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User's Manual for the Radioactive Decay and Accumulation Code RADAC

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MANAGED BY
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Royes Salmon
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ABSTRACT

The RADAC computer code calculates radioactive decay and accumulation of decayed products using an algorithm based on the direct use of the Bateman equations and referred to here as the yield factor method. This report explains the yield factor method, gives an overview of the various modules in the RADAC code system, and describes the decay and accumulation code in detail. The RADAC code has capacity for two waste types and can accommodate up to 60 years of annual waste inputs. Decay times as high as 1 million years can be calculated. The user supplies the undecayed composition and radioactivity of the waste placed in storage each year. The code calculates the decayed composition, radioactivity, and thermal power of the accumulated waste at the end of each year and gives the results in terms of grams and curies of individual radionuclides. Calculations can be made for up to 19 waste storage sites in a single run. For each site and each waste type, calculations can be made by 1-year steps up to 60 years, by 10-year steps to 160 years, and by 6 discrete steps to 1 million years. Detailed outputs can be printed for each waste site and each time step by individual radionuclides. Summarized outputs are also available. Excluding data-preparation time, RADAC requires about 2 min to run 19 waste sites with two types of transuranic waste at each site, using a 486 DX computer with a clock speed of 33 MHz.

Because RADAC uses a preselected set of decay times and does not make in-reactor calculations, it should not be viewed as a substitute for ORIGEN2. RADAC is intended for use in applications in which accumulations at the decay times provided by the code are sufficient for the user's purposes.

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The RADAC code system has been used for the past two years to make the decay and accumulation calculations for the transuranic waste (TRUW) section of the U.S. Department of Energy (DOE) annual Integrated Data Base (IDB) report and can be adapted to making these calculations for other types of radioactive waste. The RADAC program, which is the decay and accumulation module of the system, uses an algorithm based on the Bateman equations (Bateman 1910) and referred to here as the yield factor method. The objectives of this user's manual are to explain the yield factor method and the RADAC program in detail, to describe the functions of the other modules of the system, to show the results of the verification and validation work performed thus far, and to provide information needed for maintenance and expansion of the system.

Work on RADAC has been supported as part of the IDB Program, which is jointly sponsored by the DOE Office of Civilian Radioactive Waste Management and the DOE Office of Environmental Management. Issuance of this user's manual complies with the requirements stated by DOE in Subtask 3 of the IDB Program Guidance for FY 1995.

1.2 IDB INVENTORY CALCULATIONS

The IDB Program at Oak Ridge National Laboratory (ORNL) maintains files of data on current and projected inventories of permanently discharged spent nuclear fuel and other types of radioactive waste at various sites in the United States and issues an annual report summarizing these inventories and projections. Revision 10, the most recently published of these annual IDB reports, was issued in December 1994 (DOE 1994b).

Inventory information given in the IDB report includes data on the quantities, radionuclide compositions, and radioactivity of high-level, low-level, TRU, and other radioactive wastes at the various sites. At the end of a given year, the total waste of a given type in inventory represents a decayed accumulation from the first year of waste production. The information needed to calculate the inventory each year is obtained from the sites that generate the wastes. The information furnished by the sites is on an undecayed basis; that is, each site supplies the undecayed radionuclide-by-radionuclide composition of the waste added to its inventory for each year of waste generation. The IDB working group performs the necessary calculations to determine the decayed radioactivity and composition of the total accumulated inventory of each type of waste at each site at the end of each year. For a number of years, the IDB group used the LIBGEN/WINPRO/SAS system of computer codes (Storch 1989), which contains the ORIGEN2 decay module (Croff 1980), to make accumulation-decay calculations. More recently, to avoid the complexity of the procedures used in LIBGEN/WINPRO/SAS, the RADAC system was developed and is now being used for TRU waste. It is expected that the use of the RADAC system in the IDB will be extended to other types of radioactive waste. For general users, RADAC provides a useful tool for calculating decay, with or without accumulation.

1.3 THE YIELD FACTOR METHOD

The yield factor method is a way of using the Bateman equations to calculate radioactive decay and accumulation for a fixed set of decay times. It is especially useful for radionuclides that are members of long decay chains. The basis for the method and its use are described in detail in Sect. 2; only a very brief description is given at this point. Suppose that a known mass of a single radionuclide (the "from" nuclide) is placed in an empty container at time zero. At the end of some specified decay time, one or more additional nuclides will be present; these are the decay products of the "from" nuclide. The nuclides in the container at the end of the specified decay time are referred to as the "to" nuclides. The remaining portion of the "from" nuclide is counted among these. The yield factor for a particular "from–to" combination at a particular decay time t is the ratio of the mass of the "to" nuclide present at time t to the initial mass of the "from" nuclide at time zero. A yield factor, therefore, is specified by three parameters: a "from" nuclide, a "to" nuclide, and a decay time. The values of individual yield factors are calculated by means of the Bateman equations using highly precise integer-array arithmetic. Given a complete set of yield factors for all "from–to" combinations of interest and all decay times of interest, and given the quantities of the "from" radionuclides introduced each year, the quantities of "to" nuclides resulting from the introduction of the "from" nuclides can be calculated for each year of decay and accumulation. The requirement that only a single "from" nuclide be initially present is not a limitation on the use of the code; it was used at the start of this section only as a way of explaining the method of calculation. In the usual case, a number of "from" nuclides are introduced simultaneously in each year, and the decayed accumulations of "to" nuclides are obtained by summing the contributions of the individual "from" nuclides. In calculating these contributions, the "from" nuclides are taken one at a time. The algorithm for accumulating the decayed contributions is described further in Sect. 3.2.

1.4 STRUCTURE OF THE RADAC CODE SYSTEM

An overall view of the structure of the RADAC system is given at this point as an introduction to the detailed discussion in Sects. 2 through 5. Figure 1 shows the relationships among the principal modules of the system. Data on the annual radionuclide inputs are received from the waste sites and pass through a data preparation module that puts the data into input files in the formats needed by the decay and accumulation module. The formats and structure of these and other input files are described in Sects. 4 and 5. Using the input data files, the yield factor file, and other auxiliary input data, RADAC calculates the radionuclide decays and accumulations and puts the results into output files in formats suitable for further processing. A detailed description of these calculations is given in Sect. 3.

The actinide yield factor file, YIELDACT.LIB, is a fundamental part of the RADAC system. It contains the yield factors that the code uses when making the decay-accumulation calculations for the actinides and their daughters. The actinide yield factor file currently used in the code was constructed by iterative use of the integer-array arithmetic codes IBATFIX.FOR and IBATFLT.FOR, which were designed to use the Bateman equations to calculate yield factors with a high degree of precision. The basis for the yield factor method and the manner in which the Bateman equations are used to calculate yield factors are described in Sect. 2. Section 3.7 describes the structure of the actinide yield factor file.

Most of the fission and activation products available in RADAC have decay chains that are relatively short and uncomplicated. The decay of such products can be calculated with adequate precision by use of the Bateman equations without the necessity of first calculating yield factors. Some fission and activation products have decay chains long enough or complicated enough to justify the use of the yield factor method. Yield factors for these radionuclides are contained in the fission product yield factor file, YIELDFPS.LIB. This file is discussed further in Sect. 2.5.

Once constructed, the yield factor files do not have to be revised unless changes are made in the values of nuclear constants (i.e., half-lives and branching ratios), or new radionuclides or decay times are added to the data library. The integer-array arithmetic codes are needed when changes or additions must be made to the yield factor files but are not needed for ordinary decay and accumulation calculations.

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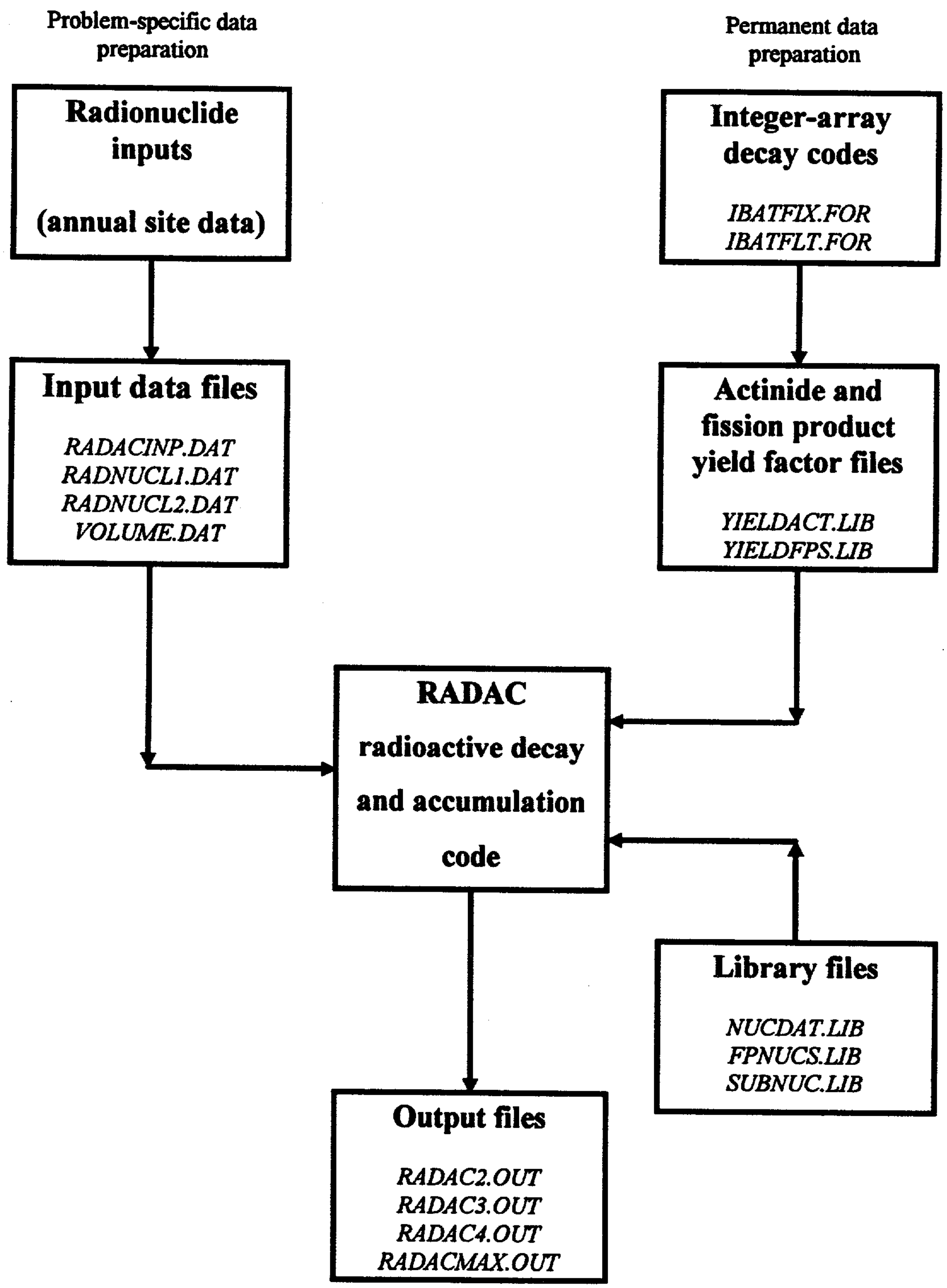

Fig. 1. Structure of RADAC code system.

2. BASIS FOR THE YIELD FACTOR METHOD

2.1 ACTINIDE SERIES, DECAY CHAINS, AND PATHS

Although the yield factor method is used in RADAC for both actinides and long-chain fission and activation products, it is primarily concerned with the decay of actinides, which are the radioactive elements having atomic numbers greater than 88. The decay daughters of actinides have atomic numbers going down as far as 83 (bismuth), 82 (lead), and 81 (thallium), and the decay paths are typically long and complicated. The length and complexity of the actinide decay paths are the principal reasons for the difficulty of the decay calculations. For these reasons, the basis for the yield factor method is discussed here in terms of the actinides and their daughters. In this discussion, different isotopes of a particular actinide or actinide daughter element will be referred to as different radionuclides, or simply as different nuclides.

The approximately 140 nuclides constituting the actinide isotopes and their daughters are conventionally divided into four series, known as the neptunium, uranium, actinium, and thorium series. These series do not intersect each other; that is, each nuclide is a member of one and only one series. A parent nuclide and its daughters are always members of the same series. Each series, therefore, is completely independent of the others insofar as decay calculations are concerned. Within each series, however, are a number of different decay routes that do intersect; in this report, these routes are referred to as chains. The file of yield factors is organized by chains. A chain does not necessarily form a single nonbranching decay route; branches may occur at several points within it. A continuous nonbranching decay route is referred to here as a path. Several paths may be necessary to describe all of the possible decay routes from a particular initial nuclide to a particular final nuclide. A single path describes a particular nonbranching decay route for each "from–to" combination within that path. A chain typically contains several paths. The manner in which yield factors for individual paths are combined to produce overall yield factors from a specific initial nuclide to a specific final nuclide is described in Sect. 2.2.

For the purposes of decay calculations, the actinide and actinide-daughter nuclides in RADAC are referred to as either "principal" or "subordinate" actinides, depending on their half-lives. Principal actinides are those that have half-lives long enough to justify their inclusion as decay-chain members when using the Bateman equations to make decay calculations. Subordinate actinides have half-lives short enough to justify the approximation that they are in secular equilibrium with their parents. This means that the curies of the daughter are assumed to be the same as those of the parent, adjusted for branching ratio. On this assumption, the daughters can be omitted from the decay chains during the decay calculations and added subsequently in amounts corresponding to secular equilibrium. This approximation is commonly used in decay codes as a way of simplifying the calculations. In RADAC, its use has the result that only principal actinides are members of the yield factor file; subordinate actinides are not.

Figures 2 through 5 show the four actinide series and most of the decay chains and paths within each series. References on which these figures are based include Kocher 1981, Browne 1986, and the ORIGEN2 decay library. Some of the paths shown are not yet available in RADAC and are so marked. The initial members of the 17 decay chains that are available in RADAC are indicated by arrows marked "Chain 1" through "Chain 17." Principal actinide nuclides in these chains are indicated by boxes with solid outlines; dotted outlines indicate subordinate actinides. Where branching occurs, the fraction of the parent that follows each branch is indicated. If one of the fractions is omitted, its value can be determined from the fact that the sum of the fractions is 1. In Fig. 2, for example, the fraction of ^{241}Pu that goes to ^{237}U is 0.0000245; the remaining fraction, which goes to ^{241}Am, is 0.9999755.

Although RADAC does not include all of the actinide and daughter nuclides, it does include all those needed for ordinary waste inventory calculations, such as the TRUW and HLW calculations for the IDB. Tables listing the principal and subordinate actinide nuclides available in RADAC are given in Sect. 4, where the permanent library data files are discussed. A list of some of the actinide and daughter radionuclides in the ORIGEN2 decay library that are not currently available in RADAC is given in Sect. 5.

2.2 THE BATEMAN EQUATIONS AND THE YIELD FACTOR

In a nonbranching radioactive-decay path, member 1 decays to form member 2, which decays to form member 3, and so on, ending with a final stable member. Early investigators of radioactive decay deduced from experimental results that the instantaneous rate of decay of each member at any given time is equal to the amount of that member present multiplied by some constant, the values of these constants being different for different radioisotopes. The constants are called decay constants; their values have been measured experimentally and are available in standard reference works. Given the initial number of atoms of each member of the path, the general problem of radioactive decay is to calculate the number of atoms of each member at the end of time *t*. The analytical solution of the system of differential equations expressing this problem has been known

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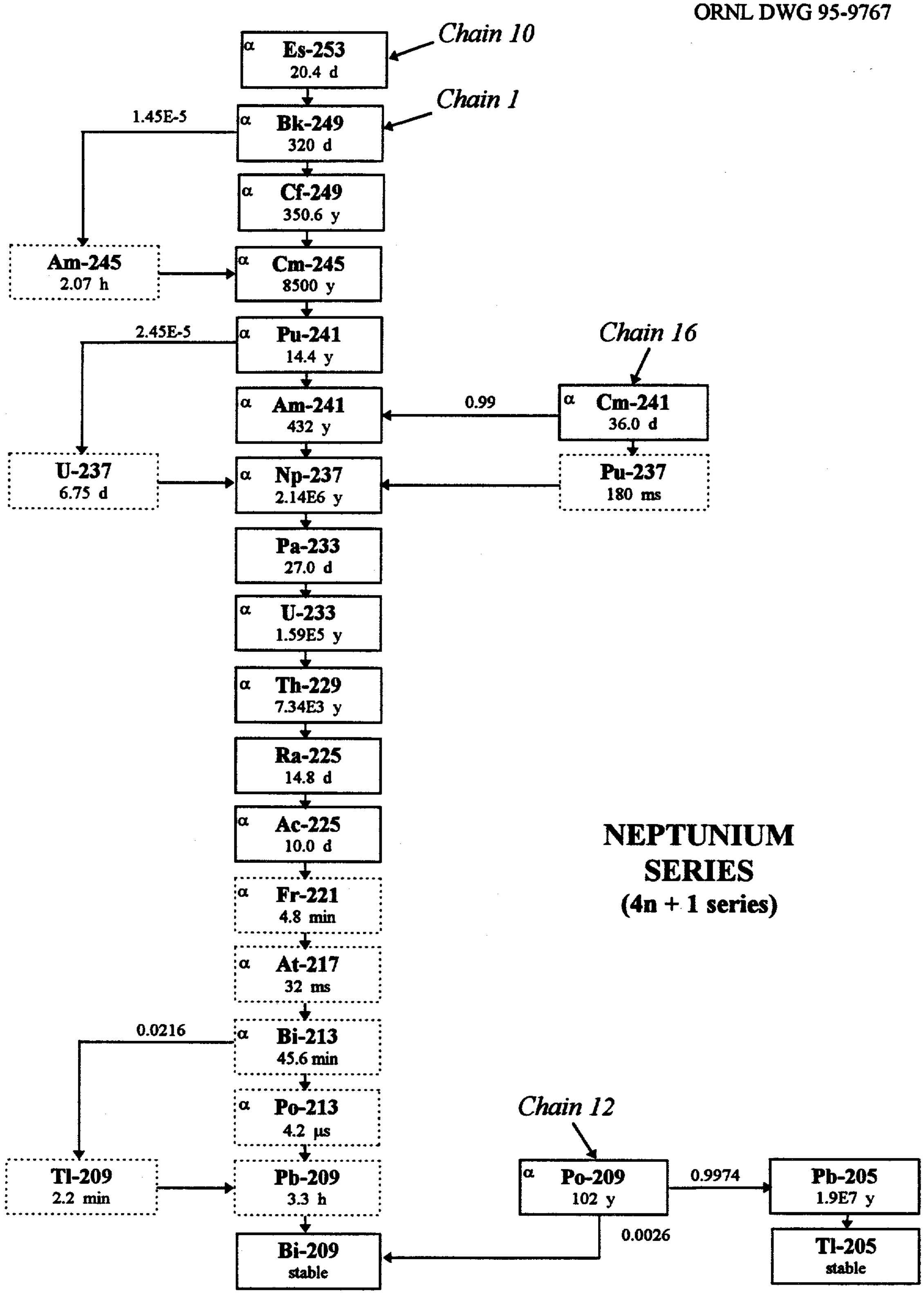

Fig. 2. Decay chains for neptunium series of actinides.

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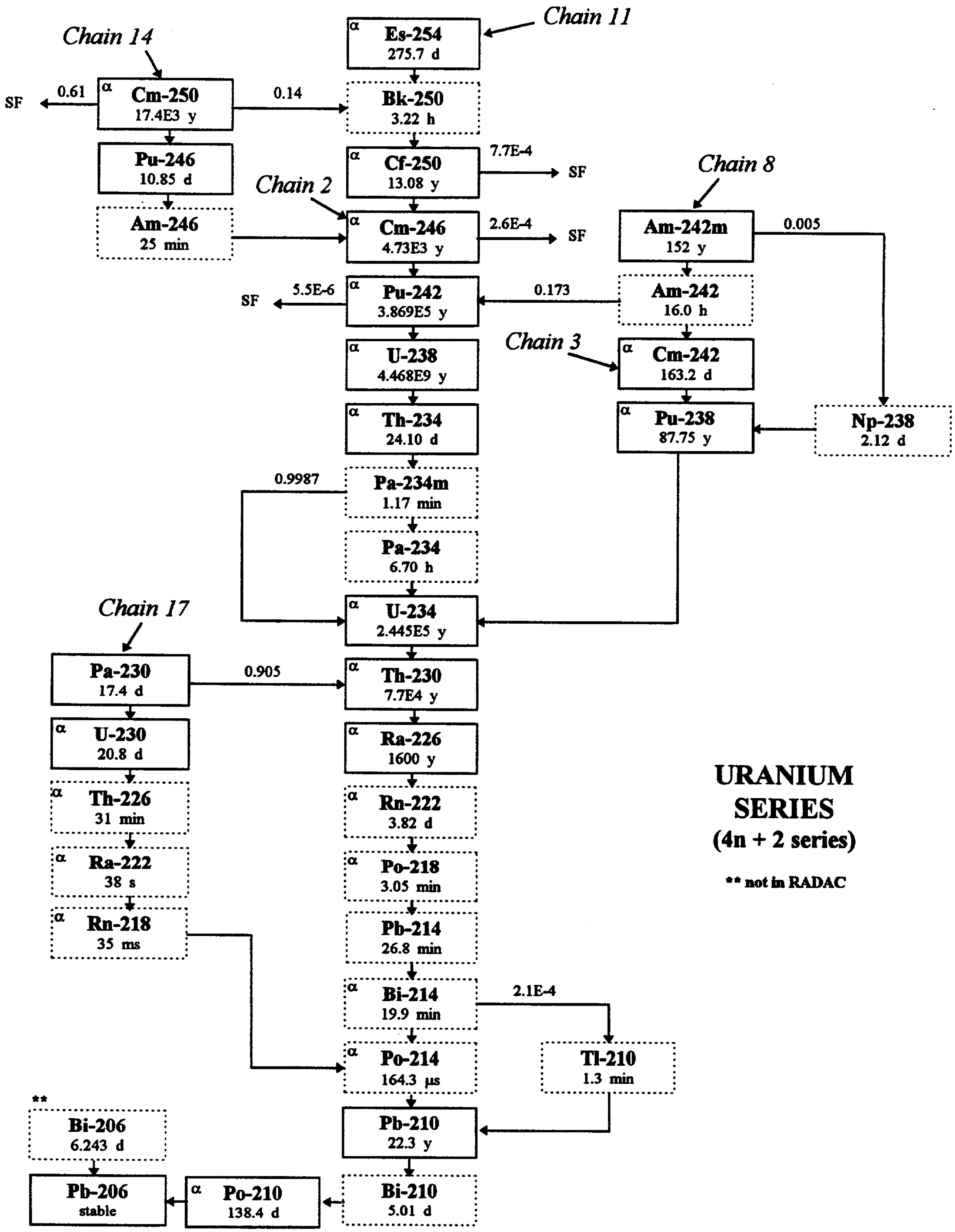

Fig. 3. Decay chains for uranium series of actinides.

