miscellaneous initialization data changes;
- ORIGEN2 commands;
- decay data library;
- cross-section/fission yield data library;
- photon data library;
- initial nuclide compositions and continuous feed and reprocessing rates;
- substitute decay, cross-section, and fission-product yield data;
- non-standard, flux-dependent reactions.

It is important to note that all of the nuclide data libraries read with the LIB command (Sect. 4.18) must be read on the same input unit. A similar statement can be made about the data libraries read with the PHO command (Sect. 4.19), although the units defined by the LIB and PHO commands may be different. The substitute data and non-standard reaction data can be read on a unit different from that used by the LIB data libraries.

Table 7.2. ORIGEN2 input organization when the libraries are on cards

Input deck	Comments	Section(s) where described
	<u>Output unit specification</u>	Table 2.3
//GO.FT04F001 DD DUMMY	Input compositions on disk or tape (Sect. 4.5)	
//GO.FT06F001 DD SYSOUT=A	Print unit for input listing, bibliography, and errors	
//GO.FT07F001 DD DUMMY	Write a material composition (Sect. 4.15)	
//GO.FT08F001 DD SYSOUT=A	Principal print unit	
//GO.FT09F001 DD DUMMY	Decay/cross-section library input from disk or tape; not used in this case	
//GO.FT10F001 DD DUMMY	Photon library input from disk or tape; not used in this case	
//GO.FT11F001 DD DUMMY	Alternate print unit	
//GO.FT12F001 DD SYSOUT=A	Print unit for unit 8 table of contents	
//GO.FT13F001 DD DUMMY	Print unit for unit 11 table of contents	
//GO.FT15F001 DD DUMMY	Debugging information	
//GO.FT16F001 DD DUMMY	Variable cross-section information	
//GO.FT50F001 DD DSN=TEMP, SPACE=(3200,(50,50),RLSE), DISP=(NEW,PASS),DCB=(RECFM=FB, LRECL=80,BLKSIZE=3200)	Temporary space for input read on unit 5	

Table 7.2 (continued)

Input deck	Comments	Section(s) where described
	<u>Miscellaneous initialization data</u>	
[Override default individual element fractional recoveries] -1	Data need not be present; -1 required	3.4
[Override default element group fractional recoveries] -1	Data need not be present; -1 required	3.5
[Override default element group membership] -1	Data need not be present; -1 required	3.6
	<u>ORIGEN2 commands</u>	
[ORIGEN2 commands]	Only commands up to and including the first STP command (Sect. 4.29) or the end command are present here.	4
	<u>Decay data library</u>	4.18, 5.1
[Activation product decay data library] -1	Some of these libraries (including their associated -1) may not be present, depending on the parameters of the LIB command (Sect. 4.18).	
[Actinide decay data library] -1		
[Fission product data library] -1		

Table 7.2 (continued)

Input deck	Comments	Section(s) where described
⋮	<u>Cross-section data libraries</u>	4.18, 5.2
[Activation product cross-section data library] -1	Some of these libraries (including their associated -1) may not be present, depending on the parameters of the LIB command (Sect. 4.18).	
[Actinide cross-section data library] -1		
[Fission product cross-section data library] -1		
	<u>Photon data libraries</u>	4.19, 5.5
[Activation product photon data library] -1	Some or all of these libraries may not be present, depending on the parameters of the PHO command (Sect. 4.19) and whether it is present.	
[Actinide photon data library] -1		
[Fission product photon data library] -1		

Table 7.2 (continued)

Input deck	Comments	Section(s) where described
	<u>Composition, feed rates, and removal rates</u>	
[Initial nuclide or element mass] 0		4.6, 6.1
[Continuous nuclide or element feed rates] 0		4.6, 6.2
[Continuous element removal rates]		4.6, 6.3
	<u>Branch or stop</u>	
[Begin input with miscellaneous data above]	If (NSTP.EQ.1), read new miscellaneous input data, read new ORIGEN2 commands, and execute new commands.	
[Begin input with ORIGEN2 commands above]	If (NSTP.EQ.2), read new ORIGEN2 commands and execute.	
[Begin input with decay data libraries]	If (NSTP.EQ.3), execute existing ORIGEN2 commands again.	
	If (NSTP.EQ.4) or no STP command is used, terminate execution.	

```
/*
//GO.FT03F001 DD *
```

Table 7.2 (continued)

Input deck	Comments	Section(s) where described
⋮	<u>Substitute data</u>	4.18, 4.20
[Activation product decay data] [Actinide decay data] [Fission product decay data] [Activation product cross-section data] [Actinide cross-section data] [Fission product cross-section data]	Some or all of these data may not be present, depending on the parameters of the LIB command (Sect. 4.18). If the libraries are on cards, these substitutes can be manually placed in the appropriate library, eliminating the need for this section.	
	<u>Non-standard reactions</u>	4.18, 5.4
[Non-standard, flux-dependent reactions]	May not be present, depending on parameters of the LIB command (Sect. 4.18)	
/* //		

7.3 ORIGEN2 Input Deck Organization — Nuclide Data Libraries on Tape or a Direct-Access Device

The organization of the ORIGEN2 input deck, assuming that the decay, cross-section, fission product yield, and photon libraries are on tape or a direct-access device, is given in Table 7.3. A summary of the input deck order is as follows:

- control cards defining input/output units and data library files;
- miscellaneous initialization data;
- ORIGEN2 operational commands;
- initial nuclide compositions and continuous feed and reprocessing rates;
- substitute decay, cross-section, and fission product yield data;
- non-standard, flux-dependent reactions.

As in Sect. 7.2, it is important to note that all of the nuclide data libraries read with the LIB command (Sect. 4.18) must be read on the same input unit. A similar statement can be made about the data libraries read with the PHO command, although the units defined by the LIB and PHO commands (Sect. 4.19) may be different. The substitute data cards must be read on a different unit from that used by the LIB data libraries.

Table 7.3. ORIGEN2 input organization when the libraries are on a direct-access device

Input deck	Comments	Section(s) where described
	<u>Output unit specification</u>	Table 2.3
//GO.FT04F001 DD DUMMY	Input compositions on disk or tape (Sect. 4.5)	
//GO.FT06F001 DD SYSOUT=A	Print unit for input listing, bibliography, and errors	
//GO.FT07F001 DD DUMMY	Write a material composition (Sect. 4.15)	
//GO.FT08F001 DD SYSOUT=A	Principal print unit	
//GO.FT11F001 DD DUMMY	Alternate print unit	
//GO.FT12F001 DD SYSOUT=A	Print unit for unit 8 table of contents	
//GO.FT13F001 DD DUMMY	Print unit for unit 11 table of contents	
//GO.FT15F001 DD DUMMY	Debugging information	
//GO.FT16F001 DD DUMMY	Variable cross-section information	
//GO.FT50F001 DD DSN=TEMP, SPACE=(3200,(50,50),RLSE), DISP=(NEW,PASS),DCB=(RECFM=FB, LRECL=80,BLKSIZE=3200)	Temporary space for input read on unit 5	
	<u>Decay data library</u>	
//GO.FT09F001 DD DSN=ORIGEN2.DECAY, DISP=SHR	Activation product, actinide and fission product decay libraries in one file	4.18, 5.1

Table 7.3 (continued)

Input deck	Comments	Section(s) where described
	Cross-section data library	
// DD DSN=ORIGEN2.XSEC,DISP=SHR	Activation product, actinide, and fission product cross-section libraries in one file	4.18, 5.2
	Photon data library	4.19, 5.5
//GO.FT10F001 DD DSN=ORIGEN2.PHOTON, DISP=SHR	Activation product, actinide, and fission product photon data in one file	
//GO.FT05F001 DD *		
	Miscellaneous initialization data	
[Override default individual fractional recoveries] -1	Data need not be present; -1 required	3.4
[Override default element group fractional recoveries] -1	Data need not be present; -1 required	3.5
[Override default element group membership] -1	Data need not be present; -1 required	3.6

Table 7.3 (continued)

Input deck	Comments	Section(s) where described
	<u>ORIGEN2 commands</u>	
[ORIGEN2 commands]	Only commands up to and including the first STP command (Sect. 4.29) or the end command are present here.	4.0
	<u>Composition, feed rates, and removal rates</u>	
[Initial nuclide or element mass] 0		4.6, 6.1
[Continuous nuclide or element feed rates] 0		4.6, 6.2
[Continuous element removal rates]		4.6, 6.3
	<u>Branch or stop</u>	4.29
[Begin input with miscellaneous input data above]	If (NSTP.EQ.1), read new miscellaneous input data, new ORIGEN2 commands, and execute new commands.	
[Begin input with ORIGEN2 commands above]	If (NSTP.EQ.2), read new ORIGEN2 commands and execute.	
[Begin input with decay data libraries]	If (NSTP.EQ.3), execute existing ORIGEN2 commands again.	
	If (NSTP.EQ.4) or no STP command is used, terminate execution.	
/* //GO.FT03F001 DD *		

Table 7.3 (continued)

Input deck	Comments	Section(s) where described
	<u>Substitute data</u>	4.18, 4.20
[Activation product decay data]	Some or all of these data may not be present, depending on the parameters of the LIB command (Sect. 4.18).	
[Actinide decay data]		
[Fission product decay data]		
[Activation product cross-section data]		
[Actinide cross-section data]		
[Fission product cross-section data]		
	<u>Non-standard reactions</u>	
[Non-standard, flux-dependent reactions]	May not be present, depending on parameters of the LIB command (Sect. 4.18)	4.18, 5.4
/*		
//		

8. DESCRIPTION OF ORIGEN2 INPUT AND OUTPUT

This section presents and describes a specific ORIGEN2 calculation. The example calculationally irradiates fresh 3.2%-enriched uranium oxide fuel and the cladding associated with the fuel, reprocesses the fuel, and then decays the high-level and cladding wastes. Other instructions that do not meaningfully contribute to the calculation have been included for demonstration purposes.

Section 8.1 describes the ORIGEN2 input deck that is listed in Appendix A. Section 8.2 contains a generic description of ORIGEN2 output, which is necessary because of the apparent difficulty many users experience when trying to read ORIGEN2 printout. Section 8.3 describes representative portions of the output (listed in Appendixes B-F) resulting from execution of the input deck described in Sect. 8.1.

8.1 Description of Sample ORIGEN2 Input

The sample ORIGEN2 input deck described here is listed in Table A.1 of Appendix A. Except for the first few cards (which are dictated by local computer conventions), all of the cards necessary to perform the specified calculations are present, assuming that ORIGEN2 exists as an object deck on a direct-access device or tape. In the discussion to follow, specific cards in the input deck will be referred to by the card number given in the left-hand column in Table A.1.

Cards 1 through 5 call for the cataloged procedure in which a FORTRAN program is compiled (optimizing compiler), link-edited, and executed. Cards 6 through 89 constitute "MAIN" (see Sect. 2.1); they are the only parts of ORIGEN2 that are present in the FORTRAN language. These cards are a specific case of the general version of MAIN shown in Fig. 2.1 and correspond to case 1 in Table 2.2. The most significant aspects of MAIN are described on the comment cards contained in the listing in Table A.1.

Following MAIN on cards 90 through 105 is a series of job control cards for ORIGEN2. Cards 91 and 92 point to the compiled subroutines of ORIGEN2 (i.e., the object module), which reside on a direct-access device in this example. Card 93 points to the OVERLAY statements, which are used to arrange the ORIGEN2 subroutines in a space-minimizing configuration. The OVERLAY statements are also stored on a direct-access device and are listed in Table A.2 of Appendix A. Cards 95 and 96 point to the decay and cross-section/fission product yield libraries that are stored on a direct-access device. The data sets are concatenated to prevent ORIGEN2 from encountering an end-of-file when it begins to read the cross-section data. ORIGEN2 will continue if the cross-section data set is not concatenated (i.e., the cross-section data set is given as GO.FT09F002 DD, etc.). However, in this case, an error message will be printed. Card 97 points to the photon library, which is stored on a direct-access device. Cards 98 through 102 and 105 point several ORIGEN2 output units to the line printer (see Sect. 2.5). Unit 6 is automatically pointed to the line printer by the ORNL operating system and must be included explicitly on systems where this is not done. Card 94, which is the output unit for the PCH command, is pointed to the card punch. Cards 103 and 104 define the scratch data set to which SUBROUTINE LISTIT (see Sect. 2.6) writes the input data read on unit 5 while they are also being listed on unit 6.

Cards 106 through 290 constitute the input to ORIGEN2 that is read on unit 5. Only the highlights of the input on unit 5 will be discussed since many of these cards result from straightforward application of the commands in Sect. 4. Cards 107 through 113 override various of the fractional reprocessing recoveries, as described in Sects. 3.4 through 3.6. Cards 125 through 128 are the LPU commands that indicate the nuclides for which substitute data are to be provided. The first LPU command is associated with the first negative library identifier on the LIB command [(card 129), i.e., the fission product decay library (library identifier = -3)]. The second LPU command is associated with the second negative library identifier (viz., -21), and so forth. The substitute data cards are to be read on unit 3, as indicated on the LIB card. Additionally, the LIB command calls for two non-standard reactions to be read on unit 3. Cards 134 through 142 read various input material compositions and store them in storage vectors. Cards 143 through 158 constitute the irradiation of the oxide fuel material, with specific power being specified. Two aspects of this section should be noted: (1) the use of the BUP commands (cards 146 and 158) to define the steps in which the characteristic burnup is to be determined; and (2) the use of the right portion of the IRP commands for comments, which is permitted on all cards after the last required character. Cards 159 through 162 output the results of the fuel irradiation. The OPTn commands result in only the gram summary tables for all three output segments (activation products, actinides, and fission products) being printed along with all nuclide aggregations for the activation product curies table (see Sect. 8.2 for a more detailed discussion). Cards 166 and 167 are superfluous for the purposes of this calculation. They have only been included for the purpose of describing the output they produce on unit 15, and will be discussed further in Sect. 8.3.4. Cards 168 through 186 irradiate the fuel cladding material by specifying the flux level; however, since the flux is given as -1.0, the flux actually used is taken from the appropriate step of the fuel irradiation above. Cards 191 through 194 write several vectors in a format suitable for input to ORIGEN2 at a later date. Card 195 temporarily halts the reading of the ORIGEN2 commands and begins execution of those already read. The "2" in the STP command indicates that when execution of the preceding commands is complete, new commands, but not new miscellaneous initialization data, are to be read. Cards 196 through 226 define the input material compositions read by the INP commands on cards 134 through 142. Note the use of comments on the right portion of the cards and the zeroes (first character on card) that terminate the execution of each INP command. Card 227 begins the new set of commands required by the previous STP command. Cards 230 through 232 again read decay, cross-section/fission product yield, and photon libraries. No additional job control cards are required because the units are rewound after the libraries have been read. Cards 234 through 240 reprocess the fuel to generate the high-level waste (HLW) composition as well as the composition of the fuel residual in the cladding. Cards 243 through 265 and 266 through 288 constitute the decay and output of the high-level waste and cladding waste. Note that this information is being output on both units 6 and 11 by the use of two OUT commands for each waste. Card 289 indicates that, after execution of the previous commands, the job is completed.

Cards 291 through 306 contain the unit 3 input to ORIGEN2. Cards 292 through 300 contain the information to override data in the libraries being read from a direct-access device on unit 9 (see Sect. 5.3), and their presence is required by cards 125 through 128. Cards 301 and 302 contain the two non-standard reactions (see Sect. 5.4) required by the first LIB command (card 129). Cards 303 through 306 contain the substitute data for the second set of LPU/LIB commands (cards 230 and 231). Note that only the decay information is required since only the decay libraries are being read.

8.2 Generic Description of ORIGEN2 Output

Previous experience has shown that many people have difficulty in reading ORIGEN output and, because of the greater number of output units and table types, even greater difficulty with ORIGEN2 output. The principal problem appears to be in finding the correct table in the generally massive amount of output produced by ORIGEN2. This section represents an attempt to alleviate the problem by giving a generic description of the organization of ORIGEN2 output. Section 8.3 will describe in detail the sample output in Appendix B.

ORIGEN2 output is arranged in a hierarchical form containing four levels. Thus, the first objective is to establish the overall (first-level) organization of the output. This is done in Sect. 8.2.1. Next, in Sect. 8.2.2, the principal component of the first-level organization, which is called an "output grouping," is dissected. Finally, in Sect. 8.2.3 a single ORIGEN2 output page is analyzed.

8.2.1 Overall organization of ORIGEN2 output

The overall organization of a typical ORIGEN2 output is summarized in Table 8.1. The overall organization contains the first level of the output hierarchy and, in some cases, the second level. Most of the output in the first level is relatively short, with the exception of the "Output N," which will be discussed later.

The card input echo is simply a listing of the input read on the card reader. This function is controlled from MAIN (see Sect. 2.6), and the unit numbers can be changed readily by changing the calling arguments to SUBROUTINE LISTIT.

The listing of the miscellaneous input data, the ORIGEN2 commands, and the data libraries is to ensure that the information read by ORIGEN2 was received properly. The listing of the most voluminous of these three items, the data libraries, can be controlled by the LIP (Sect. 4.16) command. The details of these data are contained in the sections indicated in Table 8.1 and will not be discussed further here.

The output tables, which generally comprise the largest fraction of the ORIGEN2 output by far, will be discussed in detail in Sect. 8.2.2.

All of the information printed on unit 6 is numbered sequentially by page. The table of contents printed on unit 12 lists the various types of information printed in the ORIGEN2 output and the page where each begins. It is hoped that this device will minimize the amount of searching required to find a particular piece of information in a large volume of output.

The variable cross-section information printed on unit 16 gives the values of each of the cross sections that vary with burnup for each irradiation step. Several types of data are given, including (1) the list of isotopes and cross sections (i.e., capture or fission) that are varying, (2) the previous and current cross-section values, (3) the location of the values being varied in the ORIGEN2 arrays, (4) the location of the fission product yields that must be altered when fission cross sections are changed, (5) an indication of the burnup anticipated for the current irradiation step (this is what the variable cross sections depend on),

Table 8.1. Overall organization of ORIGEN2 output

Description of output	Unit[a]	Section where described
Card input echo	6	8.2
Miscellaneous input	6	3
Fission neutron yield per neutron-induced fission		
(alpha,n) neutron production rate		
Fission neutron yield per spontaneous fission		
Individual-element fractional reprocessing recoveries		
Element-group fractional reprocessing recoveries		
Assignment of elements to fractional recovery groups		
Elemental chemical toxicities		
Listing of ORIGEN2 commands	6	4
Data libraries	6	5
Decay		
Activation product segment		
Actinide segment		
Fission product segment		
Cross section		
Activation product segment		
Actinide segment		
Fission product segment		
Photon		
Activation product segment		
Actinide segment		
Fission product segment		
Output 1[b]	6	8.2.1
Output 2[b]	6	8.2.1
.		
.		
.		
Output N[b]	6	8.2.1
Table of contents	12	8.2
Variable cross-section information	16	8.2
Debugging and other internal information	15	8.2

[a]Assuming that the unit assignments given in Table 2.3 are used.

[b]See Table 8.2 for a description of the organization of each output grouping.

Note: If an STP command (see Sect. 4.24) is used, the output after "Output N" in the above table will begin with miscellaneous input (NSTP=1), ORIGEN instruction listing (NSTP=2), or Output N+1 (NSTP=3).

and (6) an indication of which actinide isotope with direct fission product yields is being used to account for those actinides (i.e., ^{237}Np, ^{240}Pu, etc.) that do not have a direct fission product yield.

The debugging and other internal information that is printed on unit 15 is generally most useful in monitoring the progress of the calculation. The execution of each command begins with the printing of a one-line message that indicates the number and type of command being executed. Other information that is printed here includes:

1. parameters related to the calculation of the flux by an IRP command (Sect. 4.22),
2. the average recoverable energy per fission for each irradiation step,
3. parameters calculated during the execution of a FAC command (Sect. 4.4), and
4. parameters calculated during the execution of a KEQ command (Sect. 4.10).

The information discussed above generally constitutes the output in a typical ORIGEN2 calculation. However, under conditions where an extremely large amount of output is desired, it may prove useful to direct a limited amount of the output to unit 6 and the majority of the output to unit 11. Unit 11 could be a direct-access device, tape, or microfiche writer. In any case, the output directed to unit 11 will be the Output N information, and unit 13 will be the table of contents for unit 11.

Finally, there is one type of ORIGEN2 output which, although rarely generated, can be very useful for some debugging purposes. This output is a listing of the "matrix" of reaction rates that are the parameters in the differential equations being solved by ORIGEN2 and that connect each isotope with its parents and progeny. This output, controlled by the LIB command (Sect. 4.17), would require roughly 75 pages for an ORIGEN2 calculation that includes all nuclides.

8.2.2 Description of the organization of an output group

The organization of the information contained in one of the Output N sections in Table 8.1 is summarized in Table 8.2. This will be called an "output grouping" henceforth. An output grouping results from the execution of one OUT command (Sect. 4.5). The output grouping contains the second, third, and fourth levels of the ORIGEN2 hierarchical output.

An output grouping can contain six second-level sections: reactivity and burnup data, an activation product segment, an actinide segment (including daughters), a fission product segment, neutron emission rates, and photon emission rates.

The reactivity and burnup data consist of less than one page of information summarizing the fluxes, burnups, specific power, and infinite multiplication factor data for each of the vectors being printed. In addition, the information related to the size of the ORIGEN2 case (see Tables 2.1 and 2.2) is summarized here. The output of this information can be controlled by the OUT command (Sect. 4.5).

The activation product segment consists of the output of one or more "table types" containing information for only the activation products. A table type is characterized by the units of the table, such as mass (grams), radioactivity (curies), thermal power (watts), or neutron absorption rate (neutrons/sec). Twenty-four table types are available in ORIGEN2; these are listed in Table 4.3. The table types that are printed are controlled by the OPTL command (Sect. 4.25). For each table type, there are four possible aggregations: nuclide, element, summary isotope, and summary element. The aggregation(s) that are printed are also controlled by the OPTL command. The nuclide aggregation lists the specified characteristic of each nuclide in each of the vectors being printed. The element aggregation lists the specified characteristic for each chemical element in each of the vectors being printed. The summary aggregations contain the same type of information as the regular tables except that only those nuclides (or elements) which contribute more than a certain fraction (i.e., cutoff value) to the total for all activation product isotopes are listed. The cutoff values are specified with the

Table 8.2. Organization of an output grouping

Reactivity and burnup data

Activation product segment

Table type 1[a]

- Nuclide aggregation
- Element aggregation
- Summary isotope aggregation
- Summary element aggregation

Table type 2[a]

- Nuclide aggregation
- Element aggregation
- Summary isotope aggregation
- Summary element aggregation

Table type 24[a]

- Nuclide aggregation
- Element aggregation
- Summary isotope aggregation
- Summary element aggregation

Actinide segment
[same table types and aggregations as for activation products]

Fission product segment
[same table types and aggregations as for activation products]

Neutron production rates

- (alpha,n)
- Spontaneous fission

Photon production rates

Activation product segment
- Summation tables
- Principal contributor tables

Actinide segment
[same aggregations as for activation products]

Fission product segment
[same aggregations as for activation products]

[a]The table types that are actually printed can be controlled with the OPTn commands (see Sects. 4.25–4.27).

Note: An "output grouping" results from the execution of a single OUT command (see Sect. 4.5).

CUT command (Sect. 4.9). It should be noted that some table types, such as fission rate and alpha radioactivity, are not applicable to activation products and cannot be printed.

The actinide segment and the fission product segment in Table 8.2 are very similar to the activation product segment described above and will not be discussed in detail. The table types and aggregations printed for the actinides and the fission products are controlled by the OPTA (Sect. 4.26) and the OPTF (Sect. 4.27) commands respectively.

The neutron production rate tables are relatively compact and straightforward. Each consists of a one-page listing of the neutron production rates from (alpha,n) reactions for each nuclide in each vector printed and a one-page listing of the neutron production rates from spontaneous fission for each nuclide in each vector printed. Both of these tables are "summary tables" since the contribution of each nuclide to the total is tested against a cutoff value specified by the CUT command (Sect. 4.9). If the isotope's contribution is less than the cutoff, the isotope is not printed.

The final second-level section of the output grouping is the photon production rates. This is further broken down into an activation product segment, actinide segment, and a fission product segment. Since the photon production rate output for each of these segments is substantially the same, only the activation product segment will be described in detail. The activation product photon output consists of summation tables and principal contributor tables. The summation tables list the photon production rates for each vector printed as a function of 18 photon energy groups. Summation tables are given in units of photons/sec and MeV $watt^{-1}$ sec^{-1}. The principal contributor tables list the photon production rates for each nuclide that contributes more than a specified fraction (i.e., a cutoff value set with the CUT command) to the total photon production rate for each group.

8.2.3 Description of a single ORIGEN2 output page

A typical ORIGEN2 output page, taken from one of the output groupings, is shown in Fig. 8.1. The page number, output unit number, and segment (i.e., activation product, actinide, or fission product) are given in the upper, right-hand corner. The page number is correlated with the table of contents, as mentioned previously.

Next, in the upper left portion of the page, the following information is given:

1. the title for this output grouping (specified with a TIT command, Sect. 4.2);
2. the average specific power (MW per basis unit), burnup (MWd per basis unit), and flux (neutrons cm^{-2} sec^{-1}), the calculation of which depends on the BUP command (Sect. 4.14);
3. the aggregation (e.g., nuclide table, element summary table, etc.) and table type (i.e., radioactivity, curies); and
4. the output grouping basis (specified with a BAS command, Sect. 4.3).

If no real specific power/burnup/flux information is available, all parameters are set to 1.0.

Below the output grouping basis, and spanning the entire page, are the vector headings. Unless altered, these headings will be the irradiation or decay times for the vector. Alphanumeric vector headings can be inserted by using the HED command (Sect. 4.7).

The remainder of the output page is occupied by the main body of the ORIGEN2 output information. The leftmost column lists the nuclide (or element), and the remainder of the horizontal line gives the characteristic (i.e., curies) of that isotope for each of the times or conditions of each vector.

At the end of each aggregation, vector totals are given. Cumulative totals [e.g., total activation product (AP) plus actinide (ACT) plus fission product (FP) curies] for each vector are given at the end of each table type.

OUTPUT UNIT = 6 PAGE 18

DECAY OF FBR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: CONCENTRATIONS, GRAMS

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SE+0.05S P	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
H 1	2.977E 00	2.977E 00	2.977E 00	2.977E 00	2.977E 00	2.977E 00	2.977E 00	2.977E 00	2.977E 00	2.977E 00	2.977E 00	2.977E 00
H 2	5.900E-03	5.900E-03	5.900E-03	5.900E-03	5.900E-03	5.900E-03	5.900E-03	5.900E-03	5.900E-03	5.900E-03	5.900E-03	5.900E-03
H 3	1.326E-05	1.120E-05	7.564E-06	2.462E-06	4.839E-08	6.446E-13	5.563E-30	0.0	0.0	0.0	0.0	0.0
H 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE 3	2.412E-10	2.055E-06	5.696E-06	1.080E-05	1.321E-05	1.326E-05	1.326E-05	1.326E-05	1.326E-05	1.326E-05	1.326E-05	1.326E-05
HE 4	1.168E-01	1.168E-01	1.168E-01	1.168E-01	1.168E-01	1.168E-01	1.168E-01	1.168E-01	1.168E-01	1.168E-01	1.168E-01	1.168E-01
HE 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LI 6	4.849E-06	4.849E-06	4.849E-06	4.849E-06	4.849E-06	4.849E-06	4.849E-06	4.849E-06	4.849E-06	4.849E-06	4.849E-06	4.849E-06
LI 7	2.652E-02	2.692E-02	2.692E-02	2.692E-02	2.692E-02	2.692E-02	2.692E-02	2.692E-02	2.692E-02	2.692E-02	2.692E-02	2.692E-02
LI 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BE 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BE 9	2.851E-04	2.851E-04	2.851E-04	2.851E-04	2.851E-04	2.851E-04	2.851E-04	2.851E-04	2.851E-04	2.851E-04	2.851E-04	2.851E-04
BE 10	5.883E-07	9.883E-07	9.883E-07	9.883E-07	9.882E-07	9.881E-07	9.878E-07	9.870E-07	9.840E-07	9.755E-07	9.464E-07	6.408E-07
BE 11	C.C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 10	1.905E-06	1.905E-06	1.905E-06	1.905E-06	1.905E-06	1.905E-06	1.906E-06	1.906E-06	1.909E-06	1.918E-06	1.947E-06	2.253E-06
B 11	1.904E-01	1.904E-01	1.904E-01	1.904E-01	1.904E-01	1.904E-01	1.904E-01	1.904E-01	1.904E-01	1.904E-01	1.904E-01	1.904E-01
B 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C 12	3.965E 01	3.965E 01	3.965E 01	3.965E 01	3.965E 01	3.965E 01	3.965E 01	3.965E 01	3.965E 01	3.965E 01	3.965E 01	3.965E 01
C 13	4.578E-01	4.978E-01	4.978E-01	4.978E-01	4.978E-01	4.978E-01	4.978E-01	4.978E-01	4.978E-01	4.978E-01	4.978E-01	4.978E-01
C 14	2.111E-01	2.110E-01	2.108E-01	2.103E-01	2.085E-01	2.036E-01	1.870E-01	1.468E-01	6.295E-02	5.600E-03	1.175E-06	0.0
C 15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N 13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N 14	4.715E 01	4.715E 01	4.715E 01	4.715E 01	4.715E 01	4.716E 01	4.717E 01	4.721E 01	4.730E 01	4.736E 01	4.736E 01	4.736E 01
N 15	1.952E-01	1.952E-01	1.952E-01	1.552E-01	1.952E-01	1.952E-01	1.952E-01	1.952E-01	1.952E-01	1.952E-01	1.952E-01	1.952E-01
N 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O 16	2.794E 02	2.794E 02	2.794E 02	2.794E 02	2.794E 02	2.794E 02	2.794E 02	2.794E 02	2.794E 02	2.794E 02	2.794E 02	2.794E 02
O 17	1.132E-01	1.132E-01	1.132E-01	1.132E-01	1.132E-01	1.132E-01	1.132E-01	1.132E-01	1.132E-01	1.132E-01	1.132E-01	1.132E-01
O 18	6.429E-01	6.429E-01	6.429E-01	6.429E-01	6.429E-01	6.429E-01	6.429E-01	6.429E-01	6.429E-01	6.429E-01	6.429E-01	6.429E-01
O 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 19	5.350E-03	5.350E-03	5.350E-03	5.350E-03	5.350E-03	5.350E-03	5.350E-03	5.350E-03	5.350E-03	5.350E-03	5.350E-03	5.350E-03
F 20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NE 20	1.875E-07	1.875E-07	1.875E-07	1.875E-07	1.875E-07	1.875E-07	1.875E-07	1.875E-07	1.875E-07	1.875E-07	1.875E-07	1.875E-07
NE 21	8.182E-10	8.182E-10	8.182E-10	8.182E-10	8.182E-10	8.182E-10	8.182E-10	8.182E-10	8.182E-10	8.182E-10	8.182E-10	8.182E-10
NE 22	1.518E-09	1.518E-09	1.518E-09	1.518E-09	1.518E-09	1.518E-09	1.518E-09	1.518E-09	1.518E-09	1.518E-09	1.518E-09	1.518E-09
NE 23	C.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 23	7.484E-03	7.484E-03	7.484E-03	7.484E-03	7.484E-03	7.484E-03	7.484E-03	7.484E-03	7.484E-03	7.484E-03	7.484E-03	7.484E-03
NA 24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 24M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MG 24	8.329E-04	8.329E-04	8.329E-04	8.329E-04	8.329E-04	8.329E-04	8.329E-04	8.329E-04	8.329E-04	8.329E-04	8.329E-04	8.329E-04
MG 25	1.616E-04	1.616E-04	1.616E-04	1.616E-04	1.616E-04	1.616E-04	1.616E-04	1.616E-04	1.616E-04	1.616E-04	1.616E-04	1.616E-04
MG 26	1.446E-04	1.446E-04	1:446E-04	1.446E-04	1.446E-04	1.446E-04	1.446E-04	1.446E-04	1.446E-04	1.446E-04	1.446E-04	1.446E-04
MG 27	C.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MG 28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL 27	8.238E 01	8.238E 01	8.238E 01	8.238E 01	8.238E 01	8.238E 01	8.238E 01	8.238E 01	8.238E 01	8.238E 01	8.238E 01	8.238E 01
AL 28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL 29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL 30	C.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI 28	1.161E 02	1.161E 02	1.161E 02	1.161E 02	1.161E 02	1.161E 02	1.161E 02	1.161E 02	1.161E 02	1.161E 02	1.161E 02	1.161E 02
SI 29	6.127E 00	6.127E 00	6.127E 00	6.127E 00	6.127E 00	6.127E 00	6.127E 00	6.127E 00	6.127E 00	6.127E 00	6.127E 00	6.127E 00
SI 30	4.182E 00	4.182E 00	4.182E 00	4.182E 00	4.182E 00	4.182E 00	4.182E 00	4.182E 00	4.182E 00	4.182E 00	4.182E 00	4.182E 00

Fig. 8.1. Typical ORIGEN2 output page.

8.3 Description of Sample ORIGEN2 Output

This section describes five different types of sample output produced by ORIGEN2: output on unit 6, units 12 and 13, unit 15, unit 16, and unit 7. Since the output from some of these units, particularly unit 6, can be extremely voluminous, only representative excerpts have been included in some cases. All output described in this section was produced by the sample input deck described in Sect. 8.1.

8.3.1 ORIGEN2 output on unit 6

The sample ORIGEN2 output printed on unit 6 is given in Appendix B. There are two principal types of output on unit 6: reactivity and burnup information, and the ORIGEN2 output grouping. The output grouping, in turn, consists of various table types (e.g., watts, grams, etc.) for each of the nuclide segments (activation products, actinides, and fission products), neutron production tables, and photon production tables.

The sample reactivity and burnup information is given in Appendix B.1, Table B.1. The first seven of the ten lines present for all of the output vectors contain information pertinent to only the output vector to which it corresponds. The last three lines contain average information for the entire output. The "SIZE OF MMAX" information tells the number of nuclides that have a given number of associated nuclear reactions [i.e., MMAX(3) means that a nuclide has three reactions]. The information below the MMAX data indicates the size of the problem executed. This information is needed to variably dimension ORIGEN2.

Samples of the table types that are output for each of the nuclide segments are given in Appendix B.2, Tables B.2 through B.5. Because of the length of the output, only the activation product radioactivity table is included. Table B.2 is the activation product nuclide radioactivity table for the long-term decay of the cladding waste. This table contains the curies of the radioactive nuclides in the cladding associated with 1 metric ton of initial heavy metal as a function of decay time. This table is quite long because each of the 684 nuclides is listed, regardless of whether it is significant. Table B.3 is the element aggregation corresponding to the nuclide aggregation in Table B.2. Again, all elements are printed, irrespective of their magnitude. Table B.4 is the nuclide summary table aggregation. Here, only the most significant nuclides contained in Table B.2 are listed. Finally, Table B.5 gives the element summary table corresponding to Table B.4. As is evident, the summary aggregations are considerably shorter than the nuclide or element aggregations. However, the summary aggregations should be used with caution since omission of a nuclide because the cutoff fraction was too high could require the repetition of a lengthy (and therefore expensive) computer run.

Appendix B.3 gives sample neutron production rate tables. Table B.6 is the neutron production rate from (alpha,n) reactions. The neutron production rates are given by nuclide and in toto for the composition in each vector. Table B.7 is identical except that the neutron production rates are from spontaneous fission events. These tables are produced only for the actinides since only these nuclides emit significant numbers of spontaneous neutrons or alpha particles. It should be noted that these tables are summary tables (i.e., only the most significant isotopes are output). The neutron production rate totals for each table and for both tables together are given for the table as output and for all nuclides, whether output or not, to ensure that no significant nuclides were left out.

Appendix B.4 contains the sample photon production.rate output. Table B.8 is an example of the photon summation tables, in this case for the fission products in high-level waste. The upper half of Table B.8 gives the photon production rate in each of 18 energy groups as a function of decay time in units of photons/sec. Totals are given in units of photons/sec and MeV/sec. The lower half of Table B.3 gives the specific energy release rate for each group as a function of decay time in units of MeV (of gamma power) sec^{-1} [watt (of reactor power)]$^{-1}$. Totals are given in units of MeV sec^{-1} $watt^{-1}$ and (gamma) watts. All of the units, except the specific energy release rate, are per basis unit.

8.3.2 ORIGEN2 output on units 12 and 13

ORIGEN2 outputs the tables of content for units 6 and 11 on units 12 and 13 respectively. These tables of content are given in Table C.1 (unit 12) and C.2 (unit 13). The hierarchical nature of the ORIGEN2 output is evident in these tables of content, particularly Table C.1. It is hoped that the use of this output by ORIGEN2 will greatly alleviate the difficulties many users encounter when trying to find a specific datum in the sometimes-massive output.

8.3.3 ORIGEN2 output on unit 16

The output on unit 16 is information related to the changing of the variable actinide cross sections included in ORIGEN2. Sample output from unit 16 is given in Appendix D. The variable cross sections are altered by linear interpolation based on the anticipated burnup during the next irradiation step. Thus, the first output on unit 16 contains parameters related to the anticipated burnup during the next irradiation step and the weighting factors used in the cross-section interpolation. Then, a small table is output containing several pieces of information for each nuclide with a variable cross section. The pieces of information in this table are as follows:

1. NUCLID: Six-digit nuclide identifier.
2. XSEC TYPE: Type of cross section; 1 = (n,gamma), 2 = (n,gamma) to an excited state of the daughter, 4 = (n,fission).
3. TOCAP(I), I=: I is the location of the cross section in array TOCAP, which contains the total neutron absorption cross section. This is meaningless for fission cross sections.
4. A(N), N = N is the location of the reaction rate corresponding to the cross section being varied in the matrix of reaction rates (i.e., A).
5. FP YIELD INDIC ARR: Number of the array containing the locations of the fission product yields that have to be adjusted when fission cross sections are varied.

6. FISS(J): Location of the fission cross section in array FISS, which contains all fission cross sections.
7. A(N): Value of A(N) for the N in item 4 above; not meaningful for fission cross sections.
8. TOCAP(I): Value of TOCAP(I) for the I in item 3 above.
9. A(N) FP YIELD: Value of A(N) for a single, arbitrarily chosen fission product yield; not meaningful if item 5 equals zero.
10. FISS(J): Value of FISS(J) for the location in item 6 above.
11. OLD XSEC: Value of the cross section during the previous irradiation step.
12. NEW XSEC: Value of the cross section during the upcoming irradiation step.

All of these pieces of information, in one fashion or another, serve to indicate whether the routines that vary the actinide cross sections are functioning properly. Under normal circumstances, this output is not useful and can be suppressed. Two sequential, variable cross-section output segments are given in Appendix D so that the movement of the old and new cross sections can be seen.

8.3.4 ORIGEN2 output on unit 15

A sample output containing debugging and internal information is given in Appendix E. This output, which is printed on unit 15, serves three principal functions. The first function, which is useful in some debugging situations, is to print a single line of information just before each command is executed. This output immediately indicates the command that was being executed when the error occurred. This output also prints information concerning the number of each command type. With respect to this latter feature, it should be noted that, for the purposes of counting the number of commands of a particular type, the IRP, IRF, and DEC commands are all counted as IRF commands. This means that there will always be a total of zero IRP and DEC instructions.

The second function of the output on unit 15 is to provide selected internal information calculated by ORIGEN2. This type of information is printed for the following commands: IRP, IRF, KEQ, and FAC. The significance of the printed information is discussed below.

The information printed for both the IRP and IRF commands is basically the same. Most of the parameters printed are intermediate values used in SUBROUTINE FLUXO to calculate the flux when the power is given, or vice versa. These values will not be described in detail, but the nomenclature in the unit 15 output is the same as that in FLUXO, so that the interested user can readily perform the flux/power calculation with a hand calculator if required. The parameters printed on unit 15 that may be of more general interest are as follows:

TSEC: absolute time at the end of the current irradiation step, sec

DELT: duration of the current irradiation step, sec

EPF1, EPF2, EPF3: recoverable energy per fission associated with the zero, first, and second time derivatives used in the flux/power calculation, MeV/fission

EPFAVG: average, recoverable energy per fission for this time step, MeV/fission

FLUX: calculated or specified flux for the irradiation step, neutrons sec^{-1} cm^{-2}

POWER: calculated or specified power for the irradiation step, MW per basis unit

This type of information can be useful as input to auxiliary hand calculations or in finding errors in some situations.

The internal information printed for the KEQ command (command number 52 in Appendix E) is related to the calculated neutron production and destruction rates, the infinite multiplication factors, and fraction of the allocated material that is included in the final mixture. The parameters are defined as follows:

NPROA, NPROB, NPROC: relative neutron production rates of vectors NKEQ(1), NKEQ(2), and NKEQ(3) respectively (see Sect. 4.10)

NDESA, NDESB, NDESC: relative neutron destruction rates of vectors NKEQ(1), NKEQ(2), and NKEQ(3) respectively

IMFA, IMFB, IMFC: infinite multiplication factors (= NPROn/NDESn) of vectors NKEQ(1), NKEQ(2), and NKEQ(3) respectively

FRC: (IMFB-IMFA)/(IMFA-IMFC)

FRD: FRC*NDESB/NDESC

The neutron production and destruction rates are relative because they have not been multiplied by the neutron flux.

The internal information printed for the FAC command is relatively simple compared with that for the irradiation and KEQ commands. The FAC output information on unit 15 consists of the value of NFAC(1) on the FAC instruction and the value of FACTOR[NFAC(1)] (see Sect. 4.4).

The third function of unit 15 is to provide a mechanism for printing internal ORIGEN2 error messages. There are three general types of error messages contained in ORIGEN2. The first is related to the size of the problem being specified. If the specification requires arrays that exceed the size of those arrays actually present, an error message will be output indicating the dimension exceeded.