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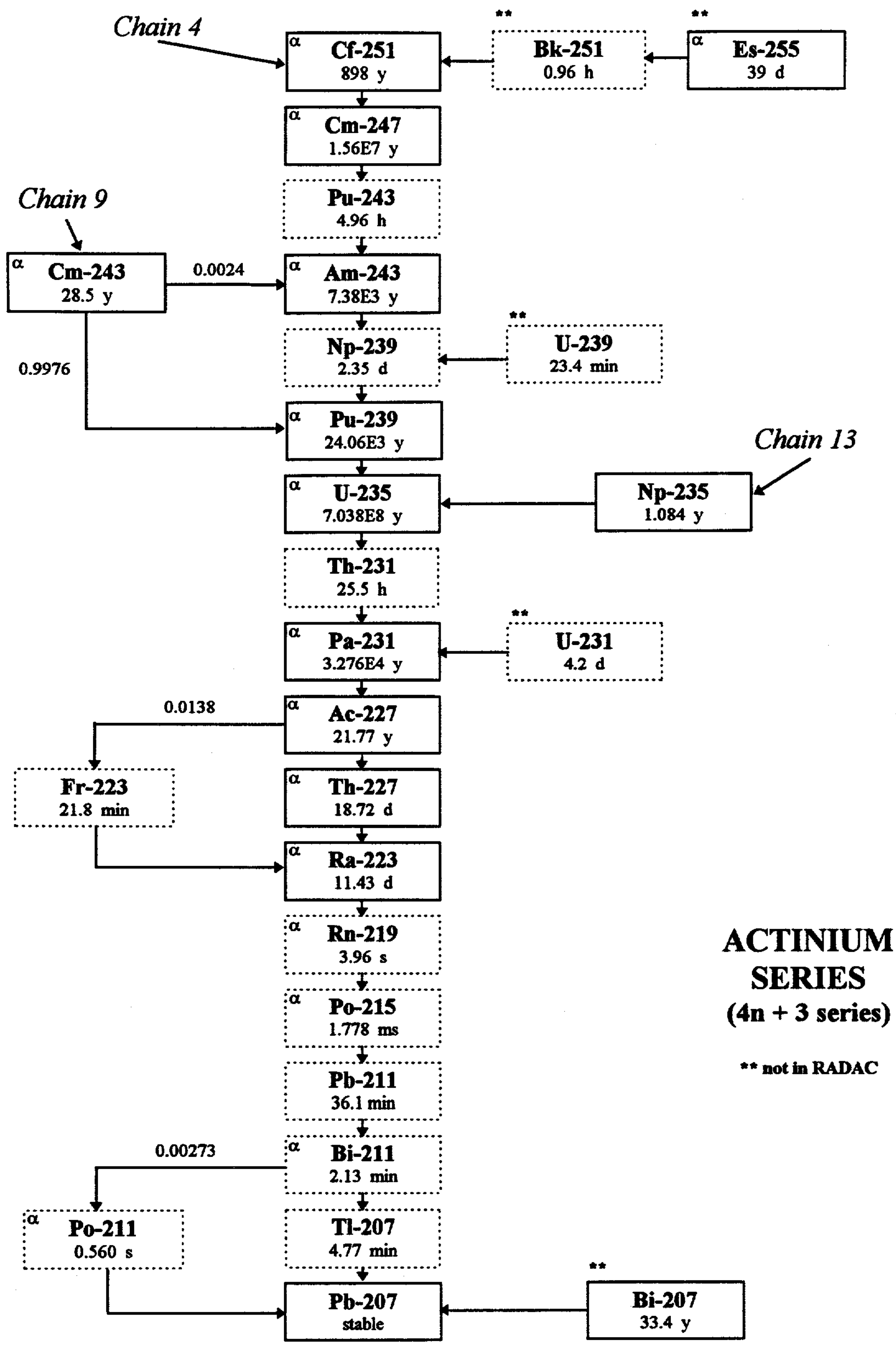

Fig. 4. Decay chains for actinium series of actinides.

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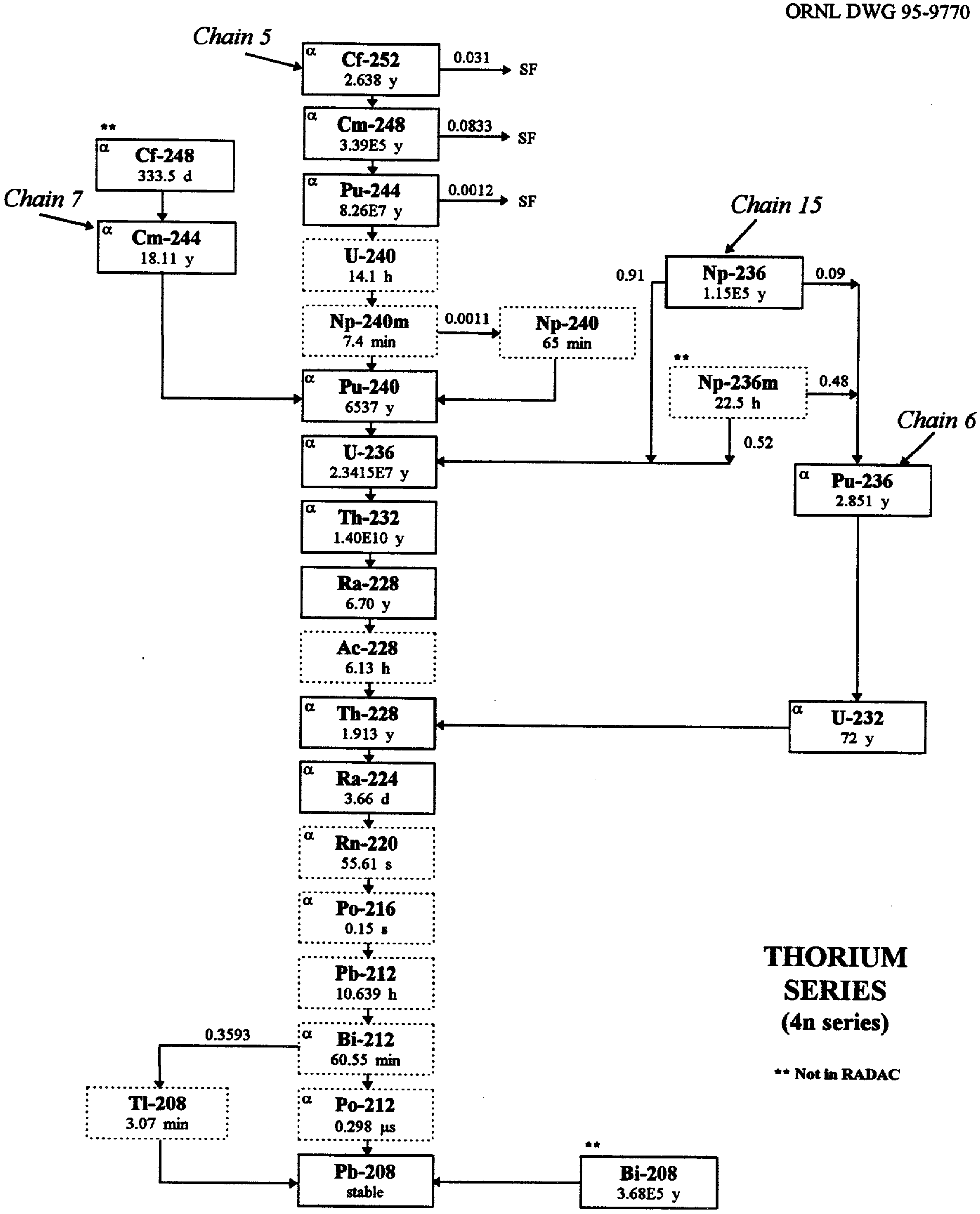

Fig. 5. Decay chains for thorium series of actinides.

for many years and, in 1910, was expanded and organized into a symmetrical general form by Bateman. Bateman's form of the solution is usually referred to as "the Bateman equations." These can be found in standard textbooks (Evans 1955, Etherington 1958, Kaplan 1963, Choppin 1980) and have been used as the starting point for a number of computer programs for calculating radioactive decay. The Bateman equations provide the mathematical basis for the calculation of yield factors. The algorithms for these calculations are developed in this section. The Bateman equations are mathematically exact, and their validity is not in question. However, because of their form, they are difficult to evaluate to the desired degree of precision when decay paths are long, especially when decay constants differ widely in magnitude. This is discussed in Sect. 2.3.

The Bateman equation used as the starting point for the yield factor method describes the decay of a "from" actinide, member 1, to a "to" actinide, member m, by a single nonbranching decay path. For the purpose of developing the algorithm, it is assumed at this point that member 1 is the only member initially present. If $N_{1,0}$ is the number of initial atoms of member 1 and $N_{m,t}$ is the number of atoms of member m at time t, the Bateman equation for this case can be written in the following form:

$$\frac{N_{m,t}}{N_{1,0}} = \lambda_1 \lambda_2 \dots \lambda_{m-1} \sum_{j=1}^{m} e^{-\lambda_j t} \prod_{i=1(i \neq j)}^{m} \frac{1}{\lambda_i - \lambda_j} \quad . \tag{1}$$

in which

λ_i = decay constant of nuclide i, s^{-1}, and

t = decay time, s.

Time units other than seconds can be used in Eq. 1 and in the equations that follow, but the units of λ must be the same as those of t^{-1}. Direct use of Eq. 1 requires that the path contain at least two members. For the case of only one member, that is, the case in which the "to" nuclide is the same as the "from" nuclide, the equation used is

$$\frac{N_{1,t}}{N_{1,0}} = e^{-\lambda_1 t} \quad . \tag{2}$$

The following discussion applies to the case in which m is at least 2. In general, there can be more than one decay path from member 1 to member m. The fraction of member 1 that goes to member m by path p is denoted by B_p. Then, for each path from member 1 to member m,

$$\left[\frac{N_{m,t}}{N_{1,0}}\right]_{path\ p} = B_p \lambda_1 \lambda_2 \ldots \lambda_{m-1} \sum_{j=1}^{m} e^{-\lambda_j t} \prod_{i=1 (i \neq j)}^{m} \frac{1}{\lambda_i - \lambda_j} \quad . \tag{3}$$

Decay proceeds independently along each path, and the solutions for the paths are additive; these are inherent properties of the differential equations of decay. The summation for all paths from a particular member 1 to a particular member m is

$$\frac{N_{m,t}}{N_{1,0}} = \sum_{all\ paths} B_p \lambda_1 \lambda_2 \ldots \lambda_{m-1} \sum_{j=1}^{m} e^{-\lambda_j t} \prod_{i=1 (i \neq j)}^{m} \frac{1}{\lambda_i - \lambda_j} \quad . \tag{4}$$

Because the different paths from the "from" nuclide to the "to" nuclide may have different lengths as well as different members, the subscripts of the decay constants in Eq. 4 must relate specifically to the members of the particular decay path being calculated. The paths collected under the summation sign labeled "all paths" must all start with the same "from" nuclide and end with the same "to" nuclide. For a given path, the path factor B_p must take into account any spontaneous fission encountered along the path, so that B_p will properly represent the atom fraction of the "from" nuclide that goes to the "to" nuclide by path p.

The yield factor from member 1 to member m for decay time t is obtained by multiplying Eq. 4 by the atomic mass ratio A_m/A_1:

$$Y(1,m,t) = \frac{A_m}{A_1} \sum_{all\ paths} B_p \lambda_1 \lambda_2 \ldots \lambda_{m-1} \sum_{j=1}^{m} e^{-\lambda_j t} \prod_{i=1 (i \neq j)}^{m} \frac{1}{\lambda_i - \lambda_j} \quad . \tag{5}$$

As stated in Sect. 2.1, the file of yield factors is organized by chains. Equation 5 provides the means for calculating all the yield factors for a given chain by summing the yield factors for the paths that connect the various combinations of "from" and "to" nuclides of the chain. The calculation of yield factors for a given chain by Eq. 5 starts with the selection of the first radionuclide of the chain as the "from" nuclide. Then, for a given "from–to" combination, the

Bateman equation for a single path to the "to" nuclide (Eq. 3) is calculated for each such path in turn, and the results are added. After accounting for all of the daughters of the first member of the chain, the process is repeated using the second member as the "from" nuclide. Thus, by iterative use of Eqs. 3 and 5, yield factors can be calculated for all combinations of "from" and "to" nuclides in the chain for all desired decay times. For a given initial input quantity of any "from" nuclide in the chain, the amounts of its daughters added to the total accumulated inventory of decay products at the end of a given decay period can then be determined by multiplying the input quantity by the appropriate yield factor for each daughter. The total accumulations of all decay products at the end of a given year are determined by adding the results of the individual "to" nuclide calculations for all the years of accumulation through that year. The accumulation algorithm, which accumulates the results year by year and radionuclide by radionuclide, is discussed in Sect. 3.2. The arrangement of yield factors in the yield factor file is described in Sect. 3.7.

2.3 PRECISION DIFFICULTIES IN THE BATEMAN EQUATIONS

When decay chains are long (for example, twelve members) and decay constants differ widely in magnitude, computations of radionuclide abundances by direct evaluation of Eqs. 3 and 4, using ordinary floating-point arithmetic, tend to suffer from loss of precision. The extent of this loss depends on the length of the chain, the precision of the method used in performing the arithmetic calculations, the magnitudes of the input variables, and the limitations of the computer. The loss of precision is not due to any lack of exactness in the Bateman equations themselves, but is entirely due to the numerical difficulty of precisely evaluating the expressions in the equations. The ORIGEN2 code achieves satisfactory precision by using a combination of techniques generally centered around the matrix exponential method but incorporating several other procedures designed to circumvent computational problems (Croff 1983). The yield factor method achieves precision by the direct use of integer-array arithmetic to evaluate the Bateman equations.

The underlying reason for the loss of precision encountered in the direct evaluation of the Bateman equations is that the summation on the right side of Eq. 3 consists of the sum of a number of positive and negative terms, and, for a member fairly far down a decay path, the exact sum of the positive terms is very close to that of the negative terms. Because of this, the accumulation of small round-off errors in the calculation of individual positive and negative terms has a destructive effect on the precision of the summation. When the round-off errors in individual terms are of approximately the same magnitude as the magnitude of the result being sought, the loss of precision is so severe that the calculated results can become worthless. The problem of loss of precision cannot be solved simply by using double-precision floating-point arithmetic. Double-precision arithmetic does not have the precision necessary to obtain meaningful results in the direct (nonreformulated) application of the Bateman equations to long decay chains. A tool much more precise is needed, and integer-array arithmetic fills this need.

2.4 CALCULATION OF ACTINIDE YIELD FACTORS

The IBAT computer codes were developed for the purpose of calculating yield factors with extremely high precision. The codes do this by evaluating the right-hand side of Eq. 5, path by path, by the use of integer-array arithmetic. In IBATFIX.FOR, each decimal number is represented by an array of 48 three-digit integers with the decimal point located at the midpoint of the array. The integer-array representation of each number, therefore, provides for 72 digits after the decimal point. Individual arithmetic operations such as addition, subtraction, multiplication, and division are performed by subroutines that operate on the integer arrays. The evaluation of *e* raised to a power is handled by representing the exponential in power series form and calculating the individual terms and the sum of the series arithmetically. IBATFLT.FOR represents a decimal number by an array of 60 three-digit integers in which the location of the decimal point is indicated in floating-point notation by the value of the first integer. Both programs were used in various stages of the development of the yield factor file YIELDACT.LIB. Numerous tests confirmed that the two programs give essentially identical results.

The IBAT codes and various auxiliary codes were used to calculate yield factors for 17 decay chains of up to 13 principal actinides each for 70 decay times ranging from 1 to 999,940 years. These yield factors are the elements of the yield factor data file YIELDACT.LIB. When executing the RADAC code, the YIELDACT.LIB file is read into array SYIELD(404, 70). The first subscript of SYIELD is a function of the chain number and the positions of the "from" and "to" nuclides in the chain. The second subscript gives the decay time. The first 60 decay times are in one-year steps, and the next 4 are in ten-year steps. The final 6 decay times are for 240, 440, 940, 9,940, 99,940, and 999,940 years, respectively. When combined with an initial decay of 60 years, the last 6 factors give overall decay times of 300, 500, 1,000, 10,000, 100,000, and 1,000,000 years. This is discussed further in Sect. 3.3. Section 3.7 describes the structure of the file YIELDACT.LIB and shows how the subscripts of SYIELD are related to the locations of the yield factors in the file.

For the calculation of the yield factors, only the principal actinides were included as members of the decay chains; the subordinate (short-lived daughter) actinide members were omitted. The RADAC program first calculates the abundances of the principal actinides on the basis of their yield factors. It then calculates the abundances of the subordinate actinides on the assumption that they are in secular equilibrium with their parents. On this assumption, the number of curies of a short-lived daughter is equal to that of its parent, adjusted for branching ratio as necessary. The basis for this assumption can be found in standard textbooks such as those previously cited. To maintain an atom balance, the atoms of the subordinate actinides thus arbitrarily introduced into the decay chain are subtracted from the downstream principal actinides in proportion to their abundances. In view of the fact that the longest-lived subordinate actinide used in RADAC has a half-life of less than 7 days, this method of calculating the abundances of short-lived daughters and adjusting the abundances of downstream actinides should give results sufficiently accurate for waste inventory calculations in which the shortest decay period of interest is one year.

Examples demonstrating the precision of the integer-array package used in the IBAT codes are given in Sect. 7.

2.5 DECAY OF FISSION PRODUCTS AND ACTIVATION PRODUCTS

A list of the 98 fission products and activation products currently included in the code library is given in Sect. 4. In the inputs and in the calculations, the code makes no distinction between fission products and activation products; they are listed together in one file, FPNUCS.LIB, along with their relevant nuclear properties (half-lives, curies per gram, etc.). Decay calculations for short-chain fission products and activation products are made by direct use of the Bateman equations using single-precision floating-point arithmetic. This gives satisfactorily precise results for decay chains of two members or less. The abundances of short-lived daughters of fission and activation products are calculated from those of their parents using the assumption of secular equilibrium. Long-chain fission and activation products (those that have decay chains consisting of at least one long-lived radioactive daughter or more than one decay path) are identified by type number 13. The yields of the daughters of type-13 radionuclides are calculated by means of the fission product yield factor file YIELDFPS.LIB. Both double-precision and integer-array arithmetic were used in the construction of this file depending on the complexity of the decay chain. The manner of use of this file is analogous to that of the actinide yield factor file.

3. CALCULATIONS PERFORMED BY RADAC

3.1 GENERAL

The computer code RADAC performs the radioactive decay and accumulation calculations for the RADAC system. In a single run, the code can handle up to two waste types (for example, contact-handled and remote-handled TRU wastes), 19 waste sites, 60 years of waste addition, and up to 1 million years of decay. Decay and accumulation are calculated for a series of discrete time steps. One-year steps are used for decay times up to 60 years; 10-year steps are used from 60 to 160 years. Above 160 years, the decay times are 300, 500, 1,000, 10,000, 100,000, and 1,000,000 years. Accumulation of decayed products occurs at the end of each time step. For each time step, the code calculates the composition, radioactivity, and thermal power of the accumulated waste for each site and each waste type and stores the results in terms of grams and curies of each individual radionuclide. For each site and waste type, thermal power is stored as a total at the end of each time step.