The second type of message is similar to the first, except it is the individual command count that is checked. That is, if the number of a particular command actually used exceeds the allowable number, as given in Sect. 4, an error message will be printed. Neither of these two error types will stop program execution.

The third type of error is printed when the command key word defining the type of command does not match one of the 30 key words contained internally in ORIGEN2. In this case, a message will be printed and program execution will be terminated.

8.3.5 ORIGEN2 output on unit 7

A listing of the sample ORIGEN2 output written by unit 7 is given in Appendix F. This output is generated by the PCH commands in the sample problem listed in Appendix A. The format of the output written on unit 7 is the same as the ORIGEN2 input format for specifying material compositions (see Sect. 6). Note that the compositions of four different materials are listed in Appendix F (viz., fresh uranium oxide fuel, spent uranium oxide fuel, fresh cladding, and irradiated cladding). Only the non-zero masses (in g-atoms) are output. The PCH command also outputs the average burnup, flux, and power associated with each material on the termination card for each material. These values are required if the compositions are to be read by ORIGEN2 on unit 4, and are ignored if the compositions are read on unit 5 (see Sect. 4.6).

9. REFERENCES

1. M. J. Bell, ORIGEN — The ORNL Isotope Generation and Depletion Code, ORNL-4628 (May 1973).

2. A. G. Croff, ORIGEN2 — A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code, ORNL-5621 (in press).

3. A. G. Croff, M. A. Bjerke, G. W. Morrison, and L. M. Petrie, Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Code, ORNL/TM-6051 (September 1978).

4. A. G. Croff and M. A. Bjerke, Alternative Fuel Cycle PWR Models for the ORIGEN Computer Code, ORNL/TM-7005 (February 1980).

5. A. G. Croff, R. L. Haese, and N. B. Gove, Updated Decay and Photon Libraries for the ORIGEN Code, ORNL/TM-6055 (February 1979).

6. L. M. Petrie, Computer Sciences Division, Oak Ridge National Laboratory, personal communication to A. G. Croff, November 1978.

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APPENDIXES

APPENDIX A: SAMPLE ORIGEN2 INPUT DECK LISTING

Appendix A.1: Sample ORIGEN2 Input Deck

Table A.1. Sample ORIGEN2 input deck

```
// EXEC FORTQCLG,PARM.FORT='XREF',
//  REGION.FORT=400K,
// PARM.LKED='OVLY,LIST,MAP',
//  PARM.GO='EU=-1,DUMP=I',
// REGION.GO=600K
//FORT.SYSIN DD *
C
C CASE  1   CASE  1   CASE  1   CASE  1   CASE  1   CASE  1   CASE  1
C
      LOGICAL   LONG
      INTEGER*2 LOCA,NONO,KD,LOC,NGP,NGN,NGR,NYIELD,NONP,NQ,NMAX,KAP,
     $LOCP,NPUDPP
      DOUBLE PRECISION CIMN,CSUM
      DIMENSION XNEW(  13,1676),COEFF(   7,1676),NPROD(   7,1676),
     $NMAX(1676),KAP(1676)
      DIMENSION STTPPB(  10,10),ISTOTI(  10,03),IS(  10),RSTOTI(  10)
      DIMENSION A(6500),LOCA(6500),NPUDPP( 880,   3)
      DIMENSION DR(   4),ER(   4),FR(   4)
      DIMENSION YIELD(3300),NYIELD( 880),RMULV(   4,3)
      DIMENSION ALPHN( 132),NUCAN( 132),NUCSFU( 132),NY( 132),YY( 132),
     $FPSF( 132),FPA( 132)
      COMMON /JUNK/ERR,IDM(1),ILITE,IACT,IFP,ITOT,ILMAX,IAMAX,IFMAX,
     $ITMAX,IZMAX,AXN,QIN,FLUX,POWER,INDEX,TFPBAV(4),IPHMAX
      COMMON /MAIN03/NSTP,ANMUL,ANEXP,NABMAX,      ICNMAX,IAPMAX,IFYMAX
C 1766 WORDS ARE NECESSARY IN /NUDSCR/ BEGINNING WITH S
C /NUDSCR/ IS USED FOR MULTIPLE PURPOSES.
      COMMON /NUDSCR/DUM1(   7,1676),DUM2(   6,1676),S(2),CIMN(1676),
     $ CSUM(1676),NONP(1676),NQ(1676),XP(1676),XPAR(1676),XTEMP(1676),
     $ D(1676),AP(3500),LOCP(3500),LONG(1676)
      COMMON /BIG/NUCL(1676),Q(1676),FG(0004),TOCAP(1676),GENNEU( 132),
     $ALPHAN( 132),SPONF( 132),SPNU( 132),FISS( 132),NUCAB(1676),
     $AMPC(1676),WMPC(1676),XSTORE(   10,1676),DIS(1676),B(1676),
     $ABUND( 450),NONO(1676),KD(1676),LOC(6500),NGP(1676),NGN(1676),
     $NGR(7900),GGR(7900)
C DR,ER, AND FR PROVIDE A CONVENIENT MECHANISM FOR INITIALIZING VARIABLE
C MULTIPLIER ARRAY RMULV.
      EQUIVALENCE (DR(1),RMULV(1,1)),(ER(1),RMULV(1,2)),
     $(FR(1),RMULV(1,3))
      EQUIVALENCE (DUM1(1,1),COEFF(1,1)),(DUM2(1,1),NPROD(1,1)),
     $(NONP(1),NMAX(1)),(KAP(1),NQ(1)),(XNEW(1,1),DUM1(1,1))
      EQUIVALENCE (XP(1),ALPHN(1)),(ALPHN( 132),NUCAN(1)),(NUCAN( 132),
     $NUCSFU(1)),(NUCSFU( 132),NY(1)),(NY( 132),YY(1)),(YY( 132),
     $FPSF(1)),(FPSF( 132),YIELD(1)),(YIELD(3300),NYIELD(1))
      CALL Q105F(6)
C INITIALIZE PAGE COUNTER
      NPAGE=IPAGE(0)
      LX=   10
      MX=   13
      LC=    7
      ILMAX=  700
      IAMAX=  132
      IFMAX=  880
      ITMAX= 1676
      IZMAX= 6500
      IPHMAX=7900
      IAPMAX=3500
      IFYMAX=3300
      NABMAX= 450
      ICNMAX=    3
      IFD=  880
      LAM=    4
C NEUTRONS PER NEUTRON-INDUCED FISSION: 0=THERMAL SPECTRUM; 1=FAST SPECTRUM
```

Table A.1 (continued)

```
      NYTP=1
      NYTP=0
C CALL SUBROUTINE TO READ CARD INPUT FROM UNIT 5, PRINT IT ON UNIT 6, AND
C WRITE IT ON UNIT 50.  UNIT 50 IS THEN REWOUND AND ORIGEN2 READS THE DATA
C FROM UNIT 50.
      CALL LISTIT(5,6,50)
      REWIND 50
C MAIN1 HANDLES THE MISCELLANEOUS INITIALIZATION DATA
    1 CALL MAIN1(NYTP,SFNU,ALPHN,NUCAN,NUCSFU,NY,YY,ANNUL,ANEXP)
C MAIN2 READS THE ORIGEN2 COMMANDS
    2 CALL MAIN2(NSTP)
C MAIN3 EXECUTES THE ORIGEN2 COMMANDS
    3 CALL MAIN3(
     $ LONG,STTFPB,ISTOTI,IS,RSTOTI,  LX, MX, LC,IPD,
     $NUCAB,NONO,KD,LOC,NGP,NGN,NGR,NYIELD,NONP,NQ,LOCP,NMAX,KAP,
     $LOCA,NFUDPP,    CINN,CSUM,                   S,
     $NUCL,Q,FG,TOCAP,GENNEU,ALPHAN,SPONF,SFNU,FISS,AMPC,WMPC,XSTORE,
     $DIS,E,GGR,YIELD,A      ,XP,XPAR,XTEMP,D,AP,COEFF,NPROD,   XNEW,
     $ALPHN,NUCAN,NUCSFU,NY,YY,FFSF,FFA,ABUND,RMULV,LAM)
C THIS "GO TO" PROVIDES THE MECHANISM FOR EXECUTING MULTIPLE PROBLEMS WITHIN
C A SINGLE JOB.
      GO TO (1,2,3,4),NSTP
    4 CONTINUE
      CALL Q105F(6)
      STOP 100
      END
/*
//LKED.STEPLIB DD DSN=SYS1.VSPGM,DISP=SHR
//LKED.MEX DD DSN=CHEMTECH.AGC14198.O2OBJ,DISP=SHR
//   DD DISP=SHR,DSN=CHEMTECH.Q105F.DUMMYO
//LKED.SYSIN DD DISP=SHR,DSN=CHEMTECH.AGC14198.O2OVLY
//GO.FT07F001 DD SYSOUT=B,DCB=(RECFM=FB,LRECL=80,BLKSIZE=3520)
//GO.FT09F001 DD DSN=CHEMTECH.AGC14198.DECAY,DISP=SHR
//   DD DSN=CHEMTECH.AGC14198.XPWRU,DISP=SHR
//GO.FT10F001 DD DSN=CHEMTECH.AGC14198.PHOTON,DISP=SHR
//GO.FT11F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//GO.FT12F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//GO.FT13F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//GO.FT15F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//GO.FT16F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//GO.FT50F001 DD DSN=&&AGC,UNIT=SYSDA,
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200),SPACE=(3200,(50,50),RLSE)
//GO.FT51F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//GO.FT05F001 DD *
  92 1 0.99
  94 1 0.994
  -1
  5 1 0.1
  -1
  2  15
  -1
  BAS      ONE METRIC TON OF PWRU FUEL
  RDA      -1 = FRESH U FUEL WITH IMPURITIES (1 MT)
  RDA      -2 = FRESH ZIRCALOY COMPOSITION (1 KG)
  RDA      -3 = FRESH SS 304 COMPOSITION (1 KG)
  RDA      -4 = FRESH SS 302 COMPOSITION (1 KG)
  RDA      -5 = FRESH INCONEL COMPOSITION (1 KG)
  RDA      -6 = FRESH NICROBRAZE COMPOSITION (1 KG)
  RDA      WARNING:  VECTORS ARE OFTEN CHANGED WITH RESPECT TO THEIR CONTENT.
  RDA                THESE CHANGES WILL BE NOTED ON RDA CARDS.
  CUT      5 0.01 -1
  LIP      1 1 1                                                          ADR
  LPU      380900 551370 -1
  LPU      010030 060140 -1
  LPU      902320 -1
  LPU      380900        -1
```

Table A.1 (continued)

```
LIB     0 1 2 -3 -204 -205 -206 9 3 -2 1 1
PHC        101  102    103  10
OPTL      -1 24*8
TIT        INITIAL COMPOSITIONS OF UNIT AMOUNTS OF FUEL AND STRUCT MAT'LS
RDA        READ  FUEL  COMPOSITION INCLUDING IMPURITIES (1000 KG)
INP        -1  1  -1 -1 1 1
RDA        READ  ZIRCALOY COMPOSITION (1.0 KG)
INP        -2  1  -1 -1 1 1
RDA        READ  SS304 COMPOSITION (1.0 KG)
INP        -3  1  -1 -1 1 1
RDA        READ INCONEL 718 COMPOSITION (1.0 KG)
INP        -5  1  -1 -1 1 1
RDA        READ NICROBRAZE 50 COMPOSITION (1.0 KG)
INP        -6  1  -1 -1 1 1
TIT        IRRADIATION OF ONE METRIC TON OF PWRU FUEL
MOV        -1 1 0 1.0
HED        1                                                        CHARGE
BUP
IRP         26.7  37.500   1   2   4 2  END OF THIS STEP=1,000  MWD/MTIHM
IRP         66.7  37.500   2   3   4 0  END OF THIS STEP=2,500  MWD/MTIHM
IRP        133.3  37.500   3   4   4 0  END OF THIS STEP=5,000  MWD/MTIHM
IRP        266.7  37.500   4   5   4 0  END OF THIS STEP=10,000 MWD/MTIHM
IRP        400.0  37.500   5   6   4 0  END OF THIS STEP=15,000 MWD/MTIHM
IRP        440.0  37.500   6   7   4 0  END OF THIS STEP=16,500 MWD/MTIHM
IRP        533.3  37.500   7   8   4 0  END OF THIS STEP=20,000 MWD/MTIHM
IRP        666.7  37.500   8   9   4 0  END OF THIS STEP=25,000 MWD/MTIHM
IRP        733.3  37.500   9  10   4 0  END OF THIS STEP=27,500 MWD/MTIHM
IRP        800.0  37.500  10  11   4 0  END OF THIS STEP=30,000 MWD/MTIHM
IRP        880.0  37.500  11  12   4 0  END OF THIS STEP=33,000 MWD/MTIHM
BUP
OPTL       8 8 8 8 7 8 1 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTA       8 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF       8 8 8 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OUT        12  1  -1  0                                                        ADD
RDA        -10 = IRRADIATED U FUEL AT DISCHARGE
MOV        12 -10  0 1.0
RDA        THESE INSTRUCTIONS ARE HERE ONLY TO DEMONSTRATE THEIR USE
KEQ        10 12 1 2 3 -1.0
FAC        1 1 12 4 0.0
RDA        IRRADIATION OF ZIRCALOY+ INCONEL + NICROBRAZE 50 AT 100% FLUX
TIT        IRRADIATION OF ZIRCALOY+ INCONEL + NICROBRAZE 50 AT 100% FLUX
MOV        -2 1 0  223.0   ZIRCALOY
ADD        -5 1 0   12.8   INCONEL
ADD        -6 1 0    2.6   NICROBRAZE 50
ADD        -3 1 0  9.94   SS 304
HED        1                                                        CHARGE
IRF         26.7  -1.0   1   2  4  4  END OF THIS STEP = 1,000  MWD/MTIHM
IRF         66.7  -1.0   2   3  4  0  END OF THIS STEP = 2,500  MWD/MTIHM
IRF        133.3  -1.0   3   4  4  0  END OF THIS STEP = 5,000  MWD/MTIHM
IRF        266.7  -1.0   4   5  4  0  END OF THIS STEP = 10,000 MWD/MTIHM
IRF        400.0  -1.0   5   6  4  0  END OF THIS STEP = 15,000 MWD/MTIHM
IRF        440.0  -1.0   6   7  4  0  END OF THIS STEP = 16,500 MWD/MTIHM
IRF        533.3  -1.0   7   8  4  0  END OF THIS STEP = 20,000 MWD/MTIHM
IRF        666.7  -1.0   8   9  4  0  END OF THIS STEP = 25,000 MWD/MTIHM
IRF        733.3  -1.0   9  10  4  0  END OF THIS STEP = 27,500 MWD/MTIHM
IRF        800.0  -1.0  10  11  4  0  END OF THIS STEP = 30,000 MWD/MTIHM
IRF        880.0  -1.0  11  12  4  0  END OF THIS STEP = 33,000 MWD/MTIHM
OUT        12  1  -1  0                                                        ADD
RDA        -2 = FRESH ZIRCALOY, INCONEL, AND NICROBRAZE
RDA        -9 = IRRADIATED ZIRCALOY, INCONEL, AND NICROBRAZE
MOV        1  -2  0  1.0
MOV        12  -9  0  1.0
PCH        -1 -1 -1
PCH        -10  -10  -10
PCH        -2 -2 -2
PCH        -9  -9  -9
```

```
STP     2
2     922340  290.0  922350 32000.0   922380   967710.0  0 0.0     FUEL ACTINIDES
4     030000  1.0    050000 1.0       060000   89.4      070000 25.0   FUEL IMPUR
4     080000 134454.0 090000 10.7     110000   15.0      120000  2.0   FUEL IMPUR
4     130000 16.7    140000 12.1      150000   35.0      170000  5.3   FUEL IMPUR
4     200000 2.0     220000 1.0       230000   3.0       240000  4.0   FUEL IMPUR
4     250000 1.7     260000 18.0      270000   1.0       280000  24.0  FUEL IMPUR
4     290000 1.0     300000 40.3      420000   10.0      470000  0.1   FUEL IMPUR
4     480000 25.0    490000 2.0       500000   4.0       640000  2.5   FUEL IMPUR
4     740000 2.0     820000 1.0       830000   0.4       0       0.0   FUEL IMPUR
0
4     400000 979.11  500000 16.0      260000   2.25      240000  1.25     ZIRC-4
4     280000 0.02    130000 0.024     050000   0.00033   480000  0.00025  ZIRC-4
4     060000 0.120   270000 0.010     290000   0.020     720000  0.078    ZIRC-4
4     010000 0.013   250000 0.020     070000   0.080     080000  0.950    ZIRC-4
4     160000 0.035   220000 0.020     740000   0.020     230000  0.020    ZIRC-4
5     920000 0.0002  0      0.0                                           ZIRC-4
0
4     260000 688.45  240000 190.0     280000 90.0        250000 20.0      SS-304
4     060000 0.8     150000 0.45      160000 0.3         140000 10.0      SS-304
4     070000 1.3     270000 0.8       0      0.0                          SS-304
0
4     260000 180.0   240000 190.0     280000 525.0       130000 6.0       INC-718
4     060000 0.4     270000 4.7       290000 1.0         250000 2.0       INC-718
4     420000 30.0    070000 1.3       410000 55.53       160000 0.07      INC-718
4     140000 2.0     220000 8.0       0      0.0                          INC-718
0
4     260000 0.47    240000 149.5     280000 783.4       400000 0.1       NICR-50
4     130000 0.1     050000 0.05      060000 0.1         270000 0.38      NICR-50
4     250000 0.1     070000 0.066     080000 0.43        150000 103.1     NICR-50
4     160000 0.1     140000 0.51      220000 0.1         740000 0.1       NICR-50
0
BAS      ONE METRIC TON OF INITIAL HEAVY METAL
CUT      -1
LIP      0 0 0
LPU      380900 551370 -1
LIB      0 1 2 -3 0 0 0 9 3 0 1 1
PHO      101 102 103    10
MOV      -9 -8 0 1.0
RDA      *** REPROCESSING MODULE *********************************************
RDA      FUEL IS REPROCESSED AT THE TIME SPECIFIED ON THE NEXT CARD
DEC      160.0 -10  1  4 4
PRO      1  -9 12  -3  CALCULATE  0.05% OF FUEL
PRO      1 10 -5  -2   SEPARATE VOLATILES AND PUT IN -5
PRO      10  4  -2 -1  PUT HLW IN -2
PRO      4  -4 -3  -8  PUT U IN -4 AND PU IN -3
BAS      ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS
RDA      *** HLW DECAY MODULE ************************************************
TIT      DECAY OF HIGH-LEVEL PWR-U WASTE; BURNUP=33,000 MWD/MTIHM
MOV      -2 1 0 1.0
HED    1   *  HLW
DEC      0.5     1    3    5    4
DEC      1.0     3    4    5    0
DEC      3.0     4    2    5    0
DEC      10.0    2    3    5    0
DEC      30.0    3    4    5    0
DEC      100.0   4    5    5    0
DEC      300.0   5    6    5    0
DEC      1.0     6    7    7    0
DEC      3.0     7    8    7    0
DEC      10.0    8    9    7    0
DEC      30.0    9    10   7    0
```

The correction shown below should be made to the sample problem in file 2 of CCC-371/ORIGEN2-82. This need for correction was announced in the December 1983 RSIC Newsletter.

8	8	8
1	8	8
1	8	8

Should be this to reproduce sample output from RSIC tape.

```
DEC      100.0   10   11   7    0
DEC      300.0   11   -4   7    0
DEC      1.0     -4   12   8    0
RDA      OPT CARDS HERE
OPTL     8 8 8 8 2 8 1 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTA     8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF     8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OUT      -12 1 -1 0                                                   1D1
OUT      12 1 -1 0                                                    1D1
RDA      *** STRUCTURAL MATERIAL DECAY SCHEDULE *******************************
TIT      DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM
MOV      -8 3 0 1.0
RDA      FUEL IS REPROCESSED AT THE TIME SPECIFIED ON THE NEXT CARD
DEC      160.0   3    1    4 4
ADD      -9 1 0 1.0
HED      1                                              SE+0.05% Y
DEC      0.5     1    3    5    4
DEC      1.0     3    4    5    0
DEC      3.0     4    2    5    0
DEC      10.0    2    3    5    0
DEC      30.0    3    4    5    0
DEC      100.0   4    5    5    0
DEC      300.0   5    6    5    0
DEC      1.0     6    7    7    0
DEC      3.0     7    8    7    0
DEC      10.0    8    9    7    0
DEC      30.0    9    10   7    0
DEC      100.0   10   11   7    0
DEC      300.0   11   -4   7    0
DEC      1.0     -4   12   8    0
OUT      12 1 -1 0                                                    1D1
OUT      -12 1 -1 0                                                   1D1
END
/*
//GO.FT03F001 DD *
  3 280580 5 30.0 0.0 0.0 0.0 0.0 0.0
  3 0.0    0.0 0.7 0.0 0.1 0.1
  3 551370 5 25.0 0.0 0.0 0.0 0.0 0.0
  3 0.0    0.0 0.1 0.0 1.0 1.0
 204 010030 0.001 5*0.0 -1.0
 204 060140 0.01 5*0.0 -1.0
 205 552320 3.0 0.001 0.0001 0.02 0.0 0.0 -1.0
 206 280580 0.08 5*0.0 1.0
 206          0.001 0.004 0.1 0.02 0.019 0.02 0.006 0.006
  070150 060140 1.5E-08  N14(N,P PLUS N,NP)C14 CROSS SECTION
  080170 060140 2.0E-08  O17(N,ALP)C14 CROSS SECTION
  3 280500 5 30.0 0.0 0.0 0.0 0.0 0.0
  3 0.0    0.0 0.7 0.0 0.1 0.1
  3 551370 5 25.0 0.0 0.0 0.0 0.0 0.0
  3 0.0    0.0 0.1 0.0 1.0 1.0
/*
//
```

Appendix A.2: ORIGEN2 Overlay Structure

Table A.2. ORIGEN2 OVERLAY statements

```
INCLUDE MEX
   ENTRY MAIN
   INSERT MAIN
      OVERLAY A
      INSERT LISTIT
      OVERLAY A
      INSERT MAIN3
            OVERLAY C
            INSERT MAIN1
            OVERLAY C
            INSERT MAIN2
                OVERLAY F
                INSERT XSEC01
                OVERLAY F
                INSERT XSEC02
                OVERLAY F
                INSERT XSEC03
                OVERLAY F
                INSERT XSEC04
                OVERLAY F
                INSERT XSEC05
                OVERLAY F
                INSERT XSEC06
                OVERLAY F
                INSERT XSEC07
                OVERLAY F
                INSERT XSEC08
                OVERLAY F
                INSERT XSEC09
                OVERLAY F
                INSERT XSEC10
                OVERLAY F
                INSERT XSEC11
                OVERLAY F
                INSERT XSEC12
                OVERLAY F
                INSERT XSEC13
                OVERLAY F
                INSERT XSEC14
                OVERLAY F
                INSERT XSEC15
                OVERLAY F
                INSERT XSEC16
                OVERLAY F
                INSERT XSEC17
                OVERLAY F
                INSERT XSEC18
                OVERLAY F
                INSERT XSEC19
                OVERLAY F
                INSERT XSEC20
            OVERLAY C
            INSERT ADDNOV
            OVERLAY C
            INSERT NUDOC
            OVERLAY C
            INSERT NUDAT1,DECRED
            OVERLAY C
            INSERT NUDAT2,SIGRED
            OVERLAY C
            INSERT NUDAT3,ANSF
            OVERLAY C
            INSERT PHOLIB
         OVERLAY B
         INSERT TERMD
            OVERLAY D
            INSERT FLUXO,DECAY,FUDGE
            OVERLAY D
            INSERT TERM,MATREX,EQUIL
         OVERLAY B
         INSERT OUTPUT
            OVERLAY E
            INSERT OUT1
            OVERLAY E
            INSERT OUT2
         OVERLAY B
         INSERT GAMMA
         OVERLAY B
         INSERT NUTRON
```

00123

APPENDIX B: SAMPLE OF ORIGEN2 OUTPUT GROUPING (OUTPUT UNIT 6)

Appendix B.1: Reactivity and Burnup Information

Table B.1. Sample ORIGEN2 reactivity and burnup information

IRRADIATION OF ONE METRIC TON OF PWRU FUEL
POWER= 3.75000E 01MW, BURNUP= 3.30000E 04MWD, FLUX= 3.24E 14N/CM**2-SEC

REACTIVITY AND BURNUP DATA
BASIS= ONE METRIC TON OF PWRU FUEL

	CHARGE	27. D	67. D	133. D	267. D	400. D	440. D	533. D	667. D	733. D	800. D	880. D
TIME, SEC	0.0	2.31E 06	5.76E 06	1.15E 07	2.30E 07	3.46E 07	3.80E 07	4.61E 07	5.76E 07	6.34E 07	6.91E 07	7.60E 07
NEUT. FLUX	0.0	2.89E 14	2.89E 14	2.90E 14	2.95E 14	3.05E 14	3.16E 14	3.26E 14	3.40E 14	3.54E 14	3.66E 14	3.78E 14
SP POW,MW	0.0	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01
BURNUP,MWD	0.0	1.00E 03	1.50E 03	2.50E 03	5.00E 03	5.00E 03	1.50E 03	3.50E 03	5.00E 03	2.50E 03	2.50E 03	3.00E 03
K INFINITY	0.0	1.35740	1.33677	1.30318	1.22935	1.16417	1.15465	1.11488	1.05776	1.03349	1.01079	0.98405
NEUT PRODN	0.0	1.00E 04	1.01E 04	1.01E 04	9.87E 03	9.48E 03	9.34E 03	9.03E 03	8.58E 03	8.34E 03	8.13E 03	7.90E 03
NEUT DESTN	0.0	7.40E 03	7.56E 03	7.75E 03	8.03E 03	8.14E 03	8.09E 03	8.10E 03	8.11E 03	8.07E 03	8.04E 03	8.03E 03
TOT BURNUP	0.0	3.30E 04	3.30E 04	3.30E 04	3.30E 04	3.30E 04	3.30E 04	3.30E 04	3.30E 04	3.30E 04	3.30E 04	3.30E 04
AVG N FLUX	0.0	3.24E 14	3.24E 14	3.24E 14	3.24E 14	3.24E 14	3.24E 14	3.24E 14	3.24E 14	3.24E 14	3.24E 14	3.24E 14
AVG SP POW	0.0	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01	3.75E 01

SIZE OF MMAX(I): MMAX= 1 #= 848 MMAX= 2 #= 437 MMAX= 3 #= 146 MMAX= 4 #= 52 MMAX= 5 #= 108 MMAX= 6 #= 65
MMAX= 7 #= 11 MMAX= 8 #= 0 MMAX= 9 #= 0 MMAX=10 #= 0 MMAX=11 #= 0 MMAX=12 #= 0

THE NUMBER OF NON-ZERO TERMS IN A=6374
THE NUMBER OF NON-ZERO FISSION PRODUCT YIELDS=3242
ILITE= 684 IACT= 129 IFP= 858 ITOT=1671
THE NUMBER OF NON-ZERO NATURAL ABUNDANCES= 434
THE NUMBER OF NON-ZERO PHOTON YIELDS= 4725
THE MAXIMUM NUMBER OF TERMS IN AP= 3358

Appendix B.2: Sample ORIGEN2 Output Tables for Activation Products

Table B.2. Sample ORIGEN. uclide radioactivity table

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM

OUTPUT UNIT = 6

ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	5E+0.05% F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
H 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H 3	1.280E-01	1.082E-01	7.303E-02	2.376E-02	4.672E-04	6.223E-09	5.370E-26	0.0	0.0	0.0	0.0	0.0
H 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LI 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LI 7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LI 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BE 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BE 9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BE 10	2.209E-08	2.209E-08	2.209E-08	2.209E-08	2.209E-08	2.209E-08	2.208E-08	2.206E-08	2.200E-08	2.181E-08	2.116E-08	1.432E-08
BE 11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C 13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C 14	9.412E-01	9.408E-01	9.400E-01	9.378E-01	9.299E-01	9.076E-01	8.339E-01	6.547E-01	2.807E-01	2.497E-02	5.240E-06	0.0
C 15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N 13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N 14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N 15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O 17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O 18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NE 20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NE 21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NE 22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NE 23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 24M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NA 25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MG 24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MG 25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MG 26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MG 27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MG 28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL 27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL 28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL 29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AL 30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI 28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI 29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI 30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.2 (continued)

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM — OUTPUT UNIT = 6 — PAGE 35

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC — ACTIVATION PRODUCTS

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SN+0.05% F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
SI 31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI 32	2.482E-08	2.474E-08	2.456E-08	2.404E-08	2.231E-08	1.803E-08	8.545E-09	1.013E-09	5.802E-13	3.171E-22	0.0	0.0
P 31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P 32	3.603E-01	2.474E-08	2.456E-08	2.404E-08	2.231E-08	1.803E-08	8.546E-09	1.013E-09	5.803E-13	3.171E-22	0.0	0.0
P 33	3.966E-05	2.533E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P 34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S 32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S 33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S 34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S 35	5.479E-01	9.818E-05	1.762E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S 36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S 37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL 35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL 36	6.020E-06	6.020E-06	6.020E-06	6.020E-06	6.019E-06	6.016E-06	6.006E-06	5.979E-06	5.883E-06	5.618E-06	4.782E-06	6.019E-07
CL 37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL 38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL 38M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR 36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR 37	2.634E-06	1.006E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR 38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR 39	1.605E-08	1.592E-08	1.564E-08	1.485E-08	1.240E-08	7.407E-09	1.220E-09	7.057E-12	1.035E-19	0.0	0.0	0.0
AR 40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR 41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AR 42	4.097E-17	3.847E-17	3.321E-17	2.182E-17	5.015E-18	7.559E-20	3.111E-26	1.773E-44	0.0	0.0	0.0	0.0
K 39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K 40	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.345E-13
K 41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K 42	4.097E-17	3.847E-17	3.321E-17	2.182E-17	5.015E-18	7.559E-20	3.112E-26	1.773E-44	0.0	0.0	0.0	0.0
K 43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K 44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 41	9.051E-08	9.051E-08	9.051E-08	9.049E-08	9.044E-08	9.028E-08	8.974E-08	8.822E-08	8.309E-08	7.002E-08	3.847E-08	1.738E-11
CA 42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 45	1.849E-03	1.749E-05	3.310E-10	1.061E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 47	9.651E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CA 49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC 45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC 46	1.160E-01	1.348E-05	8.805E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC 46M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC 47	6.671E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC 48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC 49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SC 50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TI 46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TI 47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TI 48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TI 49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TI 50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Table 8.2 (continued)

OUTPUT UNIT = 6 PAGE 36

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
TI 51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V 49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V 50	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15
V 51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V 52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V 53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V 54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CR 50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CR 51	6.236E 02	7.772E-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CR 52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CR 53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CR 54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CR 55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MN 54	6.803E 01	5.986E 00	2.073E-02	1.904E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MN 55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MN 56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MN 57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MN 58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE 54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE 55	4.831E 03	2.171E 03	3.359E 02	1.626E 00	1.278E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE 56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE 57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE 58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE 59	3.266E 01	1.527E-06	1.204E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 58M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 58	1.438E 03	3.143E-02	4.194E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	7.286E 03	4.911E 03	1.956E 03	1.409E 02	1.413E-02	5.311E-14	0.0	0.0	0.0	0.0	0.0	0.0
CO 60M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI 58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI 59	5.154E 00	5.154E 00	5.154E 00	5.153E 00	5.150E 00	5.141E 00	5.110E 00	5.022E 00	4.727E 00	3.975E 00	2.167E 00	9.071E-04
NI 60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI 61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI 62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI 63	6.554E 02	6.408E 02	6.079E 02	5.228E 02	3.086E 02	6.838E 01	3.500E-01	9.998E-08	0.0	0.0	0.0	0.0
NI 64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI 65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NI 66	8.948E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU 62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU 63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU 64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU 65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU 66	8.962E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CU 67	4.831E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 65	2.103E-01	9.340E-03	6.520E-06	6.265E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 67	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 68	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 37

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% Y	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
ZN 69	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 69M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN 71M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GA 69	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GA 70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GA 71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GA 72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GA 72M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 71	2.272E-10	2.527E-38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 71M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 75M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 76	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 77	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE 77M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS 75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS 76	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS 77	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 76	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 77	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 77M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 79	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	1.141E-35
SE 79M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 81	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 81M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 82	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE 83M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BR 79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BR 80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BR 80M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BR 81	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BR 82	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BR 82M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BR 83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 79M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 81	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 81M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 82	0.0	0.0	0.0	0.0	0.0	0 -	0.0	0.0	0.0	0.0	0.0	0.0

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Table B.. .ontinued)

OUTPUT UNIT = 6 PAGE 38

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH*0.05% Y	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
KR 83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 83M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 84	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 85M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 87	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KR 88	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RB 85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RB 86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RB 86M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RB 87	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RB 88	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RB 89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 84	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 85M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 87	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 87M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 88	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 89	6.354E-01	1.866E-07	1.070E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 90	1.515E-04	1.411E-04	1.194E-04	7.420E-05	1.402E-05	1.200E-07	6.970E-15	1.476E-35	0.0	0.0	0.0	0.0
SR 91	C.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR 93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 89M	1.045E-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 90	1.516E-04	1.411E-04	1.195E-04	7.422E-05	1.403E-05	1.201E-07	6.972E-15	1.476E-35	0.0	0.0	0.0	0.0
Y 90M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 91	2.171E 00	4.998E-06	3.498E-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR 89	6.450E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR 90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR 91	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR 92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR 93	1.266E-01	1.266E-01	1.266E-01	1.266E-01	1.266E-01	1.265E-01	1.265E-01	1.264E-01	1.260E-01	1.249E-01	1.210E-01	8.045E-02
ZR 94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR 95	8.566E 03	5.989E-02	5.597E-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR 96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR 97	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 92	1.278E-05	4.371E-38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 93M	9.263E-03	2.500E-02	5.357E-02	9.618E-02	1.196E-01	1.202E-01	1.202E-01	1.201E-01	1.197E-01	1.186E-01	1.149E-01	7.643E-02
NB 94	1.283E 0C	1.283E 00	1.282E 00	1.281E 00	1.278E 00	1.270E 00	1.240E 00	1.158E 00	9.116E-01	4.605E-01	4.219E-02	1.949E-15
NB 95	1.652E 04	1.330E-01	1.243E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 95M	6.355E 01	4.443E-04	4.152E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 97	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 97M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 39

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% P	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
NB 98	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 93	2.524E-02	2.523E-02	2.519E-02	2.509E-02	2.475E-02	2.378E-02	2.070E-02	1.393E-02	3.480E-03	6.617E-05	6.269E-11	0.0
MO 94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 97	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 98	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 99	4.320E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO101	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC 97	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC 97M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC 99	1.056E-03	1.056E-03	1.056E-03	1.056E-03	1.056E-03	1.055E-03	1.053E-03	1.046E-03	1.022E-03	9.578E-04	7.627E-04	4.078E-05
TC100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC101	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU 96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU 97	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU 98	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU 99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU101	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU102	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU103	4.060E-03	1.628E-11	4.156E-31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU104	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU106	2.999E-13	3.812E-14	3.099E-16	3.299E-22	4.107E-43	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RU107	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH103	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH104	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH104M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH105M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH106	2.999E-13	3.812E-14	3.099E-16	3.299E-22	4.107E-43	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH106M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH107	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD102	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD103	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD104	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD106	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD107	6.455E-15	6.455E-15	6.455E-15	6.455E-15	6.455E-15	6.455E-15	6.454E-15	6.453E-15	6.448E-15	6.434E-15	6.386E-15	5.802E-15
PD107M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD108	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD109	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD109M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD111M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G107	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 40

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SN+0.05% F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
AG108	5.817E-07	5.723E-07	5.508E-07	4.938E-07	3.370E-07	1.131E-07	2.480E-09	4.509E-14	1.155E-30	0.0	0.0	0.0
AG108M	6.536E-06	6.430E-06	6.189E-06	5.549E-06	3.787E-06	1.271E-06	2.767E-08	5.066E-13	1.298E-29	0.0	0.0	0.0
AG109	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AG109M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AG110	5.267E-06	4.435E-07	3.689E-10	5.844E-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AG110M	6.968E-04	3.335E-05	2.773E-08	4.394E-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AG111	6.307E-11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AG111M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AG112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD106	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD107	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD108	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD109	2.784E-03	5.417E-04	1.189E-05	2.167E-10	5.604E-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD111M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD113	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD114	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD115	2.461E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD115M	7.168E-03	2.875E-10	1.584E-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD116	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD117	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD117M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD119	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CD121	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN113	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN113M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN114	4.360E 00	9.499E-07	2.713E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN114M	4.556E 00	9.926E-07	2.835E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN115	1.644E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16
IN116	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN116M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN117	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN117M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN118	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN119	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN119M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN120M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN121	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN113	3.485E 02	4.750E-01	9.775E-08	7.682E-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN113M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN114	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN115	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN116	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN117	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN117M	2.700E 00	7.556E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN118	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN119	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN119M	4.206E 03	1.895E 02	1.369E-01	1.451E-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

00133

Table 8.2 (continued)

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM
POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

OUTPUT UNIT = 6 PAGE 41
ACTIVATION PRODUCTS

NUCLIDE TABLE: RADIOACTIVITY, CURIES
ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% Y	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
SN120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN121	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN121M	5.748E-01	5.514E-01	5.004E-01	3.791E-01	1.436E-01	8.961E-03	5.440E-07	4.871E-19	0.0	0.0	0.0	0.0
SN122	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN123	1.420E 02	3.968E-01	4.365E-07	4.123E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN123M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN124	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN125	2.293E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN125M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB121	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB122	6.469E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB122M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB123	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB124	2.576E 00	9.863E-06	1.616E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB124M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	1.448E 03	6.833E 02	1.185E 02	7.951E-01	1.962E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB126	6.790E-03	1.667E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB126M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE121	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE121M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE122	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE123	3.977E-13	4.360E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13
TE123M	1.173E 00	2.057E-03	7.621E-10	3.215E-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE124	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE125	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE125M	3.443E 02	1.668E 02	2.892E 01	1.940E-01	4.788E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE126	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE127	9.113E-03	8.582E-06	7.461E-13	5.002E-33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE127M	9.303E-03	8.761E-06	7.617E-13	5.107E-33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE129	5.456E-10	8.311E-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE129M	8.381E-10	1.277E-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE130	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE131	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE131M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I125	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I126	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I127	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I129	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.650E-14	1.645E-14	1.581E-14
I130	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I130M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I131	3.267E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I132	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE124	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE125	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE125M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE126	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE127	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE127M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 42

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
XE129	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE129M	4.113E-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE130	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE131	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE131M	4.461E-14	8.440E-42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE132	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE133	1.477E-22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE133M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE135M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE136	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS131	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS132	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS133	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS134	3.641E-16	1.328E-16	1.262E-17	1.963E-20	1.184E-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS134M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS135	1.418E-23	1.418E-23	1.418E-23	1.418E-23	1.418E-23	1.418E-23	1.418E-23	1.418E-23	1.415E-23	1.406E-23	1.377E-23	1.050E-23
CS136	3.161E-22	2.108E-47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS137	1.258E-33	1.258E-33	1.258E-33	1.258E-33	1.258E-33	1.258E-33	1.190E-40	1.015E-60	0.0	0.0	0.0	0.0
CS138	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA130	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA131	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA131M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA132	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA133	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA133M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA135M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA136	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA136M	5.210E-23	3.473E-48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA137M	1.190E-33	1.190E-33	1.190E-33	1.190E-33	1.190E-33	1.190E-33	1.126E-40	9.598E-61	0.0	0.0	0.0	0.0
BA138	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA139	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA140	3.785E-57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BA141	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LA137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LA138	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LA139	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LA140	4.356E-57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LA141	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE136	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE137M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE138	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE139	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE139M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE140	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE141	1.305E-56	2.248E-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

00135

Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 43

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS
POWER= 1.000COE 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES
ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05Y P	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
CE142	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE143	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE144	1.612E-29	1.612E-29	1.612E-29	2.961E-37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PR141	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PR142	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PR142M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PR143	1.202E-27	5.796E-52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PR144	1.593E-29	1.593E-29	1.593E-29	2.926E-37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PR145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND142	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND143	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND144	3.584E-45	3.585E-45	3.585E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45
ND145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND146	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND147	2.368E-23	3.556E-53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND148	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND149	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND151	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM147	8.194E-20	3.864E-20	1.136E-20	-7.883E-21	-7.320E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM148	7.323E-23	3.246E-28	7.480E-47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM148M	1.218E-21	5.763E-27	1.328E-45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM149	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM151	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM152	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM144	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM146	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM147	8.033E-31	1.865E-30	2.534E-30	3.005E-30	2.812E-30	2.812E-30	2.812E-30	2.812E-30	2.812E-30	2.812E-30	2.812E-30	2.812E-30
SM148	3.005E-33	3.287E-33	3.943E-33	5.819E-33	1.238E-32	3.114E-32	9.679E-32	2.844E-31	9.409E-31	2.817E-30	9.382E-30	9.379E-29
SM149	9.961E-28	9.961E-28	9.961E-28	9.961E-28	9.961E-28	9.961E-28	9.961E-28	9.961E-28	9.961E-28	9.961E-28	9.961E-28	9.961E-28
SM150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM151	4.806E-12	4.696E-12	4.450E-12	3.815E-12	2.225E-12	4.768E-13	2.178E-15	4.447E-22	0.0	0.0	0.0	0.0
SM152	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM153	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM154	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM155	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU151	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU152	7.483E-14	6.422E-14	4.495E-14	1.622E-14	4.578E-16	1.714E-20	5.499E-36	0.0	0.0	0.0	0.0	0.0
EU152M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU153	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU154	1.077E-04	8.454E-05	4.809E-05	9.593E-06	3.370E-08	3.365E-15	0.0	0.0	0.0	0.0	0.0	0.0
EU155	5.869E-05	3.859E-05	1.451E-05	8.862E-07	4.993E-11	3.615E-23	0.0	0.0	0.0	0.0	0.0	0.0
EU156	1.224E-06	2.320E-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD152	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18
GD153	9.842E-04	4.267E-05	2.818E-08	2.310E-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD154	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD155M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD155	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 44

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% Y	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
GD156	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD157	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD158	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD159	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD160	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD161	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GD162	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TB157	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TB159	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TB160	1.724E-03	4.727E-08	1.071E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TB161	6.439E-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TB162	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY156	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY157	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY158	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY159	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY160	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY161	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY162	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY163	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY164	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY165	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY165M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY166	2.001E-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HO163	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HO165	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HO166	2.981E-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HO166M	1.312E-09	1.310E-09	1.305E-09	1.290E-09	1.239E-09	1.104E-09	7.365E-10	2.320E-10	4.070E-12	3.913E-17	1.079E-34	0.0
ER162	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER163	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER164	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER165	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER166	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER167	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER167M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER168	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER169	6.809E-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER170	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER171	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ER172	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TM169	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TM170	1.712E-10	4.658E-13	4.817E-19	3.815E-36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TM170M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TM171	2.842E-12	9.621E-13	7.686E-14	5.623E-17	5.954E-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TM172	1.449E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TM173	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB168	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB169	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB170	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB171	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB172	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB173	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 45

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS
POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES
ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05Y F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
YB174	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB175	3.608E-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB175M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB176	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB177	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LU175	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LU176	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11
LU176M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LU177	6.618E-04	4.927E-06	5.334E-11	3.465E-25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LU177M	2.877E-03	2.142E-05	2.319E-10	1.507E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF174	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF175	3.263E 00	6.330E-05	6.402E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF176	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF177	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF178	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF178M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF179	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF179M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF180M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF181	3.868E 01	6.415E-07	4.499E-25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF182	4.166E-07	4.166E-07	4.166E-07	4.166E-07	4.166E-07	4.166E-07	4.165E-07	4.165E-07	4.162E-07	4.156E-07	4.134E-07	3.857E-07
TA180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA181	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA182	1.371E 01	1.856E-02	4.203E-07	4.166E-07	4.166E-07	4.166E-07	4.165E-07	4.165E-07	4.162E-07	4.156E-07	4.134E-07	3.857E-07
TA182M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA183	4.591E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W181	3.683E-01	6.985E-04	3.111E-10	2.219E-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W182	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W183M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W183	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W184	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W185	5.739E 00	2.367E-04	1.336E-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W185M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W186	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W187	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W188	3.288E-01	5.806E-06	4.715E-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W189	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RE185	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RE186	2.886E-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RE187	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08
RE188	3.322E-01	5.866E-06	4.763E-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RE188M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RE189	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS184	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS185	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS186	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS187	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS188	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS189	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS190	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 46

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SN+0.05% F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
OS190M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS191	9.706E-06	3.759E-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS191M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS192	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS193	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OS194	4.208E-11	2.976E-11	1.325E-11	1.315E-12	4.045E-16	3.738E-26	0.0	0.0	0.0	0.0	0.0	0.0
IR191	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IR192	6.663E-04	2.655E-08	2.586E-09	2.442E-09	1.997E-09	1.123E-09	1.500E-10	4.772E-13	8.612E-22	0.0	0.0	0.0
IR192M	2.660E-09	2.637E-09	2.584E-09	2.440E-09	1.995E-09	1.122E-09	1.499E-10	4.768E-13	8.605E-22	0.0	0.0	0.0
IR193	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IR194	4.210E-11	2.977E-11	1.326E-11	1.316E-12	4.046E-16	3.739E-26	0.0	0.0	0.0	0.0	0.0	0.0
IR194M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT190	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT191	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT192	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT193	1.545E-08	1.538E-08	1.523E-08	1.482E-08	1.345E-08	1.019E-08	3.861E-09	2.413E-10	1.473E-14	1.340E-26	0.0	0.0
PT193M	3.663E-17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT194	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT195	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT195M	3.391E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT196	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT197	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT197M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT198	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT199	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PT199M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AU197	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AU198	2.435E-31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AU199	2.242E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AU200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG196	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG197	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG197M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG198	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG199	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG199M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG201	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG202	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG203	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG204	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HG205	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TL203	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TL204	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TL205	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TL206	8.596E-12	8.596E-12	8.596E-12	8.595E-12	8.595E-12	8.595E-12	8.594E-12	8.590E-12	8.576E-12	8.536E-12	8.399E-12	6.822E-12
PB204	8.609E-20	8.609E-20	8.609E-20	8.609E-20	8.609E-20	8.609E-20	8.609E-20	8.609E-20	8.609E-20	8.609E-20	8.609E-20	8.609E-20
PB205	9.130E-13	9.130E-13	9.130E-13	9.130E-13	9.130E-13	9.130E-13	9.130E-13	9.129E-13	9.128E-13	9.124E-13	9.109E-13	8.921E-13
PB206	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB207	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB208	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB209	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.2 (continued)

OUTPUT UNIT = 6 PAGE 47

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

NUCLIDE TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% Y	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
BI208	1.351E-12	1.351E-12	1.351E-12	1.351E-12	1.351E-12	1.350E-12	1.349E-12	1.344E-12	1.326E-12	1.277E-12	1.119E-12	2.054E-13
BI209	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BI210	6.018E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BI210M	8.630E-12	8.630E-12	8.630E-12	8.630E-12	8.630E-12	8.629E-12	8.628E-12	8.624E-12	8.610E-12	8.570E-12	8.433E-12	6.850E-12
BI211	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PO210	1.046E-05	4.332E-08	1.538E-13	3.452E-14	3.452E-14	3.452E-14	3.451E-14	3.450E-14	3.444E-14	3.428E-14	3.373E-14	2.740E-14
PO211	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PO211M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	4.667E 04	8.777E 03	3.055E 03	6.743E 02	3.163E 02	7.598E 01	7.802E 00	7.096E 00	6.169E 00	4.704E 00	2.446E 00	1.578E-01

Table B.3. Sample ORIGEN2 element radioactivity table

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM
POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

ACTIVATION PRODUCTS

ELEMENT TABLE: RADIOACTIVITY, CURIES
ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
H	1.280E-01	1.082E-01	7.303E-02	2.376E-02	4.672E-04	6.223E-09	5.370E-26	0.0	0.0	0.0	0.0	0.0
BE	2.209E-08	2.209E-08	2.209E-08	2.209E-08	2.209E-08	2.209E-08	2.208E-08	2.206E-08	2.200E-08	2.181E-08	2.116E-08	1.432E-08
C	9.412E-01	9.408E-01	9.400E-01	9.378E-01	9.299E-01	9.076E-01	8.339E-01	6.547E-01	2.807E-01	2.497E-02	5.240E-06	0.0
SI	2.482E-08	2.474E-08	2.456E-08	2.404E-08	2.231E-08	1.803E-08	8.545E-09	1.013E-09	5.802E-13	3.171E-22	0.0	0.0
P	3.603E-01	2.474E-08	2.456E-08	2.404E-08	2.231E-08	1.803E-08	8.546E-09	1.013E-09	5.803E-13	3.171E-22	0.0	0.0
S	5.479E-01	9.818E-05	1.762E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL	6.020E-06	6.020E-06	6.020E-06	6.020E-06	6.019E-06	6.016E-06	6.006E-06	5.979E-06	5.883E-06	5.618E-06	4.782E-06	6.019E-07
AR	2.650E-06	1.592E-08	1.564E-08	1.485E-08	1.240E-08	7.407E-09	1.220E-09	7.057E-12	1.035E-19	0.0	0.0	0.0
K	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.346E-13	2.345E-13
CA	1.849E-03	1.758E-05	9.084E-08	9.049E-08	9.044E-08	9.028E-08	8.974E-08	8.822E-08	8.309E-08	7.002E-08	3.847E-08	1.738E-11
SC	1.160E-01	1.348E-05	8.805E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15	2.304E-15
CR	6.236E 02	7.772E-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MN	6.803E 01	5.986E 00	2.073E-02	1.904E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE	4.863E 03	2.171E 03	3.359E 02	1.626E 00	1.278E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO	8.725E 03	4.911E 03	1.956E 03	1.409E 02	1.413E-02	5.311E-14	0.0	0.0	0.0	0.0	0.0	0.0
NI	6.606E 02	6.460E 02	6.130E 02	5.280E 02	3.137E 02	7.352E 01	5.460E 00	5.022E 00	4.727E 00	3.975E 00	2.167E 00	9.071E-04
CU	5.727E-23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZN	2.103E-01	9.340E-03	6.520E-06	6.265E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GE	2.272E-10	2.527E-38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SE	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	2.000E-32	1.141E-35
SR	6.356E-01	1.413E-04	1.194E-04	7.420E-05	1.402E-05	1.200E-07	6.970E-15	1.476E-35	0.0	0.0	0.0	0.0
Y	2.171E 00	1.461E-04	1.195E-04	7.422E-05	1.403E-05	1.201E-07	6.972E-15	1.476E-35	0.0	0.0	0.0	0.0
ZR	8.566E 03	1.865E-01	1.266E-01	1.266E-01	1.266E-01	1.265E-01	1.265E-01	1.264E-01	1.260E-01	1.249E-01	1.210E-01	8.045E-02
NB	1.659E 04	1.441E 00	1.336E 00	1.378E 00	1.398E 00	1.390E 00	1.360E 00	1.278E 00	1.031E 00	5.791E-01	1.571E-01	7.643E-02
MO	2.524E-02	2.523E-02	2.519E-02	2.509E-02	2.475E-02	2.378E-02	2.070E-02	1.393E-02	3.480E-03	6.617E-05	6.269E-11	0.0
TC	1.056E-03	1.056E-03	1.056E-03	1.056E-03	1.056E-03	1.055E-03	1.053E-03	1.046E-03	1.022E-03	9.578E-04	7.627E-04	4.078E-05
RU	4.060E-03	1.631E-11	3.099E-16	3.299E-22	4.107E-43	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RH	2.959E-13	3.812E-14	3.099E-16	3.299E-22	4.107E-43	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PD	6.455E-15	6.455E-15	6.455E-15	6.455E-15	6.455E-15	6.455E-15	6.454E-15	6.453E-15	6.448E-15	6.434E-15	6.386E-15	5.802E-15
AG	7.132E-04	4.079E-05	6.768E-06	6.043E-06	4.124E-06	1.384E-06	3.035E-08	5.517E-13	1.413E-29	0.0	0.0	0.0
CD	9.951E-03	5.417E-04	1.189E-05	2.167E-10	5.604E-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN	8.916E 00	1.942E-06	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16	1.662E-16
SN	4.700E 03	1.909E 02	6.373E-01	3.791E-01	1.436E-01	8.961E-03	5.440E-07	4.871E-19	0.0	0.0	0.0	0.0
SB	1.451E 03	6.833E 02	1.185E 02	7.951E-01	1.962E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE	3.454E 02	1.668E 02	2.892E 01	1.940E-01	4.788E-09	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13
I	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.652E-14	1.650E-14	1.645E-14	1.581E-14
XE	4.157E-12	8.440E-42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS	3.641E-16	1.328E-16	1.262E-17	1.965E-20	1.418E-23	1.418E-23	1.418E-23	1.418E-23	1.415E-23	1.406E-23	1.377E-23	1.050E-23
BA	5.210E-23	1.190E-33	1.190E-33	1.190E-33	1.190E-33	1.190E-33	1.126E-40	9.598E-61	0.0	0.0	0.0	0.0
LA	4.356E-57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CE	1.612E-29	1.612E-29	1.612E-29	2.961E-37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PR	1.218E-27	1.593E-29	1.593E-29	2.926E-37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ND	2.368E-23	3.585E-45	3.585E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45	9.493E-45
PM	8.323E-20	3.864E-20	1.136E-20	-7.883E-21	-7.320E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM	4.806E-12	4.696E-12	4.450E-12	3.815E-12	2.225E-12	4.768E-13	2.178E-15	4.447E-22	9.998E-28	1.002E-27	1.008E-27	1.093E-27
EU	1.676E-04	1.231E-04	6.259E-05	1.048E-05	3.375E-08	3.365E-15	5.499E-36	0.0	0.0	0.0	0.0	0.0
GD	9.842E-04	4.267E-05	2.818E-08	2.418E-17	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18	1.083E-18
TB	1.724E-03	4.727E-08	1.071E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DY	2.001E-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.3 (continued)

OUTPUT UNIT = 6 PAGE 49

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

ELEMENT TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05Y P	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
MO	1.312E-09	1.310E-09	1.305E-09	1.290E-09	1.239E-09	1.104E-09	7.365E-10	2.320E-10	4.070E-12	3.913E-17	1.079E-34	0.0
ER	6.009E-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TM	1.740E-10	1.428E-12	7.686E-14	5.623E-17	5.954E-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0
YB	3.608E-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LU	3.539E-03	2.635E-05	3.120E-10	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11	2.675E-11
HF	4.195E 01	6.436E-05	4.166E-07	4.166E-07	4.166E-07	4.166E-07	4.165E-07	4.165E-07	4.162E-07	4.156E-07	4.134E-07	3.857E-07
TA	1.371E 01	1.856E-02	4.203E-07	4.166E-07	4.166E-07	4.166E-07	4.165E-07	4.165E-07	4.162E-07	4.156E-07	4.134E-07	3.857E-07
W	6.436E 00	9.410E-04	3.111E-10	2.219E-28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RE	3.322E-01	5.800E-06	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08	1.398E-08
OS	9.706E-06	2.976E-11	1.325E-11	1.315E-12	4.045E-16	3.738E-26	0.0	0.0	0.0	0.0	0.0	0.0
IR	6.664E-04	2.922E-08	5.184E-09	4.883E-09	3.991E-09	2.245E-09	2.999E-10	9.540E-13	1.722E-21	0.0	0.0	0.0
PT	1.545E-08	1.538E-08	1.523E-08	1.482E-08	1.345E-08	1.019E-08	3.861E-09	2.413E-10	1.473E-14	1.340E-26	0.0	0.0
AU	2.266E-29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TL	8.596E-12	8.596E-12	8.596E-12	8.595E-12	8.595E-12	8.595E-12	8.594E-12	8.590E-12	8.576E-12	8.536E-12	8.399E-12	6.822E-12
PB	5.130E-13	9.130E-13	9.130E-13	9.130E-13	9.130E-13	9.130E-13	9.130E-13	9.129E-13	9.128E-13	9.124E-13	9.109E-13	8.921E-13
BI	9.987E-12	9.981E-12	9.981E-12	9.981E-12	9.981E-12	9.980E-12	9.977E-12	9.968E-12	9.936E-12	9.847E-12	9.552E-12	7.055E-12
PO	1.046E-05	4.332E-08	1.538E-13	3.452E-14	3.452E-14	3.452E-14	3.451E-14	3.450E-14	3.444E-14	3.428E-14	3.373E-14	2.740E-14
TOTAL	4.667E 04	8.777E 03	3.055E 03	6.743E 02	3.163E 02	7.598E 01	7.802E 00	7.096E 00	6.169E 00	4.704E 00	2.446E 00	1.578E-01

Table B.4. Sample ORIGEN2 summary nuclide radioactivity table

OUTPUT UNIT = 6 PAGE 50

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

SUMMARY TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05Y F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
C 14	9.412E-01	9.408E-01	9.400E-01	9.378E-01	9.299E-01	9.076E-01	8.339E-01	6.547E-01	2.807E-01	2.497E-02	5.240E-06	0.0
CR 51	6.236E 02	7.772E-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MN 54	6.803E-01	5.986E 00	2.073E-02	1.904E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE 55	4.831E 03	2.171E 03	3.359E 02	1.626E 00	1.278E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 58	1.438E 03	3.143E-02	4.194E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	7.286E 03	4.911E 03	1.956E 03	1.409E 02	1.413E-02	5.311E-14	0.0	0.0	0.0	0.0	0.0	0.0
NI 59	5.154E 00	5.154E 00	5.154E 00	5.153E 00	5.150E 00	5.141E 00	5.110E 00	5.022E 00	4.727E 00	3.975E 00	2.167E 00	9.071E-04
NI 63	6.554E 02	6.408E 02	6.079E 02	5.228E 02	3.086E 02	6.838E 01	3.500E-01	9.998E-08	0.0	0.0	0.0	0.0
ZR 93	1.266E-01	1.266E-01	1.266E-01	1.266E-01	1.266E-01	1.265E-01	1.265E-01	1.264E-01	1.260E-01	1.249E-01	1.210E-01	8.045E-02
ZR 95	8.566E 03	5.989E-02	5.597E-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 93M	9.263E-03	2.500E-02	5.357E-02	9.618E-02	1.196E-01	1.202E-01	1.202E-01	1.201E-01	1.197E-01	1.186E-01	1.149E-01	7.643E-02
NB 94	1.283E 00	1.283E 00	1.282E 00	1.281E 00	1.278E 00	1.270E 00	1.240E 00	1.158E 00	9.116E-01	4.605E-01	4.219E-02	1.949E-15
NB 95	1.652E 04	1.330E-01	1.243E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 95M	6.355E 01	4.443E-04	4.152E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 93	2.524E-02	2.523E-02	2.519E-02	2.509E-02	2.475E-02	2.378E-02	2.070E-02	1.393E-02	3.480E-03	6.617E-05	6.269E-11	0.0
SN113	3.485E 02	4.750E-01	9.775E-08	7.682E-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN119M	4.206E 03	1.895E 02	1.369E-01	1.451E-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN123	1.420E 02	3.968E-01	4.365E-07	4.123E-24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	1.448E 03	6.833E 02	1.185E 02	7.951E-01	1.962E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE125M	3.443E 02	1.668E 02	2.892E 01	1.940E-01	4.788E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SUMTOT	4.655E 04	8.777E 03	3.054E 03	6.739E 02	3.162E 02	7.597E 01	7.801E 00	7.095E 00	6.168E 00	4.704E 00	2.445E 00	1.578E-01
TOTAL	4.667E 04	8.777E 03	3.055E 03	6.743E 02	3.163E 02	7.598E 01	7.802E 00	7.096E 00	6.169E 00	4.704E 00	2.446E 00	1.578E-01

Table B.5. Sample ORIGEN2 summary element radioactivity table

OUTPUT UNIT = 6 PAGE 51

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM ACTIVATION PRODUCTS

POWER= 1.00000E 00MW, BURNUP= 1.00000E 00MWD, FLUX= 1.00E 00N/CM**2-SEC

SUMMARY TABLE: RADIOACTIVITY, CURIES

ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05Y F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
C	9.412E-01	9.408E-01	9.400E-01	9.378E-01	9.299E-01	9.076E-01	8.339E-01	6.547E-01	2.807E-01	2.497E-02	5.240E-06	0.0
CR	6.236E 02	7.772E-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MN	6.803E 01	5.986E 00	2.073E-02	1.904E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FE	4.863E 03	2.171E 03	3.359E 02	1.626E 00	1.278E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO	8.725E 03	4.911E 03	1.956E 03	1.409E 02	1.413E-02	5.311E-14	0.0	0.0	0.0	0.0	0.0	0.0
NI	6.606E 02	6.460E 02	6.130E 02	5.280E 02	3.137E 02	7.352E 01	5.460E 00	5.022E 00	4.727E 00	3.975E 00	2.167E 00	9.071E-04
ZR	8.566E 03	1.865E-01	1.266E-01	1.266E-01	1.266E-01	1.265E-01	1.265E-01	1.264E-01	1.260E-01	1.249E-01	1.210E-01	8.045E-02
NB	1.659E 04	1.441E 00	1.336E 00	1.378E 00	1.398E 00	1.390E 00	1.360E 00	1.278E 00	1.031E 00	5.791E-01	1.571E-01	7.643E-02
MO	2.524E-02	2.523E-02	2.519E-02	2.509E-02	2.475E-02	2.378E-02	2.070E-02	1.393E-02	3.480E-03	6.617E-05	6.269E-11	0.0
SN	4.700E 03	1.909E 02	6.373E-01	3.791E-01	1.436E-01	8.961E-03	5.440E-07	4.871E-19	0.0	0.0	0.0	0.0
SB	1.451E 03	6.833E 02	1.185E 02	7.951E-01	1.962E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA	3.454E 02	1.668E 02	2.892E 01	1.940E-01	4.788E-09	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13	4.361E-13
SUMTOT	4.659E 04	8.777E 03	3.055E 03	6.743E 02	3.163E 02	7.590E 01	7.801E 00	7.095E 00	6.168E 00	4.704E 00	2.445E 00	1.578E-01
TOTAL	4.667E 04	8.777E 03	3.055E 03	6.743E 02	3.163E 02	7.590E 01	7.802E 00	7.096E 00	6.169E 00	4.704E 00	2.446E 00	1.578E-01

CUMULATIVE TABLE TOTALS

AP+FP	4.667E 04	8.777E 03	3.055E 03	6.743E 02	3.163E 02	7.598E 01	7.802E 00	7.096E 00	6.169E 00	4.704E 00	2.446E 00	1.578E-01
ACT+FP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AP+ACT+FP	4.667E 04	8.777E 03	3.055E 03	6.743E 02	3.163E 02	7.598E 01	7.802E 00	7.096E 00	6.169E 00	4.704E 00	2.446E 00	1.578E-01

Appendix B.3: Sample Neutron Production Rate Tables

Table B.6. Sample ORIGEN2 (alpha,n) neutron production table

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM
(ALPHA,N) NEUTRON SOURCE, NEUTRONS/SEC
BASIS= ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SE+0.05% Y	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
BI211	8.447E-07	3.138E-06	8.321E-06	2.290E-05	7.275E-05	2.139E-04	7.291E-04	2.131E-03	6.926E-03	1.925E-02	4.415E-02	5.445E-02
PO210	3.783E-10	3.038E-09	3.809E-08	5.691E-07	1.276E-05	1.839E-04	2.682E-03	1.987E-02	1.147E-01	3.993E-01	9.099E-01	4.034E-01
PO213	2.318E-07	2.516E-07	3.215E-07	6.821E-07	4.012E-06	3.677E-05	5.709E-04	6.852E-03	7.510E-02	4.351E-01	1.697E 00	4.124E 00
PO214	6.317E-08	2.512E-07	1.222E-06	8.302E-06	8.951E-05	8.878E-04	1.037E-02	7.681E-02	4.435E-01	1.544E 00	3.518E 00	1.559E 00
PO215	1.278E-06	4.747E-06	1.259E-05	3.463E-05	1.100E-04	3.235E-04	1.103E-03	3.223E-03	1.048E-02	2.912E-02	6.678E-02	8.236E-02
PO218	2.553E-08	1.017E-07	4.945E-07	3.359E-06	3.622E-05	3.593E-04	4.195E-03	3.108E-02	1.795E-01	6.246E-01	1.423E 00	6.310E-01
AT217	1.272E-07	1.380E-07	1.764E-07	3.742E-07	2.201E-06	2.017E-05	3.132E-04	3.755E-03	4.120E-02	2.387E-01	9.309E-01	2.262E 00
RN219	9.784E-07	3.635E-06	9.638E-06	2.652E-05	8.426E-05	2.477E-04	8.445E-04	2.468E-03	8.022E-03	2.230E-02	5.114E-02	6.307E-02
RN222	1.842E-08	7.336E-08	3.568E-07	2.424E-06	2.614E-05	2.593E-04	3.027E-03	2.243E-02	1.295E-01	4.507E-01	1.027E 00	4.554E-01
FR221	8.815E-08	9.567E-08	1.222E-07	2.593E-07	1.526E-06	1.398E-05	2.171E-04	2.605E-03	2.855E-02	1.654E-01	6.452E-01	1.568E 00
RA223	5.597E-07	2.080E-06	5.514E-06	1.517E-05	4.821E-05	1.417E-04	4.832E-04	1.412E-03	4.589E-03	1.276E-02	2.926E-02	3.608E-02
RA226	1.115E-08	4.438E-08	2.159E-07	1.467E-06	1.581E-05	1.568E-04	1.831E-03	1.357E-02	7.835E-02	2.727E-01	6.215E-01	2.755E-01
AC225	6.125E-08	6.648E-08	8.494E-08	1.802E-07	1.060E-06	9.716E-06	1.508E-04	1.810E-03	1.984E-02	1.150E-01	4.483E-01	1.089E 00
TH227	6.019E-07	2.244E-06	5.951E-06	1.637E-05	5.202E-05	1.529E-04	5.214E-04	1.524E-03	4.952E-03	1.377E-02	3.157E-02	3.894E-02
TH229	3.755E-08	4.097E-08	5.234E-08	1.111E-07	6.533E-07	5.988E-06	9.295E-05	1.116E-03	1.223E-02	7.084E-02	2.763E-01	6.714E-01
TH230	1.529E-05	3.233E-05	7.325E-05	1.983E-04	7.110E-04	2.500E-03	9.365E-03	2.883E-02	9.354E-02	2.517E-01	5.746E-01	2.560E-01
PA231	8.781E-06	9.547E-06	1.133E-05	1.641E-05	3.420E-05	8.501E-05	2.626E-04	7.673E-04	2.494E-03	6.933E-03	1.590E-02	1.961E-02
U233	8.733E-06	1.133E-05	1.723E-05	3.455E-05	1.047E-04	3.872E-04	1.975E-03	7.974E-03	2.953E-02	8.733E-02	2.513E-01	5.561E-01
U234	6.672E-01	6.790E-01	7.059E-01	7.748E-01	9.459E-01	1.130E 00	1.176E 00	1.171E 00	1.151E 00	1.098E 00	9.345E-01	2.465E-01
U236	1.214E-01	1.215E-01	1.215E-01	1.217E-01	1.222E-01	1.236E-01	1.285E-01	1.406E-01	1.673E-01	1.885E-01	1.911E-01	1.860E-01
U238	1.184E-01	1.184E-01	1.184E-01	1.184E-01	1.184E-01	1.184E-01	1.184E-01	1.184E-01	1.184E-01	1.184E-01	1.184E-01	1.184E-01
NP237	2.258E-01	2.302E-01	2.323E-01	2.448E-01	3.068E-01	4.612E-01	7.366E-01	8.636E-01	8.670E-01	8.615E-01	8.421E-01	6.292E-01
PU238	2.275E 03	2.318E 03	2.195E 03	1.874E 03	1.079E 03	2.232E 02	9.553E-01	8.495E-06	1.149E-19	0.0	0.0	0.0
PU239	2.376E 02	2.376E 02	2.375E 02	2.374E 02	2.370E 02	2.357E 02	2.312E 02	2.189E 02	1.802E 02	1.022E 02	1.365E 01	2.724E-08
PU240	4.145E 02	4.147E 02	4.151E 02	4.154E 02	4.133E 02	4.047E 02	3.758E 02	3.040E 02	1.447E 02	1.736E 01	1.038E-02	4.477E-07
PU242	1.142E 00	1.142E 00	1.142E 00	1.142E 00	1.141E 00	1.141E 00	1.140E 00	1.136E 00	1.122E 00	1.082E 00	9.547E-01	1.904E-01
AM241	1.896E 02	7.390E 02	1.741E 03	3.224E 03	3.743E 03	2.741E 03	8.919E 02	3.611E 01	9.662E-03	1.797E-03	5.992E-06	0.0
AM243	1.511E 01	1.511E 01	1.510E 01	1.507E 01	1.497E 01	1.469E 01	1.376E 01	1.140E 01	5.907E 00	9.028E-01	1.266E-03	3.166E-08
CM243	2.086E 01	1.939E 01	1.636E 01	1.006E 01	1.833E 00	1.414E-02	5.710E-10	4.285E-31	0.0	0.0	0.0	0.0
CM244	1.808E 03	1.612E 03	1.233E 03	5.735E 02	3.935E 01	1.864E-02	6.918E-11	6.913E-11	6.913E-11	6.912E-11	6.908E-11	6.858E-11
TOTALS												
TABLE	4.963E 03	5.358E 03	5.855E 03	6.353E 03	5.531E 03	3.622E 03	1.517E 03	5.740E 02	3.356E 02	1.286E 02	2.928E 01	1.553E 01
ACTUAL	4.963E 03	5.358E 03	5.855E 03	6.353E 03	5.531E 03	3.622E 03	1.517E 03	5.740E 02	3.356E 02	1.286E 02	2.928E 01	1.553E 01

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Table B.7. Sample ORIGEN2 spontaneous fission neutron production table

OUTPUT UNIT = 6 PAGE 53

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM
SPONTANEOUS FISSION NEUTRON SOURCE, NEUTRONS/SEC
BASIS= ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

	SH+0.05% F	3. YR	10. YR	30. YR	100. YR	300. YR	1. KY	3. KY	10. KY	30. KY	100. KY	1. MY
U238	6.304E 00	6.304E 00	6.304E 00	6.304E 00	6.304E 00	6.304E 00	6.304E 00	6.304E 00	6.304E 00	6.304E 00	6.305E 00	6.306E 00
PU238	1.647E 02	1.678E 02	1.589E 02	1.357E 02	7.813E 01	1.616E 01	6.916E-02	6.151E-07	8.321E-21	0.0	0.0	0.0
PU240	1.143E 03	1.144E 03	1.145E 03	1.146E 03	1.140E 03	1.116E 03	1.036E 03	8.383E 02	3.991E 02	4.787E 01	2.862E-02	1.235E-06
PU242	4.682E 02	4.682E 02	4.682E 02	4.682E 02	4.681E 02	4.680E 02	4.674E 02	4.658E 02	4.600E 02	4.438E 02	3.915E 02	7.808E 01
CM242	6.440E 04	6.232E 02	9.667E 00	8.813E 00	6.405E 00	2.573E 00	1.057E-01	1.161E-05	1.593E-19	0.0	0.0	0.0
CM244	1.061E 05	9.458E 04	7.235E 04	3.365E 04	2.309E 03	1.094E 00	4.059E-09	4.057E-09	4.057E-09	4.056E-09	4.054E-09	4.025E-09
CM246	4.272E 02	4.270E 02	4.266E 02	4.253E 02	4.210E 02	4.088E 02	3.690E 02	2.753E 02	9.871E 01	5.269E 00	1.852E-04	1.770E-28
TOTALS												
TABLE	1.727E 05	9.742E 04	7.457E 04	3.584E 04	4.430E 03	2.020E 03	1.880E 03	1.586E 03	9.646E 02	5.037E 02	3.982E 02	8.449E 01
ACTUAL	1.727E 05	9.742E 04	7.457E 04	3.584E 04	4.430E 03	2.020E 03	1.880E 03	1.586E 03	9.646E 02	5.037E 02	3.982E 02	8.449E 01
OVERALL TOTALS												
TABLE	1.777E 05	1.028E 05	8.042E 04	4.220E 04	9.961E 03	5.642E 03	3.397E 03	2.160E 03	1.300E 03	6.323E 02	4.275E 02	1.000E 02
ACTUAL	1.777E 05	1.028E 05	8.042E 04	4.220E 04	9.961E 03	5.642E 03	3.397E 03	2.160E 03	1.300E 03	6.323E 02	4.275E 02	1.000E 02

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Appendix B.4: Sample Photon Production Rate Tables

Table B.8. Sample ORIGEN2 activation product photon table

PHOTON SPECTRUM FOR ACTIVATION PRODUCTS

OUTPUT UNIT = 11 PAGE 51

DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM
POWER= 1.00 MW, BURNUP= 1. MWD, FLUX= 1.00E+00 N/CM**2-SEC

18 GROUP PHOTON RELEASE RATES, PHOTONS/SECOND
BASIS= ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

EMEAN	SN+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
1.500E-02	7.027E+13	1.218E+13	4.340E+12	3.940E+11	7.005E+10	2.058E+10	6.324E+09	5.573E+09	4.069E+09	2.310E+09	9.675E+08	5.554E+08
2.500E-02	1.226E+14	2.106E+13	3.640E+12	7.527E+10	4.716E+09	1.695E+09	8.166E+08	7.434E+08	5.567E+08	2.679E+08	2.638E+07	1.292E+06
3.750E-02	1.438E+13	5.374E+12	1.149E+12	3.437E+10	1.279E+09	6.623E+08	4.750E+08	4.355E+08	3.290E+08	1.596E+08	1.504E+07	2.602E+05
5.750E-02	7.127E+12	1.228E+12	4.547E+11	3.180E+10	6.655E+08	5.959E+08	5.623E+08	5.193E+08	3.980E+08	1.957E+08	1.810E+07	4.661E+04
8.500E-02	2.594E+12	4.885E+11	1.801E+11	1.249E+10	2.625E+08	2.593E+08	2.528E+08	2.351E+08	1.834E+08	9.179E+07	8.481E+06	6.765E+03
1.250E-01	2.240E+12	2.896E+11	8.684E+10	4.941E+09	1.245E+08	1.231E+08	1.202E+08	1.122E+08	8.822E+07	4.452E+07	4.111E+06	4.576E+03
2.250E-01	5.237E+12	1.595E+12	2.886E+11	3.404E+09	7.684E+07	7.609E+07	7.430E+07	6.939E+07	5.464E+07	2.761E+07	2.541E+06	4.304E+03
3.750E-01	2.173E+13	9.160E+12	1.592E+12	1.107E+10	3.859E+06	3.661E+06	3.527E+06	3.293E+06	2.593E+06	1.310E+06	1.202E+05	2.725E+01
5.750E-01	4.043E+13	1.176E+13	2.039E+12	1.370E+10	1.569E+05	4.601E+04	1.089E+03	7.489E+01	7.089E+01	6.766E+01	5.761E+01	7.348E+00
8.500E-01	8.818E+14	3.340E+11	9.395E+10	8.807E+10	8.747E+10	8.688E+10	8.482E+10	7.923E+10	6.238E+10	3.151E+10	2.887E+09	1.626E+02
1.250E+00	5.427E+14	3.654E+14	1.455E+14	1.048E+13	1.051E+09	1.432E+04	1.430E+04	1.430E+04	1.429E+04	1.427E+04	1.419E+04	1.324E+04
1.750E+00	3.184E+11	6.184E+06	2.943E+04	6.351E+03	1.605E+02	1.243E+00	9.630E-04	1.524E-05	2.523E-06	2.522E-06	2.508E-06	2.340E-06
2.250E+00	8.946E+09	1.936E+09	7.712E+08	5.555E+07	5.571E+03	1.324E-04	1.599E-10	1.521E-10	1.519E-10	1.512E-10	1.488E-10	1.208E-10
2.750E+00	1.332E+07	5.992E+06	2.386E+06	1.719E+05	1.724E+01	1.414E-10	7.626E-11	7.623E-11	7.610E-11	7.575E-11	7.454E-11	6.054E-11
3.500E+00	6.841E-05	3.217E-07	3.913E-10	6.440E-11	5.800E-11	5.611E-11	5.608E-11	5.605E-11	5.596E-11	5.570E-11	5.481E-11	4.452E-11
5.000E+00	2.028E-05	8.398E-08	1.696E-11	1.673E-11	1.673E-11	1.673E-11	1.673E-11	1.672E-11	1.669E-11	1.661E-11	1.635E-11	1.328E-11
7.000E+00	1.316E-06	5.449E-09	1.098E-12	1.083E-12	1.083E-12	1.083E-12	1.083E-12	1.083E-12	1.081E-12	1.076E-12	1.059E-12	8.598E-13
1.100E+01	8.319E-08	3.446E-10	6.954E-14	6.859E-14	6.859E-14	6.858E-14	6.857E-14	6.854E-14	6.843E-14	6.811E-14	6.702E-14	5.444E-14
TOTAL	1.719E+15	4.296E+14	1.594E+14	1.115E+13	1.657E+11	1.109E+11	9.345E+10	8.692E+10	6.806E+10	3.461E+10	3.929E+09	5.570E+08
MEV/SEC	1.467E+15	4.686E+14	1.840E+14	1.320E+13	7.698E+10	7.431E+10	7.232E+10	6.754E+10	5.317E+10	2.686E+10	2.472E+09	9.394E+06

18GROUP SPECIFIC ENERGY RELEASE RATES, MEV/WATT-SEC
BASIS= ONE TONNE OF INITIAL HEAVY METAL AT A REPROCESSING TIME OF 160 DAYS

EMEAN	SN+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
1.500E-02	1.174E+06	1.827E+05	6.509E+04	5.910E+03	1.051E+03	3.088E+02	9.486E+01	8.360E+01	6.104E+01	3.465E+01	1.451E+01	8.331E+00
2.500E-02	3.064E+06	5.464E+05	9.101E+04	1.882E+03	1.179E+02	4.237E+01	2.042E+01	1.858E+01	1.392E+01	6.698E+00	6.595E-01	3.230E-02
3.750E-02	5.392E+05	2.015E+05	4.307E+04	1.289E+03	4.797E+01	2.484E+01	1.781E+01	1.633E+01	1.234E+01	5.984E+00	5.639E-01	9.756E-03
5.750E-02	4.098E+05	7.059E+04	2.615E+04	1.829E+03	3.827E+01	3.426E+01	3.233E+01	2.986E+01	2.288E+01	1.125E+01	1.041E+00	2.680E-03
8.500E-02	2.205E+05	4.153E+04	1.531E+04	1.062E+03	2.231E+01	2.204E+01	2.149E+01	1.999E+01	1.559E+01	7.802E+00	7.209E-01	5.751E-04
1.250E-01	2.800E+05	3.620E+04	1.086E+04	6.176E+02	1.556E+01	1.539E+01	1.502E+01	1.402E+01	1.103E+01	5.565E+00	5.138E-01	5.720E-04
2.250E-01	1.178E+06	3.509E+05	6.493E+04	7.660E+02	1.729E+01	1.712E+01	1.672E+01	1.561E+01	1.229E+01	6.212E+00	5.717E-01	9.683E-04
3.750E-01	8.150E+06	3.435E+06	5.972E+05	4.153E+03	1.447E+00	1.373E+00	1.323E+00	1.235E+00	9.725E-01	4.913E-01	4.507E-02	1.022E-05
5.750E-01	2.325E+07	6.760E+06	1.173E+06	7.877E+03	9.021E-02	2.646E-02	6.262E-04	4.306E-05	4.076E-05	3.891E-05	3.312E-05	4.225E-06
8.500E-01	7.495E+08	2.839E+05	7.986E+04	7.486E+04	7.435E+04	7.385E+04	7.210E+04	6.734E+04	5.302E+04	2.678E+04	2.454E+03	1.382E-04
1.250E+00	6.783E+08	4.567E+08	1.819E+08	1.310E+07	1.314E+03	1.790E-02	1.787E-02	1.787E-02	1.786E-02	1.783E-02	1.774E-02	1.655E-02
1.750E+00	5.571E+05	1.082E+01	5.150E-02	1.111E-02	2.809E-04	2.175E-06	1.685E-09	2.668E-11	4.432E-12	4.413E-12	4.389E-12	4.095E-12
2.250E+00	2.013E+04	4.357E+03	1.735E+03	1.250E+02	1.254E-02	2.979E-10	3.598E-16	3.423E-16	3.417E-16	3.402E-16	3.347E-16	2.719E-16
2.750E+00	3.662E+01	1.648E+01	6.562E+00	4.727E-01	4.741E-05	3.888E-16	2.097E-16	2.096E-16	2.093E-16	2.083E-16	2.050E-16	1.665E-16
3.500E+00	2.394E-10	1.126E-12	1.370E-15	2.254E-16	2.030E-16	1.964E-16	1.963E-16	1.962E-16	1.959E-16	1.950E-16	1.918E-16	1.558E-16
5.000E+00	1.014E-10	4.199E-13	8.481E-17	8.365E-17	8.365E-17	8.365E-17	8.363E-17	8.355E-17	8.346E-17	8.307E-17	8.174E-17	6.639E-17
7.000E+00	9.209E-12	3.814E-14	7.688E-18	7.583E-18	7.583E-18	7.583E-18	7.581E-18	7.578E-18	7.566E-18	7.531E-18	7.410E-18	6.019E-18
1.100E+01	9.151E-13	3.790E-15	7.649E-19	7.545E-19	7.544E-19	7.544E-19	7.543E-19	7.539E-19	7.527E-19	7.493E-19	7.372E-19	5.988E-19
TOTAL	1.467E+09	4.686E+08	1.840E+08	1.320E+07	7.698E+04	7.431E+04	7.232E+04	6.754E+04	5.317E+04	2.686E+04	2.472E+03	9.394E+00
GAM POW	2.351E+02	7.512E+01	2.950E+01	2.116E+00	1.234E-02	1.191E-02	1.159E-02	1.083E-02	8.524E-03	4.306E-03	3.963E-04	1.346E-06