The timing conventions used for the annual inputs of waste and the annual accumulations of decayed products are as follows:

1. All tabulations of quantities added or accumulated are on an end-of-year basis.
2. In preparing data for the IDB report, the site submittals give the quantities of each radionuclide added in a given year. The site submittal of the curies of a radionuclide added in a given year is understood to represent its radioactivity at the end of that year.
3. The total accumulated radioactivity at the end of year *Y* is the sum of the radioactivity of the material accumulated through the end of year *Y*-1, decayed by 1 year, plus the undecayed radioactivity of the material added to inventory during year *Y*.

In actuality, waste can be generated at any time during a year. However, to simplify the calculations, the conventions listed here have been consistently adhered to by the IDB in its radioactivity calculations for TRUW and other types of waste.

3.2 ACCUMULATION OF PRODUCTS OF DECAY

The basic accumulation algorithm used by the RADAC code is as follows:

$$Q(k,n) \times Y(k,m,t) = G(m,n+t) \quad , \tag{6}$$

in which

$Q(k,n)$ = quantity (grams) of "from" nuclide k added to inventory in year n,

$Y(k,m,t)$ = yield factor from nuclide k to nuclide m for a decay time of t years, and

$G(m, n + t)$ = grams of "to" nuclide m added to accumulation array in year $n + t$.

The accumulation array for actinides and daughters is the doubly dimensioned array GRMACC, where the first dimension identifies the nuclide and the second dimension identifies the year. Elements of the array are grams of nuclides accumulated at the end of a given year. Initially, all of the elements of the array are set at zero. When a site shows a quantity of a nuclide k added to storage in a given year n, k becomes a "from" nuclide, and the full quantity of that nuclide, $Q(k,n)$, is added to the accumulation array in year n only. Then, using the yield factors $Y(k,m,t)$, the code calculates the grams of each of the "to" nuclides m to be added to the accumulation array in each of the subsequent years $n + t$. All additions into the array are cumulative; that is, the grams added to the array are added to the grams already present in accordance with the following equation:

$$New\ accumulation(m, n + t) = Old\ accumulation(m, n + t) + G(m, n + t) \ . \qquad (7)$$

For convenience in the calculations, separate arrays are used for principal and subordinate actinide radionuclides. A similar array is used for fission and activation products. Accumulation arrays in terms of curies are also calculated; these are obtained by multiplying the arrays in grams by the specific activity (curies per gram) of each radionuclide.

A series of nested "DO" loops covers two waste types, all sites, all years in which waste is added to inventory, all "from" nuclides added in each year, all "to" nuclides resulting from the decay of the "from" nuclides, and all decay times. The structure of these loops is described in Sect. 3.4.

3.3 COMBINING YIELD FACTORS FOR DIFFERENT DECAY TIMES

If yield factors for all chain members are available for decay times t_1 and t_2, they can be combined to produce yield factors for a decay time of t_3 years, where $t_3 = t_1 + t_2$. This permits the extension of the yield factor file to additional decay times. The following equation can be used to calculate the yield factor from actinide i to actinide j over a time span of t_3 years:

$$Y_{i,j,t_3} = \sum_{p=i}^{j} \left(Y_{i,p,t_1}\right)\left(Y_{p,j,t_2}\right) \qquad (8)$$

In this equation, t_1 and t_2 are basic decay times, and $t_3 = t_1 + t_2$. The three subscripts of Y represent the "from" actinide, the "to" actinide, and the time span, respectively. The subscript p represents any precursor of j in the range $p = i$ to j, inclusive. The following basic yield factors are assumed to be known:

Y_{i,p,t_1} = yield from i to p over the time span t_1, and

Y_{p,j,t_2} = yield from p to j over the time span t_2.

This algorithm is used to calculate accumulations beyond the first 60 years. Because radionuclide inputs can be made in any integer year of the first 60 years, it is necessary to calculate an accumulation at the end of 60 years of decay. This is explained more fully in Sects. 3.5 and 3.6.

3.4 SIMPLIFIED FLOW DIAGRAM OF THE RADAC PROGRAM

Figure 6 shows a simplified schematic flow diagram of the calculations performed by the RADAC program. The blocks in the diagram are labeled A through I to key them to the detailed discussion of the calculations given in Sect. 3.5. The steps shown in Fig. 6 are as follows:

Step A Read problem data file RADACINP.DAT

Step B Read permanent library data files (radionuclide data, actinide yield factors, etc).

Step C Set up main (outer) DO 650 loop. The waste type is set at this point. Read annual volumes of waste for all sites, if called for by input signal ISIG(4) = 1.

Step D Set up main inner DO 600 loop for waste sites. The waste site is set at the start of this loop.

Step E Read site input data (annual quantities and radionuclide compositions of waste added each year) for the waste type and waste site set in DO 650 and DO 600 loops. The data for all years are read at this point.

Step F Using the actinide yield factors, calculate the annual year-end accumulations in grams for all principal actinides for all years of the study.

Step G Calculate accumulations of principal actinides in curies. Calculate accumulation of subordinate actinides for all years based on accumulation of principal actinides. Make a downward adjustment in the accumulations of any principal actinides that are preceded by one or more subordinate actinides. Store actinide output data (annual year-end accumulations) in output files for subsequent printing or other use.

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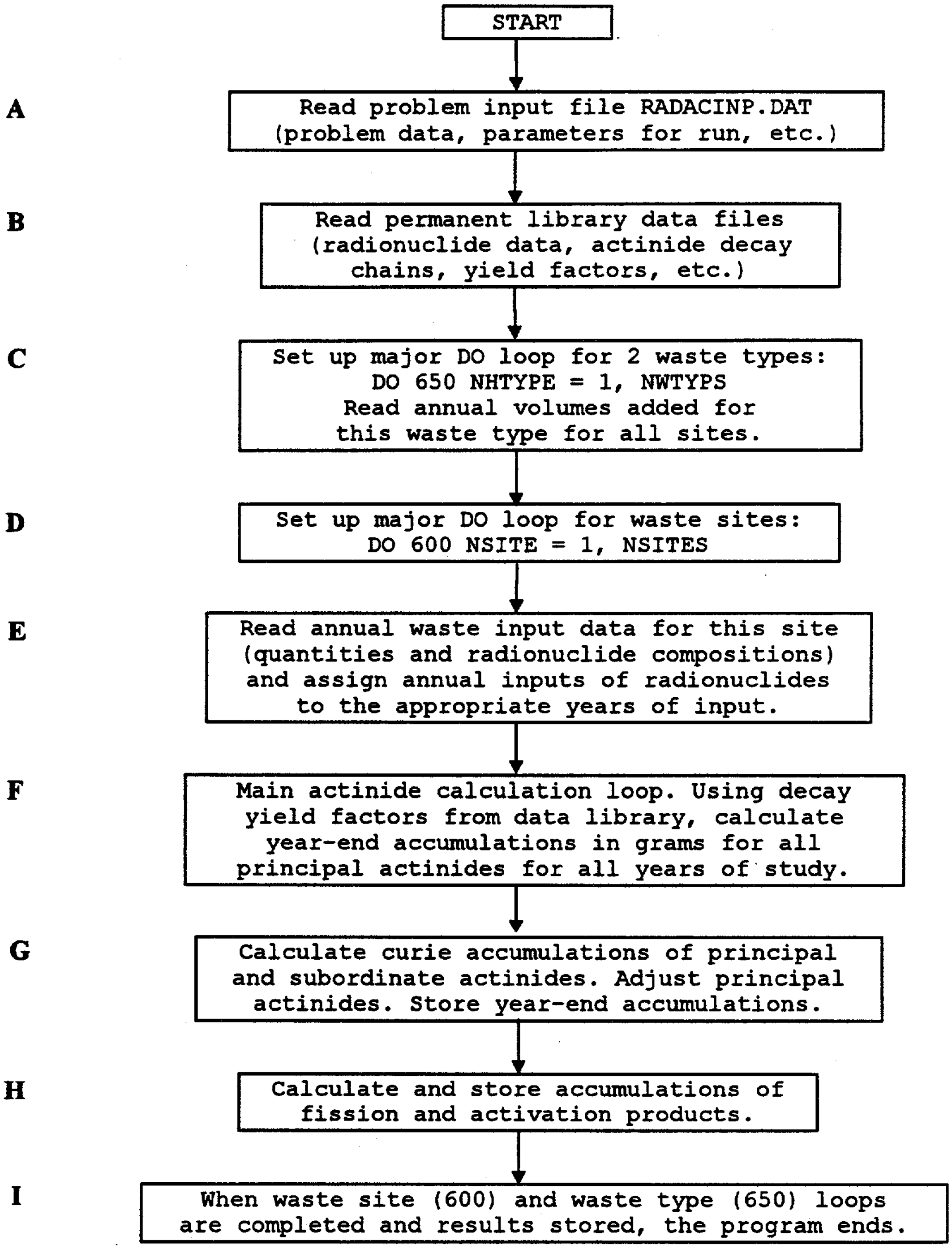

Fig. 6. Simplified schematic flow diagram of calculations performed by the RADAC program.

Step H Calculate accumulation of grams, curies, and watts for all fission and activation products for all years of the study. Store results (annual year-end accumulations) in files for subsequent printing or other use.

Step I When the DO 600 waste-site loop and the DO 650 waste-type loops are completed, the calculations are finished.

3.5 DETAILED FLOW DIAGRAM

A more detailed flow diagram of the RADAC program is shown in Fig. 7. This diagram refers to some of the actual FORTRAN statements in the program and shows more of the internal DO loop structure. The steps are again labeled A through I to key them to the same steps in Fig. 6 and are discussed here in greater detail:

Step A The problem data file RADACINP.DAT is read here; it gives the control signals that specify whether the input data are in grams or curies and control the various options. Other parameters are the starting year of the study, the number of time points for which decay calculations are to be made, the number of sites, the number of waste types, etc. The data and formats of this file are discussed in more detail in Sect. 5.2.

Step B Reading of the permanent library data files is discussed in Sect. 4. Messages are output to the screen while these files are being read so that the user can follow the progress of the program. The actinide yield factor file, YIELDACT.LIB, is read here. For a discussion of this file, see Sect. 3.7.

Step C The DO 650 loop sets the waste type, NHTYPE. The program was originally set up only for TRU waste, and types 1 and 2 were used to indicate contact-handled and remote-handled TRU waste, respectively. However, the user can use type 1 and type 2 to indicate other types of waste if desired. All that is necessary is to supply the appropriate quantities and radionuclide compositions in files RADNUCL1.DAT and RADNUCL2.DAT, respectively, for the type-1 and type-2 wastes desired by the user. If only one type is desired, the user sets NWTYPS = 1 in input file RADACINP.DAT, and the RADNUCL2.DAT input file is not read.

For the waste type specified by the DO 650 loop index, the annual volumes added (cubic meters) are read for all sites at this point and are accumulated to determine the total volume at each site at the end of each year. Because this calculation is independent of the decay calculations, it is completed at this point. Reading of the volume file can be omitted at the option of the user.

Step D The DO 600 NSITE = 1, NSITES loop, which is set up here, specifies the site for which input data will now be read and the results calculated. From this point on, the calculations of accumulated grams, curies, and watts are being done for one type of waste at a time and for one site at a time. The maximum number of sites that the program can handle is 19, and the maximum number of waste types is 2.

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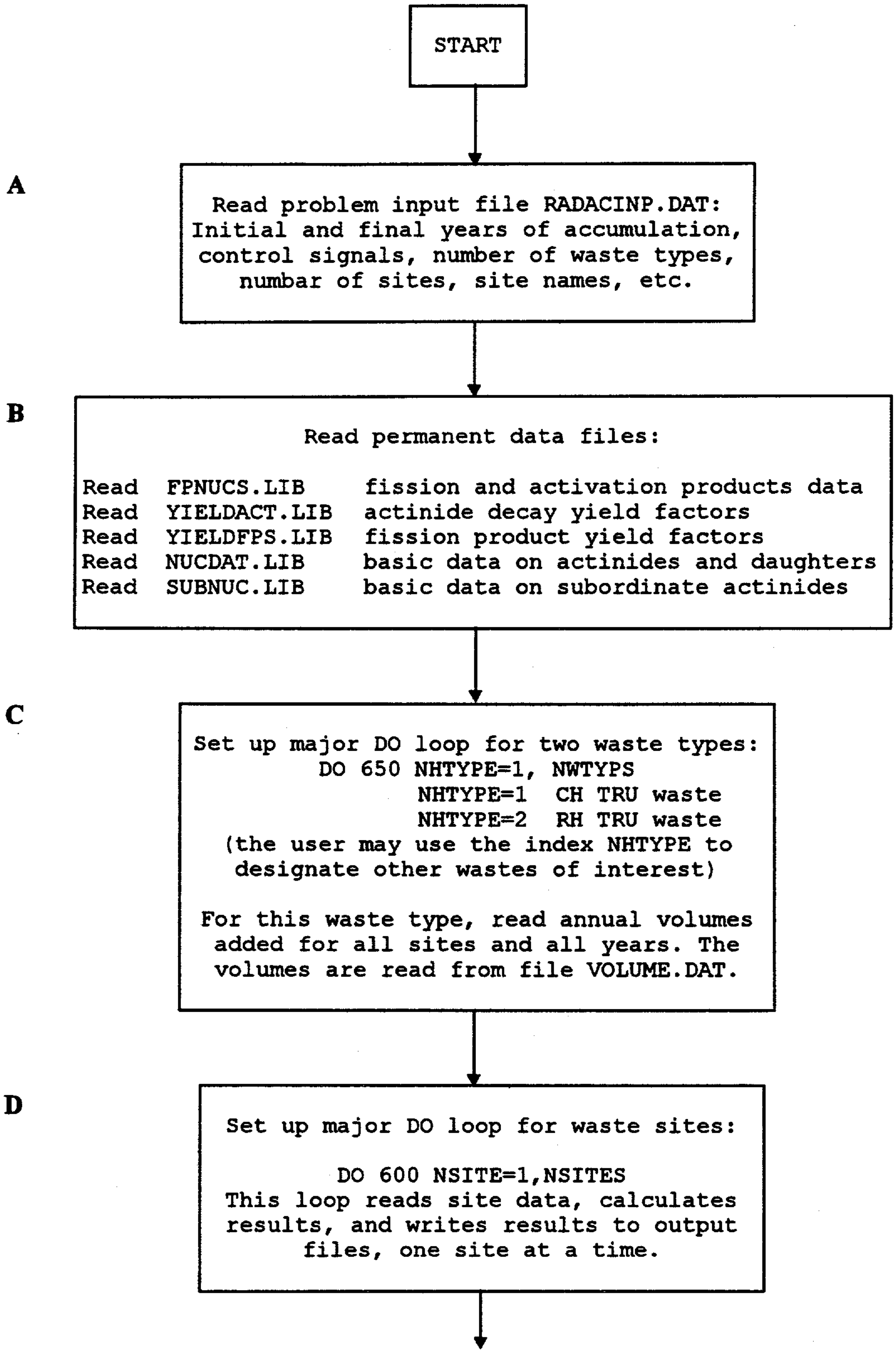

Fig. 7. Schematic flow diagram of calculations performed by RADAC (p. 1 of 4).

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E

Set up DO loops for reading site input data:

DO 60 NP60=1,200
This loop reads site data for site NSITE one page at a time. A page applies to a specific span of years (calendar years NYR1 through NYR2) during which the inputs are the same for each year. NYR1 and NYR2 are read as part of the input for each page.

DO 49 NUC40=1,200
For page NP60, the nuclide name and annual curies added are read, one nuclide at a time. Both fission products and actinides are read from the same page. On each page, the program reads the years (NYR1 to NYR2) in which the annual quantities on the page are added. A jumpout terminates the list of radionuclides on each page. Optionally, inputs can be entered in grams.

DO 47 FEEDYR=NA,NB
This loop assigns the annual additions of each radionuclide to years NYR1 through NYR2 as specified on the site inputs.

For actinides, input quantities in curies are converted to grams because the subsequent calculations are based on yield factors, which are in terms of grams. Fission products are calculated in terms of curies. For IDB use, the preferred input units are curies for both actinides and fission products.

When these DO loops (47, 49, and 60) are completed, all pages of input data have been read for this site, and the quantities of radionuclides added each year have been assigned to their respective years of addition, undecayed.

Fig. 7. Schematic flow diagram of calculations performed by RADAC (p. 2 of 4).

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F

Actinide calculations, subroutine ACTYLD.
Phase 1 covers years 1 through 61.

DO 190 FEEDYR = 1, NBMAX
This covers all time steps in which waste is added.

DO 180 N180 =1, ACTMAX
The program checks each actinide to see if a non-zero quantity was added in year FEEDYR. If yes, the decay yield factors are used to calculate the grams of that actinide and the subsequent members of that actinide chain accumulated from that input through all the subsequent time steps through year 61.
190 CONTINUE

Phase 2. Years following year 61. First, a new feed array is created showing the grams of all actinides at the end of year 61. Next, this feed array is decayed to the final year. This is done in the DO 250 loop. See text for additional details.

G

Curie accumulations are calculated for all principal actinides from gram quantities. Year-end accumulations of curies are calculated and corrections are applied to actinides that are preceded by subactinides:

```
DO 262 NYR=2,NFINAL      Curies of principal actinides are
DO 262 NID=1,45          calculated in this loop for
262 CONTINUE             all time steps.
```

Subactinide accumulations:

```
DO 275 NYR=2,NFINAL      Subactinide curies are calculated
DO 275 NID2=1,NSUBS      from principal actinide curies.
Adjustments: in each year, subactinide gram-atoms are
subtracted from the subsequent principal actinides.
275 CONTINUE
```

Actinide and subactinide calculations are complete. All accumulations of grams and curies are written to files. This is done in statements labeled 290 through 382.

Fig. 7. Schematic flow diagram of calculations performed by RADAC (p. 3 of 4).

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H

The accumulations of fission and activation products are calculated in this step. First the curies of the main fission products are done (these are the ones that are not daughters of fission products). Then the daughters of the type 13 fission products are calculated. All this is done in the 470, 450, 420, and 406 loops:

```
 DO 470 NYR=1,NBMAX
 DO 450 MFP=1,NFPMAX
 M=FPNID(MFP)
 IF(CFFINP(M,NYR1).EQ.0) GO TO 450
 IF(FPPAR(M).EQ.0)       GO TO 450
 DO 420 NYR2=NYR+1,NFINAL
 NYRDEC=NYR2-NYR1
 IF(NYR2.GT.61)NYRDEC=10*(NYR2-61)+61-NYR1
 TEXP=CONST*NYRDEC*FPDEC(M)
 IF(TEXP.GT.87.)GO TO 390
 CFFACC(M,NYR2)=CFFACC(M,NYR2)+CFFINP(M,NYR1)*EXP(-TEXP)
 390 CONTINUE
 IF(FPTYPE(M).NE.13) GO TO 420
 N13=INDX13(M)
 DO 406 N6=1,NDAUTS(N13)
 CFFACC(IDDAUT(N13,N6),NYR2)=CFFACC(IDDAUT(N13,N6),NYR2)+
1    CFFINP(M,NYR)*FPYLDS(LINEFP(N13,N6),NYRDEC)
 406 CONTINUE
 420 CONTINUE
 450 CONTINUE
 470 CONTINUE
```

The curies of the daughter fission products are calculated from those of the parents. This completes the calculations. The curie tabulations are written to the output file.

I

Totals are collected and results are written to output files for all sites. This completes the DO 600 site loop. After zeroing arrays, calculations for waste type 2, if called for, are made. This completes the DO 650 loop. After calculating and storing the combined totals for both waste types, the program ends.

Fig. 7. Schematic flow diagram of calculations performed by RADAC (p. 4 of 4).

Step E This step reads the annual waste input data (quantities and radionuclide compositions) furnished by the sites. The data are read only for the site currently being run in the DO 600 loop. For each site, the data are read one page at a time and one radionuclide at a time, as described in Sect. 5, file RADNUCL1.DAT. The loops controlling these steps are shown in Fig. 7. Upon reading the data for a given radionuclide, the program assigns the appropriate input quantity to the accumulation array for that radionuclide for the years specified in the input file. The accumulation arrays, which contain only the undecayed input quantities at this point, are as follows:

CFFACC(NID48, FEEDYR) for fission and activation products and

GRMACC(NID48, FEEDYR) for actinides,

in which NID48 is the identification number of the radionuclide and FEEDYR is the year in which the input quantity is added to inventory. FEEDYR is not a calendar (4-digit) year; it is a number ranging from 1 to NFINAL. NFINAL, the maximum number of time steps, is calculated within the program from the initial and final calendar years, YSTART and YFINAL. The maximum allowable value of NFINAL is 71, corresponding to 70 decay time steps plus 1 for the starting year. The code sets NBMAX equal to the maximum value of FEEDYR; NBMAX is used in the next step.

At this point, the accumulation arrays give the undecayed quantities accumulated as of the end of the year (or time step) specified as the index of the array. When a quantity of a radionuclide is input in a given year, the full (undecayed) quantity is added to the accumulation array in that year, because, by the convention used in the code, the quantity input in a given year is assumed to indicate the quantity added at the end of that year. Further discussion of the indexing of time dimensions is given in Sect. 3.6.