PRINCIPAL PHOTON SOURCES IN GROUP 1, PHOTONS/SEC
MEAN ENERGY= 0.015MEV

NUCLIDE	SH+0.05% F	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
C 14	8.262E+08	8.259E+08	8.252E+08	8.232E+08	8.162E+08	7.967E+08	7.320E+08	5.747E+08	2.464E+08	2.192E+07	4.600E+03	0.0
CR 51	2.632E+12	3.282E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 58	1.213E+13	2.651E+08	3.530E-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	1.437E+13	9.682E+12	3.856E+12	2.777E+11	2.786E+07	1.047E-04	0.0	0.0	0.0	0.0	0.0	0.0
NI 63	1.347E+11	1.317E+11	1.249E+11	1.075E+11	6.341E+10	1.405E+10	7.190E+07	2.054E+01	0.0	0.0	0.0	0.0
ZR 93	3.097E+07	3.097E+07	3.097E+07	3.097E+07	3.097E+07	3.096E+07	3.095E+07	3.093E+07	3.083E+07	3.055E+07	2.960E+07	1.569E+07
ZR 95	2.071E+13	1.448E+08	1.353E-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 93M	6.491E+07	1.752E+08	3.754E+08	6.739E+08	8.377E+08	8.424E+08	8.421E+08	8.413E+08	8.387E+08	8.311E+08	8.052E+08	5.355E+08
NB 94	3.957E+09	3.956E+09	3.955E+09	3.953E+09	3.943E+09	3.916E+09	3.824E+09	3.572E+09	2.912E+09	1.421E+09	1.301E+08	6.129E-06
NB 95	1.286E+13	1.035E+08	9.674E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 95M	1.750E+12	1.224E+07	1.144E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MO 93	9.990E+08	9.984E+08	9.970E+08	9.931E+08	9.794E+08	9.413E+08	8.194E+08	5.513E+08	1.377E+08	2.619E+06	2.481E+00	0.0
SN119M	6.409E+12	2.888E+11	2.087E+08	2.211E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN123	1.658E+12	4.634E+09	5.097E+03	4.816E-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	3.558E+12	1.680E+12	2.914E+11	1.954E+09	4.822E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE125M	7.262E+11	3.518E+11	6.101E+10	4.091E+08	1.010E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0

PRINCIPAL PHOTON SOURCES IN GROUP 2, PHOTONS/SEC
MEAN ENERGY= 0.025MEV

NUCLIDE	SH+0.05% F	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
C 14	1.169E+08	1.168E+08	1.167E+08	1.164E+08	1.155E+08	1.127E+08	1.035E+08	8.129E+07	3.485E+07	3.100E+06	6.507E+02	0.0
CO 60	2.483E+12	1.673E+12	6.664E+11	4.800E+10	4.814E+06	1.810E-05	0.0	0.0	0.0	0.0	0.0	0.0
NI 63	8.209E+09	8.026E+09	7.613E+09	6.549E+09	3.864E+09	8.564E+08	4.381E+06	1.252E+00	0.0	0.0	0.0	0.0
ZR 93	1.994E+06	1.994E+06	1.994E+06	1.994E+06	1.994E+06	1.994E+06	1.993E+06	1.991E+06	1.985E+06	1.967E+06	1.906E+06	1.263E+06
ZR 95	3.684E+12	2.575E+07	2.407E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 94	7.306E+08	7.306E+08	7.304E+08	7.299E+08	7.281E+08	7.232E+08	7.061E+08	6.595E+08	5.193E+08	2.623E+08	2.403E+07	1.132E-06
NB 95	1.758E+12	1.415E+07	1.322E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC 99	6.094E+05	6.094E+05	6.093E+05	6.093E+05	6.092E+05	6.088E+05	6.074E+05	6.034E+05	5.999E+05	5.527E+05	4.401E+05	2.353E+04
SN113	9.278E+12	1.264E+10	2.601E+03	2.044E-16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN119M	6.830E+13	3.078E+12	2.224E+09	2.357E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	2.270E+13	1.072E+13	1.859E+12	1.247E+10	3.077E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE125M	1.315E+13	6.368E+12	1.104E+12	7.406E+09	1.828E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0

PRINCIPAL PHOTON SOURCES IN GROUP 3, PHOTONS/SEC
MEAN ENERGY= 0.038MEV

NUCLIDE	SH+0.05% F	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
C 14	5.614E+07	5.612E+07	5.607E+07	5.593E+07	5.546E+07	5.414E+07	4.974E+07	3.905E+07	1.674E+07	1.489E+06	3.126E+02	0.0
CO 58	4.101E+11	8.960E+06	1.196E-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	1.418E+12	9.554E+11	3.805E+11	2.741E+10	2.749E+06	1.033E-05	0.0	0.0	0.0	0.0	0.0	0.0
NI 63	1.664E+09	1.627E+09	1.543E+09	1.327E+09	7.832E+08	1.736E+08	8.880E+05	2.537E-01	0.0	0.0	0.0	0.0
ZR 93	3.876E+05	3.876E+05	3.876E+05	3.876E+05	3.876E+05	3.875E+05	3.874E+05	3.870E+05	3.859E+05	3.823E+05	3.704E+05	2.464E+05
ZR 95	2.163E+12	1.512E+07	1.413E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 94	4.384E+08	4.383E+08	4.382E+08	4.379E+08	4.369E+08	4.339E+08	4.237E+08	3.957E+08	3.116E+08	1.574E+08	1.442E+07	6.790E-07

Table B.8 (continued)

NB 95	8.330E+11	6.704E+06	6.265E-06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC 99	3.406E+05	3.406E+05	3.406E+05	3.406E+05	3.405E+05	3.403E+05	3.395E+05	3.373E+05	3.297E+05	3.089E+05	2.460E+05	1.315E+04
SN123	2.232E+11	6.238E+08	6.861E+02	6.482E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	6.226E+12	2.939E+12	5.098E+11	3.419E+09	8.439E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE125M	3.050E+12	1.478E+12	2.563E+11	1.719E+09	4.242E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0

PRINCIPAL PHOTON SOURCES IN GROUP 4,PHOTONS/SEC
MEAN ENERGY= 0.058MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
C 14	4.413E+07	4.412E+07	4.408E+07	4.397E+07	4.360E+07	4.256E+07	3.910E+07	3.070E+07	1.316E+07	1.171E+06	2.457E+02	0.0
CL 36	5.055E+03	5.055E+03	5.055E+03	5.055E+03	5.054E+03	5.052E+03	5.043E+03	5.020E+03	4.940E+03	4.718E+03	4.015E+03	5.034E+02
CO 58	5.905E+11	1.290E+07	1.722E-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	1.599E+12	1.078E+12	4.292E+11	3.092E+10	3.101E+06	1.166E-05	0.0	0.0	0.0	0.0	0.0	0.0
NI 63	1.683E+08	1.646E+08	1.561E+08	1.343E+08	7.924E+07	1.756E+07	8.984E+04	2.566E-02	0.0	0.0	0.0	0.0
ZR 93	2.965E+04	2.965E+04	2.965E+04	2.965E+04	2.965E+04	2.965E+04	2.964E+04	2.961E+04	2.952E+04	2.925E+04	2.834E+04	1.345E+04
ZR 95	2.563E+12	1.792E+07	1.675E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 94	5.409E+08	5.408E+08	5.407E+08	5.403E+08	5.390E+08	5.353E+08	5.227E+08	4.882E+08	3.944E+08	1.942E+08	1.779E+07	9.377E-07
NB 95	6.431E+11	5.176E+06	4.837E-06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC 99	3.711E+05	3.711E+05	3.711E+05	3.711E+05	3.710E+05	3.707E+05	3.699E+05	3.675E+05	3.592E+05	3.366E+05	2.690E+05	1.433E+04
SN119M	1.068E+11	4.813E+05	3.478E+06	3.686E-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN123	3.169E+11	8.857E+08	9.742E+02	9.203E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	3.022E+11	1.426E+11	2.474E+10	1.659E+08	4.095E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF181	4.946E+11	8.202E+03	5.752E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA182	4.585E+11	6.208E+08	1.406E+04	1.393E+04	1.393E+04	1.393E+04	1.393E+04	1.393E+04	1.392E+04	1.390E+04	1.382E+04	1.290E+04

PRINCIPAL PHOTON SOURCES IN GROUP 5,PHOTONS/SEC
MEAN ENERGY= 0.085MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
C 14	7.238E+06	7.235E+06	7.229E+06	7.211E+06	7.151E+06	6.980E+06	6.413E+06	5.035E+06	2.159E+06	1.920E+05	4.030E+01	0.0
CL 36	2.695E+03	2.694E+03	2.694E+03	2.694E+03	2.694E+03	2.693E+03	2.688E+03	2.676E+03	2.633E+03	2.515E+03	2.140E+03	2.694E+02
CO 58	3.559E+11	7.776E+06	1.038E-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	6.289E+11	4.238E+11	1.688E+11	1.216E+10	1.219E+06	4.584E-06	0.0	0.0	0.0	0.0	0.0	0.0
ZR 95	1.108E+12	7.749E+06	7.242E-06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 94	2.548E+08	2.547E+08	2.547E+08	2.545E+08	2.539E+08	2.522E+08	2.462E+08	2.300E+08	1.811E+08	9.147E+07	8.379E+06	3.946E-07
NB 95	1.054E+11	8.478E+05	7.924E-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC 99	1.359E+05	1.359E+05	1.359E+05	1.359E+05	1.359E+05	1.358E+05	1.355E+05	1.346E+05	1.316E+05	1.233E+05	9.818E+04	5.249E+03
SN123	1.874E+11	5.238E+08	5.761E+02	5.442E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	1.352E+11	6.384E+10	1.107E+10	7.427E+07	1.833E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA182	4.403E+10	5.961E+07	1.350E+03	1.338E+03	1.337E+03	1.337E+03	1.337E+03	1.337E+03	1.336E+03	1.334E+03	1.327E+03	1.218E+03

Table 8.8 (continued)

PRINCIPAL PHOTON SOURCES IN GROUP 6,PHOTONS/SEC
MEAN ENERGY= 0.125MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
CL 36	1.517E+03	1.516E+03	1.516E+03	1.516E+03	1.516E+03	1.515E+03	1.513E+03	1.506E+03	1.492E+03	1.415E+03	1.205E+03	1.516E+02
CO 58	2.303E+11	5.031E+06	6.715E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	2.415E+11	1.628E+11	6.482E+10	4.669E+09	4.683E+05	1.761E-06	0.0	0.0	0.0	0.0	0.0	0.0
ZR 95	4.859E+11	3.397E+06	3.175E-06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 94	1.238E+08	1.238E+08	1.238E+08	1.237E+08	1.234E+08	1.226E+08	1.197E+08	1.118E+08	9.301E+07	4.446E+07	4.073E+06	1.918E-07
TC 99	4.727E+04	4.726E+04	4.726E+04	4.726E+04	4.725E+04	4.722E+04	4.711E+04	4.681E+04	4.575E+04	4.287E+04	3.414E+04	1.825E+03
SN123	1.195E+11	3.340E+08	3.673E+02	3.470E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	2.351E+11	1.110E+11	1.925E+10	1.291E+08	3.186E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE125M	3.153E+10	1.527E+10	2.648E+09	1.776E+07	4.383E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HF181	7.813E+11	1.296E+04	9.086E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA182	9.232E+10	1.250E+08	2.830E+03	2.804E+03	2.804E+03	2.804E+03	2.804E+03	2.804E+03	2.802E+03	2.798E+03	2.783E+03	2.597E+03

PRINCIPAL PHOTON SOURCES IN GROUP 7,PHOTONS/SEC
MEAN ENERGY= 0.225MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
CL 36	1.407E+03	1.407E+03	1.407E+03	1.407E+03	1.407E+03	1.406E+03	1.404E+03	1.398E+03	1.375E+03	1.313E+03	1.118E+03	1.407E+02
CO 58	2.979E+11	6.509E+06	8.688E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	7.942E+10	5.353E+10	2.132E+10	1.535E+09	1.540E+05	5.790E-07	0.0	0.0	0.0	0.0	0.0	0.0
ZR 95	2.344E+11	1.639E+06	1.531E-06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 94	7.686E+07	7.685E+07	7.683E+07	7.678E+07	7.660E+07	7.608E+07	7.428E+07	6.938E+07	5.463E+07	2.759E+07	2.528E+06	1.190E-07
NB 95M	6.408E+11	4.480E+06	4.187E-06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC 99	1.133E+04	1.133E+04	1.133E+04	1.133E+04	1.132E+04	1.132E+04	1.129E+04	1.122E+04	1.097E+04	1.027E+04	8.181E+03	4.374E+02
SN113	3.101E+11	4.225E+08	8.694E+01	6.833E-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN117M	6.237E+10	1.745E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN123	1.495E+11	4.178E+08	4.596E+02	4.342E-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB125	3.263E+12	1.540E+12	2.672E+11	1.792E+09	4.422E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA182	1.324E+11	1.792E+08	4.058E+03	4.022E+03	4.022E+03	4.022E+03	4.021E+03	4.021E+03	4.019E+03	4.012E+03	3.991E+03	3.724E+03

PRINCIPAL PHOTON SOURCES IN GROUP 8,PHOTONS/SEC
MEAN ENERGY= 0.375MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
CL 36	2.383E+02	2.383E+02	2.383E+02	2.383E+02	2.382E+02	2.381E+02	2.377E+02	2.366E+02	2.329E+02	2.224E+02	1.893E+02	2.382E+01
CR 51	1.964E+12	2.450E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	2.228E+10	1.502E+10	5.980E+09	4.307E+08	4.320E+04	1.624E-07	0.0	0.0	0.0	0.0	0.0	0.0
NB 94	3.648E+06	3.648E+06	3.647E+06	3.645E+06	3.636E+06	3.611E+06	3.526E+06	3.293E+06	2.593E+06	1.310E+06	1.200E+05	5.651E-09
AG108M	2.514E+05	2.473E+05	2.381E+05	2.135E+05	1.457E+05	4.891E+04	1.072E+03	1.949E-02	4.993E-19	0.0	0.0	0.0
SB125	1.937E+13	9.145E+12	1.586E+12	1.064E+10	2.626E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA182	1.156E+08	1.566E+05	3.545E+00	3.513E+00	3.513E+00	3.513E+00	3.513E+00	3.512E+00	3.511E+00	3.505E+00	3.486E+00	3.253E+00

PRINCIPAL PHOTON SOURCES IN GROUP 9,PHOTONS/SEC
MEAN ENERGY= 0.575MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
CL 36	7.237E+01	7.237E+01	7.237E+01	7.237E+01	7.236E+01	7.232E+01	7.221E+01	7.188E+01	7.073E+01	6.754E+01	5.749E+01	7.236E+00
CO 58	1.433E+13	3.131E+08	4.179E-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	1.279E+09	9.623E+08	3.434E+08	2.473E+07	2.481E+03	9.327E-09	0.0	0.0	0.0	0.0	0.0	0.0
Y 90	1.895E+05	1.765E+05	1.494E+05	9.281E+04	1.754E+04	1.502E+02	8.718E-06	1.946E-26	0.0	0.0	0.0	0.0
AG108M	2.345E+05	2.307E+05	2.221E+05	1.991E+05	1.359E+05	4.561E+04	9.999E+02	1.818E-02	4.657E-19	0.0	0.0	0.0
SB125	2.490E+13	1.175E+13	2.039E+12	1.367E+10	3.375E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HO166M	1.466E+01	1.463E+01	1.458E+01	1.441E+01	1.384E+01	1.233E+01	8.228E+00	2.592E+00	4.546E-02	4.371E-07	1.205E-24	0.0
HF181	1.042E+12	1.728E+04	1.212E-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA182	3.931E+06	5.322E+03	1.205E-01	1.194E-01	1.194E-01	1.194E-01	1.194E-01	1.194E-01	1.193E-01	1.191E-01	1.185E-01	1.106E-01

PRINCIPAL PHOTON SOURCES IN GROUP 10,PHOTONS/SEC
MEAN ENERGY= 0.850MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
MN 54	2.557E+12	2.250E+11	7.762E+08	7.131E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 58	5.126E+13	1.120E+09	1.495E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO 60	2.025E+10	1.365E+10	5.434E+09	3.914E+08	3.926E+04	1.476E-07	0.0	0.0	0.0	0.0	0.0	0.0
ZR 95	2.760E+14	1.929E+05	1.803E-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB 94	8.777E+10	8.776E+10	8.774E+10	8.769E+10	8.747E+10	8.688E+10	8.482E+10	7.923E+10	6.239E+10	3.151E+10	2.987E+09	1.359E-04
NB 95	5.519E+14	4.441E+09	4.151E-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TA182	5.782E+09	7.828E+06	1.773E+02	1.757E+02	1.757E+02	1.757E+02	1.757E+02	1.756E+02	1.755E+02	1.753E+02	1.743E+02	1.626E+02

PRINCIPAL PHOTON SOURCES IN GROUP 11,PHOTONS/SEC
MEAN ENERGY= 1.250MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
CO 60	5.421E+14	3.654E+14	1.455E+14	1.049E+13	1.051E+09	3.952E-03	0.0	0.0	0.0	0.0	0.0	0.0
TA182	4.707E+11	6.373E+08	1.443E+04	1.430E+04	1.430E+04	1.430E+04	1.430E+04	1.430E+04	1.429E+04	1.427E+04	1.419E+04	1.324E+04

PRINCIPAL PHOTON SOURCES IN GROUP 12,PHOTONS/SEC
MEAN ENERGY= 1.750MEV

NUCLIDE	SH+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
P 32	4.521E+03	3.103E-04	3.080E-04	3.015E-04	2.798E-04	2.261E-04	1.072E-04	1.270E-05	7.277E-09	3.977E-18	0.0	0.0
CO 58	2.657E+11	5.806E+06	7.748E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y 90	1.520E+03	1.415E+03	1.198E+03	7.441E+02	1.406E+02	1.204E+00	6.990E-08	1.480E-28	0.0	0.0	0.0	0.0
AG108	2.001E-01	1.969E-01	1.895E-01	1.699E-01	1.159E-01	3.892E-02	8.532E-04	1.551E-08	3.974E-25	0.0	0.0	0.0
AG110M	3.196E+06	1.530E+05	1.272E+02	2.015E-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SB124	5.262E+10	1.744E+05	2.857E-08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU154	6.292E+04	4.941E+04	2.810E+04	5.607E+03	1.978E+01	1.975E-06	0.0	0.0	0.0	0.0	0.0	0.0
TA182	8.319E+01	1.126E-01	2.550E-06	2.527E-06	2.527E-06	2.527E-06	2.527E-06	2.527E-06	2.525E-06	2.521E-06	2.508E-06	2.340E-06

Table B.8 (continued)

OUTPUT UNIT = 11 PAGE 56

PRINCIPAL PHOTON SOURCES IN GROUP 13,PHOTONS/SEC
MEAN ENERGY= 2.250MEV

NUCLIDE	SN+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
CO 60	2.973E+09	1.936E+05	7.712E+08	5.555E+07	5.571E+03	2.095E-08	0.0	0.0	0.0	0.0	0.0	0.0
Y 90	1.671E-01	1.556E-01	1.317E-01	8.182E-02	1.546E-02	1.324E-04	7.686E-12	1.628E-32	0.0	0.0	0.0	0.0
SB124	6.055E+09	2.007E+04	3.287E-09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BI210M	1.516E-10	1.516E-10	1.516E-10	1.516E-10	1.516E-10	1.516E-10	1.516E-10	1.515E-10	1.513E-10	1.506E-10	1.482E-10	1.203E-10

PRINCIPAL PHOTON SOURCES IN GROUP 14,PHOTONS/SEC
MEAN ENERGY= 2.750MEV

NUCLIDE	SN+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
CO 60	8.891E+06	5.992E+06	2.386E+06	1.719E+05	1.724E+01	6.481E-11	0.0	0.0	0.0	0.0	0.0	0.0
SB124	4.425E+06	1.467E+01	2.403E-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BI210M	7.597E-11	7.597E-11	7.597E-11	7.597E-11	7.597E-11	7.597E-11	7.596E-11	7.592E-11	7.580E-11	7.545E-11	7.424E-11	6.930E-11

PRINCIPAL PHOTON SOURCES IN GROUP 15,PHOTONS/SEC
MEAN ENERGY= 3.500MEV

NUCLIDE	SN+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
K 42	1.561E-11	1.466E-11	1.265E-11	8.313E-12	1.911E-12	2.879E-14	1.185E-20	6.754E-39	0.0	0.0	0.0	0.0
RH106	3.118E-07	3.962E-08	3.218E-10	3.426E-16	4.265E-37	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BI210M	5.596E-11	5.596E-11	5.586E-11	5.586E-11	5.586E-11	5.586E-11	5.585E-11	5.582E-11	5.573E-11	5.548E-11	5.459E-11	4.434E-11
PO210	6.810E-05	2.820E-07	1.001E-12	2.247E-13	2.247E-13	2.247E-13	2.247E-13	2.246E-13	2.242E-13	2.232E-13	2.196E-13	1.784E-13

PRINCIPAL PHOTON SOURCES IN GROUP 16,PHOTONS/SEC
MEAN ENERGY= 5.000MEV

NUCLIDE	SN+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
BI210M	1.666E-11	1.666E-11	1.666E-11	1.666E-11	1.666E-11	1.666E-11	1.666E-11	1.665E-11	1.662E-11	1.655E-11	1.628E-11	1.323E-11
PO210	2.028E-05	8.396E-08	2.981E-13	6.691E-14	6.691E-14	6.690E-14	6.689E-14	6.686E-14	6.675E-14	6.645E-14	6.538E-14	5.311E-14

PRINCIPAL PHOTON SOURCES IN GROUP 17,PHOTONS/SEC
MEAN ENERGY= 7.000MEV

NUCLIDE	SN+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
BI210M	1.079E-12	1.079E-12	1.079E-12	1.079E-12	1.079E-12	1.079E-12	1.079E-12	1.078E-12	1.076E-12	1.072E-12	1.054E-12	9.564E-13
PO210	1.316E-06	5.448E-09	1.934E-14	4.341E-15	4.341E-15	4.341E-15	4.340E-15	4.338E-15	4.331E-15	4.311E-15	4.242E-15	3.446E-15

PRINCIPAL PHOTON SOURCES IN GROUP 18,PHOTONS/SEC
MEAN ENERGY=11.000MEV

NUCLIDE	SN+0.05% P	3.0YR	10.0YR	30.0YR	100.0YR	300.0YR	1.0KY	3.0KY	10.0KY	30.0KY	100.0KY	1.0MY
BI210M	6.831E-14	6.831E-14	6.831E-14	6.831E-14	6.831E-14	6.831E-14	6.830E-14	6.827E-14	6.816E-14	6.784E-14	6.675E-14	5.422E-14
PO210	8.319E-08	3.445E-10	1.223E-15	2.745E-16	2.745E-16	2.745E-16	2.745E-16	2.743E-16	2.739E-16	2.726E-16	2.683E-16	2.179E-16

APPENDIX C: SAMPLE ORIGEN2 TABLE OF CONTENTS (OUTPUT UNITS 12 AND 13)

Table C.1. Sample ORIGEN2 table of contents for unit 6

```
PAGE                    TABLE OF CONTENTS ON UNIT = 12 FOR OUTPUT UNIT =  6
   1          INPUT ECHO; READ ON  5 LIST ON  6 COPY TO 50
   5          NEUTRON YIELD PER NEUTRON-INDUCED FISSION
   6          (ALPHA,N) NEUTRON YIELD PER FISSION
   7          SPONTANEOUS FISSION NEUTRON YIELD PER FISSN
   8          INDIVIDUAL ELEMENT FRACTIONAL RECOVERIES
  10          GROUP ELEMENTAL FRACTIONAL RECOVERIES
  11          ELEMENTAL ASSIGNMENT TOFRAC RECGROUP
  12          ELEMENTAL CHEMICAL TOXICITIES

  13     ORIGEN INSTRUCTIONS FOR THIS CASE


  15     NUCLIDE DATA LIBRARIES

  15          DECAY DATA LIBRARY--------  LIGHT NUCLIDE DECAY LIBRARY
  29          DECAY DATA LIBRARY--------  ACTINIDE DECAY LIBRARY
  32          DECAY DATA LIBRARY--------  FISSION PRODUCT DECAY LIBRARY
  49          CROSS SECTION LIBRARY-----   STRUCTURAL MATERIAL & ACTIVATION PRODUCT XSEC LIBRARY--PWR.U
  57          CROSS SECTION LIBRARY-----   ACTINIDE AND DAUGHTER NUCLIDES XSEC LIBRARY--PWR.U
  59          CROSS SECTION LIBRARY-----   FISSION PRODUCT XSEC AND YIELD LIBRARY--PWR.U
  75          PHOTON LIBRARY------------        UPDATED PHOTON LIBRARY: ACTIVATION PRODUCTS
  82          PHOTON LIBRARY------------        UPDATED PHOTON LIBRARY: ACTINIDES AND DAUGHTERS
  85          PHOTON LIBRARY------------        UPDATED PHOTON LIBRARY: FISSION PRODUCTS

  91     OUTPUT TABLES--TITLE=  IRRADIATION OF ONE METRIC TON OF PWRU FUEL                   RECYCLE # =  0
  91          REACTIVITY AND BURNUP DATA
              *ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS****
  92          CONCENTRATIONS, GRAMS       SUMMARY TABLE:
  94          RADIOACTIVITY,  CURIES      NUCLIDE TABLE:
 108          RADIOACTIVITY,  CURIES      ELEMENT TABLE:
 110          RADIOACTIVITY,  CURIES      SUMMARY TABLE:
              *ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS**
 113          CONCENTRATIONS, GRAMS       SUMMARY TABLE:
              *FISSION PRODUCTS********FISSION PRODUCTS********FISSION PRODUCTS********FISSION PRODUCTS*******
 115          CONCENTRATIONS, GRAMS       SUMMARY TABLE:
 117          (ALPHA,N) NEUTRON SOURCE
 118          SPONTANEOUS FISSION NEUTRON SOURCE
 119          LITE NUCLIDE PHOTON TABLE
 124          ACTINIDE NUCLIDE PHOTON TABLE
 130          FISSION PRODUCT NUCLIDE PHOTON TABLE

 138     OUTPUT TABLES--TITLE=  IRRADIATION OF ZIRCALOY+ INCONEL + NICROBRAZE 50 AT 100% FLUX    RECYCLE # =  0
 138          REACTIVITY AND BURNUP DATA
              *ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS****
 139          CONCENTRATIONS, GRAMS       SUMMARY TABLE:
 141          RADIOACTIVITY,  CURIES      NUCLIDE TABLE:
 155          RADIOACTIVITY,  CURIES      ELEMENT TABLE:
 157          RADIOACTIVITY,  CURIES      SUMMARY TABLE:
              *ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS**
 159          CONCENTRATIONS, GRAMS       SUMMARY TABLE:
              *FISSION PRODUCTS********FISSION PRODUCTS********FISSION PRODUCTS********FISSION PRODUCTS*******
 161          CONCENTRATIONS, GRAMS       SUMMARY TABLE:
 163          (ALPHA,N) NEUTRON SOURCE
 164          SPONTANEOUS FISSION NEUTRON SOURCE
```

Table C.1 (continued)

Table C.2. Sample ORIGEN2 table of contents for unit 11

```
PAGE                      TABLE OF CONTENTS ON UNIT = 13 FOR OUTPUT UNIT = 11

  1   OUTPUT TABLES--TITLE=  DECAY OF HIGH-LEVEL PWR-U WASTE; BURNUP=33,000 MWD/MTIHM            RECYCLE # =  0
  1             REACTIVITY AND BURNUP DATA
                *ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS****
  2             CONCENTRATIONS, GRAMS       SUMMARY TABLE:
  4             RADIOACTIVITY,  CURIES      NUCLIDE TABLE:
 18             RADIOACTIVITY,  CURIES      ELEMENT TABLE:
 20             RADIOACTIVITY,  CURIES      SUMMARY TABLE:
                *ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS***ACTINIDES + DAUGHTERS**
 22             CONCENTRATIONS, GRAMS       SUMMARY TABLE:
                *FISSION PRODUCTS********FISSION PRODUCTS********FISSION PRODUCTS********FISSION PRODUCTS*******
 24             CONCENTRATIONS, GRAMS       SUMMARY TABLE:
 26             (ALPHA,N) NEUTRON SOURCE
 27             SPONTANEOUS FISSION NEUTRON SOURCE
 28             LITE NUCLIDE PHOTON TABLE
 33             ACTINIDE NUCLIDE PHOTON TABLE
 40             FISSION PRODUCT NUCLIDE PHOTON TABLE

 45   OUTPUT TABLES--TITLE=  DECAY OF PWR STRUCTURAL MATERIAL WASTE: 33,000 MWD/MTHM              RECYCLE # =  0
 45             REACTIVITY AND BURNUP DATA
                *ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS*****ACTIVATION PRODUCTS****
 46             CONCENTRATIONS, GRAMS       SUMMARY TABLE:
 48             RADIOACTIVITY,  CURIES      NUCLIDE TABLE:
```

APPENDIX D: SAMPLE ORIGEN2 VARIABLE CROSS-SECTION INFORMATION
(OUTPUT UNIT 16)

IRRADIATION OF ONE METRIC TON OF PWRU FUEL RECYCLE # = 0 UNIT=16

BASIS = ONE METRIC TON OF PWRU FUEL

INITIAL VECTOR = 4 TOTAL ACT G-A = 4.181E 03 MWD/G-A = 1.194E 00 TO 2.390E 00 ANTICIPATION FACTOR= 2.002E 00

N= 1 F= 0.0 N= 2 F= 0.0 N= 3 F= 4.551E-01 N= 4 F= 4.940E-01 N= 5 F= 5.095E-02 N= 6 F= 0.0 N= 7 F= 0.0

N= 8 F= 0.0 N= 9 F= 0.0 N=10 F= 0.0 N=11 F= 0.0 N=12 F= 0.0 N=13 F= 0.0 N=14 F= 0.0

N=15 F= 0.0 N=16 F= 0.0 N=17 F= 0.0 N=18 F= 0.0 N=

L	NUCLID	XSEC TYPE	TOCAP(I) I=	A(N) N=	FP YIELD INDIC ARR	FISS(J)	A(N)	TOCAP(I)	A(N) FP YIELD	FISS(J)	OLD XSEC	NEW XSEC
1	922340	1	750	1696	0	66	5.614E-09	1.981E 01	3.512E-14	4.504E-01	1.935E 01	1.936E 01
2	922350	1	751	1701	0	67	2.959E-09	5.571E C1	3.512E-14	4.550E 01	1.023E 01	1.020E 01
3	922350	4	751	0	1	67	7.863E 65	5.550E 01	8.630E-21	4.530E 01	4.550E 01	4.530E 01
4	922360	1	752	1704	0	68	2.244E-09	7.939E 00	8.630E-21	1.975E-01	7.713E 00	7.739E 00
5	922380	1	754	1709	0	70	2.579E-10	9.952E-01	8.630E-21	1.0C4E-01	8.883E-01	8.893E-01
6	932370	1	761	1725	0	77	9.452E-09	3.312E 01	8.630E-21	5.244E-01	3.271E 01	3.260E 01
7	942380	1	769	1749	0	85	9.505E-09	3.517E 01	8.630E-21	2.396E 00	3.292E 01	3.278E 01
8	942380	4	769	0	0	85	7.863E 65	3.517E 01	8.630E-21	2.394E 00	2.396E 00	2.394E 00
9	942390	1	770	1756	0	86	1.881E-08	1.794E 02	8.630E-21	1.146E 02	6.518E 01	6.486E 01
10	942390	4	770	0	2	86	7.863E 65	1.789E 02	4.080E-19	1.140E 02	1.146E 02	1.140E 02
11	942400	1	771	1761	0	87	5.277E-08	1.826E 02	4.080E-19	5.840E-01	1.839E 02	1.820E 02
12	942410	1	772	1765	0	88	1.154E-08	1.603E 02	4.080E-19	1.205E 02	4.000E 01	3.981E 01
13	942410	4	772	0	3	88	7.863E 65	1.598E 02	1.121E 01	1.200E 02	1.205E 02	1.200E 02
14	942420	1	773	1767	0	89	8.588E-09	3.008E 01	1.121E 01	4.579E-01	2.951E 01	2.962E 01
15	952410	1	780	1784	0	96	3.127E-08	1.225E 02	1.121E 01	1.319E 00	1.084E 02	1.078E 02
16	952410	2	780	1782	0	96	3.863E-09	1.225E 02	1.121E 01	1.319E 00	1.340E 01	1.332E 01
17	952430	1	783	1790	0	99	5.485E-10	3.847E 01	1.121E 01	3.571E-01	1.906E 00	1.891E 00
18	952430	2	783	1788	0	99	1.042E-08	3.818E 01	1.121E 01	3.571E-01	3.622E 01	3.594E 01
19	962420	1	789	1797	0	105	1.576E-09	5.656E 00	1.121E 01	2.204E-01	5.426E 00	5.436E 00
20	962440	1	791	1803	0	107	9.882E-10	4.261E 00	1.121E 01	8.529E-01	3.404E 00	3.408E 00

FP YIELD ADJUSTMENT FOR UNCONNECTED ACTINIDES: CONNECTED ACT=922350LARGEST UNCONNECTED ACT=922360NEW RATIO = 1.0002623
CLD RATIO = 1.0000954 FP YIELD IN A = 4.86107E-17

IRRADIATION OF ONE METRIC TON OF PWRU FUEL   RECYCLE # = 0 .UNIT=16

BASIS = ONE METRIC TON OF PWRU FUEL

INITIAL VECTOR = 5 TOTAL ACT G-A = 4.159E 03 MWD/G-A = 2.396E 00 TO 3.598E 00 ANTICIPATION FACTOR= 1.502E 00

N= 1 F= 0.0 N= 2 F= 0.0 N= 3 F= 0.0 N= 4 F= 0.0 N= 5 F= 4.382E-01 N= 6 F= 0.0 N= 7 F= 4.476E-01

N= 8 F= 1.141E-01 N= 9 F= 0.0 N=10 F= 0.0 N=11 F= 0.0 N=12 F= 0.0 N=13 F= 0.0 N=14 F= 0.0

N=15 F= 0.0 N=16 F= 0.0 N=17 F= 0.0 N=18 F= 0.0 N=

L	NUCLID	XSEC TYPE	TOCAP(I) I=	A(N) N=	FP YIELD INDIC ARR	FISS(J)	A(N)	TOCAP(I)	A(N) FP YIELD	FISS(J)	OLD XSEC	NEW XSEC
1	922340	1	750	1696	0	66	5.708E-09	1.977E 01	3.578E-14	4.504E-01	1.936E 01	1.932E 01
2	922350	1	751	1701	0	67	3.049E-09	5.562E 01	3.578E-14	4.530E 01	1.020E 01	1.032E 01
3	922350	4	751	0	1	67	7.863E 65	5.630E 01	8.928E-21	4.598E 01	4.530E 01	4.598E 01
4	922360	1	752	1704	0	68	2.262E-09	7.856E 00	8.928E-21	1.975E-01	7.739E 00	7.656E 00
5	922380	1	754	1709	0	70	2.637E-10	9.984E-01	8.928E-21	1.004E-01	8.893E-01	8.924E-01
6	932370	1	761	1725	0	77	9.730E-09	3.345E 01	8.928E-21	5.244E-01	3.260E 01	3.293E 01
7	942380	1	769	1749	0	85	9.907E-09	3.592E C1	8.928E-21	2.394E 00	3.278E 01	3.353E 01
8	942380	4	769	0	0	85	7.863E 65	3.594E 01	8.928E-21	2.416E 00	2.394E 00	2.416E 00
9	942390	1	770	1756	0	86	1.869E-08	1.772E 02	8.928E-21	1.140E 02	6.486E 01	6.324E 01
10	942390	4	770	0	2	86	7.863E 65	1.754E 02	4.092E-19	1.122E 02	1.140E 02	1.122E 02
11	942400	1	771	1761	0	87	4.487E-08	1.524E 02	4.092E-19	5.840E-01	1.820E 02	1.518E 02
12	942410	1	772	1765	0	88	1.171E-08	1.596E 02	4.092E-19	1.200E 02	3.981E 01	3.964E 01
13	942410	4	772	0	3	88	7.863E 65	1.596E 02	1.115E 01	1.200E 02	1.200E 02	1.200E 02
14	942420	1	773	1767	0	89	8.715E-09	2.995E 01	1.115E 01	4.579E-01	2.962E 01	2.949E 01
15	952410	1	780	1784	0	96	3.138E-08	1.208E 02	1.115E 01	1.319E 00	1.078E 02	1.062E 02
16	952410	2	780	1782	0	96	3.878E-09	1.206E 02	1.115E 01	1.319E 00	1.332E 01	1.312E 01
17	952430	1	783	1790	0	99	5.658E-10	3.821E 01	1.115E 01	3.571E-01	1.891E 00	1.915E 00
18	952430	2	783	1788	0	99	1.075E-08	3.865E 01	1.115E 01	3.571E-01	3.594E 01	3.638E 01
19	962420	1	789	1797	0	105	1.610E-09	5.668E 00	1.115E 01	2.204E-01	5.436E 00	5.448E 00
20	962440	1	791	1803	0	107	1.010E-09	4.271E 00	1.115E 01	8.529E-01	3.408E 00	3.418E 00

FP YIELD ADJUSTMENT FOR UNCONNECTED ACTINIDES: CONNECTED ACT=922350LARGEST UNCONNECTED ACT=922360NEW RATIO = 1.0004616
CLD RATIO = 1.0002623 FP YIELD IN A = 5.02896E-17

03161

APPENDIX E: SAMPLE ORIGEN2 DEBUGGING AND INTERNAL INFORMATION OUTPUT (OUTPUT UNIT 15)

```
NUMBER OF COMMAND=    1 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     1 *BAS * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    2 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    3 ; THIS IS INSTRUCTION    2 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    4 ; THIS IS INSTRUCTION    3 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    5 ; THIS IS INSTRUCTION    4 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    6 ; THIS IS INSTRUCTION    5 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    7 ; THIS IS INSTRUCTION    6 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    8 ; THIS IS INSTRUCTION    7 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    9 ; THIS IS INSTRUCTION    8 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   10 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     1 *CUT * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   11 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     1 *LIP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   12 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     4 *LPU * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   13 ; THIS IS INSTRUCTION    2 OUT OF A TOTAL OF     4 *LPU * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   14 ; THIS IS INSTRUCTION    3 OUT OF A TOTAL OF     4 *LPU * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   15 ; THIS IS INSTRUCTION    4 OUT OF A TOTAL OF     4 *LPU * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   16 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     1 *LIB * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   17 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     1 *PHO * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   18 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     3 *TIT * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   19 ; THIS IS INSTRUCTION    9 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   20 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     5 *INP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   21 ; THIS IS INSTRUCTION   10 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   22 ; THIS IS INSTRUCTION    2 OUT OF A TOTAL OF     5 *INP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   23 ; THIS IS INSTRUCTION   11 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   24 ; THIS IS INSTRUCTION    3 OUT OF A TOTAL OF     5 *INP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   25 ; THIS IS INSTRUCTION   12 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   26 ; THIS IS INSTRUCTION    4 OUT OF A TOTAL OF     5 *INP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   27 ; THIS IS INSTRUCTION   13 OUT OF A TOTAL OF    18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   28 ; THIS IS INSTRUCTION    5 OUT OF A TOTAL OF     5 *INP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   29 ; THIS IS INSTRUCTION    2 OUT OF A TOTAL OF     3 *TIT * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   30 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     5 *MOV * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   31 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     2 *HED * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   32 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     2 *BUP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   33 ; THIS IS INSTRUCTION    1 OUT OF A TOTAL OF     0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 2.307E 06 DELT= 2.307E 06 T1= 7.461E-07 EPP1= 2.018E 02 FDOT= 5.028E-03 EPP2= 2.565E 02 FDDOT=-9.991E-10 EPP3= 2.137E 02
T2= 3.229E-09 T3= 5.119E-10 T1M= 1.505E-04 T2M= 5.125E-07 T3M= 9.629E-08 EPPAVG= 2.019E 02 FLUX= 2.900E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   34 ; THIS IS INSTRUCTION    2 OUT OF A TOTAL OF     0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 5.763E 06 DELT= 3.456E 06 T1= 7.453E-07 EPP1= 2.021E 02 FDOT= 3.306E-03 EPP2= 2.852E 02 FDDOT=-8.284E-10 EPP3= 2.142E 02
T2= 3.173E-09 T3= 9.340E-10 T1M= 1.506E-04 T2M= 4.542E-07 T3M= 1.764E-07 EPPAVG= 2.023E 02 FLUX= 2.897E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   35 ; THIS IS INSTRUCTION    3 OUT OF A TOTAL OF     0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 1.152E 07 DELT= 5.754E 06 T1= 7.458E-07 EPP1= 2.025E 02 FDOT= 1.000E-03 EPP2= 1.109E 03 FDDOT=-5.964E-10 EPP3= 2.152E 02
T2= 1.601E-09 T3= 1.835E-09 T1M= 1.510E-04 T2M= 5.922E-08 T3M= 3.490E-07 EPPAVG= 2.029E 02 FLUX= 2.899E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   36 ; THIS IS INSTRUCTION    4 OUT OF A TOTAL OF     0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 2.304E 07 DELT= 1.153E 07 T1= 7.509E-07 EPP1= 2.032E 02 FDOT=-1.507E-03 EPP2= 1.413E 02 FDDOT=-3.484E-10 EPP3= 2.178E 02
T2=-4.898E-09 T3= 4.392E-09 T1M= 1.526E-04 T2M=-1.431E-06 T3M= 8.421E-07 EPPAVG= 2.037E 02 FLUX= 2.919E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   37 ; THIS IS INSTRUCTION    5 OUT OF A TOTAL OF     0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 3.456E 07 DELT= 1.152E 07 T1= 7.674E-07 EPP1= 2.041E 02 FDOT=-4.638E-03 EPP2= 1.848E 02 FDDOT=-8.381E-11 EPP3= 2.408E 02
T2=-1.573E-08 T3= 1.521E-09 T1M= 1.566E-04 T2M=-3.545E-06 T3M= 2.957E-07 EPPAVG= 2.045E 02 FLUX= 2.983E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   38 ; THIS IS INSTRUCTION    6 OUT OF A TOTAL OF     0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 3.802E 07 DELT= 3.456E 06 T1= 8.055E-07 EPP1= 2.049E 02 FDOT=-5.804E-03 EPP2= 1.918E 02 FDDOT= 3.474E-11 EPP3= 1.643E 02
T2=-6.508E-09 T3= 2.524E-11 T1M= 1.650E-04 T2M=-1.424E-06 T3M= 4.920E-09 EPPAVG= 2.050E 02 FLUX= 3.131E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   39 ; THIS IS INSTRUCTION    7 OUT OF A TOTAL OF     0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 4.608E 07 DELT= 8.061E 06 T1= 8.227E-07 EPP1= 2.051E 02 FDOT=-5.635E-03 EPP2= 1.921E 02 FDDOT= 4.285E-11 EPP3= 1.722E 02
T2=-1.537E-08 T3= 6.884E-11 T1M= 1.687E-04 T2M=-3.365E-06 T3M= 1.279E-08 EPPAVG= 2.053E 02 FLUX= 3.198E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   40 ; THIS IS INSTRUCTION    8 OUT OF A TOTAL OF     0 *IRP * INSTRUCTIONS. UNIT=15
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TSEC= 5.760E 07 DELT= 1.153E 07 T1= 8.496E-07 EPF1= 2.056E 02 FDOT=-6.007E-03 EPF2= 1.946E 02 FDDOT= 9.529E-11 EPF3= 1.922E 02
T2=-2.498E-08 T3=-5.431E-10 T1M= 1.746E-04 T2M=-5.426E-06 T3M=-1.100E-07 EPFAVG= 2.059E 02 FLUX= 3.302E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   41 ; THIS IS INSTRUCTION   9 OUT OF A TOTAL OF    0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 6.336E 07 DELT= 5.754E 06 T1= 8.957E-07 EPF1= 2.062E 02 FDOT=-6.237E-03 EPF2= 1.970E 02 FDDOT= 1.564E-10 EPF3= 1.998E 02
T2=-1.439E-08 T3=-3.841E-10 T1M= 1.847E-04 T2M=-3.106E-06 T3M=-7.768E-08 EPFAVG= 2.063E 02 FLUX= 3.481E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   42 ; THIS IS INSTRUCTION  10 OUT OF A TOTAL OF    0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 6.912E 07 DELT= 5.763E 06 T1= 9.288E-07 EPF1= 2.065E 02 FDOT=-5.504E-03 EPF2= 1.965E 02 FDDOT= 1.352E-10 EPF3= 1.987E 02
T2=-1.368E-08 T3=-3.771E-10 T1M= 1.918E-04 T2M=-2.968E-06 T3M=-7.726E-08 EPFAVG= 2.066E 02 FLUX= 3.610E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   43 ; THIS IS INSTRUCTION  11 OUT OF A TOTAL OF    0 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 7.603E 07 DELT= 6.912E 06 T1= 9.580E-07 EPF1= 2.068E 02 FDOT=-4.987E-03 EPF2= 1.964E 02 FDDOT= 1.259E-10 EPF3= 1.986E 02
T2=-1.582E-08 T3=-5.716E-10 T1M= 1.981E-04 T2M=-3.444E-06 T3M=-1.182E-07 EPFAVG= 2.070E 02 FLUX= 3.724E 14 POWER= 3.750E 01
NUMBER OF COMMAND=   44 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    2 *BUP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   45 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *OPTL* INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   46 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *OPTA* INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   47 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *OPTP* INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   48 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    2 *OUT * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   49 ; THIS IS INSTRUCTION  14 OUT OF A TOTAL OF   18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   50 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    5 *MOV * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   51 ; THIS IS INSTRUCTION  15 OUT OF A TOTAL OF   18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   52 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *KEQ * INSTRUCTIONS. UNIT=15
**KEQ NPROA= 8.341E 03 NDESA= 7.955E 03 INFA= 1.048E 00 NPROB= 7.900E 03 NDESB= 7.939E 03 INFB= 9.951E-01
NPROC= 1.002E 04 NDESC= 7.282E 03 INFC= 1.377E 00 FRC=FRD BEFORE N DEST SCALING= 1.625E-01 FRD=FRAC OF VECT C INCLUDED= 1.772E-01
NUMBER OF COMMAND=   53 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *FAC * INSTRUCTIONS. UNIT=15
**FAC LD=  1  FAC(LD)= 1.0000E 00
NUMBER OF COMMAND=   54 ; THIS IS INSTRUCTION  16 OUT OF A TOTAL OF   18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   55 ; THIS IS INSTRUCTION   3 OUT OF A TOTAL OF    3 *TIT * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   56 ; THIS IS INSTRUCTION   3 OUT OF A TOTAL OF    5 *MOV * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   57 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    3 *ADD * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   58 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    3 *ADD * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   59 ; THIS IS INSTRUCTION   3 OUT OF A TOTAL OF    3 *ADD * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   60 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    2 *HED * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   61 ; THIS IS INSTRUCTION  12 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 2.307E 06 DELT= 2.307E 06 T1= 1.690E-02 EPF1= 2.019E 02 FDOT= 9.453E-10 EPF2= 2.127E 02 FDDOT=-5.695E-17 EPF3= 2.112E 02
T2= 1.090E-03 T3=-5.051E-05 T1M= 8.371E-05 T2M= 5.126E-06 T3M=-2.392E-07 EPFAVG= 2.025E 02 FLUX= 2.890E 14 POWER= 5.011E-07
NUMBER OF COMMAND=   62 ; THIS IS INSTRUCTION  13 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 5.763E 06 DELT= 3.456E 06 T1= 1.862E-02 EPF1= 2.029E 02 FDOT= 8.400E-10 EPF2= 2.129E 02 FDDOT=-4.886E-17 EPF3= 2.112E 02
T2= 1.452E-03 T3=-9.726E-05 T1M= 9.175E-05 T2M= 6.818E-06 T3M=-4.605E-07 EPFAVG= 2.036E 02 FLUX= 2.888E 14 POWER= 5.575E-07
NUMBER OF COMMAND=   63 ; THIS IS INSTRUCTION  14 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 1.152E 07 DELT= 5.754E 06 T1= 2.123E-02 EPF1= 2.041E 02 FDOT= 6.942E-10 EPF2= 2.133E 02 FDDOT=-3.817E-17 EPF3= 2.113E 02
T2= 1.997E-03 T3=-2.107E-04 T1M= 1.040E-04 T2M= 9.366E-06 T3M=-9.970E-07 EPFAVG= 2.048E 02 FLUX= 2.900E 14 POWER= 6.450E-07
NUMBER OF COMMAND=   64 ; THIS IS INSTRUCTION  15 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 2.304E 07 DELT= 1.153E 07 T1= 2.454E-02 EPF1= 2.054E 02 FDOT= 5.252E-10 EPF2= 2.139E 02 FDDOT=-2.635E-17 EPF3= 2.115E 02
T2= 3.027E-03 T3=-5.834E-04 T1M= 1.195E-04 T2M= 1.415E-05 T3M=-2.758E-06 EPFAVG= 2.062E 02 FLUX= 2.955E 14 POWER= 7.707E-07
NUMBER OF COMMAND=   65 ; THIS IS INSTRUCTION  16 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 3.456E 07 DELT= 1.152E 07 T1= 2.901E-02 EPF1= 2.068E 02 FDOT= 3.254E-10 EPF2= 2.153E 02 FDDOT=-1.381E-17 EPF3= 2.121E 02
T2= 1.874E-03 T3=-3.053E-04 T1M= 1.403E-04 T2M= 8.704E-06 T3M=-1.439E-06 EPFAVG= 2.072E 02 FLUX= 3.050E 14 POWER= 9.012E-07
NUMBER OF COMMAND=   66 ; THIS IS INSTRUCTION  17 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 3.802E 07 DELT= 3.456E 06 T1= 3.185E-02 EPF1= 2.076E 02 FDOT= 2.144E-10 EPF2= 2.168E 02 FDDOT=-8.422E-18 EPF3= 2.130E 02
T2= 3.705E-04 T3=-1.676E-05 T1M= 1.534E-04 T2M= 1.709E-06 T3M=-7.871E-08 EPFAVG= 2.077E 02 FLUX= 3.156E 14 POWER= 9.823E-07
NUMBER OF COMMAND=   67 ; THIS IS INSTRUCTION  18 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15
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TSEC= 4.608E 07 DELT= 8.061E 06 T1= 3.246E-02 EFF1= 2.078E 02 FDOT= 1.943E-10 EFF2= 2.173E 02 FDDOT=-7.771E-18 EFF3= 2.133E 02
T2= 7.833E-04 T3=-8.416E-05 T1M= 1.562E-04 T2M= 3.604E-06 T3M=-3.946E-07 EFFAVG= 2.080E 02 FLUX= 3.258E 14 POWER= 1.044E-06
NUMBER OF COMMAND=   68 ; THIS IS INSTRUCTION  19 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 5.760E 07 DELT= 1.153E 07 T1= 3.371E-02 EFF1= 2.082E 02 FDOT= 1.426E-10 EFF2= 2.190E 02 FDDOT=-5.742E-18 EFF3= 2.141E 02
T2= 8.220E-04 T3=-1.271E-04 T1M= 1.619E-04 T2M= 3.753E-06 T3M=-5.939E-07 EFFAVG= 2.084E 02 FLUX= 3.397E 14 POWER= 1.130E-06
NUMBER OF COMMAND=   69 ; THIS IS INSTRUCTION  20 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 6.336E 07 DELT= 5.754E 06 T1= 3.451E-02 EFF1= 2.085E 02 FDOT= 9.412E-12 EFF2= 3.986E 02 FDDOT= 3.763E-18 EFF3= 2.076E 02
T2= 2.708E-05 T3= 2.076E-05 T1M= 1.655E-04 T2M= 6.793E-08 T3M= 1.000E-07 EFFAVG= 2.086E 02 FLUX= 3.536E 14 POWER= 1.181E-06
NUMBER OF COMMAND=   70 ; THIS IS INSTRUCTION  21 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 6.912E 07 DELT= 5.763E 06 T1= 3.436E-02 EFF1= 2.087E 02 FDOT= 3.455E-11 EFF2= 2.396E 02 FDDOT= 1.481E-18 EFF3= 2.024E 02
T2= 9.956E-05 T3= 8.197E-06 T1M= 1.647E-04 T2M= 4.155E-07 T3M= 4.049E-08 EFFAVG= 2.088E 02 FLUX= 3.662E 14 POWER= 1.220E-06
NUMBER OF COMMAND=   71 ; THIS IS INSTRUCTION  22 OUT OF A TOTAL OF   22 *IRP * INSTRUCTIONS. UNIT=15

TSEC= 7.603E 07 DELT= 6.912E 06 T1= 3.437E-02 EFF1= 2.088E 02 FDOT= 4.536E-11 EFF2= 2.304E 02 FDDOT= 1.792E-19 EFF3= 1.570E 02
T2= 1.568E-04 T3= 1.427E-06 T1M= 1.646E-04 T2M= 6.803E-07 T3M= 9.090E-09 EFFAVG= 2.089E 02 FLUX= 3.783E 14 POWER= 1.262E-06
NUMBER OF COMMAND=   72 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    2 *OUT * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   73 ; THIS IS INSTRUCTION  17 OUT OF A TOTAL OF   18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   74 ; THIS IS INSTRUCTION  18 OUT OF A TOTAL OF   18 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   75 ; THIS IS INSTRUCTION   4 OUT OF A TOTAL OF    5 *MOV * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   76 ; THIS IS INSTRUCTION   5 OUT OF A TOTAL OF    5 *MOV * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   77 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    4 *PCM * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   78 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    4 *PCM * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   79 ; THIS IS INSTRUCTION   3 OUT OF A TOTAL OF    4 *PCM * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   80 ; THIS IS INSTRUCTION   4 OUT OF A TOTAL OF    4 *PCM * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   81 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *STP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    1 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    2 *BAS * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    2 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *CUT * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    3 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *LIP * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    4 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *LPO * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    5 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *LIB * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    6 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    1 *PRO * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    7 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    3 *MOV * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    8 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    6 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=    9 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    6 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   10 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   11 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    4 *PRO * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   12 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    4 *PRO * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   13 ; THIS IS INSTRUCTION   3 OUT OF A TOTAL OF    4 *PRO * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   14 ; THIS IS INSTRUCTION   4 OUT OF A TOTAL OF    4 *PRO * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   15 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    2 *BAS * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   16 ; THIS IS INSTRUCTION   3 OUT OF A TOTAL OF    6 *RDA * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   17 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    2 *TIT * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   18 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    3 *MOV * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   19 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    2 *MED * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   20 ; THIS IS INSTRUCTION   2 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   21 ; THIS IS INSTRUCTION   3 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   22 ; THIS IS INSTRUCTION   4 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   23 ; THIS IS INSTRUCTION   5 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   24 ; THIS IS INSTRUCTION   6 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   25 ; THIS IS INSTRUCTION   7 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   26 ; THIS IS INSTRUCTION   8 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   27 ; THIS IS INSTRUCTION   9 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   28 ; THIS IS INSTRUCTION  10 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   29 ; THIS IS INSTRUCTION  11 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   30 ; THIS IS INSTRUCTION  12 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   31 ; THIS IS INSTRUCTION  13 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   32 ; THIS IS INSTRUCTION  14 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   33 ; THIS IS INSTRUCTION  15 OUT OF A TOTAL OF    0 *DEC * INSTRUCTIONS. UNIT=15
NUMBER OF COMMAND=   34 ; THIS IS INSTRUCTION   1 OUT OF A TOTAL OF    4 *OUT * INSTRUCTIONS. UNIT=15
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APPENDIX F: LISTING OF SAMPLE PCH COMMAND OUTPUT

1	30060	1.0830E-02	30070	1.3357E-01	50100	1.8519E-02	50110	7.4074E-02
1	60120	7.3605E 00	60130	8.2619E-02	70140	1.7787E 00	70150	6.5343E-03
1	80160	8.3807E 03	80170	3.1923E 00	80180	1.7138E 01	90190	5.6316E-01
1	110230	6.5217E-01	120240	6.4958E-02	120250	8.2236E-03	120260	9.0542E-03
1	130270	6.1852E-01	140280	3.9702E-01	140290	2.0103E-02	140300	1.3345E-02
1	150310	1.1290E 00	170350	1.1317E-01	170370	3.6190E-02	200400	4.8330E-02
1	200420	3.2232E-04	200430	6.4812E-05	200440	1.0420E-03	200460	1.7449E-06
1	200480	9.4726E-05	220460	1.7217E-03	220470	1.5547E-03	220480	1.5380E-02
1	220490	1.1269E-03	220500	1.0852E-03	230500	1.4707E-04	230510	5.8679E-02
1	240500	3.3426E-03	240520	6.4385E-02	240530	7.2999E-03	240540	1.8135E-03
1	250550	3.0909E-02	260540	1.8705E-02	260560	2.9538E-01	260570	6.9217E-03
1	260580	9.3363E-04	270590	1.6949E-02	280580	2.7887E-01	280600	1.0661E-01
1	280610	4.6158E-03	280620	1.4665E-02	280640	3.7172E-03	290630	1.0878E-02
1	290650	4.8415E-03	300640	2.9916E-01	300660	1.7174E-01	300670	2.5238E-02
1	300680	1.1560E-01	300700	3.8164E-03	420920	1.5413E-02	420940	9.6850E-03
1	420950	1.6558E-02	420960	1.7391E-02	420970	9.9974E-03	420980	2.5098E-02
1	421000	9.9974E-03	471070	4.8007E-04	471090	4.4617E-04	481060	2.8888E-03
1	481080	1.9777E-03	481100	2.7777E-02	481110	2.8443E-02	481120	5.3576E-02
1	481130	2.7110E-02	481140	6.3775E-02	481160	1.6666E-02	491130	7.4839E-04
1	491150	1.6656E-02	501120	3.3675E-04	501140	2.2562E-04	501150	1.2796E-04
1	501160	4.9502E-03	501170	2.6098E-03	501180	8.1829E-03	501190	2.8960E-03
1	501200	1.0911E-02	501220	1.5490E-03	501240	1.8858E-03	641520	3.1781E-05
1	641540	3.3370E-04	641550	2.3518E-03	641560	3.2734E-03	641570	2.4948E-03
1	641580	3.9408E-03	641600	3.4641E-03	741800	1.4138E-05	741820	2.8603E-03
1	741830	1.5552E-03	741840	3.3355E-03	741860	3.1104E-03	822040	6.7554E-05
1	822060	1.1629E-03	822070	1.0664E-03	822080	2.5285E-03	832090	1.9139E-03
2	922340	1.2393E 00	922350	1.3617E 02	922380	4.0660E 03	0	0.0
0	0.0		0.0		0.0			
1	10010	8.9703E-03	10020	3.7750E-06	10030	9.0551E-03	10040	6.6664E-17
1	20030	8.0598E-05	20040	5.9353E-01	20060	2.1259E-16	30060	1.6146E-03
1	30070	1.5208E-01	30080	2.0576E-13	40090	7.0549E-05	40100	8.4116E-07
1	40110	5.3748E-19	50100	9.3346E-07	50110	7.5224E-02	50120	4.4597E-16
1	60120	7.3604E 00	60130	6.4544E-01	60140	9.5116E-03	60150	1.0694E-12
1	70140	1.7693E 00	70150	6.8554E-03	70160	1.9474E-11	80160	8.3801E 03
1	80170	3.1942E 00	80180	1.7138E 01	80190	9.1967E-12	90190	5.6315E-01
1	90200	4.7334E-12	100200	1.8751E-05	100210	7.6179E-08	100220	1.0732E-07
1	100230	6.2769E-12	110230	6.5075E-01	110240	1.7006E-06	110241	2.5315E-13
1	110250	1.6620E-14	120240	6.6372E-02	120250	8.2279E-03	120260	9.0568E-03
1	120270	2.8280E-11	120280	4.0014E-18	130270	6.1819E-01	130280	9.8048E-10
1	130290	3.6348E-13	130300	3.3030E-18	140280	3.9721E-01	140290	2.0234E-02
1	140300	1.3353E-02	140310	6.3446E-09	140320	5.5757E-12	150310	1.1286E 00
1	150320	1.1779E-05	150330	4.2421E-14	150340	9.1671E-15	160320	4.1885E-04
1	160330	2.3099E-07	160340	3.3327E-08	160350	1.9442E-05	160360	4.9012E-10
1	160370	4.5166E-14	170350	1.0343E-01	170360	9.6119E-03	170370	3.6259E-02
1	170380	1.7584E-09	170381	6.7214E-15	180360	2.5211E-08	180370	3.3509E-08
1	180380	3.5475E-05	180390	2.4157E-08	180400	2.0591E-08	180410	8,4735E-15
1	180420	4.9846E-18	190390	5.5720E-11	190400	1.6789E-06	190410	5.4474E-08
1	190420	5.3038E-12	190430	3.0207E-13	190440	1.8652E-15	200400	4.8287E-02
1	200410	4.1000E-05	200420	3.2187E-04	200430	6.4299E-05	200440	1.0407E-03
1	200450	6.4526E-07	200460	1.7431E-06	200470	2.2518E-11	200480	9.4505E-05
1	200490	2.5789E-12	210450	1.5972E-06	210460	1.3903E-08	210461	1.3360E-14
1	210470	1.8595E-10	210480	9.0616E-12	210490	1.7036E-11	210500	9.4961E-17
1	220460	1.7194E-03	220470	1.5505E-03	220480	1.5133E-02	220490	1.3752E-03
1	220500	1.0910E-03	220510	3.3993E-12	230500	1.2407E-04	230510	5.8186E-02
1	230520	3.0961E-09	230530	1.2279E-15	230540	7.8552E-18	240500	3.2308E-03
1	240510	5.8079E-06	240520	6.4477E-02	240530	7.5426E-03	240540	2.1020E-03
1	240550	8.9656E-12	250540	4.3286E-07	250550	2.9797E-02	250560	2.3818E-07
1	250570	5.8188E-15	250580	1.1580E-17	260540	1.8612E-02	260550	7.5427E-05
1	260560	2.9463E-01	260570	8.8299E-03	260580	1.0438E-03	260590	2.5109E-07
1	270580	9.3829E-06	270590	1.5144E-02	270600	1.5793E-03	270601	1.3084E-08
1	270610	1.3197E-09	270620	3.3837E-15	280580	2.7539E-01	280590	2.8969E-03
1	280600	1.0661E-01	280610	5.2417E-03	280620	1.4253E-02	280630	4.2511E-04
1	280640	3.7917E-03	280650	2.6126E-09	280660	5.8698E-13	290630	1.0759E-02

1	290640	1.2338E-07	290650	5.2473E-03	290660	1.9506E-10	290670	2.7548E-13
1	300640	2.9852E-01	300650	2.6808E-04	300660	1.7141E-01	300670	2.4962E-02
1	300680	1.1577E-01	300690	3.5232E-08	300691	3.4304E-08	300700	3.8157E-03
1	300710	2.1430E-12	300711	2.2017E-11	310690	4.6184E-04	310700	1.6503E-10
1	310710	7.3925E-07	310720	2.3478E-11	310721	5.6719E-19	320700	2.9410E-06
1	320710	4.9541E-10	320711	9.0865E-19	320720	1.0417E-08	320730	1.0334E-11
1	320740	2.0933E-13	320750	3.9625E-20	320751	8.2286E-23	320760	6.7423E-23
1	330750	7.1608E-17	330760	7.9615E-21	340760	6.0984E-19	340770	2.0844E-20
1	340780	2.8296E-22	380870	7.4980E-25	380880	2.8167E-15	380890	5.6979E-16
1	380900	7.7963E-17	380910	8.2107E-20	390890	5.9165E-13	390891	2.1073E-19
1	390900	1.3312E-17	390901	3.4010E-22	390910	1.0699E-16	390920	4.0359E-18
1	390930	1.2707E-25	390940	1.9655E-21	400890	2.3024E-12	400900	1.1980E-15
1	400910	4.8856E-09	400920	1.1646E-07	400930	4.1837E-09	400940	1.0086E-08
1	400950	1.5222E-10	400960	6.8501E-13	400970	3.9163E-14	410920	1.4243E-09
1	410930	1.4500E-09	410931	1.9492E-15	410940	5.8524E-09	410950	2.2029E-10
1	410951	6.1554E-14	410960	5.0914E-12	410970	9.9658E-14	410971	3.6548E-17
1	410980	9.5514E-18	411000	4.0549E-19	420920	1.5406E-02	420931	1.0711E-10
1	420930	6.4299E-06	420940	9.6755E-03	420950	1.4932E-02	420960	1.8721E-02
1	420970	1.0131E-02	420980	2.5123E-02	420990	7.7232E-07	421000	9.9609E-03
1	421010	7.0718E-10	430990	1.6268E-05	431000	1.2815E-12	431010	6.8687E-10
1	440990	6.0606E-11	441000	1.8889E-06	441010	3.5186E-05	441020	1.2922E-06
1	441030	5.3515E-10	441040	1.1749E-11	441050	2.6846E-17	441060	3.5416E-20
1	451030	1.8009E-10	451040	3.8469E-16	451041	7.2836E-17	451050	1.9424E-16
1	451051	2.1167E-20	451060	5.5427E-17	451061	3.9301E-19	461040	2.9382E-10
1	461050	2.1363E-12	461060	1.4404E-10	461070	2.2751E-10	461071	1.1887E-20
1	461080	1.4998E-06	461090	2.8605E-10	461091	2.7156E-14	461100	8.0442E-07
1	461110	1.6640E-13	461111	3.5335E-13	471070	4.1298E-04	471080	2.0039E-10
1	471081	4.5216E-06	471090	1.6267E-04	471091	2.3364E-13	471100	8.4972E-11
1	471101	4.1550E-06	471110	2.0979E-08	471111	1.0490E-12	471120	4.4659E-13
1	481060	2.8827E-03	481070	3.1638E-09	481080	2.0317E-03	481090	4.6896E-06
1	481100	2.6548E-02	481110	2.7504E-02	481111	7.0363E-10	481120	5.4742E-02
1	481130	8.5750E-06	481140	9.0172E-02	481150	6.1087E-06	481151	1.0388E-05
1	481160	1.6623E-02	481170	8.8990E-09	481171	4.2951E-10	481190	5.9300E-18
1	481210	4.0606E-20	491130	5.5505E-04	491140	2.6300E-10	491141	6.8305E-06
1	491150	2.6650E-04	491160	1.9718E-10	491161	3.5985E-08	491170	1.3438E-09
1	491171	6.2830E-09	491180	1.5883E-17	491190	1.5001E-16	491191	1.1355E-17
1	491200	1.3466E-25	491210	7.2837E-20	501120	3.3047E-04	501130	9.0236E-07
1	501131	5.0296E-11	501140	4.0421E-04	501150	1.1466E-04	501160	2.1196E-02
1	501170	2.8699E-03	501171	3.8631E-06	501180	8.1527E-03	501190	2.9417E-03
1	501191	1.3909E-05	501200	1.0916E-02	501210	3.3757E-08	501211	9.0588E-08
1	501220	1.5474E-03	501230	3.7148E-07	501231	3.1948E-13	501240	1.8673E-03
1	501250	1.8814E-07	501251	1.0344E-10	511210	1.4743E-05	511220	1.0307E-08
1	511221	9.7912E-14	511230	1.2013E-06	511240	9.7027E-09	511241	5.8494E-16
1	511250	1.3835E-05	511260	5.5500E-09	511261	5.6912E-13	521220	9.6282E-07
1	521230	1.0627E-08	521231	3.0443E-09	521240	4.6251E-08	521250	4.1105E-06
1	521251	1.6606E-07	521260	1.6791E-07	521270	1.4006E-12	521271	2.4074E-11
1	521280	1.4027E-12	521290	3.7408E-19	521291	6.5576E-18	521300	8.6762E-21
1	531270	5.9902E-10	531280	2.3748E-15	531290	8.0617E-16	531300	9.4802E-20
1	531301	4.6305E-22	531310	2.2052E-22	541280	1.6624E-11	541290	5.4735E-14
1	541291	2.9608E-16	541300	1.8977E-15	541310	4.0723E-18	541311	5.0879E-20
1	541320	3.8128E-19	541330	9.9055E-24	541331	1.2488E-25	541340	3.8114E-25
1	551330	1.0132E-22	551340	2.4924E-24	601460	7.3754E-19	601470	9.0780E-23
1	601480	4.2701E-19	601490	3.5507E-23	611470	1.2578E-21	611480	2.7412E-23
1	611481	1.2056E-23	611490	1.3703E-21	611500	9.5530E-25	611510	2.0324E-14
1	611520	3.7473E-19	621470	3.3320E-22	621480	1.3259E-19	621490	5.5669E-14
1	621500	9.0126E-11	621510	2.4066E-12	621520	1.8090E-11	621530	1.2515E-13
1	621540	1.8511E-11	621550	2.0842E-17	631510	1.5372E-15	631520	5.8195E-15
1	631521	7.8042E-18	631530	1.0892E-05	631540	5.3637E-06	631550	1.7303E-06
1	631560	4.2254E-07	641520	6.5381E-07	641530	5.7669E-06	641540	2.3979E-04
1	641551	2.7659E-17	641550	1.1874E-06	641560	5.2239E-03	641570	1.6809E-06
1	641580	6.6458E-03	641590	4.5121E-07	641600	3.4326E-03	641610	1.5404E-10
1	641620	1.3462E-13	651590	2.4226E-04	651600	8.8498E-06	651610	6.2218E-07
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1	661630	7.0338E-06	661640	7.8187E-07	661650	1.1746E-09	661651	4.2801E-12
1	661660	1.5872E-10	671650	1.4548E-06	671660	2.0072E-09	671661	8.8089E-09
1	681660	1.2783E-07	681670	3.9103E-09	681671	5.1821E-16	681680	3.1390E-09

1	681690	1.3034E-12	681700	5.1260E-16	681710	7.0281E-21	681720	1.6313E-23
1	691690	8.1740E-12	691700	7.9840E-13	691710	3.5732E-14	691720	1.4745E-17
1	701700	3.4448E-13	701710	9.2369E-15	701720	5.1536E-16	701730	7.6142E-19
1	701740	1.6009E-20	701750	1.7998E-23	711750	1.4551E-22	711760	1.1921E-24
1	721760	3.6578E-24	721770	1.6285E-25	731810	1.1126E-06	731820	2.4983E-08
1	731821	5.7127E-15	731830	3.9336E-09	741800	1.2413E-05	741810	3.6141E-07
1	741820	1.9093E-03	741831	2.3174E-13	741830	2.0752E-03	741840	3.7246E-03
1	741850	6.1126E-06	741851	1.0893E-13	741860	2.1300E-03	741870	1.5340E-06
1	741880	3.6586E-07	741890	1.3473E-23	751850	2.1541E-05	751860	2.0020E-07
1	751870	8.2672E-04	751880	3.6422E-07	751881	6.4746E-09	751890	2.9943E-12
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1	761900	5.7257E-07	761901	3.1226E-16	761910	6.3094E-10	761911	1.7403E-11
1	761920	4.1268E-11	761930	7.0835E-16	761940	3.1461E-16	771910	2.5372E-09
1	771920	7.1570E-10	771921	7.6023E-13	771930	2.4029E-10	771940	3.6560E-13
1	771941	8.9425E-21	781920	8.1380E-10	781930	9.0727E-12	781931	8.1175E-14
1	781940	3.5687E-11	781950	2.0060E-14	781951	7.5349E-17	781960	5.9022E-16
1	781970	5.3351E-21	781971	2.6779E-23	791970	3.2783E-19	791980	1.5157E-21
1	791990	4.9825E-22	801980	2.5802E-20	801990	5.3932E-21	802000	2.4794E-21
1	802010	6.5452E-23	802020	1.7384E-24	812050	4.0456E-15	812060	3.8293E-19
1	822040	6.7401E-05	822050	1.5317E-07	822060	1.0993E-03	822070	1.1284E-03
1	822080	2.5302E-03	822090	6.9003E-13	832080	2.7805E-09	832090	1.9135E-03
1	832100	1.8843E-09	832101	1.4478E-07	832110	6.1098E-19	842100	4.7442E-08
1	842110	3.7459E-20	842111	2.7872E-20	0	0.0	0	0.0
2	20040	5.4434E-02	812070	6.6320E-18	812080	4.2637E-15	812090	3.8622E-20
2	822060	2.7527E-16	822070	3.9546E-13	822080	8.3365E-10	822090	1.6115E-16
2	822100	2.8611E-14	822110	5.0333E-17	822120	2.4674E-12	822140	1.9731E-18
2	832080	5.7287E-20	832090	1.7886E-13	832101	2.9829E-18	832100	1.7789E-17
2	832110	2.9698E-18	832120	2.3405E-13	832130	3.7102E-17	832140	1.4651E-18
2	842100	2.7302E-16	842110	3.6437E-23	842120	1.2383E-23	842140	2.6366E-25
2	842150	4.1362E-23	842160	9.6634E-18	842180	2.2460E-19	852170	4.3753E-22
2	862180	1.3228E-23	862190	9.2018E-20	862200	3.5819E-15	862220	4.0551E-16
2	872210	3.9012E-18	872230	4.6935E-19	882220	1.4362E-20	882230	2.2956E-14
2	882240	2.0370E-11	882250	1.8096E-14	882260	6.1907E-11	882280	2.8729E-17
2	892250	1.1704E-14	892270	1.7866E-11	892280	9.5452E-15	902260	7.0298E-19
2	902270	3.8634E-14	902280	3.8621E-09	902290	1.0312E-09	902300	4.9686E-06
2	902310	6.0037E-09	902320	7.1235E-07	902330	1.5726E-12	902340	5.8632E-08
2	912310	1.1307E-06	912320	4.6846E-09	912330	6.0795E-08	912341	2.0057E-12
2	912340	1.0722E-11	912350	3.5549E-17	922300	6.7918E-16	922310	3.2777E-13
2	922320	8.0408E-07	922330	6.0520E-06	922340	7.6756E-01	922350	3.3865E 01
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2	932401	2.5990E-07	932400	9.7080E-06	932410	8.1406E-14	942360	5.2044E-07
2	942370	1.4641E-07	942380	5.3615E-01	942390	2.0667E 01	942400	9.6149E 00
2	942410	5.0754E 00	942420	1.9015E 00	942430	5.3958E-04	942440	1.3244E-04
2	942450	3.3253E-09	942460	2.6263E-11	952390	4.5118E-13	952400	1.9493E-10
2	952410	1.2381E-01	952421	1.6026E-03	952420	3.9734E-04	952430	3.5175E-01
2	952441	1.0944E-05	952440	1.3379E-05	952450	6.4938E-10	952460	4.2023E-14
2	962410	2.5272E-12	962420	4.8308E-02	962430	1.1748E-03	962440	7.7248E-02
2	962450	4.9343E-04	962460	3.7952E-04	962470	1.6322E-06	962480	6.4700E-08
2	962490	5.4634E-13	962500	2.0383E-16	972490	4.1203E-10	972500	4.5615E-13
2	972510	7.0368E-17	982490	3.5445E-11	982500	9.2525E-11	982510	9.5930E-12
2	982520	1.2817E-11	982530	3.5399E-14	982540	3.8391E-15	982550	1.0415E-19
2	992530	2.7255E-14	992541	2.9168E-17	992540	6.4237E-16	992550	3.5325E-17
2	162500	4.9342E-09	0	0.0	0	0.0	0	0.0
3	10030	1.8870E-02	30060	3.0288E-05	30070	1.4292E-06	40090	2.1416E-06
3	40100	1.2852E-05	60140	1.8561E-06	290660	2.1398E-15	300660	5.4934E-10
3	290670	3.0220E-18	300670	2.2583E-11	300680	3.3123E-13	300690	1.0081E-19
3	300691	9.8151E-20	310690	4.7822E-16	310700	1.7089E-22	320700	1.5994E-18
3	310710	1.2173E-08	270720	1.7994E-14	280720	6.7966E-12	290720	3.3165E-11
3	300720	1.0906E-06	310720	3.3181E-07	320720	2.9700E-04	270730	5.4625E-15
3	280730	9.1712E-13	290730	2.8543E-11	300730	2.8405E-10	310730	2.2383E-07
3	320730	6.0911E-04	320731	6.7571E-12	270740	9.8637E-16	280740	9.1093E-13
3	290740	5.4905E-12	300740	2.1490E-09	310740	1.1776E-08	320740	1.3034E-03
3	270750	9.7131E-17	280750	1.0175E-13	290750	7.2195E-12	300750	3.7149E-10
3	310750	5.6802E-09	320750	2.5076E-07	320751	1.1263E-10	330750	2.6673E-03

3	280760	3.9067E-14	290760	1.5510E-12	300760	3.7362E-10	310760	2.8603E-09
3	320760	6.5480E-03	330760	3.0052E-07	340760	7.0839E-05	280770	2.5481E-15
3	290770	9.5132E-13	300770	1.0609E-10	310770	2.4477E-09	320770	3.5040E-06
3	320771	1.0199E-08	330770	3.2895E-05	340770	1.3219E-02	340771	1.1488E-11
3	280780	3.9605E-16	290780	1.3898E-13	300780	1.7806E-10	310780	1.5910E-09
3	320780	2.7483E-06	330780	2.9523E-06	340780	3.1016E-02	290790	5.0233E-14
3	300790	1.8523E-11	310790	1.0540E-09	320790	4.7141E-08	330790	6.9355E-07
3	340790	7.4337E-02	340791	3.0073E-07	350790	1.0569E-06	350791	8.6937E-15
3	290800	3.2613E-15	300800	1.2300E-11	310800	6.1169E-10	320800	5.0550E-08
3	330800	4.5543E-08	340800	1.6710E-01	350800	8.5363E-11	350801	8.5576E-10
3	360800	2.8058E-06	290810	1.9724E-16	300810	5.1632E-13	310810	1.4883E-10
3	320810	2.5026E-08	330810	1.3749E-07	340810	5.1403E-06	340811	4.2764E-07
3	350810	2.6758E-01	360810	2.6142E-07	360811	4.4733E-14	300820	7.0784E-14
3	310820	1.2088E-11	320820	9.7411E-09	330820	7.6790E-08	330821	1.9959E-08
3	340820	4.1029E-01	350820	6.3227E-05	350821	7.5270E-08	360820	1.1859E-02
3	300830	4.1056E-15	310830	3.2155E-12	320830	2.8735E-09	330830	8.6573E-08
3	340830	5.4820E-06	340831	4.1890E-07	350830	8.8495E-05	360830	4.9335E-01
3	360831	6.7907E-05	310840	2.8193E-13	320840	5.9349E-10	330840	3.0193E-08
3	340840	3.3290E-06	350840	3.3353E-05	350841	2.4836E-07	360840	1.3492E 00
3	320850	2.8382E-11	330850	6.0930E-09	340850	3.7418E-07	340851	1.3552E-07
3	350850	3.5924E-06	360850	2.8348E-01	360851	3.4153E-04	370850	1.1448E 00
3	320860	5.9470E-12	330860	1.4276E-09	340860	3.0750E-07	350860	8.1343E-07
3	350861	6.6825E-08	360860	2.2076E 00	370860	2.8401E-04	370861	1.3104E-09
3	380860	4.3910E-03	320870	3.9570E-13	330870	2.3093E-10	340870	8.4637E-08
3	350870	1.8797E-06	360870	1.8325E-04	370870	2.8008E 00	380870	3.5988E-05
3	380871	5.9492E-09	320880	1.8291E-14	330880	8.5260E-12	340880	8.5369E-09
3	350880	5.7390E-07	360880	5.7452E-04	370880	6.1116E-05	380880	3.9729E 00
3	330890	9.0416E-13	340890	6.7565E-10	350890	1.0805E-07	360890	1.2873E-05
3	370890	6.6564E-05	380890	3.3837E-01	390890	4.7870E 00	390891	8.0480E-13
3	340900	2.7341E-10	350900	2.4113E-08	360900	2.1590E-06	370900	1.0769E-05
3	370901	4.4018E-06	380900	5.9552E 00	390900	1.5746E-03	390901	1.8364E-08
3	400900	2.0249E-01	400901	5.8422E-15	340910	1.3769E-11	350910	3.1751E-09
3	360910	4.3200E-07	370910	5.1796E-06	380910	3.2903E-03	390910	5.1485E-01
3	390911	1.6660E-04	400910	5.9665E 00	340920	1.0391E-12	350920	1.8674E-10
3	360920	4.5849E-08	370920	3.5155E-07	380920	1.0336E-03	390920	1.3567E-03
3	400920	6.9498E 00	350930	2.1873E-11	360930	1.1765E-08	370930	3.4793E-07
3	380930	5.4920E-05	390930	4.5593E-03	400930	7.7224E 00	410930	5.1599E-07
3	410931	4.1733E-06	350940	1.0186E-12	360940	6.6873E-10	370940	8.5494E-08
3	380940	8.7632E-06	390940	1.4648E-04	400940	7.8827E 00	410940	7.9767E-06
3	410941	4.2058E-11	350950	8.9624E-14	360950	2.2761E-10	370950	5.6530E-09
3	380950	2.8001E-06	390950	8.7553E-05	400950	8.0777E-01	410950	4.4858E-01
3	410951	3.3010E-04	420950	6.7215E 00	350960	3.3960E-15	360960	3.0776E-11
3	370960	9.6185E-10	380960	2.9875E-07	390960	1.8250E-05	400960	8.3253E 00
3	410960	2.5870E-05	420960	3.4243E-01	360970	6.2979E-13	370970	1.5253E-10
3	380970	7.9170E-09	390970	1.2698E-07	400970	8.8886E-03	410970	6.3811E-04
3	410971	8.3141E-06	420970	8.1462E 00	360980	1.0933E-13	370980	2.8141E-11
3	380980	1.3327E-08	390980	2.4359E-08	400980	4.5959E-06	410980	7.6840E-09
3	410981	4.6303E-04	420980	8.4204E 00	370990	1.5306E-12	380990	2.4392E-09
3	390990	3.7184E-08	400990	3.5265E-07	410990	2.1925E-06	410991	1.0115E-06
3	420990	3.8289E-02	430990	7.7461E 00	430991	3.0573E-03	440990	3.0584E-05
3	371000	1.7791E-13	381000	9.0013E-10	391000	1.5778E-08	401000	9.5961E-07
3	411000	2.0569E-07	411001	2.0655E-07	421000	9.2972E 00	431000	6.1029E-07
3	441000	9.5133E-01	381010	3.0649E-11	391010	6.6157E-09	401010	2.8481E-07
3	411010	9.9403E-07	421010	1.3371E-04	431010	1.2991E-04	441010	7.6418E 00
3	381020	4.6697E-12	391020	4.6007E-10	401020	1.4042E-06	411020	3.6380E-07
3	421020	9.7704E-05	431020	7.7560E-07	431021	4.7430E-08	441020	7.5488E 00
3	381030	5.2612E-14	391030	9.0585E-11	401030	3.2432E-08	411030	1.3319E-06
3	421030	8.6043E-06	431030	7.2873E-06	441030	4.9576E-01	451030	4.0409E 00
3	451031	4.4303E-04	381040	3.0398E-15	391040	3.2622E-12	401040	1.6618E-08
3	411040	4.1320E-08	421040	1.1161E-05	431040	1.3597E-04	441040	5.2094E 00
3	451040	3.6990E-06	451041	1.6344E-06	461040	2.0904E 00	391050	1.9860E-13
3	401050	3.3326E-10	411050	2.5378E-08	421050	4.4954E-06	431050	4.9441E-05
3	441050	1.6746E-03	451050	1.2097E-02	451051	1.3205E-06	461050	3.5655E 00
3	401060	6.5887E-11	411060	1.9960E-09	421060	4.0720E-07	431060	2.7135E-06
3	441060	1.6406E 00	451060	1.7435E-06	451061	2.4533E-05	461060	1.7637E 00
3	391070	6.8860E-17	401070	7.5691E-13	411070	3.8460E-10	421070	1.0664E-07

3	431070	1.1846E-06	441070	1.5695E-05	451070	8.1504E-05	461070	2.0387E 00
3	461071	1.5023E-10	471070	1.9640E-07	401080	3.5825E-13	411080	2.6001E-11
3	421080	7.0337E-09	431080	1.2321E-07	441080	1.1644E-05	451080	7.3137E-07
3	451081	1.4492E-07	461080	1.3905E 00	471080	1.3540E-13	471081	1.0266E-08
3	481080	1.8730E-08	401090	8.9631E-15	411090	6.4991E-12	421090	1.5120E-09
3	431090	5.5418E-07	441090	9.2896E-07	451090	2.4894E-06	451091	6.9150E-07
3	461090	1.6060E-03	461091	3.9184E-06	471090	6.9831E-01	471091	1.3117E-06
3	481090	2.4114E-11	411100	3.2225E-13	421100	5.4155E-10	431100	2.2183E-09
3	441100	1.8521E-07	451100	3.6190E-07	451101	2.7136E-09	461100	4.4740E-01
3	471100	3.6463E-07	471101	8.4670E-03	481100	2.9592E-01	411110	3.3956E-14
3	421110	2.2812E-11	431110	1.1318E-09	441110	7.7557E-08	451110	4.3306E-07
3	461110	9.3088E-06	461111	2.1139E-06	471110	4.6010E-03	471111	4.5861E-07
3	481110	2.4219E-01	481111	7.8431E-09	421120	7.3184E-12	431120	9.9598E-11
3	441120	1.4906E-09	451120	1.6051E-08	461120	2.6477E-04	471120	4.1370E-05
3	481120	1.4638E-01	421130	1.4874E-13	431130	3.3848E-11	441130	3.1067E-09
3	451130	2.1363E-09	461130	2.5773E-07	471130	4.9252E-05	471131	1.9167E-08
3	481130	1.3031E-03	481131	2.3174E-03	491130	9.9634E-05	491131	2.6545E-15
3	421140	2.4778E-14	431140	2.8631E-12	441140	2.5179E-09	451140	2.2887E-09
3	461140	2.8068E-07	471140	8.9354E-09	481140	1.9413E-01	491140	4.3561E-11
3	491141	9.9921E-07	501140	8.6238E-06	421150	5.9848E-16	431150	7.7322E-13
3	441150	1.6927E-10	451150	6.0548E-09	461150	7.0121E-08	471150	1.6604E-06
3	471151	9.0686E-09	481150	3.4934E-04	481151	6.6727E-04	491150	1.9760E-02
3	491151	2.8147E-05	501150	2.7271E-03	431160	2.2870E-14	441160	7.2675E-11
3	451160	3.9655E-10	461160	1.9400E-08	471160	1.2460E-07	471161	8.0588E-09
3	481160	7.0216E-02	491160	1.4620E-08	491161	2.6679E-06	501160	6.1862E-02
3	431170	1.2369E-15	441170	2.3661E-12	451170	2.7724E-10	461170	6.0846E-09
3	471170	5.5534E-08	471171	4.0197E-09	481170	9.4172E-06	481171	6.6927E-06
3	491170	2.4540E-06	491171	8.2155E-06	501170	7.0175E-02	501171	1.0882E-05
3	441180	3.1226E-11	451180	1.1688E-10	461180	3.1225E-09	471180	3.7203E-09
3	471181	1.9448E-09	481180	4.6163E-06	491180	7.6512E-09	491181	1.7580E-10
3	501180	7.0433E-02	451190	1.4455E-11	461190	1.2706E-09	471190	8.3822E-09
3	481190	4.3016E-07	481191	1.4644E-07	491190	6.5873E-08	491191	1.2362E-06
3	501190	6.9051E-02	501191	4.7478E-04	441200	3.1105E-15	451200	7.8490E-13
3	461200	1.1781E-09	471200	1.1182E-09	481200	7.6211E-08	491200	3.4010E-08
3	491201	2.3593E-09	501200	7.0323E-02	451210	1.6866E-13	461210	6.6972E-11
3	471210	1.9885E-09	481210	1.8967E-08	491210	3.5338E-08	491211	6.2326E-08
3	501210	1.5247E-04	501211	2.8898E-05	511210	6.7841E-02	451220	9.7267E-15
3	461220	4.1885E-11	471220	4.1005E-11	481220	7.7805E-09	491220	1.5248E-08