Step F This is the calculation step that uses the decay yield factors to calculate the decay and end-of-year accumulation of grams, curies, and watts for all principal actinides in the study. The general structure of the main loops (DO 190 through DO 250) is indicated in Fig. 7. The actinide decay and accumulation calculations are done in one stage if the total number of years does not exceed 61. If the total number of years exceeds 61, two stages are required. The first stage starts with the DO 190 loop. This loop sets FEEDYR, the year (more precisely, the time step) of waste addition, which ranges from 1 to NBMAX (NBMAX was determined during Step E). The DO 180 loop then looks at all the principal actinides in turn (by means of their identification numbers) to find those for which a nonzero quantity was added during FEEDYR. When such an actinide is located, its chain number (NS) and its position number in the chain (NPFEED) are identified. This permits the code to determine the location of the yield factors for this "from" actinide in the yield factor array.

The "to" actinides are all the actinides in chain NS beginning with and subsequent to the "from" actinide. The DO 120 loop goes through these "to" actinides in turn. The index of the DO 120 loop, MB, is the identification number of the "to" actinide. For each "from" and "to" combination, the line location of the yield data in the yield factor array is determined as described in Sect. 3.7.

The line number of the yield factor data having been identified, the DO 120 loop considers each year (time step) of accumulation of decay products from FEEDYR+1 to NFINAL. It does not consider FEEDYR because the addition of the feed nuclide to the accumulation array was done when the input data were read in step E.

For each time step of accumulation, the DO 120 loop determines the number of time steps of decay (YDECAY) and uses this to locate the yield factor SYIELD(LINE3, YDECAY). Then it calculates the mass (grams) of the "to" nuclide and adds it to the accumulation array.

If the total number of time steps does not exceed 61, the actinide decay and accumulation calculations are complete at this point, and stage 2 is not needed. If the number of time steps exceeds 61, a new feed array is prepared showing the masses of all the principal actinides present at the end of time step 61. This feed array is then decayed in ten-year or larger steps to the final year specified by the user. These calculations take place in the DO 250 loop and use an algorithm analogous to that used in the DO 190 loop.

Step G The accumulations of subordinate (short-lived daughter) actinides are calculated from the principal actinide curie accumulations. After calculating the subordinate actinides, a correction is made in the principal actinides. The correction consists of subtracting the gram-atoms of subordinate actinides from the gram-atoms of the subsequent principal actinides in the chain. This correction is necessary because the yield factors for the principal actinides were calculated using chains in which the principal actinides were the only members. That is, the radionuclide chains used in the calculation were stripped of all their subordinate actinides. The yield factors are therefore slightly high for actinides that are preceded by subordinate actinides. The subtraction of the gram-atoms of subordinate actinides from the gram-atoms of the subsequent principal actinides in the chain is an approximate way of correcting for this. The quantity subtracted from each downstream actinide is proportional to the amount of that actinide present. This correction is not exact, but is adequate for the applications for which the code was designed. After the subtraction, the curies of the principal actinides affected by the correction are recalculated to make them consistent with their masses.

After the year-end accumulations of grams, curies, and watts have been completed, the results are written to output files.

Step H The end-of-year accumulations of curies and watts for fission and activation products are calculated in this step. The fission product decay factors for the type 10 fission products, which were calculated in step C, are used here. The curies of type 11 daughter fission products are calculated from those of their type-10 parents. The yields of daughters of type-13 (long-chain) fission products are calculated by means of the yield factors listed in data file YIELDFPS.LIB.

After calculating the year-end accumulations of curies and watts, the results are written to output files for subsequent printing or other use. In the detailed output file, accumulations of curies are shown for each individual fission product and activation product. Accumulations of grams are not calculated for fission and activation products.

Accumulations of watts are shown only in the summary output tables, and are shown only as annual and accumulated (see next page) totals for the year for all radionuclides.

Summary tables are written to output file RADAC3.OUT showing the total year-end accumulations for actinides, fission products, and activation products combined. This file does not show a breakdown by radionuclides, but it does show separate tables for type-1 and type-2 wastes and for the total of these types.

RADAC4.OUT is a condensed output file generated only when the user wishes to specify a particular set of up to 9 decay times, as described in Sects. 5 and 6. This file contains separate summaries for each type and site specified in the input.

Step I The program ends when the DO 650 and DO 600 loops are completed.

At the end of each site calculation in the DO 600 loop, after writing the results to the output files, the subroutine ZERALL is called to zero the arrays in preparation for the next site.

Similarly, at the end of the calculations for type-1 waste in the DO 650 loop, there are a number of arrays that have to be zeroed in preparation for the type-2 waste calculations. This is done in the DO 640 loop.

3.6 INDEXING OF TIME-DIMENSIONED DATA

In the handling of inputs and outputs that have a time index, questions may arise as to the proper relationship between years and time steps, particularly when calendar years are involved (calendar years are four-digit years; e.g., 1993).

Table 1 shows an example intended to help clarify the relationships among the time variables. Column 1 of Table 1 gives the calendar year. In this example, 1970 is the only year in which waste is added. Thus the initial year of waste accumulation, YSTART, is 1970. The years shown in column 1, being calendar years, are not used as the index of any array.

Column 4 is the time-step index NYR corresponding to the end of the calendar year shown in column 1. NYR is used in the code as the time subscript of time-dimensioned variables. The variable CURACC(M, NYR), for example, gives the curies of radionuclide M accumulated at the end of the year corresponding to the time-step index NYR. NYR goes from 1 to NFINAL. In this example, NFINAL has been given its maximum allowable value of 77. The first 60 time steps (NYR = 1 to 61) are in 1-year increments, and the next 10 (NYR = 61 to 71) are in 10-year increments. The last 6 steps (NYR = 72 to 77) correspond to decay times of 300, 500, 1,000, 10,000, 100,000, and 1,000,000 years.

Table 1. Example showing relationship between calendar years and time steps[a]

End of calendar year	Decay time (years)	Yield factor time index YDECAY	Index NYR for accumulated quantities at end of year
1970	0	–	1
1971	1	1	2
1972	2	2	3
1980	10	10	11
2000	30	30	31
2020	50	50	51
2029	59	59	60
2030	60	60	61
2040	70	61	62
2050	80	62	63
2060	90	63	64
2070	100	64	65
2080	110	65	66
2090	120	66	67
2100	130	67	68
2110	140	68	69
2120	150	69	70
2130	160	70	71

[a]This example is intended to clarify the relationship among the various indices; it covers years 1970 through 2130, a span of 160 years. YSTART is 1970, YFINAL is 2130, and NFINAL is 71. In order to fit the table on one page, some intermediate years are not shown. In this example, waste is added at only one time, the end of year 1970. Column 2 shows the decay time of this waste at the end of each year. Column 3 shows the yield factor index corresponding to the decay time. Column 4 shows the corresponding index of the accumulation array. This index is displaced by one from the yield factor index because the latter starts at one year of decay, which in this case is the end of year 1971.

The array CURACC starts with the first year of waste accumulation. That is, in the array CURACC(M, NYR), NYR = 1 corresponds to the end of calendar year YSTART.

Columns 2 and 3 give the decay time in years and the corresponding yield factor time index YDECAY. YDECAY is the number of decay time increments from the end of year YSTART to the end of any other year in column 1 and is the index used to locate the decay yield factor in the array SYIELD(404, 70). The yield factor array starts with 1 year of decay; it does not contain factors for 0 years of decay. The first 60 of the 70 decay times used in the SYIELD array are in 1-year increments (1 through 60 years), the next 4 are in 10-year increments (70 through 100 years), and the last 6 are for decay times of 240, 440, 940, 9,940, 99,940, and 999,940 years. The code combines these with a decay time of 60 years, using the algorithm described in Sect. 3.3, to obtain yield factors for decay times of 300, 500, 1,000, 10,000, 100,000, and 1,000,000 years. At the end of year YSTART (1970 in this example), the number of years of decay is zero. This is in accordance with the convention used in the code (see Sect. 3.1), that the reported radioactivity of material added to inventory in a given year is assumed to be its radioactivity at the end of that year.

To make this example more concrete, suppose that a site reports that 100 curies of ^{241}Pu were placed in inventory during year 1970. The code interprets this to mean that the activity of this material is 100 curies at the end of year 1970. The activity of the ^{241}Pu at the end of year 1971 is found by multiplying 100 curies by the decay yield factor for ^{241}Pu for one year. The yield factor file (see Sect. 4.3) gives the decay yield factor from ^{241}Pu to itself for one year as 0.953, so the amount of ^{241}Pu in storage at the end of year 1971 would be 95.3 curies. The value of CURACC (*M,1*) would be 100, and the value of CURACC (*M,2*) would be 95.3, where *M* represents the identification of ^{241}Pu.

In the detailed output file RADACMAX.OUT, where the accumulated grams and curies of each actinide and the curies of each fission product are tabulated year by year, the column headings give the time in terms of all three of the time variables shown in columns 1, 2, and 4 of Table 1, that is, end of calendar year, decay time in years, and accumulation array index.

3.7 STRUCTURE OF YIELD FACTOR FILES

File YIELDACT.LIB contains the decay yield factors for the 17 actinide chains currently used in the program. The procedure by which the yield factors were calculated is described in Sect. 2. The ordering of data within the file is shown schematically in Fig. 8. The file is divided sequentially into seven decay time sequences; sequence 1 data are listed first and sequence 7 data are last. Each

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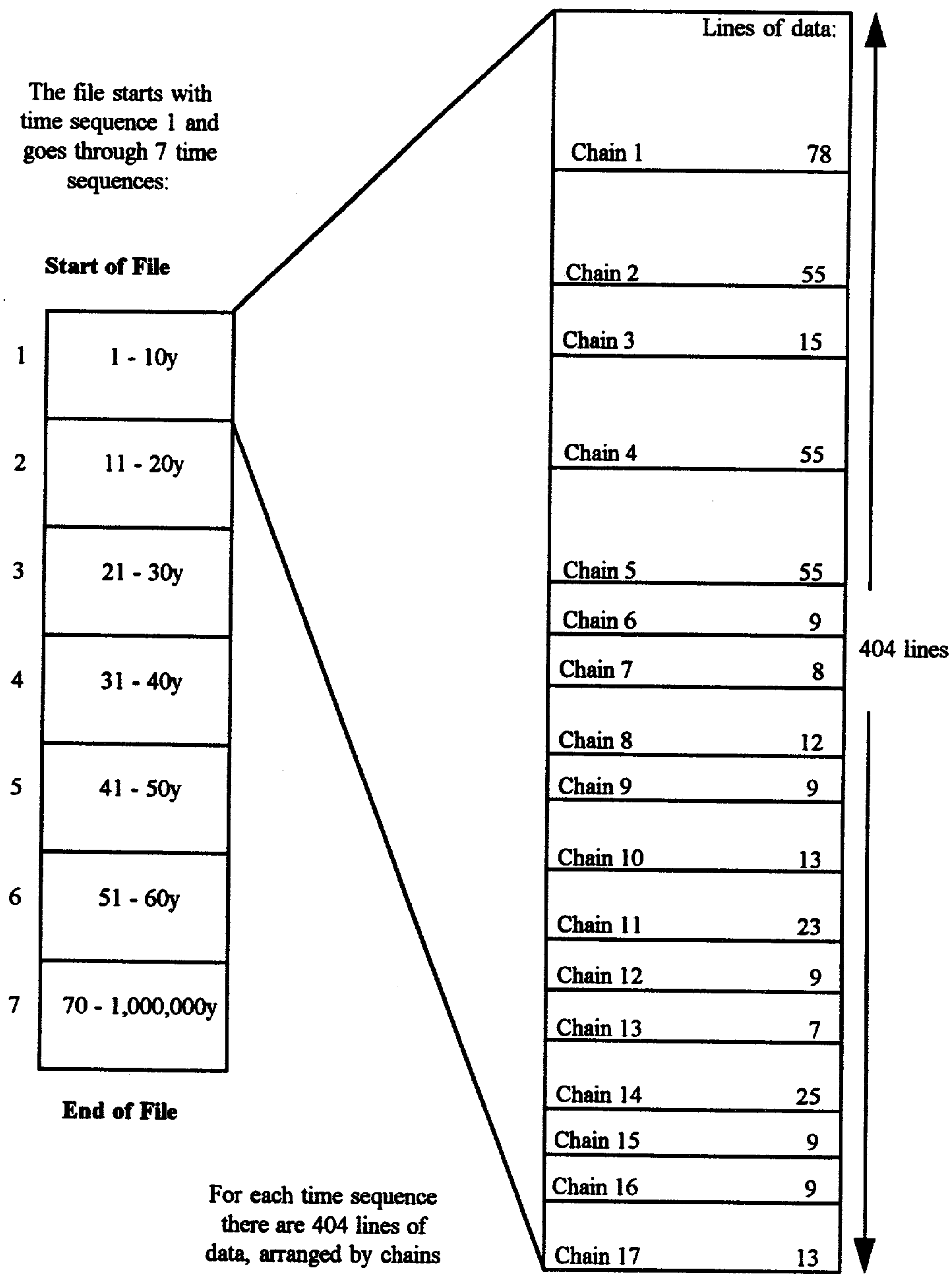

Fig. 8. Arrangement of yield factors in file YIELDACT.LIB.

sequence covers ten decay times. Sequence 1 covers decay times of 1 to 10 years in 1-year steps, sequence 2 covers decay times of 11 to 20 years in 1-year steps, etc. The final sequence, sequence 7, is in two parts. The first 4 steps cover decay times of 70 to 100 years in 10-year steps. The final 6 steps cover decay times of 240, 440, 940, 9,940, 99,940, and 999,940 years.

There are 404 lines of data for each time sequence. Each line of data gives yield factors for a unique "from–to" nuclide combination for 10 decay times. Although a given "from–to" combination may occur in more than one chain, the yield factor file YIELDACT.LIB is constructed so that duplications of data are avoided; that is, the same yield factor data are not presented more than once. The 404 lines are in the following order:

78 lines of data for chain 1
55 lines of data for chain 2
15 lines of data for chain 3
55 lines of data for chain 4
55 lines of data for chain 5
9 lines of data for chain 6
8 lines of data for chain 7
12 lines of data for chain 8
10 lines of data for chain 9
12 lines of data for chain 10
23 lines of data for chain 11
9 lines of data for chain 12
7 lines of data for chain 13
25 lines of data for chain 14
9 lines of data for chain 15
9 lines of data for chain 16
13 lines of data for chain 17

The number of lines of data required for a given chain *C* depends on the length of the chain and on whether any of its "from" actinide members are covered as "from" actinides in another chain. Any of its "from" actinide members that are not shown as "from" actinides in another chain must be represented in chain *C*. In other words, every "from" actinide must have its yields to all of its "to" nuclides listed once, but they do not have to be listed more than once. Table 2 lists the principal actinide members of each chain. The last column of Table 2 tells which of these members have not been represented as "from" actinides in a previous chain. The number of lines required to represent a "from" actinide is equal to the number of its "to" actinides, including itself. For a chain of ten members in which all members are represented as "from" actinides, there are 55 lines of data for each sequence of decay times. These 55 lines are in the following order:

Table 2. Principal actinide members of actinide chains used in RADAC

Chain number	Chain members[a]	Chain members not covered in a previous chain[b]
1	^{249}Bk, ^{249}Cf, ^{245}Cm, ^{241}Pu, ^{241}Am, ^{237}Np, ^{233}Pa, ^{233}U, ^{229}Th, ^{225}Ra, ^{225}Ac, ^{209}Bi	All
2	^{246}Cm, ^{242}Pu, ^{238}U, ^{234}Th, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{206}Pb	All
3	^{242}Cm, ^{238}Pu, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{206}Pb	^{242}Cm, ^{238}Pu
4	^{251}Cf, ^{247}Cm, ^{243}Am, ^{239}Pu, ^{235}U, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Ra, ^{207}Pb	All
5	^{252}Cf, ^{248}Cm, ^{244}Pu, ^{240}Pu, ^{236}U, ^{232}Th, ^{228}Ra, ^{228}Th, ^{224}Ra, ^{208}Pb	All
6	^{236}Pu, ^{232}U, ^{228}Th, ^{224}Ra, ^{208}Pb	^{236}Pu, ^{232}U
7	^{244}Cm, ^{240}Pu, ^{236}U, ^{232}Th, ^{228}Ra, ^{228}Th, ^{224}Ra, ^{208}Pb	^{244}Cm
8	^{242m}Am, ^{242}Pu, ^{238}U, ^{234}Th, ^{242}Cm, ^{238}Pu, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{206}Pb	^{242m}Am
9	^{243}Cm, ^{243}Am, ^{239}Pu, ^{235}U, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Ra, ^{207}Pb	^{243}Cm
10	^{253}Es, ^{249}Bk, ^{249}Cf, ^{245}Cm, ^{241}Pu, ^{241}Am, ^{237}Np, ^{233}Pa, ^{233}U, ^{229}Th, ^{225}Ra, ^{225}Ac, ^{209}Bi	^{253}Es
11	^{254}Es, ^{250}Cf, ^{246}Cm, ^{242}Pu, ^{238}U, ^{234}Th, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{206}Pb	^{254}Es, ^{250}Cf
12	^{209}Po, ^{209}Bi, ^{205}Pb, ^{205}Tl	^{209}Po
13	^{235}Np, ^{235}U, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Ra, ^{207}Pb	^{235}Np
14	^{250}Cm, ^{250}Cf, ^{246}Pu, ^{246}Cm, ^{242}Pu, ^{238}U, ^{234}Th, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{206}Pb	^{250}Cm, ^{246}Pu

Table 2. (continued)

Chain number	Chain members[a]	Chain members not covered in a previous chain[b]
15	^{236}Np, ^{236}U, ^{232}Th, ^{228}Ra, ^{228}Th, ^{236}Pu, ^{232}U, ^{224}Ra, ^{208}Pb	^{236}Np
16	^{241}Cm, ^{241}Am, ^{237}Np, ^{233}Pa, ^{233}U, ^{229}Th, ^{225}Ra, ^{225}Ac, ^{209}Bi	^{241}Cm
17	^{230}Pa, ^{230}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{206}Pb	^{230}Pa, ^{230}U

[a]Only principal actinides are listed. Subordinate actinides are shown in Figs. 2–5.
[b]Not covered means not listed as a "from" actinide.

10 lines giving the yields from member 1 to itself and to the 9 subsequent members of the chain,

9 lines giving the yields from member 2 to itself and to the 8 subsequent members of the chain,

8 lines giving the yields from member 3 to itself and to the 7 subsequent members of the chain,

and so on, down to:

1 line giving the yields from member 10 to itself.

The last column of Table 2 tells how many members of the chain must be listed as "from" nuclides because they have not been previously listed as "from" nuclides in another chain. The information in the last column explains why some chains require relatively few lines of yield factors in Fig. 8, and others require many. For example, Chain 1, which is a 12-member chain, requires 78 lines of data for each time sequence, because none of its members have been represented as "from" nuclides in a previous chain. Chain 2 is a 10-member chain in which all 10 members are represented. As indicated above, this requires 55 lines of data for each time sequence. Chain 3 has eight members, but the last six of these have already been covered as "from" actinides in chain 2. Therefore, only the first two members need be represented in the next block of yield factors. This requires 15 lines of data, i.e., eight lines giving the yields from member 1 to itself and to the seven subsequent members, followed by seven lines giving the yields from member 2 to itself and to the six subsequent members. The yields from members 3 through 8 have already been given as part of chain 2 and are not repeated.

Chains 4 and 5 are complete chains of ten members each, so each of these chains requires 55 lines. Chain 6 has five members, yields for which need be given for only the first two; and chain 7 has eight members, yields for which need be given for only the first member. Chains 8, 9, and 10 have 12, 9, and 13 members, respectively; yields in each case are given for only the first member. Chain 11 has 12 members, yields for which are given for only the first two. Chain 12 has 4 members, yields for which are given for the first 3. Chain 13 has 7 members, yields for which are given for only the first. Chain 14 has 13 members, yields for which are given for the first 2.

Chains 15 and 16 each have 9 members; yields in each case are given for only the first. Chain 17 has 7 members, yields for which are given for the first 2. This accounts for the 404 lines of data for each decay time sequence.

As an aid in visualizing the data sequence in the YIELDACT.LIB file, Table 3 shows the first 78 lines of data, which give the yield factors for chain 1 for the first time sequence, covering decay times of 1 to 10 years. The format of this table has been modified to present the yield factors in a more understandable way and give more information than is given in the actual file. The data have been printed in a 13-column format, with columns 2 and 3 showing the "from" and "to" members, respectively. The names of the "from" and "to" members are not shown in the actual file. The decay times (years) are given at the top of the yield factor columns; these times are not shown in the actual file. To save space, the yield factors in this display have been truncated to four significant figures rather than the seven significant figures used in the actual file.

Table 3 presents only a small fraction of the total data in the file YIELDACT.LIB, but should help to clarify the arrangement of data in the file. The next data in the file, following the data shown in Table 3, would be 55 lines of yield factors for chain 2, which is a complete chain of 10 members.

When executing the RADAC program, the data in file YIELDACT.LIB are read into array SYIELD (404, 70) by the following FORTRAN statements:

```
      DO 13 NYSEQ=1,7
      NYA=10*NYSEQ-9
      NYB=NYA+9
      DO 12 LINE3=1,404
      READ(33,866) (SYIELD(LINE3,NYR),NYR=NYA,NYB)
   12 CONTINUE
   13 CONTINUE

  866 FORMAT(10(1PE12.6,1X))
```

The line number (LINE3) for any given "from" and "to" combination covered by a chain is calculated as follows:

```
      LINE3=LINSUM(NS)+(NPFEED-1)*LENGTH(NS)  +MB
           -(NPFEED*(NPFEED-1))/2
```

Table 3. Partial list of yield factor file YIELDACT.LIB[a]

	FROM	TO	1	2	3	4	5	6	7	8	9	10
1	BK-249	BK-249	4.533E-01	2.055E-01	9.317E-02	4.224E-02	1.915E-02	8.681E-03	3.935E-03	1.784E-03	8.088E-04	3.667E-04
2	BK-249	CF-249	5.460E-01	7.925E-01	9.032E-01	9.522E-01	9.734E-01	9.820E-01	9.848E-01	9.850E-01	9.840E-01	9.825E-01
3	BK-249	CM-245	6.087E-04	1.946E-03	3.612E-03	5.424E-03	7.300E-03	9.204E-03	1.112E-02	1.303E-02	1.495E-02	1.686E-02
4	BK-249	PU-241	1.721E-08	1.138E-07	3.252E-07	6.638E-07	1.131E-06	1.725E-06	2.440E-06	3.272E-06	4.215E-06	5.263E-06
5	BK-249	AM-241	2.169E-10	2.954E-09	1.301E-08	3.626E-08	7.886E-08	1.469E-07	2.464E-07	3.829E-07	5.619E-07	7.885E-07
6	BK-249	NP-237	7.596E-14	2.035E-12	1.353E-11	5.081E-11	1.397E-10	3.156E-10	6.237E-10	1.118E-09	1.861E-09	2.925E-09
7	BK-249	PA-233	1.667E-21	5.474E-20	3.928E-19	1.534E-18	4.320E-18	9.922E-18	1.983E-17	3.586E-17	6.011E-17	9.497E-17
8	BK-249	U-233	2.530E-2	1.716E-19	1.889E-18	1.001E-17	3.577E-17	9.979E-17	2.353E-16	4.908E-16	9.334E-16	1.651E-15
9	BK-249	TH-229	1.509E-27	2.100E-25	3.532E-24	2.533E-23	1.144E-22	3.870E-22	1.074E-21	2.580E-21	5.559E-21	1.100E-20
10	BK-249	RA-225	5.687E-33	9.409E-31	1.686E-29	1.248E-28	5.751E-28	1.971E-27	5.520E-27	1.336E-26	2.893E-26	5.748E-26
11	BK-249	AC-225	2.938E-33	5.550E-31	1.041E-29	7.890E-29	3.685E-28	1.275E-27	3.593E-27	8.737E-27	1.900E-26	3.785E-26
12	BK-249	BI-209	7.803E-33	3.101E-30	8.975E-29	9.244E-28	5.475E-27	2.299E-26	7.634E-26	2.139E-25	5.271E-25	1.174E-24
13	CF-249	CF-249	9.980E-01	9.961E-01	9.941E-01	9.921E-01	9.902E-01	9.882E-01	9.863E-01	9.843E-01	9.824E-01	9.804E-01
14	CF-249	CM-245	1.944E-03	3.884E-03	5.820E-03	7.752E-03	9.680E-03	1.160E-02	1.352E-02	1.544E-02	1.735E-02	1.926E-02
15	CF-249	PU-241	7.677E-08	3.020E-07	6.685E-07	1.169E-06	1.798E-06	2.547E-06	3.412E-06	4.387E-06	5.466E-06	6.643E-06
16	CF-249	AM-241	1.236E-09	9.766E-09	3.254E-08	7.617E-08	1.469E-07	2.507E-07	3.932E-07	5.797E-07	8.153E-07	1.105E-06
17	CF-249	NP-237	5.186E-13	7.976E-12	3.957E-11	1.232E-10	2.968E-10	6.081E-10	1.114E-09	1.879E-09	2.978E-09	4.492E-09
18	CF-249	PA-233	1.211E-20	2.219E-19	1.174E-18	3.777E-18	9.286E-18	1.928E-17	3.567E-17	6.063E-17	9.663E-17	1.464E-16
19	CF-249	U-233	2.145E-20	8.051E-19	6.464E-18	2.794E-17	8.633E-17	2.161E-16	4.679E-16	9.117E-16	1.639E-15	2.767E-15
20	CF-249	TH-229	1.458E-26	1.117E-24	1.359E-23	7.885E-23	3.060E-22	9.223E-22	2.337E-21	5.218E-21	1.058E-20	1.988E-20
21	CF-249	RA-225	5.703E-32	5.109E-30	6.575E-29	3.924E-28	1.549E-27	4.724E-27	1.207E-26	2.711E-26	5.523E-26	1.042E-25
22	CF-249	AC-225	3.032E-32	3.060E-30	4.100E-29	2.497E-28	9.978E-28	3.067E-27	7.881E-27	1.778E-26	3.634E-26	6.874E-26
23	CF-249	BI-209	8.992E-32	1.907E-29	3.922E-28	3.227E-27	1.626E-26	6.035E-26	1.818E-25	4.706E-25	1.086E-24	2.288E-24
24	CM-245	CM-245	9.999E-01	9.998E-01	9.998E-01	9.997E-01	9.996E-01	9.995E-01	9.994E-01	9.993E-01	9.993E-01	9.992E-01
25	CM-245	PU-241	7.832E-05	1.530E-04	2.241E-04	2.919E-04	3.564E-04	4.180E-04	4.766E-04	5.325E-04	5.857E-04	6.365E-04
26	CM-245	AM-241	1.899E-06	7.473E-06	1.654E-05	2.894E-05	4.450E-05	6.306E-05	8.449E-05	1.086E-04	1.354E-04	1.645E-04
27	CM-245	NP-237	1.048E-09	8.102E-09	2.681E-08	6.255E-08	1.204E-07	2.053E-07	3.218E-07	4.743E-07	6.670E-07	9.039E-07
28	CM-245	PA-233	2.652E-17	2.361E-16	8.215E-16	1.966E-15	3.845E-15	6.623E-15	1.046E-14	1.550E-14	2.190E-14	2.978E-14
29	CM-245	U-233	5.838E-17	1.070E-15	5.662E-15	1.822E-14	4.483E-14	9.313E-14	1.723E-13	2.930E-13	4.672E-13	7.083E-13
30	CM-245	TH-229	4.739E-23	1.779E-21	1.429E-20	6.178E-20	1.910E-19	4.781E-19	1.036E-18	2.019E-18	3.631E-18	6.130E-18
31	CM-245	RA-225	1.941E-28	8.356E-27	7.040E-26	3.118E-25	9.778E-25	2.472E-24	5.392E-24	1.056E-23	1.908E-23	3.232E-23
32	CM-245	AC-225	1.068E-28	5.100E-27	4.447E-26	2.003E-25	6.348E-25	1.616E-24	3.541E-24	6.963E-24	1.261E-23	2.141E-23
33	CM-245	BI-209	3.665E-28	3.700E-26	4.959E-25	3.021E-24	1.207E-23	3.713E-23	9.542E-23	2.154E-22	4.403E-22	8.331E-22
34	PU-241	PU-241	9.530E-01	9.082E-01	8.655E-01	8.249E-01	7.861E-01	7.491E-01	7.139E-01	6.804E-01	6.484E-01	6.179E-01
35	PU-241	AM-241	4.696E-02	9.164E-02	1.341E-01	1.746E-01	2.130E-01	2.496E-01	2.844E-01	3.174E-01	3.489E-01	3.788E-01
36	PU-241	NP-237	3.847E-05	1.491E-04	3.285E-04	5.731E-04	8.799E-04	1.246E-03	1.668E-03	2.144E-03	2.670E-03	3.245E-03
37	PU-241	PA-233	1.062E-12	4.564E-12	1.041E-11	1.849E-11	2.869E-11	4.091E-11	5.505E-11	7.101E-11	8.871E-11	1.081E-10
38	PU-241	U-233	3.099E-12	2.760E-11	9.602E-11	2.298E-10	4.494E-10	7.741E-10	1.222E-09	1.812E-09	2.559E-09	3.481E-09
39	PU-241	TH-229	3.127E-18	5.733E-17	3.033E-16	9.763E-16	2.401E-15	4.989E-15	9.232E-15	1.570E-14	2.503E-14	3.794E-14
40	PU-241	RA-225	1.344E-23	2.766E-22	1.522E-21	4.998E-21	1.244E-20	2.605E-20	4.846E-20	8.276E-20	1.324E-19	2.012E-19
41	PU-241	AC-225	7.670E-24	1.721E-22	9.743E-22	3.243E-21	8.139E-21	1.714E-20	3.201E-20	5.482E-20	8.789E-20	1.338E-19
42	PU-241	BI-209	3.130E-23	1.495E-21	1.303E-20	5.873E-20	1.861E-19	4.736E-19	1.038E-18	2.041E-18	3.697E-18	6.276E-18

Table 3. (continued)

	FROM	TO	1	2	3	4	5	6	7	8	9	10
43	AM-241	AM-241	9.984E-01	9.968E-01	9.952E-01	9.936E-01	9.920E-01	9.904E-01	9.888E-01	9.873E-01	9.857E-01	9.841E-01
44	AM-241	NP-237	1.576E-03	3.149E-03	4.720E-03	6.288E-03	7.854E-03	9.417E-03	1.098E-02	1.254E-02	1.409E-02	1.564E-02
45	AM-241	PA-233	4.782E-11	1.013E-10	1.546E-10	2.079E-10	2.611E-10	3.142E-10	3.672E-10	4.201E-10	4.730E-10	5.257E-10
46	AM-241	U-233	2.032E-10	9.021E-10	2.102E-09	3.801E-09	6.000E-09	8.697E-09	1.189E-08	1.558E-08	1.977E-08	2.445E-08
47	AM-241	TH-229	2.665E-16	2.462E-15	8.738E-15	2.124E-14	4.212E-14	7.352E-14	1.176E-13	1.764E-13	2.522E-13	3.470E-13
48	AM-241	RA-225	1.202E-21	1.220E-20	4.466E-20	1.102E-19	2.206E-19	3.873E-19	6.220E-19	9.364E-19	1.342E-18	1.850E-18
49	AM-241	AC-225	7.108E-22	7.737E-21	2.895E-20	7.222E-20	1.454E-19	2.564E-19	4.130E-19	6.231E-19	8.944E-19	1.235E-18
50	AM-241	BI-209	3.523E-21	8.280E-20	4.786E-19	1.617E-18	4.110E-18	8.753E-18	1.653E-17	2.860E-17	4.631E-17	7.121E-17
51	NP-237	NP-237	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
52	NP-237	PA-233	3.396E-08	3.396E-08	3.396E-08	3.396E-08	3.396E-08	3.396E-08	3.396E-08	3.396E-08	3.396E-08	3.396E-08
53	NP-237	U-233	2.845E-07	6.029E-07	9.214E-07	1.240E-06	1.558E-06	1.877E-06	2.195E-06	2.514E-06	2.832E-06	3.150E-06
54	NP-237	TH-229	5.539E-13	2.461E-12	5.736E-12	1.038E-11	1.639E-11	2.377E-11	3.252E-11	4.263E-11	5.412E-11	6.697E-11
55	NP-237	RA-225	2.643E-18	1.256E-17	2.989E-17	5.466E-17	8.684E-17	1.265E-16	1.735E-16	2.279E-16	2.898E-16	3.591E-16
56	NP-237	AC-225	1.628E-18	8.126E-18	1.964E-17	3.617E-17	5.771E-17	8.427E-17	1.158E-16	1.524E-16	1.940E-16	2.406E-16
57	NP-237	BI-209	1.060E-17	1.155E-16	4.321E-16	1.079E-15	2.173E-15	3.832E-15	6.176E-15	9.320E-15	1.338E-14	1.849E-14
58	PA-233	PA-233	8.474E-05	7.181E-09	6.085E-13	5.156E-17	4.369E-21	3.702E-25	3.137E-29	2.659E-33	2.253E-37	1.909E-41
59	PA-233	U-233	9.999E-01	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
60	PA-233	TH-229	3.839E-06	8.137E-06	1.243E-05	1.673E-05	2.103E-05	2.532E-05	2.962E-05	3.391E-05	3.821E-05	4.250E-05
61	PA-233	RA-225	1.947E-11	4.279E-11	6.610E-11	8.942E-11	1.127E-10	1.360E-10	1.593E-10	1.826E-10	2.059E-10	2.292E-10
62	PA-233	AC-225	1.253E-11	2.828E-11	4.403E-11	5.978E-11	7.553E-11	9.127E-11	1.070E-10	1.228E-10	1.385E-10	1.542E-10
63	PA-233	BI-209	1.202E-10	6.001E-10	1.450E-09	2.671E-09	4.262E-09	6.223E-09	8.555E-09	1.126E-08	1.433E-08	1.777E-08
64	U-233	U-233	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
65	U-233	TH-229	4.298E-06	8.595E-06	1.289E-05	1.719E-05	2.148E-05	2.578E-05	3.008E-05	3.437E-05	3.866E-05	4.296E-05
66	U-233	RA-225	2.196E-11	4.527E-11	6.859E-11	9.190E-11	1.152E-10	1.385E-10	1.618E-10	1.851E-10	2.084E-10	2.317E-10
67	U-233	AC-225	1.421E-11	2.996E-11	4.571E-11	6.146E-11	7.721E-11	9.295E-11	1.087E-10	1.244E-10	1.402E-10	1.559E-10
68	U-233	BI-209	1.516E-10	6.710E-10	1.561E-09	2.821E-09	4.452E-09	6.452E-09	8.823E-09	1.156E-08	1.468E-08	1.816E-08
69	TH-229	TH-229	9.999E-01	9.998E-01	9.997E-01	9.996E-01	9.995E-01	9.994E-01	9.993E-01	9.992E-01	9.992E-01	9.991E-01
70	TH-229	RA-225	5.426E-06	5.425E-06	5.424E-06	5.424E-06	5.423E-06	5.423E-06	5.422E-06	5.422E-06	5.421E-06	5.421E-06
71	TH-229	AC-225	3.665E-06	3.665E-06	3.664E-06	3.664E-06	3.664E-06	3.663E-06	3.663E-06	3.663E-06	3.662E-06	3.662E-06
72	TH-229	BI-209	7.775E-05	1.693E-04	2.501E-04	3.363E-04	4.225E-04	5.086E-04	5.948E-04	6.809E-04	7.670E-04	8.531E-04
73	RA-225	RA-225	3.737E-08	1.396E-15	5.218E-23	1.950E-30	7.285E-38	2.803E-45	0.000E-01	0.000E-01	0.000E-01	0.000E-01
74	RA-225	AC-225	7.777E-08	2.907E-15	1.086E-22	4.059E-30	1.517E-37	5.605E-45	0.000E-01	0.000E-01	0.000E-01	0.000E-01
75	RA-225	BI-209	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01
76	AC-225	AC-225	1.011E-11	1.023E-22	1.034E-33	9.809E-45	0.000E-01	0.000E-01	0.000E-01	0.000E-01	0.000E-01	0.000E-01
77	AC-225	BI-209	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01	9.289E-01
78	BI-209	BI-209	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00

[a]This table shows the first 78 lines of the yield factor data file YIELDACT.LIB, except that the names of the actinides and the decay times have been added to clarify the structure of the file, and the number of significant figures has been reduced from 7 to 4 to fit the data into the width of a page. Headings have been added to indicate the "from" and "to" nuclides and the decay time in years.

in which NS is the chain number and NPFEED and MB are the positions in the chain of the "from" and "to" members, respectively. The variable LINSUM (NS) represents the number of lines of data prior to chain NS; the LINSUM array is given in a data statement. The variable LENGTH(NS) represents the number of members in chain NS; this also is given in a data statement. Thus, referring to the ^{249}Bk chain (chain 1, length = 12) shown in Fig. 2, if the "from" member is in position 8 in the chain (^{233}U) and the "to" member is in position 11 (^{225}Ac), the line number is:

```
LINE3 = 0 + (8-1) x 12 + 11 - (8 x 7)/2 = 67
```

and, referring to line 67 of Table 3, the yield of ^{225}Ac produced by decaying one gram of ^{233}U for one year is 1.421E−11 grams. In this case, the yield factor shows the actual yield, because there are no intervening subordinate actinides to be subtracted from the ^{225}Ac.

File YIELDFPS.LIB contains the yield factors for the long-chain (Type 13) fission products. These yield factors are given in terms of curies of daughter per curie of parent, unlike the yield factors of the actinides (file YIELDACT.LIB), which are in grams of daughter per gram of parent. The long-chain fission product yield factors were calculated by means of external programs based on the direct use of the Bateman expressions, using path summations where necessary. Double-precision floating-point arithmetic gave adequate precision in most cases. Integer-array arithmetic was used where the decay chains required greater precision.

4. OTHER PERMANENT DATA FILES

4.1 GENERAL

In addition to the actinide and fission product yield factor files, there are three other permanent data files that must be on the user's hard disk before running the RADAC code. These files are briefly discussed in this section. FORTRAN statements are shown in some cases.

4.2 ACTINIDE DATA FILE NUCDAT.LIB

This file contains the names, identification numbers, and other data on the principal actinides available in RADAC. These are the principal actinide members of the 17 decay chains shown in Figs. 2 through 5. This file does not include the subordinate actinides. Other essential data in this file are the actinide chains in which each actinide occurs, its place number in each of those chains, curies per gram, fraction of decay that takes place by alpha emission, watts per curie, and the index TRUSIG(NID), which tells whether the actinide is classified as a TRU radionuclide (alpha emitter with atomic number greater than 92 and half-life greater than 20 years). The FORTRAN read and format statements are as follows:

```
      READ(13,867)RECORD
      ACTMAX=0
      DO 23 N12=1,400
      READ(13,802)N13,ANAME,N14,N15,C16,C17,C18,N16,
                  N17,N18,C19
      IF(N13.GE.999)GO TO 24
      NID=N13
      IF(NID.GT.ACTMAX)ACTMAX=NID
      ID(N14,N15)=NID
      NAMNID(NID)=ANAME
      NAME(N14,N15)=ANAME
      NSER(NID)=N16
      NPL(NID)=N17
      TRUSIG(NID)=N18
      CURG(NID)=C16
      ALFPAR(NID)=C17
      WATCUR(NID)=C18
      AMASS(NID)=C19
   23 CONTINUE
   24 CONTINUE

  802 FORMAT(I3,2X,A7,2I4,E15.0,5X,2E10.0,3I4,E7.0)
  867 FORMAT(A80)
```

These variables are defined as follows:

NID	=	actinide identification number
ID(N14,N15)	=	same as NID, where N14 = chain and N15 = place number in chain
ANAME	=	actinide name
NAMNID(NID)	=	name of actinide with identification number NID
NSER(NID)	=	chain number for yield factor of actinide with identification number NID
NPL(NID)	=	place number for yield factor of actinide with identification number NID
CURG(NID)	=	curies per gram
ALFPAR(NID)	=	fraction of decay that is alpha decay
WATCUR(NID)	=	watts per curie

```
TRUSIG(NID)    =  1 if the actinide is defined as a TRU
                  actinide, 0 if not a TRU actinide.
```

If an actinide is a member of more than one chain, this file gives chain numbers and place numbers for all the chains in which the actinide occurs.

Reading of the file is terminated by a 999 in the field where the actinide identification number N13 would normally be read.

Table 4 lists the principal actinides available in RADAC and summarizes most of the data discussed above.