3	491221	1.6574E-10	501220	7.6086E-02	511220	4.7433E-05	511221	4.5377E-10
3	521220	4.4118E-03	451230	1.0514E-15	461230	2.3093E-12	471230	1.8444E-10
3	481230	1.1287E-08	491230	7.4960E-09	491231	2.5423E-08	501230	3.9168E-03
3	501231	3.5657E-06	511230	7.8561E-02	521230	4.8538E-05	521231	1.3917E-05
3	461240	7.8130E-13	471240	2.6203E-11	481240	2.0999E-08	491240	6.4590E-09
3	501240	1.0138E-01	511240	6.5448E-04	511241	1.0099E-10	521240	2.6361E-03
3	471250	1.1640E-11	481250	1.4342E-09	491250	3.0347E-09	491251	1.1455E-08
3	501250	1.0727E-03	501251	1.2089E-06	511250	1.1503E-01	521250	3.3062E-02
3	521251	1.3762E-03	461260	6.0032E-15	471260	1.4733E-12	481260	2.4632E-09
3	491260	4.4112E-09	501260	2.1741E-01	511260	1.1575E-04	511261	5.5375E-08
3	521260	5.8335E-03	481270	2.4560E-10	491270	3.4252E-09	491271	6.2370E-09
3	501270	4.9585E-05	501271	7.7587E-07	511270	3.4455E-03	521270	3.4536E-04
3	521271	1.2844E-02	531270	4.2074E-01	471280	4.0989E-14	481280	1.8273E-10
3	491280	1.0218E-08	501280	5.3640E-05	511280	4.6262E-05	511281	1.0321E-05
3	521280	8.6138E-01	531280	1.6700E-06	541280	2.2918E-02	481290	1.9567E-11
3	491290	1.8565E-09	501290	4.6322E-06	501291	1.7013E-06	511290	4.6725E-04
3	521290	1.2351E-04	521291	1.2879E-02	531290	1.3740E 00	541290	1.2263E-04
3	541291	4.0854E-07	481300	2.6008E-11	491300	1.2858E-09	501300	7.1738E-06
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3	531310	6.2818E-02	541310	3.2103E 00	541311	1.0420E-03	481320	1.0457E-13
3	491320	2.6405E-11	501320	5.8260E-07	511320	7.3175E-06	511321	7.2836E-06
3	521320	3.5918E-02	531320	1.0749E-03	541320	8.1298E 00	491330	2.8744E-12
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3	531330	1.3483E-02	531331	5.2107E-08	541330	8.1610E-02	541331	1.0759E-03
3	551330	8.3773E 00	491340	1.1266E-13	501340	5.2507E-10	511340	9.3742E-08
3	511341	8.4535E-08	521340	3.6048E-04	531340	6.2105E-04	531341	4.5298E-06

3	541340	1.0963E 01	541341	4.1781E-10	551340	9.0160E-01	551341	5.1823E-05
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3	531350	4.0139E-03	541350	1.1352E-03	541351	3.3206E-05	551350	2.2139E 00
3	551351	9.2993E-06	561350	1.6254E-03	561351	8.3988E-07	501360	2.5286E-12
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3	541360	1.7219E 01	551360	4.9142E-03	561360	1.2208E-01	561361	2.2035E-10
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3	561390	7.8782E-04	571390	8.7487E 00	521400	5.0203E-11	531400	3.9505E-09
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3	551410	2.5443E-06	561410	1.5758E-04	571410	2.0446E-03	581410	4.1208E-01
3	591410	7.5008E 00	521420	1.6122E-13	531420	2.2084E-11	541420	1.0646E-08
3	551420	1.0368E-07	561420	8.7000E-05	571420	7.7260E-04	581420	7.9295E 00
3	591420	5.3357E-04	591421	1.3874E-06	601420	1.7667E-01	531430	2.4586E-12
3	541430	4.4618E-10	551430	4.9994E-08	561430	1.6010E-06	571430	1.1033E-04
3	581430	1.5707E-02	591430	1.5254E-01	601430	5.2719E 00	531440	8.1179E-14
3	541440	2.6178E-10	551440	8.8721E-09	561440	9.6600E-07	571440	4.6114E-06
3	581440	2.7420E 00	591440	1.1683E-04	591441	5.7938E-07	601440	6.4145E 00
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3	551460	6.1063E-11	561460	3.7235E-08	571460	4.5705E-07	581460	6.2029E-05
3	591460	1.0615E-04	601460	4.6898E 00	541470	4.3382E-14	551470	2.9660E-11
3	561470	8.7390E-09	571470	2.6973E-07	581470	3.9563E-06	591470	4.1850E-05
3	601470	5.6003E-02	611470	9.5433E-01	621470	3.6616E-01	551480	6.9546E-13
3	561480	4.1158E-09	571480	1.3239E-08	581480	1.7899E-06	591480	6.4102E-06
3	601480	2.4978E 00	611480	1.1788E-02	611481	9.1634E-03	621480	1.0976E 00
3	561490	7.3127E-11	571490	7.3203E-09	581490	2.3266E-08	591490	4.5262E-06
3	601490	2.1546E-04	611490	1.0691E-02	621490	1.4261E-02	551500	4.0439E-16
3	561500	1.0753E-11	571500	3.2003E-10	581500	1.0892E-08	591500	2.7585E-07
3	601500	1.1770E 00	611500	7.7007E-06	621500	2.1062E 00	571510	6.0045E-11
3	581510	3.2804E-09	591510	4.9841E-08	601510	1.3765E-05	611510	1.8916E-03
3	621510	8.8906E-02	631510	5.6755E-05	561520	1.1999E-14	571520	2.1879E-12
3	581520	1.0130E-08	591520	4.6157E-08	601520	8.9341E-06	611520	3.2731E-06
3	611521	1.1285E-07	621520	8.7678E-01	631520	2.0623E-04	631521	2.8814E-07
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3	631580	2.5916E-06	641580	1.1646E-01	591590	2.1320E-15	601590	3.3690E-12
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3	601610	6.7531E-15	611610	1.4684E-12	621610	5.2787E-10	631610	4.1930E-09
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3	661650	4.4003E-07	661651	1.6291E-09	671650	8.5227E-04	661660	9.3008E-07
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1	80160	1.3985E 01	80170	5.3271E-03	80180	2.8598E-02	130270	3.0630E 00
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1	240520	9.5684E 01	240530	1.0849E 01	240540	2.6950E 00	250550	6.0720E 00
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1	280620	6.1242E 00	280640	1.5524E 00	290630	1.9036E-01	290650	8.4727E-02
1	400900	1.2976E 03	400910	2.8220E 02	400920	4.3086E 02	400940	4.3842E 02
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1	481110	6.6842E-05	481120	1.2590E-04	481130	6.3709E-05	481140	1.4987E-04
1	481160	3.9165E-05	501120	3.1654E-01	501140	2.1208E-01	501150	1.2029E-01
1	501160	4.6531E 00	501170	2.4532E 00	501180	7.6919E 00	501190	2.7222E 00
1	501200	1.0256E 01	501220	1.4561E 00	501240	1.7726E 00	721740	1.6426E-04
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1	721800	3.6137E-02	741800	3.5063E-05	741820	7.0935E-03	741830	3.8569E-03
1	741840	8.2722E-03	741860	7.7138E-03	0	0.0	0	0.0
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1	30070	3.7942E-03	30080	5.1206E-15	40090	3.2088E-05	40100	9.9612E-08
1	40110	6.2503E-20	50100	4.8576E-05	50110	1.7591E-02	50120	1.0250E-16
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1	70140	6.3790E 00	70150	2.4082E-02	70160	2.9168E-14	80160	1.3984E 01
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1	90200	1.5487E-19	100200	3.0672E-13	100210	8.7198E-13	100220	1.5344E-11
1	100230	1.9647E-18	110230	1.1885E-12	110240	1.8154E-09	110241	4.6198E-25
1	110250	4.7529E-18	120240	1.5166E-06	120250	2.4406E-06	120260	1.0728E-06
1	120270	9.1390E-11	120280	1.2928E-17	130270	3.0613E 00	130280	4.8701E-09
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1	140300	4.9045E-01	140310	5.1681E-08	140320	4.5137E-11	150310	9.2501E 00
1	150320	9.2134E-05	150330	6.4859E-10	150340	2.1045E-15	160320	6.5162E-01
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1	160370	1.3712E-13	170350	6.5167E-06	170360	2.6088E-07	170370	2.2076E-08
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1	180380	1.0243E-11	180390	4.3317E-15	180400	3.0117E-13	180410	2.8043E-18
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1	200430	9.2832E-08	200440	7.0165E-07	200450	4.2321E-09	200460	8.3108E-08
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2	822120	2.4547E-20	832090	1.7412E-21	832100	1.6584E-25	832120	2.3285E-21
2	832130	3.6419E-25	842100	2.2617E-24	862200	3.5635E-23	862220	3.7615E-24
2	882230	2.0926E-22	882240	2.0266E-19	882250	1.7770E-22	882260	5.7429E-19
2	892250	1.1488E-22	892270	1.6244E-19	892280	8.4226E-23	902270	3.5174E-22
2	902280	3.8423E-17	902290	9.8699E-18	902300	4.6608E-14	902310	5.2461E-17
2	902320	7.4281E-15	902330	1.6342E-20	902340	2.8298E-15	912310	1.0078E-14
2	912320	4.0888E-17	912330	1.0570E-15	912341	9.5913E-20	912340	2.1324E-19
2	912350	1.6154E-24	922300	6.8228E-24	922310	3.2608E-21	922320	8.0075E-15
2	922330	5.8041E-14	922340	7.2021E-09	922350	4.3185E-07	922360	1.7465E-07
2	922370	7.3198E-10	922380	1.9147E-04	922390	1.2544E-10	922400	1.2909E-14
2	922410	3.8370E-24	932350	3.6908E-17	932361	6.1558E-16	932360	5.7292E-15
2	932370	3.1980E-08	932380	1.0349E-10	932390	1.8050E-08	932401	1.1761E-14
2	932400	4.3931E-13	932410	3.6835E-21	942360	9.8776E-15	942370	4.1288E-15
2	942380	1.1706E-08	942390	9.2527E-07	942400	3.6705E-07	942410	2.4848E-07
2	942420	9.9908E-08	942430	2.8678E-11	942440	7.1168E-12	942450	1.7868E-16
2	942460	1.4115E-18	952390	2.3183E-20	952400	1.0020E-17	952410	6.3614E-09
2	952421	8.4755E-11	952420	2.0789E-11	952430	1.9003E-08	952441	5.9288E-13
2	952440	7.2490E-13	952450	3.4894E-17	952460	2.2585E-21	962410	1.3540E-19
2	962420	2.6016E-09	962430	6.2981E-11	962440	4.1088E-09	962450	2.5732E-11
2	962460	1.9246E-11	962470	8.1010E-14	962480	3.1564E-15	962490	2.6653E-20
2	962500	9.4031E-24	972490	1.9930E-17	972500	2.2064E-20	972510	3.4037E-24
2	982490	1.7034E-18	982500	4.4469E-18	982510	4.5952E-19	982520	6.0892E-19
2	982530	1.6782E-21	982540	1.8133E-22	992530	1.2892E-21	992541	1.3796E-24
2	992540	3.0312E-23	992550	1.6138E-24	162500	2.6051E-16	0	0.0
3	10030	5.6245E-10	30060	8.4970E-13	30070	3.5792E-14	40090	5.3640E-14
3	40100	3.2188E-13	60140	4.6488E-14	290660	4.9786E-23	300660	9.0600E-18
3	300670	3.2123E-19	300680	4.3732E-21	310690	5.6064E-24	310710	3.8340E-16
3	270720	7.9339E-22	280720	2.9027E-19	290720	1.4012E-18	300720	4.6186E-14
3	310720	1.4054E-14	320720	1.1581E-11	270730	2.4784E-22	280730	4.0400E-20
3	290730	1.1744E-18	300730	1.1235E-17	310730	8.8762E-15	320730	2.0944E-11
3	320731	2.6798E-19	270740	4.2855E-23	280740	3.6979E-20	290740	2.0649E-19
3	300740	7.9871E-17	310740	4.4044E-16	320740	4.0436E-11	270750	4.2217E-24
3	280750	4.1237E-21	290750	2.6482E-19	300750	1.3149E-17	310750	2.0419E-16
3	320750	9.0331E-15	320751	4.1446E-18	330750	7.7612E-11	280760	1.5255E-21
3	290760	5.2626E-20	300760	1.1725E-17	310760	9.2767E-17	320760	1.6421E-10
3	330760	8.7863E-15	340760	1.9083E-12	280770	1.0271E-22	290770	3.3022E-20
3	300770	3.2429E-18	310770	7.5177E-17	320770	1.1425E-13	320771	3.2224E-16
3	330770	1.0527E-12	340770	3.2107E-10	340771	3.6155E-19	280780	1.6047E-23
3	290780	4.7353E-21	300780	4.9634E-18	310780	4.4741E-17	320780	9.1768E-14
3	330780	9.9210E-14	340780	7.9005E-10	290790	2.0719E-21	300790	6.5657E-19
3	310790	3.3437E-17	320790	1.5657E-15	330790	2.2685E-14	340790	1.8380E-09
3	340791	9.8379E-15	350790	2.6062E-14	350791	3.8641E-22	290800	1.3007E-22
3	300800	2.9985E-19	310800	1.6504E-17	320800	1.4827E-15	330800	1.4290E-15
3	340800	3.9161E-09	350800	3.5362E-18	350801	3.6684E-17	360800	1.0938E-13
3	290810	8.2123E-24	300810	1.8458E-20	310810	4.2853E-18	320810	6.9267E-16
3	330810	4.2325E-15	340810	1.6020E-13	340811	1.2017E-14	350810	6.2046E-09
3	360810	1.0899E-14	360811	1.9023E-21	300820	2.6983E-21	310820	3.7326E-19
3	320820	2.5572E-16	330820	2.1073E-15	330821	5.8147E-16	340820	8.9360E-09
3	350820	1.5831E-12	350821	1.8078E-15	360820	2.7836E-10	300830	1.6220E-22
3	310830	1.0437E-19	320830	7.4451E-17	330830	2.2077E-15	340830	1.6605E-13
3	340831	1.1898E-14	350830	2.6037E-12	360830	1.0872E-08	360831	1.9972E-12
3	310840	1.1297E-20	320840	2.0258E-17	330840	8.1840E-16	340840	9.1245E-14
3	350840	9.2607E-13	350841	9.0799E-15	360840	2.7108E-08	320850	8.4030E-19
3	330850	1.4991E-16	340850	9.5226E-15	340851	3.4895E-15	350850	9.6972E-14
3	360850	5.6042E-09	360851	9.2199E-12	370850	2.2090E-08	320860	1.8233E-19
3	330860	3.3914E-17	340860	7.3283E-15	350860	2.0970E-14	350861	1.7167E-15
3	360860	4.1453E-08	370860	5.7319E-12	370861	3.4075E-17	380860	8.1930E-11
3	320870	1.1074E-20	330870	4.6136E-18	340870	2.1796E-15	350870	4.8515E-14
3	360870	4.7259E-12	370870	5.1998E-08	380870	9.7469E-13	380871	1.6008E-16
3	320880	7.4832E-22	330880	2.8646E-19	340880	2.2654E-16	350880	1.3669E-14
3	360880	1.4744E-11	370880	1.5755E-12	380880	7.3130E-08	330890	3.3286E-20
3	340890	1.9311E-17	350890	2.3314E-15	360890	3.1679E-13	370890	1.6895E-12
3	380890	8.1723E-09	390890	8.4827E-08	390891	3.4605E-20	340900	7.0472E-18
3	350900	4.7803E-16	360900	5.2841E-14	370900	2.6725E-13	370901	1.2158E-13

3	380900	1.0873E-07	390900	2.8714E-11	390901	7.0515E-16	400900	3.2370E-09
3	400901	2.2647E-22	340910	4.4887E-19	350910	7.2756E-17	360910	1.0676E-14
3	370910	1.3550E-13	380910	8.8063E-11	390910	1.3030E-08	390911	4.4615E-12
3	400910	1.1098E-07	340920	4.4125E-20	350920	6.8528E-18	360920	1.2632E-15
3	370920	9.4894E-15	380920	2.9086E-11	390920	3.8245E-11	400920	1.4007E-07
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3	390930	1.3530E-10	400930	1.6538E-07	410930	1.2415E-14	410931	8.1083E-14
3	350940	3.5772E-20	360940	1.6047E-17	370940	2.4563E-15	380940	2.6238E-13
3	390940	4.4684E-12	400940	1.7375E-07	410940	3.3909E-13	410941	1.8305E-18
3	350950	3.8595E-21	360950	8.9241E-18	370950	1.5933E-16	380950	8.4326E-14
3	390950	2.7501E-12	400950	2.4212E-08	410950	1.3067E-08	410951	9.9162E-12
3	420950	1.4779E-07	350960	1.4737E-22	360960	1.1902E-18	370960	3.1425E-17
3	380960	9.0385E-15	390960	5.7700E-13	400960	1.9603E-07	410960	8.8016E-13
3	420960	6.7485E-09	360970	2.7166E-20	370970	5.1274E-18	380970	2.4452E-16
3	390970	4.0717E-15	400970	2.9399E-10	410970	2.1146E-11	410971	2.7509E-13
3	420970	2.0117E-07	360980	4.7291E-21	370980	1.0687E-18	380980	4.2945E-16
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3	420980	2.1246E-07	370990	6.1023E-20	380990	8.5874E-17	390990	1.2117E-15
3	400990	1.1877E-14	410990	7.4283E-14	410991	3.8499E-14	420990	1.3020E-09
3	430990	2.0090E-07	430991	1.0396E-10	440990	6.8569E-13	371000	7.6581E-21
3	381000	3.3856E-17	391000	5.2073E-16	401000	3.2160E-14	411000	7.0548E-15
3	411001	7.0842E-15	421000	2.4119E-07	431000	1.5806E-14	441000	2.1451E-08
3	381010	1.1840E-18	391010	2.2349E-16	401010	9.5274E-15	411010	3.4656E-14
3	421010	4.7109E-12	431010	4.5773E-12	441010	2.0698E-07	381020	1.9028E-19
3	391020	1.6741E-17	401020	4.8866E-14	411020	1.3100E-14	421020	3.5876E-12
3	431020	2.8485E-14	431021	2.0236E-15	441020	2.1614E-07	381030	2.2291E-21
3	391030	3.5957E-18	401030	1.2075E-15	411030	5.0289E-14	421030	3.3386E-13
3	431030	2.8319E-13	441030	1.8944E-08	451030	1.3308E-07	451031	1.6929E-11
3	381040	1.3621E-22	391040	1.4086E-19	401040	6.8087E-16	411040	1.6566E-15
3	421040	4.5572E-13	431040	5.5701E-12	441040	1.8472E-07	451040	1.2166E-13
3	451041	5.3755E-14	461040	6.0199E-08	391050	8.0633E-21	401050	1.3806E-17
3	411050	1.0585E-15	421050	1.9018E-13	431050	2.1037E-12	441050	7.1196E-11
3	451050	5.1418E-10	451051	5.6139E-14	461050	1.3816E-07	401060	2.3352E-18
3	411060	8.1458E-17	421060	1.7799E-14	431060	1.1979E-13	441060	7.1201E-08
3	451060	7.5478E-14	451061	1.0422E-12	461060	7.1008E-08	391070	1.9796E-24
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3	441070	7.0508E-13	451070	3.6614E-12	461070	8.9950E-08	461071	6.0668E-18
3	471070	8.3984E-15	401080	1.6101E-20	411080	1.1387E-18	421080	3.1048E-16
3	431080	5.5585E-15	441080	5.2741E-13	451080	3.3128E-14	451081	6.5660E-15
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3	401090	4.1035E-22	411090	2.9546E-19	421090	6.7767E-17	431090	2.4947E-14
3	441090	4.2118E-14	451090	1.1293E-13	451091	3.1370E-14	461090	7.2766E-11
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3	411100	1.4736E-20	421100	2.4517E-17	431100	9.9634E-17	441100	8.3700E-15
3	451100	1.6366E-14	451101	1.2374E-16	461100	2.0036E-08	471100	1.6580E-14
3	471101	3.8260E-10	481100	1.3236E-08	411110	1.5563E-21	421110	1.0424E-18
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3	461111	9.5337E-14	471110	2.0652E-10	471111	2.0584E-14	481110	1.0599E-08
3	481111	3.5080E-16	421120	3.3493E-19	431120	4.5192E-18	441120	6.6463E-17
3	451120	7.1348E-16	461120	1.1772E-11	471120	1.8388E-12	481120	6.2290E-09
3	421130	6.8093E-21	431130	1.5390E-18	441130	1.3836E-16	451130	9.4139E-17
3	461130	1.1344E-14	471130	2.1680E-12	471131	8.4373E-16	481130	5.8733E-11
3	481131	9.4828E-11	491130	3.9021E-12	491131	1.1283E-22	421140	1.1351E-21
3	431140	1.3057E-19	441140	1.1261E-16	451140	9.9720E-17	461140	1.2128E-14
3	471140	3.8609E-16	481140	7.9683E-09	491140	1.6985E-18	491141	3.8751E-14
3	501140	3.2517E-13	421150	2.7433E-23	431150	3.5380E-20	441150	7.6644E-18
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3	501150	1.1058E-10	431160	1.0466E-21	441160	3.2990E-18	451160	1.7521E-17
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3	471171	1.7031E-16	481170	3.9925E-13	481171	2.8404E-13	491170	1.0409E-13
3	491171	3.4838E-13	501170	2.7412E-09	501171	4.3181E-13	441180	1.4316E-18
3	451180	5.3412E-18	461180	1.3695E-16	471180	1.5577E-16	471181	8.3063E-17
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3	451190	6.5215E-19	461190	5.6112E-17	471190	3.5933E-16	481190	1.8167E-14
3	491191	6.1846E-15	491190	2.7806E-15	491191	5.2199E-14	501190	2.6674E-09
3	501191	1.8890E-11	441200	1.4247E-22	451200	3.5776E-20	461200	5.2625E-17
3	471200	4.8126E-17	481200	3.2093E-15	491200	1.4317E-15	491201	9.9315E-17
3	501200	2.7019E-09	451210	7.7083E-21	461210	3.0210E-18	471210	8.6605E-17
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3	501211	1.0614E-12	511210	2.6049E-09	451220	4.4482E-22	461220	1.8969E-18
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3	501271	3.1205E-14	511270	1.3993E-10	521270	1.3972E-11	521271	5.0609E-10
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3	521291	4.8527E-10	531290	4.3523E-08	541290	3.8547E-12	541291	1.3507E-14
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3	511301	5.8963E-13	521300	8.0388E-08	531300	5.2479E-12	531301	2.5362E-14
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3	511330	2.2824E-13	521330	2.7151E-12	521331	6.6510E-12	531330	4.5911E-10
3	531331	1.9955E-15	541330	2.7600E-09	541331	3.7446E-11	551330	2.1876E-07
3	491340	5.0103E-21	501340	2.1132E-17	511340	3.4086E-15	511341	3.0480E-15
3	521340	1.1325E-11	531340	2.0939E-11	531341	1.7439E-13	541340	2.7598E-07
3	541341	1.6688E-17	551340	2.1140E-08	551341	1.3518E-12	561340	5.4295E-09
3	501350	8.1707E-19	511350	2.5635E-16	521350	4.7808E-14	531350	1.3711E-10
3	541350	3.9573E-11	541351	1.1882E-12	551350	5.6878E-08	551351	2.2086E-13
3	561350	3.2020E-11	561351	1.7769E-14	501360	1.0928E-19	511360	7.5498E-18
3	521360	2.6075E-14	531360	2.2404E-13	531361	7.0443E-14	541360	4.4956E-07
3	551360	1.5576E-10	561360	3.8467E-09	561361	6.9841E-18	511370	1.6030E-18
3	521370	1.3581E-15	531370	6.1565E-14	541370	1.2195E-12	551370	2.2684E-07
3	561370	5.5554E-09	561371	3.4837E-14	511380	9.7361E-20	521380	1.6627E-16
3	531380	7.7878E-15	541380	4.0107E-12	551380	1.0272E-11	551381	4.9460E-14
3	561380	2.2311E-07	571380	6.5250E-13	511390	9.6797E-21	521390	8.8725E-18
3	531390	1.2818E-15	541390	1.4202E-13	551390	2.8392E-12	561390	2.6067E-11
3	571390	2.1389E-07	521400	2.0263E-18	531400	1.2432E-16	541400	3.0332E-14
3	551400	2.8819E-13	561400	5.5743E-09	571400	7.5144E-10	581400	2.1084E-07
3	521410	2.9843E-20	531410	1.0222E-17	541410	1.3897E-15	551410	8.2176E-14
3	561410	5.1950E-12	571410	6.7437E-11	581410	1.3272E-08	591410	1.8033E-07
3	521420	7.2760E-21	531420	8.8091E-19	541420	3.4695E-16	551420	3.2621E-15
3	561420	2.8240E-12	571420	2.5148E-11	581420	1.8969E-07	591420	1.2810E-11
3	591421	3.3308E-14	601420	3.7197E-09	531430	1.0395E-19	541430	1.5780E-17
3	551430	1.4967E-15	561430	5.0914E-14	571430	3.5082E-12	581430	4.9866E-10
3	591430	4.7958E-09	601430	1.2669E-07	531440	3.5886E-21	541440	1.0041E-17
3	551440	3.0845E-16	561440	2.9774E-14	571440	1.4451E-13	581440	7.0736E-08
3	591440	3.0198E-12	591441	1.4953E-14	601440	1.3222E-07	541450	1.1614E-18
3	551450	4.3865E-17	561450	9.1045E-15	571450	7.8288E-14	581450	5.2585E-13
3	591450	6.2926E-11	601450	1.1122E-07	541460	7.5951E-20	551460	2.3353E-18
3	561460	1.2501E-15	571460	1.5024E-14	581460	2.0520E-12	591460	3.5129E-12
3	601460	1.1272E-07	541470	1.9709E-21	551470	1.2608E-18	561470	3.1176E-16
3	571470	9.0589E-15	581470	1.3258E-13	591470	1.4042E-12	601470	1.8597E-09
3	611470	2.7679E-08	621470	8.6113E-09	551480	3.0795E-20	561480	1.6142E-16
3	571480	4.6377E-16	581480	6.1539E-14	591480	2.2091E-13	601480	6.4930E-08
3	611480	3.4067E-10	611481	2.6485E-10	621480	2.5152E-08	561490	3.0984E-18

3	571490	2.7344E-16	581490	8.2399E-16	591490	1.6119E-13	601490	7.6048E-12
3	611490	3.5064E-10	621490	4.7421E-10	551500	1.8388E-23	561500	4.7016E-19
3	571500	1.2690E-17	581500	4.0761E-16	591500	1.0327E-14	601500	3.5210E-08
3	611500	2.5391E-13	621500	5.6045E-08	571510	2.5018E-18	581510	1.2709E-16
3	591510	1.9102E-15	601510	5.2739E-13	611510	7.2499E-11	621510	2.8910E-09
3	631510	1.9376E-12	561520	5.4625E-22	571520	9.5935E-20	581520	4.0791E-16
3	591520	1.8058E-15	601520	3.5140E-13	611520	1.2880E-13	611521	4.5956E-15
3	621520	2.7818E-08	631520	6.3289E-12	631521	9.1927E-15	641520	2.0884E-12
3	571530	1.4480E-20	581530	9.3754E-18	591530	5.5427E-16	601530	2.0631E-14
3	611530	1.1288E-13	621530	2.5054E-10	631530	2.2026E-08	641530	2.3113E-12
3	571540	2.7033E-22	581540	2.3335E-18	591540	2.3640E-17	601540	1.1659E-10
3	611540	3.5977E-14	611541	3.8988E-15	621540	8.8639E-09	631540	7.3955E-09
3	641540	4.0107E-10	581550	5.4101E-20	591550	7.0738E-18	601550	1.7544E-15
3	611550	4.9744E-15	621550	2.1273E-13	631550	2.8133E-09	641551	4.6259E-23
3	641550	1.4698E-11	581560	8.3860E-21	591560	3.6985E-19	601560	1.4911E-15
3	611560	1.0393E-15	621560	3.5786E-12	631560	7.9881E-10	641560	1.2302E-08
3	581570	2.0245E-22	591570	7.4946E-20	601570	3.0386E-17	611570	2.6792E-15
3	621570	3.4185E-14	631570	5.7261E-12	641570	2.0449E-11	591580	2.1135E-21
3	601580	8.8356E-18	611580	4.9459E-17	621580	1.0369E-13	631580	1.1584E-13
3	641580	4.7078E-09	591590	9.7908E-23	601590	1.5479E-19	611590	1.2718E-17
3	621590	3.0635E-15	631590	2.4814E-14	641590	1.8944E-12	651590	7.1791E-10
3	601600	1.6555E-20	611600	4.7667E-19	621600	2.3759E-15	631600	5.3189E-16
3	641600	3.5259E-10	651600	2.4790E-11	661600	4.9790E-11	601610	3.0989E-22
3	611610	6.7341E-20	621610	2.4124E-17	631610	1.9108E-16	641610	1.1729E-15
3	651610	3.7422E-12	661610	1.1276E-10	611620	9.6721E-22	621620	4.6310E-18
3	631620	3.5319E-16	641620	1.4307E-15	651620	1.0582E-15	651621	5.7851E-16
3	661620	1.0220E-10	621630	6.6846E-20	631630	4.4953E-18	641630	8.8163E-17
3	651630	1.2003E-15	661630	7.9555E-11	621640	9.4416E-21	631640	1.2986E-19
3	641640	4.8451E-16	651640	8.3147E-17	661640	1.1978E-11	621650	1.2625E-22
3	631650	2.3542E-20	641650	1.2411E-17	651650	6.6142E-18	661650	1.9862E-14
3	661651	7.3537E-17	671650	3.8394E-11	661660	4.2216E-14	671660	6.5492E-14
3	671661	3.8108E-13	681660	1.2171E-11	681670	8.2359E-13	681671	3.3573E-20
3	681680	2.1832E-12	681690	9.7999E-16	691690	1.3866E-14	681700	3.2558E-18
3	691700	2.2523E-15	701700	2.1507E-15	681710	4.4639E-23	691710	2.0464E-16
3	701710	1.1074E-16	681720	1.0361E-25	691720	8.4536E-20	701720	8.4733E-18
0		0.0	0.0	0.0				

ORIGEN2: A VERSATILE COMPUTER CODE FOR CALCULATING THE NUCLIDE COMPOSITIONS AND CHARACTERISTICS OF NUCLEAR MATERIALS

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ORIGEN2 is a versatile point-depletion and radioactive-decay computer code for use in simulating nuclear fuel cycles and calculating the nuclide compositions and characteristics of materials contained therein. It represents a revision and update of the original ORIGEN computer code, which was developed at the Oak Ridge National Laboratory (ORNL) and distributed worldwide beginning in the early 1970s. Included in ORIGEN2 are provisions for incorporating data generated by more sophisticated reactor physics codes, a free-format input, and a highly flexible and controllable output; with these features, ORIGEN2 has the capability for simulating a wide variety of fuel cycle flow sheets.

The decay, cross-section, fission product yield, and photon emission data bases employed by ORIGEN2 have been extensively updated, and the list of reactors that can be simulated includes pressurized water reactors, boiling water reactors, liquid-metal fast breeder reactors, and Canada deuterium uranium reactors. A number of verification activities have been undertaken, including (a) comparison of ORIGEN2 decay heat results with both calculated and experimental values, and (b) comparison of predicted spent fuel compositions with measured values. The agreement between ORIGEN2 and the comparison bases is generally very good. Future work concerning ORIGEN2 will involve continued maintenance and user support along with additional verification studies and limited modifications to enhance its flexibility and usability. ORIGEN2 can be obtained, free of charge, from the ORNL Radiation Shielding Information Center.

INTRODUCTION

A wide variety of computer codes are now available for calculating the nuclide composition of nuclear reactor fuels during irradiation. Many of these codes are complex and highly developed, involving the use of multiple-energy-group neutron spectra and cross sections to calculate the composition of the nuclear fuel as a function of both space and time. On the other hand, these codes are incomplete in that they only calculate the amounts of a limited number of nuclides known to be significant in the cases of interest. While it might appear that such an approach could cause problems, the selection of the nuclides included in the calculation has been refined to the point that the codes are more than adequate to accomplish the tasks for which they were intended: the design, heat transfer analysis, and fuel management of nuclear reactors.

However, there is an entirely different class of problems for which these reactor physics codes are inappropriate because they are cumbersome, expensive to use, and provide too little detail concerning the composition of the material of interest. Although this class of problems lies principally in the domain of the out-of-reactor fuel cycle, it also encompasses some aspects of the analysis of potential reactor accidents. The principal requirements of a reactor physics code for this class of problems are that (a) it provide ample information concerning the composition of nuclear materials, and (b) it have the capability for determining the principal characteristics of the nuclear materials (e.g., radioactive decay heat, neutron emission). The neutronics calculation in this type of code need only be sophisticated enough to accurately determine the composition of the nuclear material of interest.

In this country, ORIGEN (Ref. 1) and ORIGEN2 (Ref. 2) are the most widely used computer codes for addressing this class of problems. The ORIGEN code was written at Oak Ridge National Laboratory (ORNL) in the late 1960s and early 1970s by Bell and Nichols as a versatile tool for calculating the buildup and decay of nuclides in nuclear materials. At that time, the required nuclear data bases (decay, cross-section/fission product yield, and photon) and reactor models [UO_2 or $(U,Pu)O_2$ pressurized water reactors (PWRs), liquid-metal fast breeder reactor (LMFBR), high-temperature gas-cooled reactor (HTGR), and molten-salt breeder reactor] were also developed based on the then-available information. ORIGEN was principally intended for use in generating spent fuel and waste characteristics (composition, thermal power, etc.) that would form the basis for the study and design of fuel reprocessing plants, spent fuel shipping casks, waste treatment and disposal facilities, and waste shipping casks. Since these fuel cycle operations were being examined generically, and thus were expected to encompass a wide range of fuel characteristics, it was only necessary that the ORIGEN calculations be representative of this range. Satisfactory results were obtained by using decay and photon data from the *Table of Isotopes*,[3] tabulated thermal cross sections and resonance integrals,[4] and chain fission product yields.[5] The resonance integrals of the principal fissile and fertile species were adjusted to obtain agreement with experimental values and more sophisticated calculations.

ORIGEN rapidly gained popularity because of its relative simplicity and convenient detailed output. About 200 organizations acquired it through the ORNL Radiation Shielding Information Center; an unknown number obtained it from other users. Some of these organizations began using ORIGEN for applications that required calculations with greater precision and specificity than those for which it had originally been intended. An example of this is its use in environmental impact studies which required relatively precise calculations of minor isotopes such as ^{3}H, ^{14}C, ^{232}U, and $^{242,244}Cm$. The initial responses to these requirements were attempts to update specific aspects of ORIGEN and its data bases[6,7]; however, such efforts led to inconsistencies and a larger number of different data bases.

In an effort to remedy the problems described above, a concerted program was initiated in 1975 to update ORIGEN and its associated data bases and reactor models. The outgrowth of this program was the ORIGEN2 computer code, which has been acquired by 110 organizations since its release in September 1980.

One additional longstanding problem with the ORIGEN computer code was inadequate documentation for many of the more recent uses, particularly those involving regulatory proceedings. Thus, a special effort was made during the updating process to document all the data sources and calculational methods employed and to disseminate the results as widely as practicable. This paper is one of several approaches being used to achieve this dissemination goal, namely, by providing an overall description of the ORIGEN2 computer code for an audience of diverse interests and backgrounds.

FUNCTIONAL DESCRIPTION

ORIGEN2 is a flexible reactor physics code that provides various nuclear material characteristics in easily comprehensible form, and in a variety of useful engineering units, while employing a relatively unsophisticated neutronics calculation. The output is capable of displaying great detail concerning the contribution of each individual nuclide to the overall totals for each engineering unit (characteristic). The nuclides contained in the ORIGEN2 data bases have been divided into three segments: 130 actinides, 850 fission products, and 720 activation products (a total of 1700 nuclides). These segments are formed by aggregating the 1300 unique nuclides (300 stable) in the data bases since some nuclides appear in more than one segment.

ORIGEN2, which is written entirely in the FORTRAN language, was developed for and is maintained on large IBM computers such as the 360, 370, and 3033 series. However, it has also been implemented on the UNIVAC, CDC 7000 series, CRAY computers, and possibly others of which the author is unaware. The computer requirements are variable, depending on the size of the problem being analyzed; however, the largest problem normally considered by ORIGEN2 will require ~200 000 decimal words of core storage plus the typical complement of peripheral devices. A minimum case will require about one-third of the core storage of the maximum case. If core storage is a constraint, the size of the executable element can be reduced somewhat by making internal adjustments to ORIGEN2, which will not severely limit the user's flexibility. Execution times are difficult to characterize because of the variability in computer speed and the sizes of cases analyzed. However, on most modern computers, a typical case will require no more than a few minutes of central processor unit time.

The principal use of ORIGEN2 is to calculate the radionuclide composition and other related properties of nuclear materials. The characteristics that can be computed by ORIGEN2 are listed in Table I. Most of these can be presented on a fractional basis so that the total characteristic for all nuclides in a given segment is 1.0 (exceptions are the neutrons, photons, and elemental isotopic compositions). The materials

TABLE I

Nuclear Material Characteristics Computed by ORIGEN2

Parameter	Units[a]
Mass	g, g·atom
Fractional isotopic composition (each element)	Atomic fraction, weight fraction
Radioactivity	Ci, αCi
Thermal power	Watt of recoverable energy (excluding neutrinos)
Toxicity	
Radioactive and chemical ingestion	m^3 of water to dilute to acceptable levels
Radioactive inhalation	m^3 of air to dilute to acceptable levels
Neutronic	
Neutron absorption rate	n/s
Fission rate	fission/s
Neutron emission	
Spontaneous fission	n/s
(α,n)	n/s
Photon emission	
Number of photons in 18 energy groups	photon/s, MeV of photon/W of reactor power
Total heat	W, MeV/s

[a]All of these can be calculated on a fractional as well as an absolute basis except fractional isotopic composition, neutron emission, and photon emission.

most commonly characterized include spent reactor fuels, radioactive wastes [principally high-level waste (HLW)], recovered elements (e.g., uranium, plutonium), uranium ore and mill tailings, and gaseous effluent streams (e.g., noble gases). However, materials such as water samples from the Three Mile Island Nuclear Power Station, Unit 2, irradiated research reactor targets, process streams in an HTGR fuel refabrication plant, and fallout from nuclear weapons have also been characterized.

The input structure for ORIGEN2 has been substantially changed as compared with that for ORIGEN. The ORIGEN2 input was designed for maximum flexibility with respect to simulating the situation being analyzed, while also being straightforward and simple to prepare. The method employed, in effect, has reduced the overall ORIGEN2 problem to a number of specific operations such as "read a data base," "input a composition," "output results," etc. Each of these is invoked by a single input card describing the type of operation and giving various parameters that define the details of the operation. Using these operations (there are currently 32), one can essentially define the flow sheet of the case to be analyzed no matter how complex it becomes. ORIGEN2 executes these operational commands sequentially as they are encountered in the input stream. The storage of intermediate and final nuclear material compositions in ORIGEN2 is indexed, and the user has detailed control over these compositions to the extent that they can be added together, multiplied by a constant, written to an output device, or "reprocessed" into multiple streams that can then be stored, printed, and/or further manipulated. The straightforward nature of the input results from the sequential execution of the input operational commands. The simplicity of the input results from the one-operation-per-card attribute and the free-format feature.

At this point, it is appropriate to describe the general sequence of the input and use this as a vehicle for defining more specifically the type of information required by ORIGEN2. Since the flexibility inherent in ORIGEN2 makes definition of a general case impossible, the description of the input will be based on the following hypothetical case:

> Calculate and output the thermal power (radioactive decay heat) and radioactivity of HLW that would result from the reprocessing of 1 metric ton of initial heavy metal (ton) of 33 GWd/ton spent PWR fuel for decay times between its generation and 1 million years.

The general sequence of operations that must be specified in the ORIGEN2 input to accomplish this calculation is as follows:

1. Read the appropriate radioactive decay, cross section (includes fission product yields), and photon data bases.

2. Read the composition of fresh PWR fuel, including trace impurities.

3. Irradiate the fresh fuel to a burnup of 33 GWd/ton, thereby generating the composition of the spent fuel.

4. Decay the spent fuel for a time corresponding to the lag time between discharge and reprocessing.

5. Employ the reprocessing operation to remove the recovered elements (uranium and plutonium), as well as certain other nuclides (noble gases, iodine, tritium), yielding the radionuclide composition of the HLW when generated.

6. Decay the HLW for various times ranging up to 1 million years.

7. Specify that the thermal power (watt) and the radioactivity (curie) of the material stored (i.e., the HLW) should be output.

It is important for the reader to recognize some of the more subtle aspects inherent in this process. That discussion follows.

In general, a single decay and photon data base will suffice for virtually all cases that would ever be considered. However, this does not hold true for the cross-section data since the effective cross sections of all nuclides, particularly the actinides, are generally a strong function of the type of reactor being considered and the concentrations of the nuclides. These effects can only be accounted for by sophisticated reactor physics codes, and it is by means of these codes that the cross sections supplied with ORIGEN2 were produced.

Determination of the composition of the input nuclear material can be one of the most vexing problems faced by the user. Although the concentrations of the major actinide nuclides (e.g., $^{235,238}U$, $^{239-242}Pu$) are generally well known, trace constituents are often parents of nuclides that are important in out-of-reactor situations. For example, the ^{14}C that is present in the spent fuel results from nitrogen impurities (ranging from essentially 0 to 100 ppm) in the fresh fuel. As a part of the information generated during the updating of the ORIGEN2 reactor models, detailed (but generic) compositions of both the fresh fuel and the fresh fuel assembly structural materials are given for each reactor type.

The irradiation is almost always accomplished by using a series of operations since a single operation results in unacceptably large numerical errors in the algorithms employed in ORIGEN2. A typical irradiation would require five to eight operations, although more can be used if the compositions at the intermediate burnups are of interest.

The postirradiation radioactive decay of the spent fuel is a rather trivial calculation, usually involving a single decay step. The reprocessing of the spent fuel to yield the HLW composition is also very simple if the user knows the processing recoveries (or losses) of the elements in the spent fuel. ORIGEN2 contains default values for these parameters, and provisions have been made for the user to substitute other values if desired.

The decay of the HLW is very similar to the irradiation of the fuel described above. It is necessary that multiple time steps be taken to prevent unacceptably large errors. However, this is not normally a problem when decaying radioactive materials since the objective is usually to obtain the time-dependent behavior of some characteristic and a number of intermediate time steps will be used anyway.

The final step in the calculation is to specify the characteristics desired in the output and call for the output to be generated. The internal storage of ORIGEN2 contains the nuclide composition of each material at each time step, in units of g·atom, in a large array. The output operation multiplies the g·atom of each nuclide by a factor which converts units to the desired characteristic (e.g., watts) for each time step and prints the result. The nuclide values are then totaled to obtain element totals. One of the primary functions of the decay and photon data bases is to supply the data necessary to generate the nuclide-dependent conversion factors (e.g., decay heat per decay).

A listing of the ORIGEN2 input that would have to be supplied by the user to accomplish the hypothetical calculation described above is given in Fig. 1. Comments have been included to indicate the various major portions of the input.

DESCRIPTION OF CALCULATIONAL METHODS

This section gives a narrative description of the calculational methods used in ORIGEN2. A detailed mathematical description of these methods is available elsewhere.[2]

As might be expected, most of the calculations carried out by ORIGEN2 are essentially trivial, involving reading and storing data bases, converting units from g·atom to other characteristic units, and writing the results to output devices. There are, however, two unique features of ORIGEN2 that require explanation: (a) the method for storing the equations that describe the buildup and decay of nuclides, and (b) the methods employed to solve these equations.

Before describing these features, we must briefly outline the problem being solved by ORIGEN2. In general, the rate at which the amount of nuclide i changes as a function of time ($= dX_i/dt$) is described by a nonhomogeneous first-order ordinary differential equation as follows:

$$\frac{dX_i}{dt} = \sum_{j=1}^{N} l_{ij}\lambda_j X_j + \phi \sum_{k=1}^{N} f_{ik}\sigma_k X_k - (\lambda_i + \phi\sigma_i + r_i)X_i + F_i \ , \quad i = 1, \ldots, N \ , \quad (1)$$

where

X_i = atom density of nuclide i

N = number of nuclides

l_{ij} = fraction of radioactive disintegration by other nuclides, which leads to formation of species i

λ_i = radioactive decay constant

ϕ = position- and energy-averaged neutron flux

f_{ik} = fraction of neutron absorption by other nuclides, which leads to formation of species i

σ_k = spectrum-averaged neutron absorption cross section of nuclide k