4.3 SUBACTINIDE DATA FILE SUBNUC.LIB

This file contains data on the subordinate actinides. These are the short-lived daughter actinides whose curies are assumed to be equal to those of the parent actinide, adjusted for branching factor as necessary. The file is read by the following statements:

```
      READ(12,867)RECORD
      READ(12,867)RECORD

      DO 28 N8=1,400
        READ(12,807)N118,ANAME,A2NAME,N19,N20,Z20,Z21,
                    Z22,Z23,Z24,Z25
      IF(N118.GE.999)GO TO 29
      IF(Z20.EQ.0.)Z20=1.0
      NSUBS=N8
      N18=N118-100
      SUBID(N18)=N18
      SUBNAM(N18)=ANAME
      PARID(N18)=N19
      IDOWN(N18)=N20
      YLDSUB(N18)=Z20
      SUBCRG(N18)=Z21
      ALFSUB(N18)=Z22
      WTCSUB(N18)=Z23
      SUBRWT(N18)=Z24
      SMASS (N18)=Z25
 28   CONTINUE
 29   CONTINUE

807 FORMAT(I3,1X,A7,2X, A7,1X, I2,1X,I2,1X,
           E9.0,E10.0,2E9.0, E7.0,E6.0)
867 FORMAT(A80)
```

Table 4. Principal (long-lived) actinides and daughters used in RADAC[a]

ID and name		Half-life (s)	Decay constant (s^{-1})	Curies per gram	Watts per curie	Alpha fraction
1	^{206}Pb	STABLE	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	^{207}Pb	STABLE	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	^{208}Pb	STABLE	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	^{210}Pb	7.0370E+08	9.8500E-10	7.6365E+01	2.3140E-04	0.0000E+00
5	^{209}Bi	STABLE	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	^{210}Po	1.1960E+07	5.7955E-08	4.4932E+03	3.2020E-02	1.0000E+00
7	^{223}Ra	9.8790E+05	7.0164E-07	5.1225E+04	3.5560E-02	1.0000E+00
8	^{224}Ra	3.1620E+05	2.1921E-06	1.5933E+05	3.4280E-02	1.0000E+00
9	^{225}Ra	1.2790E+06	5.4194E-07	3.9215E+04	7.0030E-04	0.0000E+00
10	^{226}Ra	5.0490E+10	1.3728E-11	9.8898E-01	2.8840E-02	1.0000E+00
11	^{228}Ra	2.1144E+08	3.2783E-09	2.3409E+02	7.6960E-05	0.0000E+00
12	^{225}Ac	8.6400E+05	8.0225E-07	5.8050E+04	3.4890E-02	1.0000E+00
13	^{227}Ac	6.8710E+08	1.0088E-09	7.2353E+01	4.8360E-04	1.3800E-02
14	^{227}Th	1.6170E+06	4.2866E-07	3.0744E+04	3.6450E-02	1.0000E+00
15	^{228}Th	6.0370E+07	1.1482E-08	8.1987E+02	3.2660E-02	1.0000E+00
16	^{229}Th	2.3160E+11	2.9929E-12	2.1278E-01	3.0550E-02	1.0000E+00
17	^{230}Th	2.4300E+12	2.8525E-13	2.0191E-02	2.8260E-02	1.0000E+00
18	^{232}Th	4.4340E+17	1.5633E-18	1.0970E-07	2.4180E-02	1.0000E+00
19	^{234}Th	2.0820E+06	3.3292E-07	2.3164E+04	4.0490E-04	0.0000E+00
20	^{231}Pa	1.0340E+12	6.7036E-13	4.7246E-02	3.0090E-02	1.0000E+00
21	^{233}Pa	2.3330E+06	2.9711E-07	2.0760E+04	2.2670E-03	0.0000E+00
22	^{232}U	2.2720E+09	3.0508E-10	2.1409E+01	3.2060E-02	1.0000E+00
23	^{233}U	5.0020E+12	1.3857E-13	9.6828E-03	2.9030E-02	1.0000E+00
24	^{234}U	7.7160E+12	8.9832E-14	6.2502E-03	2.8770E-02	1.0000E+00
25	^{235}U	2.2210E+16	3.1209E-17	2.1621E-06	2.6160E-02	1.0000E+00
26	^{236}U	7.3890E+14	9.3808E-16	6.4715E-05	2.7050E-02	1.0000E+00
27	^{238}U	1.4100E+17	4.9159E-18	3.3628E-07	2.5330E-02	1.0000E+00
28	^{237}Np	6.7530E+13	1.0264E-14	7.0511E-04	3.0520E-02	1.0000E+00
29	^{236}Pu	8.9970E+07	7.7042E-09	5.3149E+02	3.4760E-02	1.0000E+00
30	^{238}Pu	2.7690E+09	2.5032E-10	1.7124E+01	3.3100E-02	1.0000E+00
31	^{239}Pu	7.5940E+11	9.1276E-13	6.2177E-02	3.0780E-02	1.0000E+00
32	^{240}Pu	2.0630E+11	3.3599E-12	2.2792E-01	3.1100E-02	1.0000E+00
33	^{241}Pu	4.5440E+08	1.5254E-09	1.0305E+02	3.0960E-05	2.4500E-05
34	^{242}Pu	1.2210E+13	5.6769E-14	3.8192E-03	2.9490E-02	1.0000E+00
35	^{244}Pu	2.6070E+15	2.6588E-16	1.7741E-05	2.8960E-02	9.9870E-01
36	^{241}Am	1.3640E+10	5.0817E-11	3.4330E+00	3.3180E-02	1.0000E+00
37	^{243}Am	2.3290E+11	2.9762E-12	1.9940E-01	3.2100E-02	1.0000E+00
38	^{242}Cm	1.4100E+07	4.9159E-08	3.3072E+03	3.6800E-02	1.0000E+00
39	^{245}Cm	2.6820E+11	2.5844E-12	1.7174E-01	3.3140E-02	1.0000E+00
40	^{246}Cm	1.4930E+11	4.6426E-12	3.0726E-01	3.2700E-02	9.9974E-01
41	^{247}Cm	4.9230E+14	1.4080E-15	9.2806E-05	3.1910E-02	1.0000E+00
42	^{248}Cm	1.0700E+13	6.4780E-14	4.2527E-03	1.2430E-01	9.1740E-01
43	^{251}Cf	2.8340E+10	2.4458E-11	1.5865E+00	3.5680E-02	1.0000E+00
44	^{252}Cf	8.3250E+07	8.3261E-09	5.3780E+02	7.1280E-02	9.6910E-01

Table 4. (continued)

ID and name		Half-life (s)	Decay constant (s^{-1})	Curies per gram	Watts per curie	Alpha fraction
45	^{244}Cm	5.7150E+08	1.2129E-09	8.0915E+01	3.4930E-02	1.0000E+00
46	^{249}Bk	2.7650E+07	2.5069E-08	1.6391E+03	7.4000E-04	1.0000E+00
47	^{249}Cf	1.1060E+10	6.2672E-11	4.0978E+00	4.6210E-02	1.0000E+00
48	^{242m}Am	4.7970E+09	1.4450E-10	9.7220E+00	3.9450E-04	5.0000E-03
49	^{243}Cm	8.9940E+08	7.7068E-10	5.1635E+01	3.6640E-02	9.9760E-01
50	^{253}Es	1.7686E+06	3.9192E-07	2.5220E+04	5.7910E-04	1.0000E+00
51	^{254}Es	2.3820E+07	2.9099E-08	1.8652E+03	3.9210E-02	1.0000E+00
52	^{250}Cf	4.1280E+08	1.6791E-09	1.0935E+02	3.7100E-02	9.9923E-01
53	^{209}Po	3.2189E+09	2.1534E-10	1.6772E+01	4.0711E-02	9.9740E-01
54	^{205}Pb	6.0906E+14	1.1381E-15	9.0370E-05	2.9050E-05	0.0000E+00
55	^{205}Tl	STABLE	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
56	^{235}Np	3.4220E+07	2.0256E-08	1.4031E+03	5.8100E-05	0.0000E+00
57	^{250}Cm	5.4910E+11	1.2623E-12	8.2194E-02	7.3099E-01	2.5000E-01
58	^{246}Pu	9.3744E+05	7.3940E-07	4.8928E+04	8.4185E-04	0.0000E+00
59	^{236}Np	3.6290E+12	1.9100E-13	1.3175E-02	2.0175E-03	0.0000E+00
60	^{241}Cm	3.1104E+06	2.2285E-07	1.5052E+04	4.1108E-03	1.0000E-02
61	^{230}Pa	1.5034E+06	4.6107E-07	3.2631E+04	4.2697E-03	0.0000E+00
62	^{230}U	1.7971E+06	3.8570E-07	2.7298E+04	3.5518E-02	1.0000E+00

[a]All of the radionuclides listed here are of Type 20. This type includes all the actinides and daughters whose abundances are calculated by means of yield factors. Although listed as "long-lived", some of the actinides or actinide daughters listed here have half-lives of less than 12 days. Subordinate (Type 21) actinides are listed in Table 5. Type and ID numbers are needed when entering input data for a run.

The first line is supplied for convenience in editing; it gives the column numbers of the data fields. The data read in the DO 18 loop are as follows:

```
N18     =  subordinate actinide identification number
ANAME   =  SUBNAM(N18) = name of subordinate actinide
A2NAME  =  name of parent actinide
N19     =  PARID(N18) = identification number of parent
           actinide
N20     =  ISUBTR (N18) = identification of actinide
           from which subordinate actinide is to be
           subtracted.  If zero, no subtraction is made.
Z20     =  YLDSUB(N18) = fraction of parent actinide
           that goes to subordinate actinide
Z21     =  SUBCRG(N18) = curies/gram for subordinate
           nuclide
Z22     =  ALFSUB(N18) = alpha decay fraction for
           subordinate nuclide
Z23     =  WTCSUB(N18)= watts/curie for subordinate
           nuclide
Z24     =  SUBRWT(N18) = atomic mass ratio, downstream
           principal actinide to upstream subactinide
```

Table 5 lists the subordinate actinides in RADAC and summarizes much of the data described above.

4.4 FISSION PRODUCT DATA FILE FPNUCS.LIB

This file contains identification numbers and other basic information for fission products, activation products, and their radioactive daughters. Table 6 lists the fission and activation products available in RADAC and summarizes most of the data in FPNUCS.LIB. The contents of FPNUCS.LIB are as follows:

Lines 1-2:

These two lines contain narrative information not used in the calculations. Format is A80. Both lines must be used or left blank. Read statements are as follows:

```
READ(20,867)RECORD
READ(20,867)RECORD
```

Table 5. Subordinate (short-lived daughter) actinides in RADAC[a]

Subordinate (short-lived daughter) actinide	Half-life (s)	Parent actinide[b]	Half-life of parent (s)	Branching ratio[c]
^{207}Tl	2.8620E+02	^{223}Ra	9.8790E+05	0.9972
^{208}Tl	1.8420E+02	^{224}Ra	3.1620E+05	0.3593
^{209}Tl	1.3200E+02	^{225}Ac	8.6400E+05	0.0216
^{210}Tl	7.8000E+01	^{226}Ra	5.0490E+10	0.00021
^{209}Pb	1.1880E+04	^{223}Ac	8.6400E+05	1.0
^{211}Pb	2.1660E+03	^{223}Ra	9.8790E+05	1.0
^{212}Pb	3.8300E+04	^{224}Ra	3.1620E+05	1.0
^{214}Pb	1.6080E+03	^{226}Ra	5.0490E+10	1.0
^{210}Bi	4.3300E+05	^{210}Pb	7.0370E+08	1.0
^{211}Bi	1.2780E+02	^{223}Ra	9.8790E+05	1.0
^{212}Bi	3.6330E+03	^{224}Ra	3.1620E+05	1.0
^{213}Bi	2.7390E+03	^{225}Ac	8.6400E+05	1.0
^{214}Bi	1.1940E+03	^{226}Ra	5.0490E+10	1.0
^{211}Po	5.6000E-01	^{223}Ra	9.8790E+05	0.0028
^{212}Po	3.0000E-07	^{224}Ra	3.1620E+05	0.6407
^{213}Po	4.2000E-06	^{225}Ac	8.6400E+05	0.9784
^{214}Po	1.6430E-04	^{226}Ra	5.0490E+10	1.0
^{215}Po	1.7800E-03	^{223}Ra	9.8790E+05	1.0
^{216}Po	1.5000E-01	^{224}Ra	3.1620E+05	1.0
^{218}Po	1.8300E+02	^{226}Ra	5.0490E+10	1.0
^{217}At	3.2300E-02	^{225}Ac	8.6400E+05	1.0
^{218}Rn	3.5000E-02	^{230}U	1.7971E+06	1.0
^{219}Rn	3.9600E+00	^{223}Ra	9.8790E+05	1.0
^{220}Rn	5.5600E+01	^{224}Ra	3.1620E+05	1.0
^{222}Rn	3.3040E+05	^{226}Ra	5.0490E+10	1.0
^{221}Fr	2.8800E+02	^{225}Ac	8.6400E+05	1.0
^{223}Fr	1.3080E+03	^{227}Ac	6.8710E+08	0.0138
^{222}Ra	3.8000E+01	^{230}U	1.7971E+06	1.0
^{228}Ac	2.2070E+04	^{228}Ra	2.1144E+08	1.0
^{226}Th	1.8600E+03	^{230}U	1.7971E+06	1.0
^{231}Th	9.1870E+04	^{235}U	2.2210E+16	1.0
^{234m}Pa	7.0200E+01	^{235}U	2.2210E+16	1.0
^{234}Pa	2.4120E+04	^{234}Th	2.0820E+06	0.0013
^{237}U	5.8320E+05	^{241}Pu	4.5440E+08	0.0000245
^{240}U	5.0760E+04	^{244}Pu	2.6070E+15	0.9987
^{238}Np	1.8290E+05	^{242m}Am	4.7970E+09	0.005
^{239}Np	2.0350E+05	^{243}Am	2.3290E+11	1.0
^{240}Np	3.9000E+03	^{244}Pu	2.6070E+15	0.0011
^{240m}Np	4.4400E+02	^{244}Pu	2.6070E+15	0.9987
^{237}Pu	1.8000E-04	^{241}Cm	3.1104E+06	0.01
^{242}Pu	1.7840E+04	^{247}Cm	4.9230E+14	1.0
^{242}Am	5.7670E+04	^{242m}Am	4.7970E+09	0.995
^{245}Am	7.4520E+03	^{249}Bk	2.7650E+07	0.0000145
^{246}Am	1.5000E+03	^{246}Pu	9.3744E+05	1.0
^{250}Bk	1.1600E+04	^{254}Es	2.3820E+07	1.0

[a]The longest-lived of the subordinate actinides listed here is ^{237}U; its half-life is about 6.75 days.
[b]The parent listed here is the closest principal parent actinide.
[c]This the ratio used to calculate the curies of the daughter from the curies of the parent.

Table 6. Fission and activation products used in RADAC[a]

Name	Type	ID	Half-life (s)	Decay constant (s^{-1})	Curies per gram	Watts per curie
^{3}H	10	1	3.8970E+08	1.7787E-09	9.6513E+03	3.3630E-05
^{14}C	10	2	1.8080E+11	3.8338E-12	4.4577E+00	2.9300E-04
^{22}Na	10	65	8.2110E+07	8.4417E-09	6.2462E+03	1.4131E-02
^{24}Na	10	66	5.4000E+04	1.2836E-05	8.7063E+06	2.7676E-02
^{32}P	11	67	1.2355E+06	5.6103E-07	2.8539E+05	1.0123E-02
^{32}Si	10	62	2.0512E+10	3.3792E-11	1.7190E+01	1.2432E-03
^{35}S	10	68	7.6032E+06	9.1165E-08	4.2401E+04	9.9101E-04
^{36}Cl	10	69	9.4990E+12	7.2971E-14	3.2996E-02	1.4729E-03
^{40}K	10	70	4.0390E+16	1.7161E-17	6.9840E-06	3.6136E-03
^{45}Ca	10	71	1.4080E+07	4.9229E-08	1.7808E+04	4.5702E-04
^{46}Sc	10	72	7.2400E+06	9.5739E-08	3.3880E+04	1.2562E-02
^{50}V	10	73	1.2623E+24	5.4911E-25	1.7877E-13	1.1011E-02
^{51}Cr	10	23	2.3940E+06	2.8954E-07	9.2415E+04	2.1430E-04
^{54}Mn	10	3	2.7000E+07	2.5672E-08	7.7389E+03	4.9750E-03
^{55}Fe	10	4	8.2050E+07	8.4479E-09	2.5003E+03	3.2000E-05
^{58}Co	10	74	6.1150E+06	1.1335E-07	3.1814E+04	5.9733E-03
^{58m}Co	10	75	3.2940E+04	2.1043E-05	5.9059E+06	1.4599E-04
^{59}Fe	10	5	3.8880E+06	1.7828E-07	4.9188E+04	7.7320E-03
^{59}Ni	10	8	2.5246E+12	2.7456E-13	7.5752E-02	3.9800E-05
^{60}Co	10	7	1.6630E+08	4.1681E-09	1.1308E+03	1.5400E-02
^{63}Ni	10	9	2.9033E+09	2.3874E-10	6.1688E+01	1.0060E-04
^{65}Zn	10	64	2.1070E+07	3.2897E-08	8.2387E+03	3.4952E-03
^{67}Ga	10	14	2.8176E+05	2.4601E-06	5.9770E+05	1.1150E-03
^{75}Se	10	92	1.0350E+07	6.6971E-08	1.4536E+04	2.4100E-03
^{79}Se	10	30	2.0500E+12	3.3812E-13	6.9672E-02	2.4860E-04
^{81}Kr	10	76	6.6230E+12	1.0466E-13	2.1033E-02	1.2314E-04
^{85}Kr	10	42	3.3830E+08	2.0489E-09	3.9239E+02	1.4960E-03
^{86}Rb	10	98	1.6120E+06	4.2999E-07	8.1390E+04	4.5200E-03
^{87}Rb	10	31	1.4820E+18	4.6771E-19	8.7512E-08	8.3590E-04
^{89}Sr	10	77	4.3630E+06	1.5887E-07	2.9058E+04	3.4525E-03
^{90}Sr	10	10	9.1900E+08	7.5424E-10	1.3642E+02	1.1590E-03
^{90}Y	11	11	2.3040E+05	3.0085E-06	5.4414E+05	5.5350E-03
^{91}Y	10	78	5.0550E+06	1.3712E-07	2.4529E+04	3.5869E-03
^{93}Mo	10	80	1.1040E+11	6.2785E-12	1.0990E+00	9.3536E-05
^{93}Zr	13	12	4.8280E+13	1.4357E-14	2.5130E-03	2.9000E-04
^{93m}Nb	10	13	4.2920E+08	1.6150E-09	2.8268E+02	1.7700E-04
^{94}Nb	10	79	6.4060E+11	1.0820E-12	1.8738E-01	1.0176E-02
^{95}Nb	10	24	3.0370E+06	2.2823E-07	3.9108E+04	4.7910E-03
^{95}Zr	13	59	5.5280E+06	1.2539E-07	2.1485E+04	5.0590E-03
^{95m}Nb	13	60	3.1180E+05	2.2231E-06	3.8092E+05	1.3876E-03
^{99}Tc	10	15	6.7220E+12	1.0312E-13	1.6955E-02	5.0080E-04
^{99m}Tc	10	81	2.1670E+04	3.1986E-05	5.2595E+06	8.4182E-04
^{103}Ru	13	82	3.3940E+06	2.0423E-07	3.2277E+04	3.3412E-03
^{103m}Rh	10	83	3.3670E+03	2.0586E-04	3.2535E+07	2.2987E-04

Table 6. (continued)

Name	Type	ID	Half-life (s)	Decay constant (s^{-1})	Curies per gram	Watts per curie
^{106}Ru	10	16	3.2110E+07	2.1587E-08	3.3151E+03	5.9380E-05
^{106}Rh	11	17	2.9900E+01	2.3182E-02	3.5601E+09	1.8940E-02
^{107}Pd	10	32	2.0500E+14	3.3812E-15	5.1440E-04	5.9280E-05
^{108}Ag	11	84	1.4220E+02	4.8745E-03	7.3471E+08	3.7184E-03
^{108m}Ag	10	85	4.0080E+09	1.7294E-10	2.6067E+01	9.6733E-03
^{109}Cd	10	48	4.0090E+07	1.7290E-08	2.5821E+03	1.1600E-04
^{109m}Ag	11	55	3.9600E+01	1.7504E-02	2.6141E+09	5.1480E-04
^{110}Ag	11	50	2.4600E+01	2.8177E-02	4.1697E+09	7.1750E-03
^{110m}Ag	10	61	2.1590E+07	3.2105E-08	4.7511E+03	1.6677E-02
^{113m}Cd	10	49	4.6040E+08	1.5055E-09	2.1688E+02	1.6810E-03
^{113m}In	11	86	5.9690E+03	1.1612E-04	1.6728E+07	2.3266E-03
^{113}Sn	10	87	9.9450E+06	6.9698E-08	1.0040E+04	1.6635E-04
^{119m}Sn	10	51	2.1170E+07	3.2742E-08	4.4789E+03	5.1620E-04
^{121m}Sn	10	52	1.5770E+09	4.3954E-10	5.9132E+01	2.0010E-03
^{121}Sn	10	53	9.6480E+04	7.1844E-06	9.6653E+05	1.2080E-03
^{123}Sn	10	88	1.1160E+07	6.2110E-08	8.2199E+03	3.1192E-03
^{123m}Sn	10	54	2.4050E+03	2.8821E-04	3.8143E+07	3.6400E-03
^{125}I	10	44	5.1581E+06	1.3438E-07	1.7500E+04	3.4750E-04
^{125}Sb	13	25	8.7410E+07	7.9298E-09	1.0327E+03	3.1220E-03
^{125m}Te	10	56	5.0110E+06	1.3833E-07	1.8014E+04	8.3950E-04
^{126}Sn	10	33	3.1560E+12	2.1963E-13	2.8375E-02	1.2470E-03
^{126}Sb	11	34	1.0710E+06	6.4720E-07	8.3614E+04	1.8480E-02
^{126m}Sb	11	35	1.1400E+03	6.0802E-04	7.8553E+07	1.2730E-02
^{127m}Te	13	57	9.4180E+06	7.3598E-08	9.4335E+03	5.3720E-04
^{127}Te	10	58	3.3660E+04	2.0593E-05	2.6395E+06	1.3490E-03
^{129}I	10	45	4.9540E+14	1.3992E-15	1.7656E-04	4.6200E-04
^{131}I	13	46	6.9470E+05	9.9776E-07	1.2398E+05	3.3920E-03
^{131m}Xe	10	47	1.0280E+06	6.7427E-07	8.3786E+04	9.6080E-04
^{133}Ba	10	89	3.3890E+08	2.0453E-09	2.5033E+02	2.6190E-03
^{133}Xe	10	93	4.5320E+05	1.5295E-06	1.8720E+05	1.0800E-03
^{134}Cs	10	26	6.5070E+07	1.0652E-08	1.2940E+03	1.0170E-02
^{135}Cs	10	36	7.2580E+13	9.5501E-15	1.1516E-03	3.3380E-04
^{137}Cs	10	18	9.4670E+08	7.3217E-10	8.6997E+01	1.1050E-03
^{137m}Ba	11	19	1.5310E+02	4.5274E-03	5.3795E+08	3.9210E-03
^{141}Ce	10	90	2.8090E+06	2.4676E-07	2.8488E+04	1.4622E-03
^{142}Ce	10	37	3.3110E+18	2.0935E-19	2.3999E-08	0.0000E-01
^{144}Ce	13	20	2.4560E+07	2.8223E-08	3.1904E+03	6.6240E-04
^{144}Pr	13	21	1.0370E+03	6.6842E-04	7.5561E+07	7.3410E-03
^{144}Nd	10	38	6.6230E+22	1.0466E-23	1.1831E-12	0.0000E-01
^{147}Pm	13	22	8.2790E+07	8.3724E-09	9.2713E+02	3.6700E-04
^{147}Sm	10	6	3.3770E+18	2.0526E-19	2.2729E-08	1.3693E-02
^{148}Sm	10	100	2.5250E+23	2.7451E-24	3.0194E-13	1.1923E-02
^{150}Eu	10	63	1.1298E+09	6.1351E-10	6.6580E+01	9.1168E-03
^{151}Sm	10	39	2.8400E+09	2.4407E-10	2.6311E+01	1.1730E-04
^{152}Eu	13	27	4.2920E+08	1.6150E-09	1.7296E+02	7.5540E-03