```
-1
-1
-1
RDA  SPECIFY WHICH DATA BASES ARE TO BE PRINTED
LIP  0 1 0
RDA  READ DECAY AND CROSS SECTION DATA BASES
LIB  0  1  2  3  204  205  206  9  3  0  1  1
RDA  READ PHOTON DATA BASE
PHO  101  102  103  10
RDA  SET BASIS FOR CALCULATION
BAS   ONE METRIC TON INITIAL HEAVY METAL
RDA  READ INITIAL FUEL COMPOSITION
INP  1  1  -1  -1  1  1
HED  1  CHARGE
RDA  BUP COMMANDS SURROUND BASIS IRRADIATION STEPS
BUP
RDA  IRRADIATE FUEL
IRP  100.0  37.5  1  2  4  2
IRP  300.0  37.5  2  3  4  0
IRP  500.0  37.5  3  4  4  0
IRP  700.0  37.5  4  5  4  0
IRP  880.0  37.5  5  6  4  0
BUP
RDA  DECAY OF FUEL OVER SHORT-TERM
DEC   60.0  6  7  4  1
DEC   90.0  7  8  4  0
DEC  120.0  8  9  4  0
DEC  150.0  9  10  4  0
DEC  180.0  10  11  4  0
DEC    1.0  11  12  5  0
RDA PRINT FUEL IRRADIATION AND DECAY RESULTS
TIT   IRRADIATION AND SHORT-TERM DECAY OF PWR-U FUEL
OPTL  4*8 1 8 1 17*8
OPTA  4*8 1 8 1 17*8
OPTF  4*8 1 8 1 17*8
OUT  12 1  -1  0
RDA  **  FUEL REPROCESSING
RDA    REMOVE VOLATILES FROM 150-DAY-OLD FUEL
PRO  10  -1  -2  -2
RDA    SEPARATE U/PU FROM HLW
PRO  -1 -3 1 -1
RDA    SEPARATE U AND PU
PRO  -3 -5 -6 -8
HED  1  '  HLW
RDA  DECAY HLW FOR ONE MILLION YEARS
DEC  0.5  4  2  5  1
DEC  1.0  2  3  5  0
DEC  5.0  3  4  5  0
DEC  10.0  4  5  5  0
DEC  100.0  5  6  5  0
DEC  300.0  6  7  5  0
DEC  1.0  7  8  7  0
DEC  10.0  8  9  7  0
DEC  100.0  9  10  7  0
DEC  300.0  10  11  7  0
DEC  1.0  11  12  8  0
RDA  PRINT HLW DECAY RESULTS
TIT   DECAY OF PWR-U HLW
OUT  12 1 -1 0
END
2   922340  290.0  922350 32000.0  922380  967710.0  0 0.0   FUEL ACTINIDES
4   030000  1.0    050000 1.0      060000  89.4      070000 25.0   FUEL IMPUR
4   080000 134454.0 090000 10.7    110000  15.0      120000  2.0   FUEL IMPUR
4   130000 16.7    140000 12.1     150000  35.0      170000  5.3   FUEL IMPUR
4   200000 2.0     220000 1.0      230000  3.0       240000  4.0   FUEL IMPUR
4   250000 1.7     260000 18.0     270000  1.0       280000  24.0  FUEL IMPUR
4   290000 1.0     300000 40.3     420000  10.0      470000  0.1   FUEL IMPUR
4   480000 25.0    490000 2.0      500000  4.0       640000  2.5   FUEL IMPUR
4   740000 2.0     820000 1.0      830000  0.4       0       0.0   FUEL IMPUR
0
```

Fig. 1. Sample ORIGEN2 input.

r_i = continuous removal rate of nuclide i from the system

F_i = continuous feed rate of nuclide i.

Since N nuclides are being considered, there are N equations of the same general form, one for each nuclide. Solution (integration) of this set of simultaneous differential equations by ORIGEN2 yields the amounts of each nuclide ($= X_i$) present at the end of each time step (integration interval).

Storage of Equation Coefficients

As is evident by inspection of Eq. (1), it is theoretically possible for each nuclide to be produced by all $(N - 1)$ of the other nuclides in the system being considered. This would require ~2.9 million decimal words of in-core storage capacity, which is well beyond the capacity of generally used computers. In reality, however, the average number of parents is normally <12. Thus, if a case is considering 1700 nuclides, then at least 1700 − 12 = 1688 of the coefficients of the X_j on the right side of Eq. (1) would be zeros and similarly for all other nuclides. The net result would be an extremely sparse 1700 × 1700 matrix of coefficients of the X_j (i.e., ~99.8% zeros). The sparseness of the matrix can be used to advantage by employing indexing techniques that store only the nonzero elements of the matrix.

This technique works in the following manner:

1. Input data containing the half-lives, decay branching fractions, cross sections, and fission product yields for each parent nuclide are read from data bases.

2. The daughter of each nuclear transformation (e.g., beta decay, neutron capture) is determined, and the transformation rate and identity of the daughter are stored temporarily in an array.

3. The temporary array is then searched to find all of the parents (X_j) of each daughter nuclide (X_i).

4. The transformation rate of each parent of daughter nuclide X_i and the identity of that parent are stored sequentially in one-dimensional floating-point and integer arrays, respectively, with the decay transformations being stored first.

5. Counters are maintained to indicate the array locations at which the transformations producing each daughter nuclide, X_i, begin and the number of the transformations that are decay transformations.

The floating-point array of transformation rates, called the transition matrix, is stored permanently since it is invariant for a given case. (Note that certain exceptions to this invariance are discussed below.) The transition matrix and its accompanying integer arrays use <20 000 decimal words of storage as compared with the 2.9 million that would be required to store the entire matrix.

Calculation of Flux and Power

After the transition matrix and its associated arrays have been established, it is possible to begin irradiation and decay calculations. The user specifies an initial composition of the material to be irradiated (e.g., fresh UO_2), the flux or power that it is to produce (for irradiation calculations only), and the length of the time step over which the flux, power, or radioactive decay is applicable. The composition of the material at the end of the irradiation step is then calculated in three general steps:

1. The transition matrix parameters that are time-step dependent are set.

2. The neutron flux is calculated from the power (or vice versa) and the transition matrix is adjusted accordingly.

3. The nuclide composition at the end of the time step is calculated using a complementary set of mathematical techniques.

These three steps are described in greater detail in the following.

In general, the transition matrix parameters (including fission product yields) are assumed to be constant for all time steps unless the entire transition matrix is regenerated. However, during the initial phases of the updating process that resulted in ORIGEN2, it was noted that the cross sections in the sophisticated reactor physics codes varied during irradiation as a result of changes in the nuclide concentrations or the neutron energy spectrum. These cross-section variations were particularly significant for the major actinide nuclides present in nuclear materials. As a result, the cross sections of the major actinide nuclides have been included in ORIGEN2 as a function of burnup. At the beginning of each time step, ORIGEN2 estimates the average nuclear material burnup for the time step, obtains the appropriate actinide cross sections by interpolation, and then substitutes these into the transition matrix.

A second area in which parameters were assumed to be constant in ORIGEN, but are now variable in ORIGEN2, concerns the fission product yields. Specifically, it had been assumed in the past that the fission products were only produced by a few actinide nuclides, such as $^{235,238}U$ and $^{239,241}Pu$, and that other actinides did not produce fission products even though they were fissioning. This assumption was necessitated because (a) fission product yields were not available for most actinides, and (b) a prohibitive amount of computer storage would have been required. The accuracy of this assumption, although very good for thermal reactors (within a few tenths of a percent), may be rather poor for fast reactors (i.e., LMFBRs) since a significant fraction of the fissions can come from nuclides that do not normally have fission product yields. The approach taken in ORIGEN2 to accommodate these fissions without using an excessive amount of storage was to

1. calculate the total fission rate from all actinides without explicit fission product yields
2. identify the nuclide that is the largest contributor to this fission rate
3. find the actinide having explicit fission product yields that is the nearest neighbor to this largest contributor
4. adjust the fission product yields of the nearest neighbor to account for the total number of fissions from actinides that do not have explicit yields.

This adjustment is performed for every irradiation time step since the relative fission rates can change significantly during a typical irradiation.

At this point, the transition matrix coefficients have been fully established and the next step is to calculate the flux or power. This calculation is relatively simple in concept but somewhat complex in practice. For the sake of clarity, let us assume that the power to be generated from the fuel is specified and that the flux must be calculated. The first approximation to this calculation is as follows:

$$\phi = \frac{6.242 \times 10^{18}\,(P)}{\sum_i X_i^f \sigma_i^f R_i} \quad , \tag{2}$$

where

ϕ = instantaneous neutron flux ($n \cdot cm^{-2} \cdot s^{-1}$)

P = power (MW)

X_i^f = amount of fissile nuclide i in fuel (g·atom)

σ_i^f = microscopic fission cross section for nuclide i (b)

R_i = recoverable energy per fission for nuclide i (MeV/fission).

The difficulty with this equation is that, since the amount of fissile nuclide i present is known only at the beginning of the time step, it gives the neutron flux at the beginning of the time step instead of the average neutron flux, which is the desired parameter. The approach taken in ORIGEN2 is to expand Eq. (2) in a Taylor series through the second-order terms with the fissile nuclide composition X_i^f as the time-dependent variable. The average neutron flux is then obtained by integrating this expansion over the length of the time step and dividing by the length of the time step. The average neutron flux for the current time step is subsequently divided by the average neutron flux for the previous time step (equal to 1.0 for the first time step). The resulting ratio is used to multiply all of the flux-dependent transformation rates in the transition matrix, thus adjusting them to the correct flux for the current time step.

Three additional points should be noted about the calculation of flux or power. The first is that the calculation of the average power over the time step, given the average neutron flux, is accomplished in a manner analogous to that described above for the converse case (i.e., by using an integrated Taylor series expansion to account for the composition change during the time step). However, the average power is used only for informational purposes since it is the flux that is employed in adjusting the transition matrix. The second point is that the parameter R_i, which is the recoverable energy per fission, is assumed to be a function of the fissioning nuclide in ORIGEN2 according to the following:

$$R_i\ (\text{MeV/fission}) = 1.29927 \times 10^{-3}(Z^2 A^{0.5}) + 33.12 \quad , \tag{3}$$

where Z and A are the atomic number and atomic mass, respectively, of the fissioning nuclide. Values calculated with this equation are within 1% of experimental data[8] for nuclides between ^{232}Th and ^{242}Pu. This approach represents a significant change from that employed in ORIGEN, which assumed a constant 200 MeV/fission for all fissioning nuclides, and was found to be necessary if the cross sections calculated by more sophisticated reactor physics codes were to be incorporated into ORIGEN2 data bases. Finally, the calculation of flux and/or power is unnecessary during the decay of nuclear material and therefore is not performed. The composition at the end of a time step is determined by using only the portions of the transition matrix that are independent of flux.

Solution of the Simultaneous Equations

The final step in the calculational procedure is to solve the system of simultaneous differential equations represented by the coefficients in the transition matrix. The method employed by ORIGEN2 is really a composite of three solution methods, the centerpiece of which is the matrix exponential technique for solving differential equations (described below). However, computational problems are encountered when the exponential technique is applied to a matrix with widely separated eigenvalues, which is certainly the case for ORIGEN2 since the coefficients in the matrix range from half-lives of seconds to billions of years. This difficulty can be circumvented by employing asymptotic versions of the analytical solutions to the nuclide buildup and depletion equations.

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The composite solution procedure begins with the implementation of a set of asymptotic solutions that is suitable for handling the buildup and decay of short-lived nuclides [i.e., nuclides with removal lives (= 1.0/total removal rate) <14.4% of the time step] that do not have long-lived precursors (e.g., most fission products). These nuclides will reach a constant concentration (equilibrium) within the time step; thus, the simple asymptotic solutions giving this value can be used to calculate their concentrations at the end of the time step.

The second phase of the composite solution begins with the generation of a reduced transition matrix, which is formed by including only the long-lived members of the full transition matrix. This reduced transition matrix is then solved for the concentrations of the long-lived nuclides by employing the matrix exponential method. In the homogeneous case (i.e., no continuous material feed), the system of equations that is being solved can be denoted by

$$\dot{\boldsymbol{X}} = \mathbf{A}\boldsymbol{X} \ , \tag{4}$$

where

$\dot{\boldsymbol{X}}$ = time derivative of the nuclide concentrations (a column vector)

$\mathbf{A}$ = transition matrix (full or reduced) containing the transformation rates (a 1700 × 1700 matrix largely filled with zeros)

$\boldsymbol{X}$ = nuclide concentrations (a column vector).

This equation has the solution

$$\boldsymbol{X}(t) = \exp(\mathbf{A}t)\boldsymbol{X}(0) \ , \tag{5}$$

where

$\boldsymbol{X}(t)$ = concentration of each nuclide at time t

$\boldsymbol{X}(0)$ = vector of initial nuclide concentrations

t = time at end of time step.

The matrix exponential method generates $\boldsymbol{X}(t)$ by using the series representation of the exponential function and incorporating enough terms so that the answer achieves the specified degree of accuracy. The calculation of the terms in the series is greatly facilitated by the use of a recursion relationship.

The final phase of the composite solution method involves using yet another set of asymptotic solutions to the differential equations to calculate the concentrations of short-lived nuclides which have long-lived parents. A Gauss-Seidel successive substitution algorithm is employed to solve the asymptotic solutions for this limited category of nuclides. At this point, the concentrations of all nuclides at the end of the time step have been calculated and stored. The results can either be output or used as the initial concentrations for the next time step.

INPUT DATA BASES

Three principal types of input data bases are required by the ORIGEN2 computer code: radioactive decay, photon production, and cross section. Each of these data bases is divided into three segments, as described earlier in the functional description of ORIGEN2. Only one or two of the segments may be required in a given case if they include the nuclides of interest. The following sections describe the function and content of each data base and the sources of the data.

Radioactive Decay Data Base

The decay data base[9] is required for all ORIGEN2 calculations. It supplies the following information:

1. the list of nuclides to be considered
2. the decay half-lives and the decay branching fractions for beta (negatron) decay to ground and excited states, positron plus electron capture decay to ground and excited states, internal transitions, alpha decay, spontaneous fission decay, and delayed neutron (beta plus neutron) decay
3. the recoverable heat per decay for each radioactive parent
4. the isotopic compositions of naturally occurring elements
5. the radionuclide maximum permissible concentration (MPC) values from Appendix B, Table II of Ref. 10.

The list of nuclides to be considered by ORIGEN2 is defined by six-digit nuclide identifiers in the decay library. The nuclide identifier is defined as

$$\text{NUCLID} = 10\,000{*}Z + 10{*}A + M \ ,$$

where

NUCLID = six-digit nuclide identifier

Z = atomic number of nuclide (1 to 99)

A = atomic mass of nuclide (integer)

M = state indicator, 0 = ground state, 1 = excited state.

The six-digit identifier for an element follows the pattern set by the nuclide identifier

$$\text{NELID} = 10\,000{*}Z \ ,$$

where NELID is the element identifier and Z is as described previously. The NUCLID or NELID terms are used to (a) identify information on the input records of the decay, photon, and cross-section libraries, (b) determine the masses used in specifying the input composition, and (c) supply atomic numbers and masses for internal use in ORIGEN2.

The half-lives and decay branching fractions are used to define the transformation rates in the transition matrix, as described previously. The recoverable-heat-per-decay values are employed in generating output tables, which give the decay heat produced by nuclear materials. Recoverable heat is defined as that heat which would be deposited within the nuclear material itself or a very large surrounding shield. Calculationally, it can be determined by subtracting the neutrino energy emitted during beta, positron, and electron capture decays from the energy difference between the parent and daughter states during decay. In the case of alpha and internal transition decays, the recoverable heat per decay is identical to the energy difference between nuclear states. In the case of spontaneous fission, a constant 200 MeV of recoverable energy per fission is assumed. The decay data for 427 of the longer lived nuclides were obtained from the Evaluated Nuclear Structure Data File[11] (ENSDF) at ORNL. Data for the remaining radioactive nuclides (~600) were taken from ENDF/B-IV (Ref. 12).

The isotopic compositions of the naturally occurring elements are used by ORIGEN2 to determine the amount of each isotope that should be initially present in a nuclear material when the amount of an element is given. This is very convenient when specifying the amounts of structural materials (e.g., cladding) that are to be irradiated. The isotopic compositions were taken from Ref. 13.

As noted earlier, the MPC values in the ORIGEN2 decay data base were taken from 10CFR20 (Ref. 10). These values designate the maximum allowable concentration of each radionuclide in water or air, in units of curies per cubic metre water (or air). Although their absolute applicability to many situations is debatable, they do provide a consistent method for calculating the relative toxicity of a nuclear material. This toxicity is calculated by first dividing the radioactivity of each nuclide (in curies) by its MPC value (in curies per cubic metre), yielding the volume of water or air (in cubic metres) required to dilute the nuclide to its MPC value. A relative measure of the toxicity of the material and the contribution of each nuclide to that toxicity is then obtained by summing these dilution volumes. It is important to note that this toxicity does not account for any other pathway effects such as retardation due to sorption.

Photon Data Base

The photon data base[9] supplies the number of photons per decay in an 18-energy-group structure. These values are used to output a table giving the number of photons and the photon energy emission rate in 18 energy groups as a function of irradiation or decay time. They are also used to generate a summary table listing the principal nuclide contributors to each of the 18 energy groups. The types of photons that have been included in the data bases are gamma rays, x rays, conversion photons, (α,n) gamma rays, prompt and fission product gamma rays from spontaneous fission, and bremsstrahlung. Prompt gamma rays from fission and neutron capture are not included. The photon data were taken from ENSDF (Ref. 11).

At present, three photon data bases are available, depending on the type of bremsstrahlung (which is medium dependent) that is included. The first and second data bases include bremsstrahlung from a UO_2 matrix and an H_2O matrix, respectively; the third includes no bremsstrahlung. A master data base containing discrete gamma-ray and x-ray transitions and bremsstrahlung in a 70-energy-group structure is maintained at ORNL to facilitate the generation of photon data bases in alternative energy group structures.

Cross-Section Data Bases

The function of the cross-section data bases is to supply ORIGEN2 with cross sections and fission product yields. The types of cross sections normally included are (n,γ) to ground and excited states, $(n,2n)$ to ground and excited states, $(n,3n)$ and $(n,\text{fission})$ for the actinides, and (n,p) and (n,α) for the activation products and fission products. In addition, a separate mechanism has been incorporated into ORIGEN2 to accommodate any other flux-dependent reaction that is not included in this list [e.g., the $^{18}O(n,n'\alpha)^{14}C$ reaction]. Fission product yields have been included for fissions in ^{232}Th, $^{233,235,238}U$, and $^{239,241}Pu$. Yield values for ^{245}Cm and ^{249}Cf, which are included to facilitate some special types of calculations, are the same as those for ^{241}Pu since data for the transplutonium nuclides are not available in ENDF/B-IV.

There are a large number of possible cross-section data bases for the ORIGEN2 computer code since the one-group cross sections are highly reactor- and fuel-type specific. The types of reactors for which cross-section libraries are now available are as follows[14-18]:

1. uranium and U-Pu cycle PWRs and boiling water reactors (BWRs)
2. alternative fuel cycle (thorium-based fuels; extended burnup) PWRs
3. once-through Canada deuterium uranium reactors
4. U-Pu cycle LMFBRs
5. thorium cycle LMFBRs
6. Fast Flux Test Facility
7. Clinch River Breeder Reactor.

Calculation of the one-group cross sections is a complex process that is specific to the reactor type being considered and must be performed by sophisticated reactor physics codes external to ORIGEN2. In general, such calculations involve generation of multiple-energy-group (27 to 127 energy groups) cross-section data bases.[19] These are then weighted with an approximate neutron spectrum, resulting in a few-group cross-section data base that accounts for self-shielding effects within the fuel rods. The few-group cross sections for the most important nuclides are subsequently used to perform a one- or two-dimensional depletion calculation, resulting in (a) a prediction of the composition of the spent fuel and (b) a set of burnup-dependent cross sections (discussed previously) that can be incorporated into ORIGEN2 to enable it to account for concentration and neutron spectrum changes. The composition predicted by the depletion code is used to generate a multigroup neutron energy spectrum, which becomes the weighting function to generate one-group cross sections and spectrum-weighted fission product yields for the ORIGEN2 cross-section data bases. This spectrum is also used to generate the ORIGEN2 flux parameters THERM, RES, and FAST, which are employed to weight thermal cross sections, resonance integrals, and threshold cross sections, respectively, when they cannot be obtained in multigroup format.

The multigroup cross sections were obtained from ENDF/B-IV (Ref. 12) and/or ENDF/B-V (Ref. 20), depending on the availability of data at the time the calculations were performed. Thermal cross sections and resonance integrals were taken from Ref. 21. Virtually all of the fission product yields are independent yields and were taken from ENDF/B-IV. The exceptions are the fission yields of the very light nuclides (e.g., tritium) that result from ternary (three-particle) fission, which were based on a search of the (sparse) literature.

ORIGEN2 RESULTS

This section gives a more specific description of the output produced by ORIGEN2. The information density of ORIGEN2 output is extremely high and can be very confusing to the uninitiated user. Therefore, we first provide a generic description of the organization of ORIGEN2 output, which is extremely hierarchical. Second, we describe, in detail, a single output page that epitomizes ORIGEN2 output. Finally, a short discussion of other types of output that have been made available is given.

Output Organization

The organization of the information produced by one ORIGEN2 output operation is summarized in Table II. This first level of output, henceforth called an "output grouping," contains the second, third, and fourth levels of the ORIGEN2 hierarchical output.

TABLE II

Organization of an ORIGEN2 Output Grouping*

Second Level	Third Level	Fourth Level
Reactivity and burnup data		
Activation product segment[a]	Table type 1 (e.g., g)	Nuclide, element, summary aggregations
	⋮	⋮
	Table type 24 (e.g., toxicity)	Nuclide, element, summary aggregations
Actinide segment[a]	Table type 1 (e.g., g)	Nuclide, element, summary aggregations
	⋮	⋮
	Table type 24 (e.g., toxicity)	Nuclide, element, summary aggregations
Fission product segment[a]	Table type 1 (e.g., g)	Nuclide, element, summary aggregations
	⋮	⋮
	Table type 24 (e.g., toxicity)	Nuclide, element, summary aggregations
Neutron production rate tables	(α,n); spontaneous fission	
Photon production rate tables	Activation products	Summation tables Principal contributor tables
	Actinides	Summation tables Principal contributor tables
	Fission products	Summation tables Principal contributor tables

*An output grouping is defined by a specific radioactive material to be characterized in the output. Multiple sequential output groupings are typical in ORIGEN2 output.

[a]The table types and aggregations to be printed are controlled by the user.

An output grouping can contain six second-level sections:

1. reactivity and burnup data
2. activation product segment
3. actinide segment (including daughters)
4. fission product segment
5. neutron emission rates
6. photon emission rates.

The reactivity and burnup data consist of less than one page of information summarizing the fluxes, burnups, specific power, and infinite multiplication factors for each of the columns (or vectors) being printed. (A vector gives the radionuclide composition or characteristics of a material at a point in time.) In addition, the information related to the size of the ORIGEN2 case is summarized here.

The activation product segment consists of the output of one or more (third-level) "table types" containing information for only the activation products. A table type is characterized by the units of the table, such as mass (in grams), radioactivity (in curies), thermal power (in watts), or neutron absorption rate (in neutrons per second). The table types that are available in ORIGEN2 are listed in Table I; the table types that are printed are controlled by the user. There are four possible (fourth-level) aggregations for each table type: nuclide, element, summary nuclide, and summary element. The aggregation(s) that are printed are also controlled by the user. The nuclide aggregation lists the specified characteristic of each nuclide in each of the vectors being printed. The element aggregation lists the specified characteristic for each chemical element in each of the vectors being printed. The summary aggregations contain the same type of information as the regular tables except that only those nuclides (or elements) that contribute more than a certain fraction (also under user control) to the total for all activation product isotopes are listed. It should be noted that some table types, such as fission rate and alpha radioactivity, are not applicable to activation and fission products and cannot be printed.

The actinide and fission product segments in Table II are very similar to the activation product segment described above; therefore, they will not be discussed in detail. The table types and aggregations printed for the actinides and the fission products are also controlled by the user.

The neutron production rate tables are relatively compact and straightforward. Each consists of a one-page listing of the neutron production rates from (α,n) reactions for each nuclide in each vector printed and a one-page listing of the neutron production rates from spontaneous fission for each nuclide in each vector printed. Both of these are "summary tables" since the contribution of each nuclide to the total is tested against a cutoff value to determine whether it will be printed.

The final second-level section of the output grouping contains the photon production rates. This segment is further broken down into three sections: activation product, actinide, and fission product. Since the photon production rate output for each of these sections is substantially in the same form, only the activation product section will be described in detail. The activation product photon output consists of summation tables and principal contributor tables. The summation tables list the photon production rates for each vector printed as a function of 18 photon energy groups; they are given in units of photons per second and mega-electron-volt per watt per second. The principal contributor tables list the photon production rates for each nuclide that contributes more than a specified fraction (i.e., a cutoff value set in the input) to the total photon production rate for each group.

Description of an Output Page

A typical ORIGEN2 output page is shown in Fig. 2. The page number, output unit number, and segment (i.e., activation product, actinide, or fission product) are given in the upper right corner. The page number is correlated with a table of contents that is printed by ORIGEN2.

Next, in the upper left center portion of the page, the following information is given:

1. title for this output (user specified)
2. average power (megawatts per basis unit), burnup (megawatt-days per basis unit), and flux (in neutrons per square centimetre per second)
3. segment (i.e., fission products)
4. aggregation (i.e., nuclide table)
5. table type (i.e., radioactivity, curies)
6. basis of the calculation
7. calculated results.

Below the output grouping basis (item 6 above), and spanning the entire page, are the vector headings. Unless altered, these headings will be the ending irradiation or decay times for each vector. Alphanumeric vector headings can be inserted and changed by the user.

The remainder of the output page is occupied by the main body of the ORIGEN2 output information. The leftmost column lists the nuclide (or element), while the remainder of the horizontal line gives the characteristic (i.e., grams) of that nuclide for each of the times or conditions of each vector.

Vector totals are presented at the end of each aggregation. Cumulative totals (e.g., total activation

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OUTPUT UNIT = 6 PAGE 54

*IRRADIATION AND SHORT-TERM DECAY OF PWR-U FUEL ← TITLE (OUTPUT GROUPING)

FISSION PRODUCTS ← SEGMENT

POWER= 3.75000E+01 MW, BURNUP= 3.30000E+04 MWD, FLUX= 3.24E+14 N/CM**2-SEC ← POWER / BURNUP / FLUX

AGGREGATION → 7 NUCLIDE TABLE: RADIOACTIVITY, CURIES ← TABLE TYPE

ONE METRIC TON INITIAL HEAVY METAL ← BASIS

CALCULATED RESULTS; IRRADIATION TIMES (100.0D – 880.0D); DECAY TIMES (60.0D – 1.0YR)

	CHARGE	100.0D	300.0D	500.0D	700.0D	880.0D	60.0D	90.0D	120.0D	150.0D	180.0D	1.0YR
XE143	0.0	1.905E+04	1.723E+04	1.643E+04	1.627E+04	1.638E+04	0.0	0.0	0.0	0.0	0.0	0.0
CS143	0.0	4.482E+05	3.947E+05	3.668E+05	3.384E+05	3.239E+05	0.0	0.0	0.0	0.0	0.0	0.0
BA143	0.0	1.576E+06	1.464E+06	1.381E+06	1.328E+06	1.296E+06	0.0	0.0	0.0	0.0	0.0	0.0
LA143	0.0	1.753E+06	1.633E+06	1.542E+06	1.482E+06	1.446E+06	0.0	0.0	0.0	0.0	0.0	0.0
CE143	0.0	1.761E+06	1.641E+06	1.550E+06	1.491E+06	1.456E+06	1.073E-07	2.901E-14	7.845E-21	2.121E-27	5.737E-34	0.0
PR143	0.0	1.720E+06	1.631E+06	1.540E+06	1.481E+06	1.445E+06	7.507E+04	1.621E+04	3.499E+03	7.555E+02	1.631E+02	1.263E-02
ND143	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I144	0.0	5.778E+00	5.753E+00	5.928E+00	6.303E+00	6.727E+00	0.0	0.0	0.0	0.0	0.0	0.0
XE144	0.0	3.094E+03	2.859E+03	2.782E+03	2.811E+03	2.881E+03	0.0	0.0	0.0	0.0	0.0	0.0
CS144	0.0	1.079E+05	9.986E+04	9.663E+04	9.524E+04	9.578E+04	0.0	0.0	0.0	0.0	0.0	0.0
BA144	0.0	1.250E+06	1.134E+06	1.054E+06	1.001E+06	9.672E+05	0.0	0.0	0.0	0.0	0.0	0.0
LA144	0.0	1.584E+06	1.458E+06	1.367E+06	1.307E+06	1.270E+06	0.0	0.0	0.0	0.0	0.0	0.0
CE144	0.0	3.535E+05	8.164E+05	1.069E+06	1.199E+06	1.255E+06	1.084E+06	1.008E+06	9.369E+05	8.708E+05	8.093E+05	5.152E+05
PR144	0.0	3.637E+05	8.264E+05	1.078E+06	1.209E+06	1.266E+06	1.084E+06	1.008E+06	9.369E+05	8.708E+05	8.094E+05	5.152E+05
PR144M	0.0	4.254E+03	9.811E+03	1.284E+04	1.440E+04	1.508E+04	1.301E+04	1.210E+04	1.124E+04	1.045E+04	9.712E+03	6.182E+03
ND144	0.0	2.132E-11	1.750E-10	4.320E-10	7.615E-10	1.104E-09	1.167E-09	1.195E-09	1.222E-09	1.246E-09	1.265E-09	1.378E-09
I145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE145	0.0	2.523E+02	2.600E+02	2.737E+02	2.961E+02	3.196E+02	0.0	0.0	0.0	0.0	0.0	0.0
CS145	0.0	2.655E+04	2.477E+04	2.354E+04	2.385E+04	2.408E+04	0.0	0.0	0.0	0.0	0.0	0.0
BA145	0.0	6.089E+05	5.616E+05	5.299E+05	5.112E+05	5.011E+05	0.0	0.0	0.0	0.0	0.0	0.0
LA145	0.0	1.109E+06	1.033E+06	9.781E+05	9.439E+05	9.246E+05	0.0	0.0	0.0	0.0	0.0	0.0
CE145	0.0	1.180E+06	1.106E+06	1.050E+06	1.016E+06	9.968E+05	0.0	0.0	0.0	0.0	0.0	0.0
PR145	0.0	1.181E+06	1.107E+06	1.051E+06	1.016E+06	9.972E+05	0.0	0.0	0.0	0.0	0.0	0.0
ND145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SM145	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
XE146	0.0	1.776E+01	1.762E+01	1.810E+01	1.918E+01	2.042E+01	0.0	0.0	0.0	0.0	0.0	0.0
CS146	0.0	3.632E+03	3.432E+03	3.378E+03	3.438E+03	3.537E+03	0.0	0.0	0.0	0.0	0.0	0.0
BA146	0.0	2.193E+05	2.022E+05	1.923E+05	1.879E+05	1.864E+05	0.0	0.0	0.0	0.0	0.0	0.0
LA146	0.0	7.065E+05	6.617E+05	6.308E+05	6.142E+05	6.064E+05	0.0	0.0	0.0	0.0	0.0	0.0
CE146	0.0	9.117E+05	8.649E+05	8.254E+05	8.102E+05	8.017E+05	0.0	0.0	0.0	0.0	0.0	0.0
PR146	0.0	9.145E+05	8.680E+05	8.326E+05	8.135E+05	8.050E+05	0.0	0.0	0.0	0.0	0.0	0.0
ND146	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM146	0.0	6.179E-02	5.901E-01	1.418E+00	2.402E+00	3.343E+00	3.275E+00	3.241E+00	3.208E+00	3.175E+00	3.142E+00	2.947E+00
SM146	0.0	2.625E-10	8.575E-09	3.641E-08	9.059E-08	1.643E-07	1.663E-07	1.673E-07	1.683E-07	1.692E-07	1.702E-07	1.758E-07
XE147	0.0	1.471E+00	1.497E+00	1.564E+00	1.681E+00	1.808E+00	0.0	0.0	0.0	0.0	0.0	0.0
CS147	0.0	5.325E+02	5.217E+02	5.294E+02	5.546E+02	5.849E+02	0.0	0.0	0.0	0.0	0.0	0.0
BA147	0.0	4.814E+04	4.480E+04	4.319E+04	4.289E+04	4.320E+04	0.0	0.0	0.0	0.0	0.0	0.0
LA147	0.0	3.371E+05	3.169E+05	3.041E+05	2.986E+05	2.970E+05	0.0	0.0	0.0	0.0	0.0	0.0
CE147	0.0	6.883E+05	6.588E+05	6.361E+05	6.256E+05	6.224E+05	0.0	0.0	0.0	0.0	0.0	0.0
PR147	0.0	7.051E+05	6.762E+05	6.535E+05	6.431E+05	6.401E+05	0.0	0.0	0.0	0.0	0.0	0.0
ND147	0.0	7.010E+05	6.725E+05	6.511E+05	6.420E+05	6.404E+05	1.492E+04	2.277E+03	3.473E+02	5.300E+01	8.086E+00	7.340E-05
PM147	0.0	3.774E+04	9.432E+04	1.269E+05	1.298E+05	1.295E+05	1.310E+05	1.283E+05	1.256E+05	1.229E+05	1.203E+05	1.052E+05
SM147	0.0	2.989E-08	2.726E-07	6.173E-07	9.671E-07	1.242E-06	1.382E-06	1.451E-06	1.519E-06	1.585E-06	1.650E-06	2.020E-06
CS148	0.0	3.219E+01	3.228E+01	3.336E+01	3.552E+01	3.793E+01	0.0	0.0	0.0	0.0	0.0	0.0
BA148	0.0	7.620E+03	7.306E+03	7.251E+03	7.424E+03	7.675E+03	0.0	0.0	0.0	0.0	0.0	0.0
LA148	0.0	1.209E+05	1.149E+05	1.117E+05	1.113E+05	1.121E+05	0.0	0.0	0.0	0.0	0.0	0.0
CE148	0.0	4.827E+05	4.688E+05	4.582E+05	4.561E+05	4.584E+05	0.0	0.0	0.0	0.0	0.0	0.0
PR148	0.0	5.333E+05	5.207E+05	5.102E+05	5.085E+05	5.115E+05	0.0	0.0	0.0	0.0	0.0	0.0
ND148	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM148	0.0	6.592E+04	1.696E+05	2.276E+05	2.614E+05	2.784E+05	7.080E+02	3.575E+02	2.146E+02	1.297E+02	7.837E+01	3.498E+00
PM148M	0.0	7.830E+03	1.986E+04	2.585E+04	2.821E+04	2.855E+04	1.043E+04	6.303E+03	3.809E+03	2.302E+03	1.351E+03	6.219E+01

Fig. 2. Sample ORIGEN2 output page.

product plus actinide plus fission product curies) for each vector are given at the end of each table type.

Other Types of Output

The results described above are typically output to paper[22]; however, there are several alternatives to this procedure. The first general class of alternatives involves different output media in the same format described above. Since ORIGEN2 can produce a large amount of output easily, and since paper is both expensive and cumbersome, one of the most desirable approaches is to output only the most commonly used results on paper and write a very detailed output to microfiche, which is both inexpensive and compact. Another output method that is often used involves a nonvisual medium such as magnetic tape or a direct-access storage device. Each of these offers the advantage of being repetitively searchable to make available only the desired information for a particular use (see below). In addition, magnetic tape is a very convenient method for transporting large volumes of output between sites.

The second general class of alternatives involves searching and manipulating the ORIGEN2 results so that they appear in a different format or so that only a particular piece of information is output. An example of this is a code written at ORNL that accesses ORIGEN2 output, distills and summarizes the results of interest to the user (e.g., the most important nuclides or a specific element), and outputs the result as a table or a plot on paper or film.[23]

APPLICATIONS OF ORIGEN2

As might be expected, the versatility of ORIGEN2 and its predecessors and their simplicity of use have encouraged users to apply them to a wide variety of situations. Some of these situations are described in the following.

One of the first applications of ORIGEN2, which is still very common today, involves using the output as a design basis for nuclear fuel cycle facilities and operations. The thermal power tables are used to determine the heating load in fuel pools, shipping casks, reprocessing plants, and waste repositories. The photon and neutron tables are used as the input to shielding design codes for postfission fuel cycle facilities. The composition of the fuel is used in the design of the separations processes in a fuel reprocessing plant.

A second application of ORIGEN2, which has become increasingly popular (and may be the most popular at present), involves its use in supplying the radionuclide composition of process or facility inventories for risk analyses. One major aspect of risk analyses is to define the materials that could be released by a postulated accident sequence. This release is usually specified as a certain fraction of each element present in the inventory. Thus, it is vital to know both the elemental and the nuclide compositions of the entire inventory of the facility or operation. Examples of this are the Reactor Safety Study[24] and the ORNL project to assess actinide partitioning-transmutation.[25]

A third use of ORIGEN2 involves employing the results of ORIGEN2 as the basis for projecting the composition and characteristics of radioactive wastes. For example, accumulated radioactivity of HLW at a point in the future from some nuclear power scenario is almost always based on the radioactivity calculations provided by ORIGEN or ORIGEN2. These codes have performed this function for many years at ORNL (e.g., Refs. 26 and 27) and continue to do so in an ongoing program that supplies waste inventories and projections to the U.S. Department of Energy[28,29] (DOE).

The final common use of ORIGEN2 is in support of nuclear power licensing and regulation. Both ORIGEN and ORIGEN2 have been used to supply or verify the material composition and characteristics that formed the basis for licensing fuel cycle facilities. In addition, ORIGEN or ORIGEN2 calculations formed the basis for regulatory efforts such as defining ALARA (e.g., Ref. 30), the GESMO study,[31] and waste management rulemaking by DOE (Refs. 32 and 33), the U.S. Environmental Protection Agency,[34] and the U.S. Nuclear Regulatory Commission[35,36] (NRC).

ORIGEN2 has also been employed in more uncommon applications that may require substantial code modifications or utilize only part of the code. One major class of these applications involves process simulation using the matrix-solution capabilities of ORIGEN2, particularly in cases where simultaneous mass transport and radioactive irradiation or decay calculations are needed. Examples of this type of application are as follows:

1. The ORIGEN code was modified by the NRC to produce the GALE computer codes,[37,38] which model the effluent releases from BWRs and PWRs.

2. ORIGEN2 (without modification) was used to calculate the composition and characteristics of all of the input, internal, and output streams in an HTGR fuel refabrication plant.

3. A modification of ORIGEN2 [called ORGENTRE (Ref. 39)], which is currently being used at ORNL, allows a more detailed simulation of the processes generating the wastes, thus providing the capability for process trade-off studies.

In a second class of uncommon applications, ORIGEN and ORIGEN2 are tied directly to more sophisticated reactor physics codes. The more sophisticated

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codes only account for a few nuclides but are capable of providing the neutron spectrum that can be used to generate one-group cross sections for ORIGEN2. ORIGEN2, in turn, provides the detail necessary in many safety-related aspects of reactor operation as well as an excellent composition for use in the next irradiation time step. It should be noted that the cross sections used in ORIGEN2 should be the result of a multidimensional depletion calculation and not a static spectrum calculation. Experience has shown that the latter method does not produce cross sections that are truly appropriate for the system being analyzed in thermal reactors; thus, the depletion code is necessary to account for all relevant effects.

VERIFICATION

Verification is a very important aspect of any computer code, particularly if it is to be used in licensing and other regulatory matters. With respect to ORIGEN2, the question that is being addressed is whether it will predict compositions and characteristics that conform to reality. Thus, the major prerequisite for any verification study is the availability of accurate measurements of well-characterized samples that can be used as a basis for comparison. The aspects of ORIGEN2 that are verifiable are the composition, thermal power, photon spectrum, and neutron emission rate of some specified nuclear material.

Unfortunately, very few adequate benchmarks exist for verification purposes, particularly in the case of modern light water reactors (LWRs). Virtually no measurements have been made of either photon spectra or neutron emission rates, and verification will be extremely difficult because of the dependence of measurements on self-shielding, geometry, and detector efficiency. The benchmark status with respect to the composition and thermal power is somewhat better since measurements have been made and documented. The problem in this instance is that many of the benchmarks are either too poorly characterized in a historical sense (initial composition, irradiation history) and/or the measurements were made using very inaccurate methods and are thus meaningless. However, a few comparisons have been made between ORIGEN2 and reasonably well-characterized benchmarks; these are summarized below.

The thermal power predicted by ORIGEN2 is an important parameter as well as being one that is relatively easy to benchmark. Two recent studies serve to indicate the accuracy of ORIGEN2 in this regard. The first study[9] compares the decay heat predictions of ORIGEN2 with those from the American Nuclear Society (ANS) decay heat standard[40]; the results are summarized in Fig. 3. This comparison is limited in that (a) it only applies to fission products, (b) neutron capture effects are excluded, and (c) the standard is based on calculated (not measured) results at decay times beyond ~1 day. A direct comparison yielded the top curve, which begins to deviate monotonically after ~1 month. Examination of the calculations upon which the ANS standard was based revealed an incorrect assumption in the ENDF/B-IV data base used for the standard (i.e., that ^{99}Tc was stable). A repeat of the calculation after the ORIGEN2 decay data base was altered to include the incorrect ENDF/B value yielded the bottom curve, which is within ±2% at decay times between ~20 s and 30 yr. The ORIGEN2 result is somewhat low at very short times because many of the very short-lived fission products have been combined with their daughters to conserve space in ORIGEN2.

A second, and somewhat more encompassing, verification of ORIGEN2 was conducted at Hanford Engineering Development Laboratory using spent fuel from the Turkey Point Unit 3 PWR (Ref. 41). The results from three separate fuel assemblies showed that ORIGEN2 overpredicted the decay heat by 5 to 6% at decay times between 2 and 3 yr, which is considered to be excellent agreement when the uncertainties in burnup and other parameters are taken into account. It is interesting to note that ORIGEN2 overpredicts decay heat on the actual spent fuel, whereas it underpredicts the ANS decay heat standard for the same time period.

Verification of the composition predictions made by ORIGEN2 is a very wide-ranging subject due to the large number of nuclides accommodated by the code. The assumption is generally made that most of the fission products will be accurate if the actinide buildup and depletion are correct because they are heavily dependent on the fission yields, which are relatively well known and do not vary substantially from case to case. For this reason, verification efforts have concentrated on the much more complex actinide region.

During the last few years, a substantial amount of work has been done to characterize LWR fuels. As a result, measurements have been made on three sets of samples that were irradiated to ~30 GWd/ton in commercial PWRs. Two sets of samples resulted from the discharges of the second and fourth cycles of Turkey Point Unit 3 reactor,[42-44] and the third set was obtained from the H. B. Robinson Unit 2 reactor.[45] Measurements for the Turkey Point samples included the ^{148}Nd/^{238}U ratio, which is indicative of fuel burnup. This ratio was matched by ORIGEN2 for each sample, and then the isotopic compositions of the uranium and plutonium were compared. A burnup monitor was not measured in the case of the H.B. Robinson samples, but the burnup was estimated to be 30 GWd/ton.

Results of the comparison for each of the groups of samples are presented in Tables III, IV, and V. Table III gives a comparison of the ORIGEN2 versus

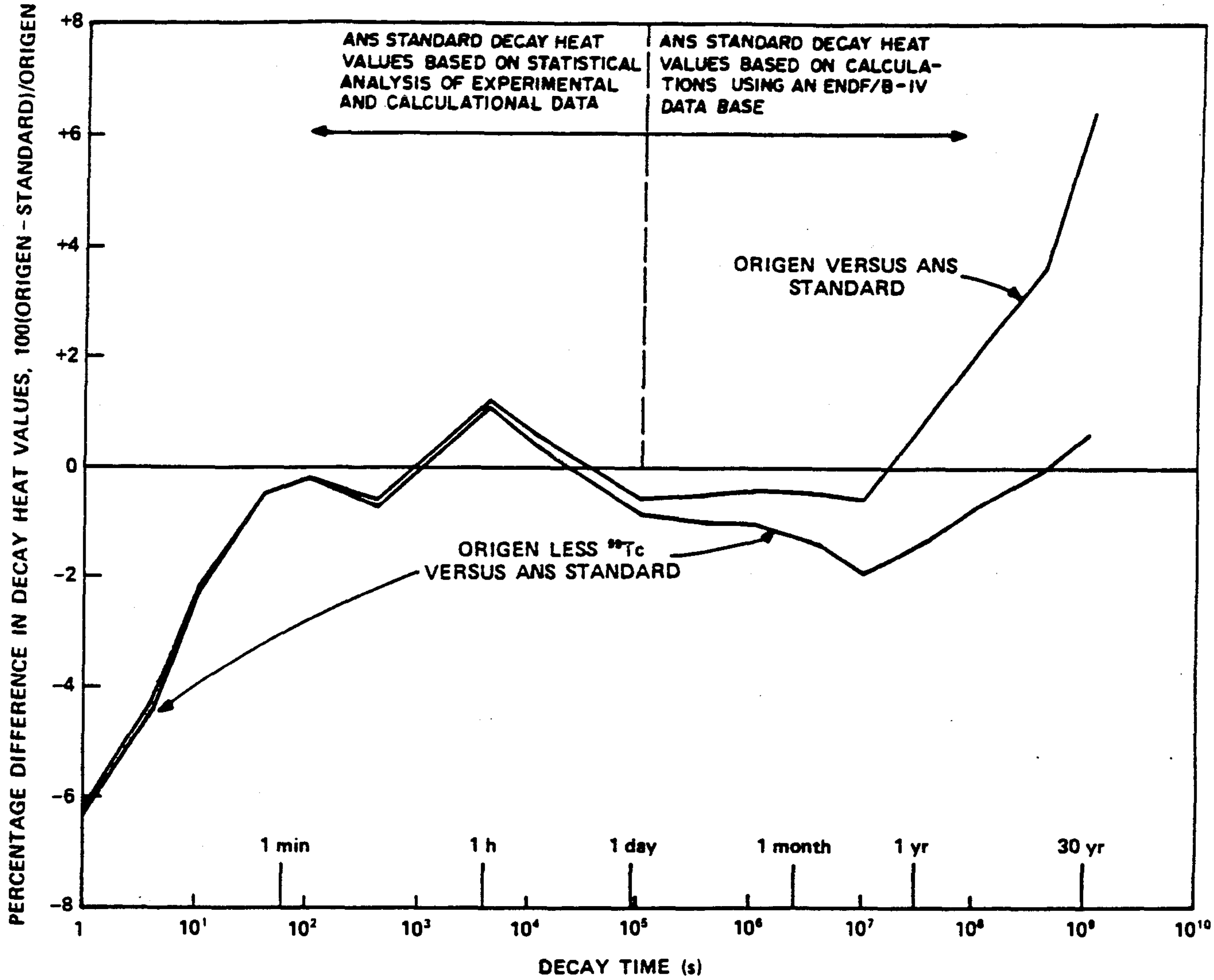

Fig. 3. Differences between ORIGEN2 and ANS Standard 5.1 decay heat values for 10^{13}-s irradiation of ^{235}U.

the experimental values of the uranium and plutonium isotopes for all three sets of samples. The Turkey Point sets are designated by B and D, according to the lot of fuel from which the assemblies were derived. As is evident, the overall agreement is quite good, particularly for the D set and for the H. B. Robinson fuel; however, a few significant differences and anomalies exist. The first is that ^{238}Pu is both significantly and consistently underpredicted by ORIGEN2. The exact source of this difference is unknown because experimental values for ^{237}Np are unavailable. The same type of discrepancy occurs for ^{242}Pu, and its source is also difficult to pinpoint since no information is available on the absolute amounts of americium and curium; thus, it is impossible to show whether the ^{242}Pu destruction rate is too high or its production rate is too low.

The agreement of the measured B set compositions with ORIGEN2 values is markedly worse than that for the other two sets. Although the reason for this is not apparent, internal inconsistencies are present in the measured B set compositions (i.e., differing isotopic analyses of samples taken from exactly symmetrical positions in a single fuel assembly). Thus, it would appear that the B set may not be a satisfactory benchmark.

Table IV shows the difference between ORIGEN2 calculations and experimental results concerning the H. B. Robinson americium and curium isotopic composition. The agreement is excellent when we consider the number of neutron captures required to form these nuclides and the complexity of the actinide calculations. The discrepancy in the ^{242}Cm value is not regarded as significant since an error in decay time of only 3 weeks can account for an 11% error in the isotopic composition. The difference

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TABLE III

Comparison of the Experimentally Determined Uranium and Plutonium Compositions of Spent Fuel with ORIGEN2 Calculations

Parameter	Difference Between Experimental and ORIGEN2 Uranium and Plutonium Parameters [(02 − EXP)/EXP, %][a]		
	Turkey Point		
	B Set	D Set	H. B. Robinson
$^{235}U/U$	7.7	−2.3	0.1
$^{236}U/U$	−4.3	−0.7	−3.2
$^{238}Pu/Pu$	−12.1	−4.0	−9.0
$^{239}Pu/Pu$	0.2	1.5	−0.4
$^{240}Pu/Pu$	−3.9	−1.7	1.2
$^{241}Pu/Pu$	14	0.9	1.8
$^{242}Pu/Pu$	−10	−7.6	−2.6
Total plutonium	2.6	2.1	
Burnup, GWd/ton	19.3 to 26.9	29.6 to 30.6	30
Cycles in reactor	1,2	2 to 4	1,2
Number of samples	8	5	1

[a]02 = ORIGEN2; EXP = experimental.

TABLE IV

Comparison of the Experimentally Determined Americium and Curium Compositions of Spent Fuel with ORIGEN2 Calculations for H. B. Robinson Fuel

Parameter	Difference in Experimental and ORIGEN2 Americium and Curium Parameters [(02 − EXP)/EXP, %][a]
$^{241}Am/Am$	−5.0
$^{242}Am/Am$	1.0
$^{243}Am/Am$	8.3
$^{242}Cm/Cm$	−11
$^{243}Cm/Cm$	5.0
$^{244}Cm/Cm$	1.3
$^{245}Cm/Cm$	−20
$^{246}Cm/Cm$	−3.8
$^{247}Cm/Cm$	0
$^{248}Cm/Cm$	Poor statistics

[a]02 = ORIGEN2; EXP = experimental.

TABLE V

Comparison of Experimentally Determined Noble Gas Compositions of Turkey Point D Spent Fuel with ORIGEN2 Calculations

Measured Parameter (at.%)	Average over Five Fuel Elements	
	Experimental	ORIGEN2
$^{82}Kr/Kr$	---	0.3
$^{83}Kr/Kr$	12.0	11.6
$^{84}Kr/Kr$	32.4	31.6
$^{85}Kr/Kr$	4.2	5.5
$^{86}Kr/Kr$	51.4	51.0
$^{130}Xe/Xe$	---	0.3
$^{131}Xe/Xe$	8.2	8.4
$^{132}Xe/Xe$	20.8	20.9
$^{134}Xe/Xe$	28.0	27.6
$^{136}Xe/Xe$	43.0	42.8

between the ORIGEN2 calculations and the experimental results for ^{245}Cm, on the other hand, is noteworthy. Since the capture products of ^{245}Cm are in good agreement, the difficulty probably stems from the evaluated fission cross section in the original data source.

Finally, Table V compares the isotopic compositions of the noble gases removed from the plenum of the D set fuel rods with those obtained by using ORIGEN2. Agreement is excellent in all cases, with the possible exception of the $^{85}Kr/Kr$ ratio, where the ORIGEN2 prediction is 31% higher than the experimental result. Since ^{85}Kr is the only radioactive isotope listed in Table V, we conclude that the noble gases were released to the plenum via fuel cracking that occurred during the first ascent to full power and that the 10.7-yr ^{85}Kr had a few extra years to decay to the lower level found in the experimental results. This hypothesis is supported by the fact that the experimentalists could only find 0.2% of the noble gases produced by fission in the plenum, indicating a short, one-time release.

FUTURE ACTIVITIES

As with any widely distributed and versatile computer code that uses data from many sources, the maintenance and support of ORIGEN2 are never-ending tasks. Specific work that will be undertaken in the future includes:

1. Maintenance and user support—keep data bases current with best available data and address users' questions concerning applications of ORIGEN2.

2. Implementation—perform generic calculations characterizing nuclear materials of interest to the nuclear community and publish the results in a readily accessible understandable form.

3. Verification—continue to compare ORIGEN2 calculations with all relevant benchmarks and develop additional benchmarks where none are available.

4. Modification and improvement—add new reactor models and software capabilities as required by the user community.

Through these activities, ORIGEN2 will remain a versatile tool for characterizing nuclear materials for both present and future applications.

AVAILABILITY

ORIGEN2 can be obtained, free of charge, by sending a magnetic tape to the ORNL Radiation Shielding Information Center.[a] The user will be supplied with the computer code, a user's manual,[46] all relevant data libraries, a sample input deck, and a sample output.

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C0196

MARTIN MARIETTA

Internal Correspondence

MARTIN MARIETTA ENERGY SYSTEMS, INC.

August 24, 1990

Debasish Mukherjee
216 Seneca St., Upper Apt.
Fulton, NY 13069

Dear Mr. Mukherjee:

I received your FAX concerning possible errors in equation (2) of Allen Croff's Nuclear Technology article (Vol. 62, September 1983, p. 341).

As far as I can determine, this is an error in the Nuclear Technology article. Fortunately, the value of 1.0365×10^{19} is used in SUBROUTINE FLUXO of the ORIGEN2 code. I cannot determine if this was ever an actual error in the ORIGEN2 code. I did, however, find that a similar problem was identified in the original ORIGEN code documentation back in 1981. In that case, the suspect equation used the macroscopic cross section, while the ORIGEN code used the microscopic cross section. This would account for the difference of 0.602.

What I believe may have happened is that the Nuclear Technology article may have listed "microscopic" for the cross section in Eq. 2 when in fact the "macroscopic" cross section was used. This may have been an error at the time, or an accidental change from an over-zealous editor.

Sincerely yours,

Scott B. Ludwig

Scott B. Ludwig, Project Manager
Chemical Technology Division

cc: SBL Files (POWER.ERR)
A. G. Croff
N. Hatmaker, RSIC, Bldg. 6025, MS-6362

C00371/ALLCP/02
READ.ME

Introducing: ORIGEN2 Version 2.1 (8-1-91) CCC-371 (A, E)
No new documentation was published for this release. This file and FILES.LST contain information on how to install and run this package. Please read this entire file.

Here's a version of ORIGEN2 for both MAINFRAME and 80386/80486 PC applications. Included on these DS/HD diskettes (in compressed mode) is the entire ORIGEN2 code package, including all the cross section libraries previously available only with the mainframe versions.

Enhancements: In this 1991 version, 5 LWR libraries documented in ORNL/TM-11018 were added to the package. Array sizes are set quite large in PARAMS.O2, including using 30 storage vectors instead of 10, so that ORIGEN2 can handle most any problem size. Finally, the distributed PC and Mainframe source codes ARE IDENTICAL. Running on other computers will likely require changes to date and time routines. See the README.UNX file for changes required on HP and DEC Alpha.

Limitations: 80386 and 80486 PCs require a coprocessor.

Installation: The package is distributed in a self-extracting compressed DOS file which is distributed on 2 diskettes. The compression was performed using the programs of PKware, Inc. See the INSTALL.BAT file on diskette 1 for installation information.

Execution: Sample problem batch files expect the ORIGEN2.1 executable to be in \ORIGEN2\CODE. If the default directory structure is altered, this path must be edited in the batch file.

Mainframe users will need to upload 3 files to compile and link the source code (ORIGEN2.FOR, HEADER.O2, and PARAMS.O2). The directory for SAMPLES (x:\ORIGEN2\SAMPLES) contains 3 sample problems run on the VAX at ORNL. The user will need to upload appropriate data files referred to in the *.COM (VAX command files), such as the DECAY.LIB, cross section, photon yield, and associated input files to the mainframe. Conversion to other mainframes should be fairly easy.

PC users should look at the *.BAT files included in the x:\ORIGEN2\SAMPLES\PCx directories (These samples are identical to those run on the VAX). Thanks to Lahey for the F77L-EM/32 compiler and to Rob Tayloe (Battelle Columbus) for his work on ORIGEN2 for 386/486 PCs.

ORIGEN2.1 uses filenames like "TAPE??.OUT" to connect files to logical units. The batch files rename the user's output files to SAMP_1.??? , where ??? is a more meaningful name (.PCH, .VXS, .DBG, or .ECH), which is defined in the FILES.LST file.

When an input error is encountered, Lahey-compiled executables open a file called F77L3.EER in an attempt to define the error message. This file is distributed in the ORIGEN2\CODE subdirectory. This subdir may be included in the path, or the file can be copied to the directory from which ORIGEN2 is run.

For more information, see x:\ORIGEN2\CODE\FILES.LST

************* Updates to ORIGEN2.1 *****************
In June 1996 the source was not modified, but the code was recompiled with Lahey F77L-EM/32 V5.10 to replace the Lahey F77 V4.00 executables, which were distributed with the original 1991 release of ORIGEN2.1. This was done because Lahey V4.00 is incompatible with Windows95. The 5.10 executables can be run in a DOS window of either Windows95, Windows98 or WindowsNT.

In the May 1999 update, the installation procedure was simplified; and files in the sample problems directories were reorganized so that the PC output generated at ORNL is distributed in a separate subdirectory for each test case (i.e., SAMPLES\PC?\OUT). The batch files will rename user output files so that users can compare their output with that from the developer. These changes are cosmetic; there were NO changes to the code, executable or data files. Tips for Unix users were added in README.UNX

Scott B. Ludwig
ORIGEN2 Code Coordinator
Oak Ridge National Laboratory
(423) 574-7916 FTS 624-7916
8-15-91

written by Scott Ludwig, ORNL 8-15-91
revised by RSICC 5-11-99

CCC-371/ORIGEN2.1
README.UNX
Notes added - May 1999

ORIGEN2.1 was installed on DEC Alpha OSF/1 and on HP running HP-UX 10.

The changes listed below solved most of the problems, but things like date and time routines were not polished. The date/time calls work some places but not in others, indicating that additional changes are required to find all the statements where date and time are called/written. Test case results differed somewhat from the distributed results.

Additional changes may be required on some systems.

DEC modifications to code:

```
************  Main routine ORIGEN2  *************

Add before DIMENSION DR
>       COMMON /CAW/MMDDYY,HHMMSS                                     CAW    10
Add after COMMON /MAIN03/
>       CHARACTER MMDDYY*9,HHMMSS*8                                   CAW    20


************  Unnamed BLOCK DATA  *************

Change
<       DATA NUCLB /-1,942380,942390,942400,942420,952410,962420,962440,-1BLK 1610
<      *    ,11*0/                                                    BLK 1620
to
>       DATA NUCLB /942380,942390,942400,942420,952410,962420,962440,-1   BLK 1610
>      *    ,12*0/                                                    BLK 1620


************  Subroutine IDENTIFY  *************

Change
<         CHARACTER*11 MMDDYY
to
>         COMMON /CAW/MMDDYY,HHMMSS
>         CHARACTER*9 MMDDYY
Change
<     10 FORMAT (' ORIGEN2 V2.1 (8-1-91), ',
<        1  'Run on ',a11,' at ',a8)
from
>     10 FORMAT (' ORIGEN2 V2.1 (8-1-91), ','RUN ON ',A9,' AT ',A8)
```

DEC compilation:

```
f77 -fpe4 -c *.f (fsplit was used to separate the subroutine source files)
f77 -o origen2.exe *.o
```

HP compilation:

```
f77 +autodblpad +E1 +E4 -K +T -c *.f
f77 -o origen2.exe *.o /usr/lib/end.o
```

--

The ORIGEN2, Version 2.1 (8-1-91) package is designed to be installed onto a PC hard drive from DS/HD 5.25" or 3.5" diskettes. The first diskette contains a file called INSTALL.BAT, that unpacks the files to your hard drive. Users should look at READ.ME on Disk #1 for installation instructions and options.

The following directory structure is used:

```
\ORIGEN2
        \CODE
        \INPUTS       - example inputs for various reactor models
                \BWR
                \CANDU
                \LMFBR
                \PWR
        \LIBS
        \SAMPLES
                \PC1 - original ORIGEN2 sample problem
                \PC2 - fuel only irradiation using new PWRUS library
                \PC3 - Am-242m decay only
                \VAX1 - same as above, except run on a VAX.
                \VAX2
                \VAX3
```

****

*** ORIGEN2 CODE ***

Directory of C:\ORIGEN2\CODE

					**** Description of file ****
F77L3	EER	40432	01-22-91	5:56p	- 386/486 Lahey Fortran Error messages
HEADER	O2	3879	08-01-91	2:10a	- block letter header on ORIGEN2 output
ORIGEN2	EXE	1173039	08-01-91	2:10a	- 386/486 executable
ORIGEN2	FOR	901130	08-01-91	2:10a	- Fortran source for ORIGEN2, V2.1
PARAMS	O2	2479	08-01-91	2:10a	- ORIGEN2 Variable Dimension data
TUNE	EXE	38545	06-05-90	9:04p	- for tuning the ORIGEN2.EXE
TUNEO2	BAT	22	08-01-91	2:10a	- runs TUNE.EXE on ORIGEN2.EXE
FILES	LST	11960	08-01-91	2:10a	- This file.

****

*** INPUT FILE EXAMPLES ***

A number of example inputs are included with this update of ORIGEN2. These inputs provide the user with a modest starting point on which to develop his own input files. Total space: 177324 bytes.

Directory of C:\ORIGEN2\INPUTS\PWR

PWRU	INP	11330	08-01-91	2:10a
PWRU50	INP	13001	08-01-91	2:10a
PWRUE	INP	12941	08-01-91	2:10a
PWRUS	INP	11312	08-01-91	2:10a

Directory of C:\ORIGEN2\INPUTS\BWR

BWRU	INP	17295	08-01-91	2:10a
BWRUE	INP	16670	08-01-91	2:10a
BWRUS	INP	17273	08-01-91	2:10a
BWRUS0	INP	17286	08-01-91	2:10a

BWRUX INP 16592 08-01-91 2:10a

Directory of C:\ORIGEN2\INPUTS\CANDU

CANDUNAU 5494 08-01-91 2:10a
CANDUSEU 5330 08-01-91 2:10a

Directory of C:\ORIGEN2\INPUTS\LMFBR

AMOPUUUX 16400 08-01-91 2:10a
EMOPUUUX 16400 08-01-91 2:10a

****
*** DATA LIBRARIES FOR ORIGEN2 ***
This update of the code package includes all libraries previously available with ORIGEN2 plus revised LWR models for standard- and extended-burnups. These new libraries are called: PWRUS.LIB, PWRUE.LIB, BWRUS.LIB, BWRUSO.LIB, and BWRUE.LIB. Parameters needed for the LIB or PHO command are included in the columns on the right. The user should see the ORIGEN2 users manual and the other references for additional information about each library (See the list of references at the bottom of this file. Total space 9039598 bytes.

Directory of C:\ORIGEN2\LIBS

					Activation Products	Actinides &Daughters	Fission Products	Var. XS
*** Decay data ***					NLIB(2)	NLIB(3)	NLIB(4)	
DECAY	LIB	278636	08-01-91	2:10a	1	2	3	
*** Photon yield data ***					NPHO(1)	NPHO(2)	NPHO(3)	
GXH2OBRM	LIB	167526	08-01-91	2:10a	101	102	103 or	
GXNOBREM	LIB	102418	08-01-91	2:10a	101	102	103 or	
GXUO2BRM	LIB	167526	08-01-91	2:10a	101	102	103	
*** Cross section/FP yield data ***					NLIB(5)	NLIB(6)	NLIB(7)	NLIB(12)
** Thermal **								
THERMAL	LIB	172036	08-01-91	2:10a	201	202	203	0
** LWRs - PWR **								
PWRU	LIB	173266	08-01-91	2:10a	204	205	206	1
PWRPUU	LIB	173266	08-01-91	2:10a	207	208	209	2
PWRPUPU	LIB	173266	08-01-91	2:10a	210	211	212	3
PWRDU3TH	LIB	173266	08-01-91	2:10a	213	214	215	7
PWRPUTH	LIB	173266	08-01-91	2:10a	216	217	218	8
PWRU50	LIB	173266	08-01-91	2:10a	219	220	221	9
PWRD5D35	LIB	173266	08-01-91	2:10a	222	223	224	10
PWRD5D33	LIB	173266	08-01-91	2:10a	225	226	227	11
PWRUS	LIB	173676	08-01-91	2:10a	601	602	603	38
PWRUE	LIB	173676	08-01-91	2:10a	604	605	606	39
** LWRs - BWR **								
BWRU	LIB	173266	08-01-91	2:10a	251	252	253	4
BWRPUU	LIB	173266	08-01-91	2:10a	254	255	256	5
BWRPUPU	LIB	173266	08-01-91	2:10a	257	258	259	6
BWRUS	LIB	173676	08-01-91	2:10a	651	652	653	40
BWRUSO	LIB	173676	08-01-91	2:10a	654	655	656	41
BWRUE	LIB	173676	08-01-91	2:10a	657	658	659	42
** CANDUs **								

```
CANDUNAU LIB    173266 08-01-91   2:10a    401    402    403    21
CANDUSEU LIB    173266 08-01-91   2:10a    404    405    406    22
** LMFBRs **
EMOPUUUC LIB    173512 08-01-91   2:10a    301    302    303    18
EMOPUUUA LIB    173512 08-01-91   2:10a    304    305    306    19
EMOPUUUR LIB    173512 08-01-91   2:10a    307    308    309    20
AMOPUUUC LIB    173512 08-01-91   2:10a    311    312    313    12
AMOPUUUA LIB    173512 08-01-91   2:10a    314    315    316    13
AMOPUUUR LIB    173512 08-01-91   2:10a    317    318    319    14
AMORUUUC LIB    173512 08-01-91   2:10a    321    322    323    15
AMORUUUA LIB    173512 08-01-91   2:10a    324    325    326    16
AMORUUUR LIB    173512 08-01-91   2:10a    327    328    329    17
AMOPUUTC LIB    173512 08-01-91   2:10a    331    332    333    32
AMOPUUTA LIB    173512 08-01-91   2:10a    334    335    336    33
AMOPUUTR LIB    173512 08-01-91   2:10a    337    338    339    34
AMOPTTTC LIB    173512 08-01-91   2:10a    341    342    343    29
AMOPTTTA LIB    173512 08-01-91   2:10a    344    345    346    30
AMOPTTTR LIB    173512 08-01-91   2:10a    347    348    349    31
AMO0TTTC LIB    173512 08-01-91   2:10a    351    352    353    35
AMO0TTTA LIB    173512 08-01-91   2:10a    354    355    356    36
AMO0TTTR LIB    173512 08-01-91   2:10a    357    358    359    37
AMO1TTTC LIB    173512 08-01-91   2:10a    361    362    363    23
AMO1TTTA LIB    173512 08-01-91   2:10a    364    365    366    24
AMO1TTTR LIB    173512 08-01-91   2:10a    367    368    369    25
AMO2TTTC LIB    173512 08-01-91   2:10a    371    372    373    26
AMO2TTTA LIB    173512 08-01-91   2:10a    374    375    376    27
AMO2TTTR LIB    173512 08-01-91   2:10a    377    378    379    28
FFTFC    LIB    173266 08-01-91   2:10a    381    382    383     0
CRBRC    LIB    173266 08-01-91   2:10a    501    502    503     0
CRBRA    LIB    173266 08-01-91   2:10a    504    505    506     0
CRBRR    LIB    173266 08-01-91   2:10a    507    508    509     0
CRBRI    LIB    173266 08-01-91   2:10a    510    511    512     0
```

```
********************************************************************************
*** SAMPLE PROBLEMS FOR ORIGEN2 ***
```

Three sample problems are provided with this update of the ORIGEN2 package. Each sample was run on both a PC and VAX mainframe. The *.BAT files on the PC and *.COM files on the VAX provide the job control function. File names of the format TAPE*.INP or TAPE*.OUT are restricted for use by ORIGEN2. Input files may use any other name. The extension on the output files is as follows: (total space for samples = 6061547 bytes

```
*.DBG   - Unit 15 output - ORIGEN2 Debugging and Internal Information
*.ECH   - Unit 50 output - Input Echo
*.PCH   - Unit 7 output -  Output from ORIGEN2 PCH command.
*.U11   - Unit 11 output tables plus unit 13 table of contents (concat.)
*.U6    - Unit 6 output table plus unit 12 table of contents (concat.)
*.VXS   - Unit 16 output (variable cross section data)
```

```
 Directory of C:\ORIGEN2\SAMPLES\PC1

SAMP_1   BAT      3013 08-01-91   2:10a
SAMP_1   DBG     26860 08-01-91   2:10a
SAMP_1   ECH     15498 08-01-91   2:10a
SAMP_1   PCH     63090 08-01-91   2:10a
SAMP_1   U11    614554 08-01-91   2:10a
SAMP_1   U3        593 08-01-91   2:10a
SAMP_1   U5       9110 08-01-91   2:10a
```

```
SAMP_1    U6     1857629 08-01-91    2:10a
SAMP_1    VXS      81311 08-01-91    2:10a

 Directory of  C:\ORIGEN2\SAMPLES\VAX1

SAMP_1    COM       3183 08-01-91    2:10a
SAMP_1    DBG      26860 08-01-91    2:10a
SAMP_1    ECH      15501 08-01-91    2:10a
SAMP_1    PCH      63090 08-01-91    2:10a
SAMP_1    U11     614553 08-01-91    2:10a
SAMP_1    U3         593 08-01-91    2:10a
SAMP_1    U5        9110 08-01-91    2:10a
SAMP_1    U6     1857628 08-01-91    2:10a
SAMP_1    VXS      81311 08-01-91    2:10a

 Directory of C:\ORIGEN2\SAMPLES\PC2

SAMP_2    BAT       3044 08-01-91    2:10a
SAMP_2    DBG       9211 08-01-91    2:10a
SAMP_2    ECH       4592 08-01-91    2:10a
SAMP_2    INP       2812 08-01-91    2:10a
SAMP_2    U11      24974 08-01-91    2:10a
SAMP_2    U6       70197 08-01-91    2:10a
SAMP_2    VXS      37936 08-01-91    2:10a

 Directory of  C:\ORIGEN2\SAMPLES\VAX2

SAMP_2    COM       3209 08-01-91    2:10a
SAMP_2    DBG       9211 08-01-91    2:10a
SAMP_2    ECH       4595 08-01-91    2:10a
SAMP_2    INP       2812 08-01-91    2:10a
SAMP_2    U11      24973 08-01-91    2:10a
SAMP_2    U6       70196 08-01-91    2:10a
SAMP_2    VXS      37936 08-01-91    2:10a

 Directory of C:\ORIGEN2\SAMPLES\PC3

SAMP_3    BAT       3043 08-01-91    2:10a
SAMP_3    DBG       7116 08-01-91    2:10a
SAMP_3    ECH       4182 08-01-91    2:10a
SAMP_3    INP       1698 08-01-91    2:10a
SAMP_3    U11      35658 08-01-91    2:10a
SAMP_3    U6      154398 08-01-91    2:10a
SAMP_3    VXS          3 08-01-91    2:10a

 Directory of  C:\ORIGEN2\SAMPLES\VAX3

SAMP_3    COM       3208 08-01-91    2:10a
SAMP_3    DBG       7116 08-01-91    2:10a
SAMP_3    ECH       4185 08-01-91    2:10a
SAMP_3    INP       1698 08-01-91    2:10a
SAMP_3    U11      35657 08-01-91    2:10a
SAMP_3    U6      154397 08-01-91    2:10a
SAMP_3    VXS          3 08-01-91    2:10a
```

****

NOTES * NOTES * NOTES * NOTES * NOTES * NOTES * NOTES * NOTES * NOTES * NOTES *

1. DOCUMENTATION OF ORIGEN2 AND ITS DATA BASES IS AS FOLLOWS:

A.	SUMMARY REPORT	ORNL-5621 (JULY 1980)
B.	USER'S MANUAL	ORNL/TM-7175 (JULY 1980)
C.	(U,PU) FUEL CYCLE PWR & BWR MODELS	ORNL/TM-6051 (SEPT 1978)
D.	ALTERNATIVE FUEL CYCLE PWR MODELS	ORNL/TM-7005 (FEB 1980)
E.	CANDU MODELS	ORNL/TM-7177(NOVEMBER 1980)
F.	LMFBR MODELS	ORNL/TM-7176(OCTOBER 1981)
G.	CRBR MODELS	NUREG/CR-2762 (JULY 1982)
H.	DECAY AND PHOTON LIBRARIES	ORNL/TM-6055 (FEB 1979)
I.	REVISED PWR & BWR MODELS	ORNL/TM-11018 (DEC 1989)

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

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Date: May 23, 2002

To: Jennie Manneschmidt

From: S. B. Ludwig and A. G. Croff

Subject: **Revision to ORIGEN2 – Version 2.2**

This note transmits ORIGEN2 V2.2 to the ORNL RSICC for distribution. This is the first update to ORIGEN2 in nearly 10 years, and was stimulated by a user discovering a discrepancy in the mass of fission products calculated using ORIGEN2 V2.1. The problem, diagnosis and solutions employed, results, and issues arising are discussed below.

Problem: The user's problem involved irradiating a mixture of 40% Pu and 60% minor actinides (Np, Am, Cm) for about 1300 days at a high power level to reach a burnup of 350 MWd/kg. The total mass of fission products was under-predicted by nearly 10%, and a fact that was readily detected because the total mass of fission products and actinides should remain constant.

Diagnosis: There were two causes of the discrepancy.

1. ORIGEN2 accounts for fission products produced by fissioning minor actinides that do not have an explicit fission product yield library (e.g., Np, Am, and Cm-244) by adjusting the fission product yields of a nearby actinide that does have fission product yield library (e.g., Pu-239) (called "nearest connected actinide") based on the relative total fission rate of all the fissioning minor actinides and the actinide having a fission product yield library. The logic in the algorithm that calculates the total fission rate of the minor actinides was flawed so that this total fission rate for the minor actinides was prematurely terminated, thus resulting in under-prediction of the fission product mass. This error was previously not discovered as most problem cases involved fuel compositions that were composed primarily of uranium and/or plutonium.
2. As a result of the relatively small amount of Pu (in relation to the large fraction of fissioning minor actinides), use of long time steps (up to 400 days), and high specific power in the problem case, a majority of total fissions in the minor actinides and the actinide having a fission product yield library increases significantly during a time step. The adjustment of the fission product yields takes place using the actinide composition (and total fission rate) at the beginning of the time step. As a result, the adjustment factor is too low at the end of the time step, which leads to under prediction of the fission product mass. This can be fixed by simply decreasing the duration of the time step.

Results: Code modifications, as well as reducing the irradiation time step to no more than 100 days/step reduced the discrepancy from ~10% to 0.16%.

Issues Arising:

A. The bug described in Diagnosis 1 above does not noticeably affect the fission product mass in typical ORIGEN2 calculations involving reactor fuels because essentially all of the fissions come from actinides that have explicit fission product yield libraries. Thus, most previous ORIGEN2 calculations that were otherwise set up properly should not be affected.
B. Similarly, the use of excessively long time steps during irradiation is not likely to have adversely affected previous calculations of the fission product mass because the calculated adjustment factor is very small and changes very slowly in typical cases due to relative paucity of minor actinides composition in the fuel matrix.
C. The fission product mass in previous calculations involving high concentrations of minor actinides may have been under-predicted to a noticeable extent.
D. There are certain cases for which ORIGEN2 predictions of fission product mass would still be substantially under-predicted. These cases would involve irradiation of minor actinides exclusively (i.e., in which the concentration of U-233 plus U-235 plus Pu-239, which have fission product yield libraries, is essentially zero) should not be undertaken. In this case it is impossible for ORIGEN2 to adjust the fission product production rate without major modifications to ORIGEN2, which is not likely in the foreseeable future. The suggested work-around is a separate calculation to irradiate an actinide having a fission product yield library to the same burnup as the minor actinides to better estimate the resulting fission product composition.

Other notes:

ORIGEN2 continues to be successfully run on PCs under all versions of the Windows operating system, at least through Windows 2000.