Table 6. (continued)

Name	Type	ID	Half-life (s)	Decay constant (s^{-1})	Curies per gram	Watts per curie
^{152}Gd	13	99	3.4080E+21	2.0339E-22	2.1782E-11	1.3012E-02
^{153}Gd	10	43	2.0910E+07	3.3149E-08	3.5269E+03	9.0220E-04
^{154}Eu	10	28	2.7140E+08	2.5540E-09	2.6996E+02	8.9330E-03
^{155}Eu	10	29	1.5650E+08	4.4291E-09	4.6515E+02	7.2640E-04
^{160}Tb	10	40	6.2470E+06	1.1096E-07	1.1289E+04	8.1450E-03
^{169}Yb	10	94	2.7660E+06	2.5060E-07	2.4138E+04	2.5120E-03
^{175}Hf	10	95	6.0480E+06	1.1461E-07	1.0661E+04	2.4220E-03
^{182}Ta	10	41	9.9360E+06	6.9761E-08	6.2396E+03	8.8910E-03
^{192}Ir	10	96	6.3950E+06	1.0839E-07	9.1896E+03	6.1050E-03
^{201}Tl	10	97	2.6317E+05	2.6338E-06	2.1331E+05	8.3000E-04

[a]The code makes no calculational distinction between fission products and activation products. They are divided into types 10, 11, and 13. If the nuclide is type 10, decay is calculated by a simple exponential decay equation. A type 11 nuclide is a short-lived daughter whose curies are calculated as the product of the curies of a parent nuclide and the branching ratio from the parent to the daughter. A type 13 nuclide is the initial member of a decay chain of several members, yields of which are calculated by the use of tabulated decay yield factors.

Lines 3 and subsequent:

Each line contains data on a particular radionuclide. The data are as follows:

FPNAME	=	name (for example, Cs-137).
MASS	=	atomic mass.
FPTYPE	=	type.
FPNID	=	identification number.
FPPAR	=	identification number of parent (if any). A nonzero value for FPPAR in this file indicates that the nuclide is a short-lived daughter whose curies are calculated from those of the parent.
THALF	=	half-life(s).
FPWATC	=	watts/curie.
FPBRAN	=	if the nuclide is a short-lived daughter, FPBRAN gives the atoms of daughter produced per atom of parent decayed.

The following quantities are calculated:

FPCURG	=	curies/gram.
FPDEC	=	decay constant, λ, s^{-1}.

In calculating FPCURG, the value of Avogadro's number is taken as 6.023E23.

The format for reading the data is as follows:

```
844 FORMAT(A7,I4,3(1X,I3),1X,3(E10.0,1X),E7.0,6I3).
```

The end of the file is signalled by putting ZZZZZ in the space where the next radionuclide name would normally be read or 999 in the space where FPTYPE would be read. In the example, both of these are done, although either one would be sufficient.

If FPPAR is zero or blank, the nuclide is of type 10 or 13, and its decay is calculated within the program by the exponential decay relationship, Eq. 2, in which the fraction remaining at the end of time t is given by e raised to the $-\lambda t$ power. If FPPAR is nonzero, the nuclide is a short-lived daughter, and its curies are calculated as the curies of the parent multiplied by the branching ratio from the parent to the daughter, FPBRAN.

5. USER-PREPARED INPUT DATA FILES

5.1 INTRODUCTION

With one minor exception, which is discussed in Sect. 5.2.1, the RADAC code gets its inputs from fixed-format data files rather than from the console. Permanent data files, which contain data that do not change from problem to problem, were discussed in Sects. 3 and 4. Problem-specific data files, which must be prepared for each problem by the user, are discussed in this section.

The number of problem-specific files that the user must prepare to run a problem varies from two to four depending on the number of waste types and on whether waste volumes, as well as radionuclide masses and radioactivities, are to be accumulated. If there is only one waste type and no volume data are involved, two files are sufficient, RADACINP.DAT and RADNUCL1.DAT. If there are two waste types, a third file is needed, RADNUCL2.DAT, which gives the radionuclide inputs for waste type 2. If volume data are to be accumulated, a fourth file is needed, VOLUME.DAT, which gives volume inputs for both types of waste.

Instructions for the preparation of these files are given in the remainder of this section, principally through the use of example problems. Input and output files for these examples are shown in a series of exhibits numbered to correspond to the example numbers.

5.2 EXAMPLE 1

Example 1 has one waste type and does not have volume input data, so the only files to be prepared by the user are the two mandatory input files, RADACINP.DAT and RADNUCL1.DAT. In this example, there are three radionuclide inputs, Am-241, Ni-63, and I-125. These nuclides are introduced at the end of year 1970 and decayed for time periods up to 160 years. There are no other radionuclide inputs. Example 1 illustrates the preparation of the mandatory input data files. It also illustrates the use of the optional output file RADAC4.OUT, which provides a summary of results short enough to be conveniently examined by the user.

5.2.1 Example 1, File RADACINP.DAT

This file, shown in Exhibit 1.1, defines the run parameters and options and contains all the run-specific information needed except the names and quantities of the radionuclides and the years in which they are added. In the upper part of the exhibit, the file has been annotated with explanatory

Exhibit 1.1. Input file RADACINP.DAT for Example 1.

Annotated File:

```
Line
 1   RADACINP.DAT  FOR EXAMPLE 1, USER'S MANUAL. SEE RADACINP.009. 5/4/95.
 2   ISIG(1)=1: INPUT IS IN GRAMS.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
 3   ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=0  NO VOLUMES READ.
 4   ISIG(6)=9: 9 DECAY TIMES IN OUTPUT OU4: 1,2,5,10,20,50,100,120,160Y.
 5   LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
 6   STARTING YEAR 1970, FINAL YEAR 2130. ONE SITE, LLNL. ONE WASTE TYPE.
```

Column 1

Control signals ISIG(x) x = 1 through 10

```
 7    0001 0000 0000 0000 0000 0009 0000 0000 0000 0000
```

Final year; Number of waste types

```
 8    1970 2130 0001 0001
```

Starting year; Number of sites

```
 9    LLNL
```

Site

Column 2

```
10    0001 0002 0005 0010 0020 0050 0100 0120 0160
```

Accumulations at these decay times will be shown in RADAC4.OUT

Comments:

Line 1 – 6: User notes and remarks—not used in calculations. All 6 lines must be used, even if left blank.

Line 7: Format is 16I5. See text Sect. 5 and Table 7 for explanation of control signals.

Line 8: First year of waste input is 1970. Final year of decay is 2130. One site, one waste type. Format 16I5. The number of years of waste additions is not shown in this file; it is shown in RADNUCL1.DAT.

Line 9: Name of site, up to 4 letters. Format 16(1x, A4). Use 2 lines if number of sites exceeds 16.

Line 10: The user lists here up to 9 decay times for which results will be shown in output file RADAC4.OUT. The number of decay times selected is given by the value of ISIG(6); the maximum allowable number is 9. Format for line 10 is 16I5. Line 10 is not used if ISIG(6) = 0.

Actual File:

```
RADACINP.DAT  FOR EXAMPLE 1, USER'S MANUAL. SEE RADACINP.009. 5/4/95.
ISIG(1)=1: INPUT IS IN GRAMS.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=0  NO VOLUMES READ.
ISIG(6)=9: 9 DECAY TIMES IN OUTPUT OU4: 1,2,5,10,20,50,100,120,160Y.
LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
STARTING YEAR 1970, FINAL YEAR 2130. ONE SITE, LLNL. ONE WASTE TYPE.
 0001 0000 0000 0000 0000 0009 0000 0000 0000 0000
 1970 2130 0001 0001
 LLNL
 0001 0002 0005 0010 0020 0050 0100 0120 0160
```

material and comments; the lower part of the exhibit shows the file as actually entered into the computer.

The number of lines of data in RADACINP.DAT can vary from 9 to 12; in this case there are 10. The contents of these lines are as follows:

- **Lines 1–6** contain user-supplied narrative information such as problem description, sources of data, options used, etc. These are only for the user's reference and are not used in the calculations. The file must provide these six lines even if they are blank. Format for each line is A80. In the example shown, the entries in these lines start in column 1.
- **Line 7** contains the control signals ISIG(1) through ISIG(10). Format for this line is 16I5. These signals control the options used in the problem. The options controlled by each signal are described in Table 7. The options selected for Example 1 are as follows:

ISIG(1) = 1	Inputs are in grams.
ISIG(2) = 0	This is the normal mode. The user does not wish to retain the option of changing the value of ISIG(3) from the console.
ISIG(3) = 0	Outputs will show all actinides and daughters, not just TRU actinides. TRU actinides are defined as alpha-emitting radionuclides with atomic numbers greater than 92 and half-lives of 20 years or more.
ISIG(4) = 0	The user will not supply volume data in this example.
ISIG(5) = 0	Short-lived daughters of fission products will not be automatically added when their parents are added.
ISIG(6) = 9	The optional output file RADAC4.OUT will be produced in addition to the regular output files. It will show radionuclide outputs for the nine decay times listed in line 10 of the input.
ISIG(7) = 0	The high-range decay time option (decay times from 300 to 1,000,000 years) will not be used. No results will be calculated at any decay times greater than 160 years.
ISIG(8) = 0	Subordinate actinides will be added whenever their parents are added, including year 1.
ISIG(9) = 0	Writing of output to file RADACMAX.OUT will not be suppressed; all output files will be produced normally.

Table 7. Options controlled by ISIG(I)

Option selected	Result
ISIG(1) = 1	Input data are in g/year.
ISIG(1) = 2	Input data are in Ci/year.
ISIG(2) = 0	This is the normal mode. The user supplies the value of ISIG(3) as part of the input data and will not be prompted during the run to supply a value for ISIG(3). For more explanation, see ISIG(3) and ISIG(10).
ISIG(2) = 1	The user will be prompted to supply a value for ISIG(3) from the console.
ISIG(3) = 0	Normal mode. Actinides in outputs will include all actinides and daughters. Fission products will be shown and included in curies and watts.
ISIG(3) = 1	Actinides in outputs will include only TRU or some other specified group of actinides. Fission products will not be shown and will not be included in totals. See ISIG(10) for selection of other specified actinides.
ISIG(4) = 0	File VOLUME.DAT is not read and may be omitted. Volumes are shown in outputs as zeros.
ISIG(4) = 1	File VOLUME.DAT is read normally. Summarized cumulative volumes will be shown in output.
ISIG(5) = 0	Short-lived daughters of fission products will not be automatically added when parent fission product is added as an input.
ISIG(5) = 1	Short-lived daughters of fission products will be automatically added when parent fission product is added as an input.
ISIG(6) = 0	The user-selected decay time option is not used. Output file RADAC4.OUT will not be produced.
ISIG(6) = N	This permits the user to select a particular set of N decay times, results for which are shown in output file RADAC4.OUT. N is the total number of low-range and high-range decay times desired. The maximum value of N is 9. The selected low-range decay times (decay times up to 160 years) are entered in RADACINP.DAT, line 10. Any high-range decay times desired (times from 300 to 1 million years) are entered by means of ISIG(7), which cannot exceed 6.
ISIG(7) = 0	High-range decay times (decay times greater than 160 years) are not desired.
ISIG(7) = M	This is the high-range decay time option; it must be used if decay times greater than 160 years are desired. The available high-range decay times are 300, 500, 1,000, 10,000, 100,000, and 1,000,000 years. Results for the first M of these will be shown in output file RADAC4.OUT. All of the following limitations apply: (1) M cannot exceed 6, (2) M cannot exceed N, the value of ISIG(6), and (3) the number of low-range decay times specified by the user must be equal to N – M.
ISIG(8) = 0	Subactinides are added whenever their parent actinides are added, including year 1.
ISIG(8) = 1	Subactinides are added whenever their parent actinides are added, except year 1.

Table 7. (continued)

Option selected	Result
ISIG(9) = 0	All output files are produced normally.
ISIG(9) = 1	Output file RADACMAX.OUT is not produced. Other output files are produced normally.
ISIG(10) = 0	ISIG(10) works in conjunction with ISIG(3). If the user sets ISIG(10) = 0 and ISIG(3) = 1, the output will show only TRU actinides. If both ISIG(10) and ISIG(3) are 0, the output will show all nuclides.
ISIG(10) = L (L = 1 to 16)	Output modified to show L specified actinides only. This is used in conjunction with ISIG(3) = 1. The user selects L principal actinides to be shown in output; the maximum number is 16. No other nuclides will be shown. The identification numbers of the selected actinides are entered in line 11 of RADACINP.DAT. The actinides selected must be principal actinides.

ISIG(10) = 0 — The option whereby the user restricts the output files to show only a particular group of actinides will not be used. Outputs will show all radionuclides present.

- **Line 8** gives the first year of waste input (1970), the final year of decay (2130), the number of waste sites (1), and the number of waste types (1). Format is 16I5. The number 1970 is in columns 2 through 5, the number 2130 is in columns 7 through 10, etc.
- **Line 9** gives the names of the waste sites used. Here there is only one, LLNL. Format is 16(1X, A4), so no more than 16 sites can be listed on line 9. If there had been more than 16 sites in this problem (the maximum capacity of the program is 19), the remaining sites would have been listed on line 10. In that case, the line shown below as line 10 would have been line 11.
- **Line 10** (or 11, if NSITES exceeds 16) gives the decay times in years. This line of data is not needed unless ISIG(6) > 0, signalling the use of the optional condensed output file RADAC4.OUT. This file gives actinide accumulations in both grams and curies and fission product accumulations in curies at the decay times specified in line 10. The same information is also given in the normal output files RADACMAX.OUT, RADAC2.OUT, and RADAC3.OUT, which give accumulations at other decay times as well. Format for line 10 is 16I5.

5.2.2 Example 1, File RADNUCL1.DAT

This file is shown in Exhibit 1.2. Again, the upper part of the exhibit shows the file annotated with explanatory material, and the lower part shows the file as it is actually read into the computer. RADNUCL1.DAT lists the quantities of waste type 1 radionuclides added and the years in which they are added. The lines of data are as follows:

- **Lines 1–3** contain user-supplied narrative. This information is for the user's convenience only and is not used in the calculations. Format for each line is A80. In the example, the entries in these lines start in column 1. The three lines must be supplied, even if blank.
- **Line 4** gives the page numbers of radionuclide inputs and the years of radionuclide additions that apply to each page. As used here, "page" means the list of radionuclide inputs in a particular year. In this example, radionuclide inputs are being made in only one year, 1970, so only one page of radionuclide inputs is required; this is numbered page 01 of 01.

Exhibit 1.2. Input file RADNUCL1.DAT for Example 1.

Annotated File:

Line

```
1   RADNUCL1.DAT  EXAMPLE 1, USER'S MANUAL.  SEE RADNUCL1.009, 5/4/95.
2   EXAMPLE IS IN USER'S MANUAL. SEE CHAPTER ON INPUT DATA. ONE SITE, LLNL.
3   NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
```

Pages of nuclide additions for this site (NP2) — **Years in which this page of nuclides is added** (NYR1, NYR2)

```
4   PAGE  01 OF 01      FOR YEARS 1970 THROUGH 1970 INCLUSIVE.
```

NP1 **NP2** **NYR1** **NYR2**

```
5   FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,1PE10.4)
6   1234567890123456789012345678901234567890123456789012345678901234567890
7     NAME    TYPE NID                                GRAMS/YEAR
```

Nuclide type — **Nuclide ID from FPNUCS.LIB, NUCDAT.LIB or SUBNUC.LIB**

```
8     AM-241  20  36                                  1.0000E+00
9     NI-63   10  09                                  1.2500E+01
10    I-125   10  44                                  1.3465E-03
11    ZZZZZ   99 999
```

Termination signal (99)

Comments:

Lines 1–3 and 5–7: User-supplied narrative; used for any information desired. Lines are not used in the calculations, but must be read, even if blank. Maximum width is 80 columns. Lines 6 and 7 are used as user aids. Line 6 is useful for counting columns.

Line 4: Format is 6x, I2, 4x, I2, 16x, I4, 9x, I4. If NP1 = NP2, the code knows it is reading the last page of data for this site. If NYR2 is greater than NYR1, this page of radionuclide additions is added in each year from NYR1 to NYR2, inclusive.

Lines 8, 9 and 10: These show the radionuclide inputs in the year(s) specified in Line 4. The nuclide names are not needed by the code and are listed only for user-related purposes. The code uses the type number and nuclide identification number to identify the nuclide. Entries are in grams or curies depending on whether ISIG(1) was entered as 1 or 2. Nuclides may be listed in any order. No waste additions can be made after year YSTART+60.

Line 11: A 99 in columns 11–12 is the termination signal for the page.

Actual File:

```
RADNUCL1.DAT  EXAMPLE 1, USER'S MANUAL.  SEE RADNUCL1.009, 5/4/95.
EXAMPLE IS IN USER'S MANUAL. SEE CHAPTER ON INPUT DATA. ONE SITE, LLNL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  01 OF 01      FOR YEARS 1970 THROUGH 1970 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,1PE10.4)
1234567890123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                               GRAMS/YEAR
  AM-241  20  36                                1.0000E+00
  NI-63   10  09                                1.2500E+01
  I-125   10  44                                1.3465E-03
  ZZZZZ   99 999
```

As the years shown in line 4 indicate, this page of inputs applies to year 1970 only. Because the formats are fixed, the page numbers and year numbers must be in the columns shown.

- **Lines 5–7** are for the user's convenience and may contain any information desired; this information is not used in the calculations. Format is A80 for each line. In the example, line 6 is used as a placemarker line for column numbers. The three lines must be supplied.
- **Lines 8–10** show the radionuclide inputs for the year or years specified in line 4 for this page of inputs. Radionuclides may be listed in any order; one line is required for each radionuclide listed. Each line gives a radionuclide name, type number, ID number, and annual input quantity. Names, type numbers, and ID numbers are given in Table 6 for fission and activation products and in Table 4 for actinides. The only actinides that can be entered are principal (type 20) actinides; these are the ones listed in Table 4. Short-lived daughter fission products (type 11) should not be entered unless their parent (type 10) fission products are entered. Up to 300 radionuclides can be entered in a given year. It is important not to list the same nuclide more than once on the same page. If this happens, the program will use the last entry for that nuclide. Annual radionuclide inputs in this example are given in grams; this was indicated by entering ISIG(1) = 1 (see Exhibit 1.1, line 7). If ISIG(1) had been 2, annual radionuclide inputs would have been given in curies. The final year of waste additions for any site must not exceed YSTART + 60.
- **Line 11** is the termination signal for this "page" of data. Termination is signalled by a 99 in columns 10 through 11. Each page must have a termination signal in the line after the last line of radionuclide inputs.

Further information on file RADNUCL1.DAT is given in Sect. 5.8.

5.2.3 Example 1, Output File RADAC4.OUT

Exhibit 1.3 shows the optional output file RADAC4.OUT for Example 1. This file lists the quantities of actinides and actinide daughters accumulated at the end of each of the nine years specified in line 10 of input data file RADACINP.DAT. These quantities are tabulated first in grams and then in curies. Quantities of fission and activation products are then tabulated in curies. Because there are only nine decay times to be shown, RADAC4.OUT is a more convenient file for the examination of radionuclide-by-radionuclide results than the more lengthy RADACMAX.OUT, which tabulates results at all the decay time steps from the initial year to the final year.

Exhibit 1.3. Output file RADAC4.OUT for Example 1.

SUMMARY OF RESULTS, **GRAMS**, FOR ALL MAIN ACTINIDES, NOT JUST TRU NUCLIDES, FOR END OF YEAR SHOWN
SITE = LLNL WASTE TYPE = CH

DECAY	0	1	2	5	10	20	50	100	120	160
BI-209	0.0000E+00	3.5116E-21	8.2675E-20	4.1075E-18	7.1186E-17	1.1826E-15	4.6866E-14	7.4346E-13	1.5335E-12	4.7910E-12
RA-225	0.0000E+00	1.2023E-21	1.2202E-20	2.2057E-19	1.8500E-18	1.5106E-17	2.3655E-16	1.8624E-15	3.1942E-15	7.4551E-15
AC-225	0.0000E+00	7.1081E-22	7.7374E-21	1.4542E-19	1.2348E-18	1.0144E-17	1.5942E-16	1.2566E-15	2.1557E-15	5.0325E-15
TH-229	0.0000E+00	2.6647E-16	2.4621E-15	4.2123E-14	3.4702E-13	2.8086E-12	4.3748E-11	3.4383E-10	5.8953E-10	1.3754E-09
PA-233	0.0000E+00	4.7817E-11	1.0126E-10	2.6108E-10	5.2574E-10	1.0487E-09	2.5683E-09	4.9440E-09	5.8422E-09	7.5544E-09
U-233	0.0000E+00	2.0315E-10	9.0209E-10	5.9998E-09	2.4451E-08	9.8325E-08	6.0870E-07	2.3767E-06	3.3882E-06	5.9030E-06
NP-237	0.0000E+00	1.5758E-03	3.1491E-03	7.8537E-03	1.5645E-02	3.1041E-02	7.5774E-02	1.4571E-01	1.7215E-01	2.2255E-01
AM-241	1.0000E+00	9.9840E-01	9.9680E-01	9.9201E-01	9.8409E-01	9.6844E-01	9.2295E-01	8.5183E-01	8.2494E-01	7.7369E-01
FR-221	0.0000E+00	2.3273E-25	2.5333E-24	4.7611E-23	4.0429E-22	3.3213E-21	5.2196E-20	4.1143E-19	7.0579E-19	1.6477E-18
AT-217	0.0000E+00	2.5629E-29	2.7898E-28	5.2432E-27	4.4522E-26	3.6576E-25	5.7480E-24	4.5309E-23	7.7725E-23	1.8145E-22
BI-213	0.0000E+00	2.1332E-24	2.3221E-23	4.3641E-22	3.7057E-21	3.0443E-20	4.7843E-19	3.7712E-18	6.4694E-18	1.5103E-17
PO-213	0.0000E+00	3.2003E-33	3.4836E-32	6.5471E-31	5.5594E-30	4.5672E-29	7.1775E-28	5.6577E-27	9.7054E-27	2.2658E-26
TL-209	0.0000E+00	2.1789E-27	2.3718E-26	4.4575E-25	3.7851E-24	3.1095E-23	4.8868E-22	3.8520E-21	6.6079E-21	1.5426E-20
PB-209	0.0000E+00	9.0785E-24	9.8822E-23	1.8573E-21	1.5771E-20	1.2956E-19	2.0361E-18	1.6050E-17	2.7532E-17	6.4275E-17
TOTAL	1.0000E+00	9.9997E-01	9.9995E-01	9.9987E-01	9.9974E-01	9.9948E-01	9.9872E-01	9.9754E-01	9.9709E-01	9.9624E-01

SUMMARY OF RESULTS, **CURIES**, FOR ALL MAIN ACTINIDES, NOT JUST TRU ACTINIDES, FOR END OF YEAR SHOWN
SITE = LLNL WASTE TYPE = CH

DECAY	0	1	2	5	10	20	50	100	120	160
BI-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RA-225	0.0000E+00	4.7147E-17	4.7852E-16	8.6498E-15	7.2547E-14	5.9239E-13	9.2763E-12	7.3033E-11	1.2526E-10	2.9235E-10
AC-225	0.0000E+00	4.1263E-17	4.4915E-16	8.4415E-15	7.1680E-14	5.8887E-13	9.2543E-12	7.2947E-11	1.2514E-10	2.9213E-10
TH-229	0.0000E+00	5.6700E-17	5.2388E-16	8.9630E-15	7.3839E-14	5.9762E-13	9.3087E-12	7.3160E-11	1.2544E-10	2.9266E-10
PA-233	0.0000E+00	9.9267E-07	2.1022E-06	5.4200E-06	1.0914E-05	2.1772E-05	5.3319E-05	1.0264E-04	1.2128E-04	1.5683E-04
U-233	0.0000E+00	1.9671E-12	8.7347E-12	5.8095E-11	2.3675E-10	9.5206E-10	5.8939E-09	2.3013E-08	3.2808E-08	5.7157E-08
NP-237	0.0000E+00	1.1111E-06	2.2204E-06	5.5377E-06	1.1031E-05	2.1887E-05	5.3429E-05	1.0274E-04	1.2138E-04	1.5692E-04
AM-241	3.4330E+00	3.4275E+00	3.4220E+00	3.4056E+00	3.3784E+00	3.3246E+00	3.1685E+00	2.9243E+00	2.8320E+00	2.6561E+00
FR-221	0.0000E+00	4.1263E-17	4.4915E-16	8.4415E-15	7.1680E-14	5.8887E-13	9.2543E-12	7.2947E-11	1.2514E-10	2.9213E-10
AT-217	0.0000E+00	4.1263E-17	4.4915E-16	8.4415E-15	7.1680E-14	5.8887E-13	9.2543E-12	7.2947E-11	1.2514E-10	2.9213E-10
BI-213	0.0000E+00	4.1263E-17	4.4915E-16	8.4415E-15	7.1680E-14	5.8887E-13	9.2543E-12	7.2947E-11	1.2514E-10	2.9213E-10
PO-213	0.0000E+00	4.0371E-17	4.3945E-16	8.2591E-15	7.0132E-14	5.7615E-13	9.0544E-12	7.1371E-11	1.2243E-10	2.8582E-10
TL-209	0.0000E+00	8.9127E-19	9.7017E-18	1.8234E-16	1.5483E-15	1.2720E-14	1.9989E-13	1.5757E-12	2.7030E-12	6.3101E-12
PB-209	0.0000E+00	4.1263E-17	4.4915E-16	8.4415E-15	7.1680E-14	5.8887E-13	9.2543E-12	7.2947E-11	1.2514E-10	2.9213E-10
TOTAL	3.4330E+00	3.4275E+00	3.4220E+00	3.4056E+00	3.3784E+00	3.3247E+00	3.1686E+00	2.9245E+00	2.8323E+00	2.6564E+00

Exhibit 1.3. Output file RADAC4.OUT for Example 1 (continued).

SUMMARY OF RESULTS, **CURIES**, FOR FISSION PRODUCTS, FOR END OF YEAR SHOWN
SITE = LLNL   WASTE TYPE = CH

DECAY	0	1	2	5	10	20	50	100	120	160
NI63	7.7123E+02	7.6544E+02	7.5969E+02	7.4271E+02	7.1526E+02	6.6335E+02	5.2915E+02	3.6306E+02	3.1228E+02	2.3103E+02
I125	2.3568E+01	3.3931E-01	4.8852E-03	1.4579E-08	9.0188E-18	3.4512E-36	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
TOTAL	7.9479E+02	7.6578E+02	7.5970E+02	7.4271E+02	7.1526E+02	6.6335E+02	5.2915E+02	3.6306E+02	3.1228E+02	2.3103E+02

The quantities of radionuclides shown in RADAC4.OUT are the end-of-year decayed accumulations collected in the actinide and fission product accumulation arrays. In cases where there are inputs of radionuclides in more than one year, these accumulations represent the summation of the "to" nuclides resulting from all the annual inputs of "from" nuclides. Because Example 1 has only one year of radionuclide inputs, it does not illustrate the accumulation feature of the code, but only the decay feature. Example 1 is equivalent to an ordinary decay calculation in which a group of several radionuclides, all input in the same year, are decayed for a specified set of decay times. Because of this, it was possible to compare the results obtained by RADAC in this example with those obtained by running the ORIGEN2 decay module on the same radionuclide inputs. The ORIGEN2 results are shown in Exhibit 1.4. It can be seen that the RADAC results agree fairly well with those of ORIGEN2. A number of intermediate decay times were used in the ORIGEN2 run to increase the precision of the results. This example establishes a pattern for the verification of RADAC by comparison with ORIGEN2.

5.3 EXAMPLE 2: HIGH-RANGE DECAY TIMES

Example 2 shows how the extended decay time option is used; in all other respects, it is identical to Example 1. It illustrates the simultaneous use of ISIG(6) and ISIG(7).

5.3.1 Example 2, File RADACINP.DAT

Input file RADACINP.DAT for Example 2 is shown in Exhibit 2.1. The only differences from Example 1 (Exhibit 1.1) are in lines 7 and 10. The value of ISIG(6) is still 9, indicating that the special output file RADAC4.OUT will be used and will show results for 9 decay times. Now, however, ISIG(7) is 6, indicating that 6 of the 9 decay times will be high-range times, that is, times greater than 160 years. As shown in Table 7, the high-range decay times that are available to be used are 300, 500, 1000, 10K, 100K, and 1M (1000K) years. Results for all 6 of these decay times will be shown in output file RADAC4.OUT. The remaining 3 of the 9 decay times shown in RADAC4.OUT can be any integer values up to 60 years or any integer divisible by 10 from 60 to 160 years. The decay times selected for this example, and entered in line 10 of Exhibit 2.1, are 1, 5, and 160 years.

(Text continued on page 63)

Exhibit 1.4. Output file ORIGEN2.OUT for Example 1.

5 SUMMARY TABLE: CONCENTRATIONS, **GRAMS**

	CHARGE	1.0YR	2.0YR	5.0YR	10.0YR	20.0YR	50.0YR	100.0YR	120.0YR	160.0YR
HE4	0.000E+00	2.660E-05	5.315E-05	1.326E-04	2.640E-04	5.239E-04	1.279E-03	2.459E-03	2.906E-03	3.756E-03
TL209	0.000E+00	2.994E-27	3.126E-26	5.186E-25	4.184E-24	3.267E-23	4.966E-22	3.879E-21	6.646E-21	1.549E-20
PB209	0.000E+00	1.248E-23	1.303E-22	2.161E-21	1.743E-20	1.361E-19	2.069E-18	1.616E-17	2.769E-17	6.454E-17
BI209	0.000E+00	4.343E-21	1.041E-19	4.835E-18	7.893E-17	1.257E-15	4.781E-14	7.498E-13	1.544E-12	4.814E-12
BI213	0.000E+00	2.931E-24	3.061E-23	5.078E-22	4.096E-21	3.198E-20	4.862E-19	3.798E-18	6.507E-18	1.517E-17
PO213	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.145E-30	4.798E-29	7.294E-28	5.698E-27	9.762E-27	2.275E-26
AT217	0.000E+00	3.522E-29	3.677E-28	6.100E-27	4.921E-26	3.842E-25	5.841E-24	4.563E-23	7.817E-23	1.822E-22
FR221	0.000E+00	3.198E-25	3.339E-24	5.539E-23	4.468E-22	3.489E-21	5.304E-20	4.143E-19	7.098E-19	1.655E-18
RA225	0.000E+00	1.446E-21	1.510E-20	2.505E-19	2.020E-18	1.578E-17	2.398E-16	1.873E-15	3.209E-15	7.481E-15
AC225	0.000E+00	9.768E-22	1.020E-20	1.692E-19	1.365E-18	1.066E-17	1.620E-16	1.266E-15	2.168E-15	5.053E-15
TH229	0.000E+00	2.665E-16	2.782E-15	4.616E-14	3.723E-13	2.907E-12	4.420E-11	3.453E-10	5.915E-10	1.379E-09
PA233	0.000E+00	4.782E-11	1.070E-10	2.667E-10	5.314E-10	1.054E-09	2.574E-09	4.949E-09	5.847E-09	7.559E-09
U233	0.000E+00	2.032E-10	1.003E-09	6.368E-09	2.572E-08	9.985E-08	6.110E-07	2.380E-06	3.392E-06	5.908E-06
NP237	0.000E+00	1.576E-03	3.149E-03	7.854E-03	1.564E-02	3.104E-02	7.577E-02	1.457E-01	1.721E-01	2.226E-01
AM241	1.000E+00	9.984E-01	9.968E-01	9.920E-01	9.841E-01	9.684E-01	9.229E-01	8.518E-01	8.249E-01	7.737E-01
SF250	0.000E+00	6.815E-15	1.362E-14	3.397E-14	6.766E-14	1.342E-13	3.277E-13	6.302E-13	7.445E-13	9.625E-13
TOTAL	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00

7 SUMMARY TABLE: RADIOACTIVITY, **CURIES**

	CHARGE	1.0YR	2.0YR	5.0YR	10.0YR	20.0YR	50.0YR	100.0YR	120.0YR	160.0YR
TL209	0.000E+00	1.225E-18	1.279E-17	2.122E-16	1.712E-15	1.336E-14	2.032E-13	1.587E-12	2.719E-12	6.337E-12
PB209	0.000E+00	5.671E-17	5.921E-16	9.823E-15	7.924E-14	6.187E-13	9.405E-12	7.347E-11	1.259E-10	2.934E-10
BI213	0.000E+00	5.671E-17	5.921E-16	9.823E-15	7.924E-14	6.187E-13	9.405E-12	7.347E-11	1.259E-10	2.934E-10
PO213	0.000E+00	5.548E-17	5.793E-16	9.611E-15	7.753E-14	6.053E-13	9.202E-12	7.189E-11	1.232E-10	2.871E-10
AT217	0.000E+00	5.671E-17	5.921E-16	9.823E-15	7.924E-14	6.187E-13	9.405E-12	7.347E-11	1.259E-10	2.934E-10
FR221	0.000E+00	5.671E-17	5.921E-16	9.823E-15	7.924E-14	6.187E-13	9.405E-12	7.347E-11	1.259E-10	2.934E-10
RA225	0.000E+00	5.671E-17	5.921E-16	9.823E-15	7.924E-14	6.187E-13	9.405E-12	7.347E-11	1.259E-10	2.934E-10
AC225	0.000E+00	5.671E-17	5.921E-16	9.823E-15	7.924E-14	6.187E-13	9.405E-12	7.347E-11	1.259E-10	2.934E-10
TH229	0.000E+00	5.671E-17	5.921E-16	9.823E-15	7.924E-14	6.187E-13	9.405E-12	7.347E-11	1.259E-10	2.934E-10
PA233	0.000E+00	9.928E-07	2.221E-06	5.538E-06	1.103E-05	2.189E-05	5.344E-05	1.028E-04	1.214E-04	1.569E-04
U233	0.000E+00	1.967E-12	9.716E-12	6.167E-11	2.491E-10	9.670E-10	5.917E-09	2.305E-08	3.285E-08	5.721E-08
NP237	0.000E+00	1.111E-06	2.221E-06	5.538E-06	1.103E-05	2.189E-05	5.344E-05	1.028E-04	1.214E-04	1.569E-04
AM241	3.433E+00	3.428E+00	3.422E+00	3.406E+00	3.379E+00	3.325E+00	3.169E+00	2.925E+00	2.832E+00	2.656E+00
TOTAL	3.433E+00	3.428E+00	3.422E+00	3.406E+00	3.379E+00	3.325E+00	3.169E+00	2.925E+00	2.833E+00	2.657E+00

Exhibit 1.4. Output file ORIGEN2.OUT for Example 1 (continued).

5 SUMMARY TABLE: CONCENTRATIONS, **GRAMS**

	CHARGE	1.0YR	2.0YR	5.0YR	10.0YR	20.0YR	50.0YR	100.0YR	120.0YR	160.0YR
NI 63	1.250E+01	1.241E+01	1.231E+01	1.204E+01	1.159E+01	1.075E+01	8.576E+00	5.884E+00	5.061E+00	3.744E+00
CU 63	0.000E+00	9.382E-02	1.869E-01	4.621E-01	9.072E-01	1.749E+00	3.924E+00	6.616E+00	7.439E+00	8.756E+00
TE125	0.000E+00	1.327E-03	1.346E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03
I125	1.347E-03	1.939E-05	2.791E-07	8.328E-13	5.151E-22	1.971E-40	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01

7 SUMMARY TABLE: RADIOACTIVITY, **CURIES**

	CHARGE	1.0YR	2.0YR	5.0YR	10.0YR	20.0YR	50.0YR	100.0YR	120.0YR	160.0YR
NI63	7.713E+02	7.655E+02	7.598E+02	7.428E+02	7.153E+02	6.634E+02	5.292E+02	3.631E+02	3.123E+02	2.311E+02
I125	2.357E+01	3.393E-01	4.886E-03	1.458E-08	9.017E-18	3.449E-36	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL	7.949E+02	7.659E+02	7.598E+02	7.428E+02	7.153E+02	6.634E+02	5.292E+02	3.631E+02	3.123E+02	2.311E+02

Exhibit 2.1. Input file RADACINP.DAT for Example 2.

Annotated File:

```
Line
 1   RADACINP.DAT  FOR EXAMPLE 2, USER'S MANUAL. SEE RADACINP.009. 5/4/95.
 2   ISIG(1)=1: INPUT IS IN GRAMS.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
 3   ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=0  NO VOLUMES READ.
 4   ISIG(6)=9: 9 DECAY TIMES IN OUTPUT OU4: 1,5,160,300,500,1K,10K,100K,1MY.
 5   LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
 6   STARTING YEAR 1970, FINAL YEAR 2130. ONE SITE, LLNL. ONE WASTE TYPE.
```

Column 1

Column 2 — **Control signals ISIG(x) x = 1 through 10**

```
 7    0001 0000 0000 0000 0000 0009 0006 0000 0000 0000
```

Final year — **Number of waste types**

```
 8    1970 2130 0001 0001
```

Starting year — **Number of sites**

```
 9    LLNL
```

Site

```
10    0001 0005 0160
```

Accumulations at these decay times and high range times will be shown in RADAC4.OUT

Comments:

Line 1 - 6: User notes and remarks, not used in calculations. All 6 lines must be used, even if left blank.

Line 7: Format is 16I5. Data for lines 7, 8, 9 and 10 must be in columns shown.

Line 8: First year of waste input is 1970. Final year of decay is 2130. One site, one waste type. Format is 16I5.

Line 9: Name of waste site, up to 4 letters. Format 16(1x, A4). Two lines are used if number of sites exceeds 16.

Line 10: The user lists here up to 9 decay times for which results will be shown in output file RADAC4.OUT. The number of decay times selected is given by the value of ISIG(6); the maximum allowable number is 9. Format for line 10 is 16I5. Line 10 is not used if ISIG(6) = 0. RADAC4.OUT will also show results at high-range decay times selected.

Actual File:

```
RADACINP.DAT  FOR EXAMPLE 2, USER'S MANUAL. SEE RADACINP.009. 5/4/95.
ISIG(1)=1: INPUT IS IN GRAMS.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=0  NO VOLUMES READ.
ISIG(6)=9: 9 DECAY TIMES IN OUTPUT OU4: 1,5,160,300,500,1K,10K,100K,1MY.
LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
STARTING YEAR 1970, FINAL YEAR 2130. ONE SITE, LLNL. ONE WASTE TYPE.
 0001 0000 0000 0000 0000 0009 0006 0000 0000 0000
 1970 2130 0001 0001
 LLNL
 0001 0005 0160
```

5.3.2 Example 2, File RADNUCL1.DAT

Exhibit 2.2 shows file RADNUCL1.DAT, which gives the radionuclide inputs for Example 2. The radionuclide inputs are identical to those used in Example 1 (see Exhibit 1.2). A few minor changes have been made in the user-selected narrative lines.

5.3.3 Example 2, Output File RADAC4.OUT

Exhibit 2.3 shows output file RADAC4.OUT for Example 2. The output for Example 2 differs from that of Example 1 (see Exhibit 1.3) only in the selection of a different set of decay times. Where the same decay time occurs in both examples, the results are identical.

As in Example 1, the RADAC results for Example 2 were compared against ORIGEN2 results by making an ORIGEN2 run at the same decay times. The ORIGEN2 outputs are shown in Exhibit 2.4. It can be seen that the agreement between Exhibits 2.3 and 2.4 is fairly good, both at low-range and high-range decay times.

5.4 EXAMPLE 3: MORE THAN ONE YEAR OF INPUT

Examples 1 and 2 had radionuclide inputs in only one year, 1970. Example 3 has inputs in years 1970, 1971, and 1975. It has one site, identified as ORNL. Radionuclides entered as inputs are different from those in Examples 1 and 2.

5.4.1 Example 3, File RADACINP.DAT

Exhibit 3.1 shows file RADACINP.DAT for Example 3. ISIG(1) is 2, indicating that radionuclide inputs are to be in curies. ISIG(6) and ISIG(7) are 9 and 2 respectively, indicating that output file RADAC4.OUT will be used and will show results for 9 decay times, the first 7 of which are the low-range times shown in line 10. The remaining 2 will be the first 2 high-range decay times, 300 and 500 years. For the explanation of this, see ISIG(6) and ISIG(7) in Table 7.

5.4.2 Example 3, File RADNUCL1.DAT

Exhibit 3.2 shows the three "pages" of radionuclide inputs for Example 3, one "page" for each year of input. The radionuclides used as inputs in this example are different from those used in Examples 1 and 2. Each page of inputs has the same general format as the single page used for Example 1, which was shown in Exhibit 1.2. The important lines in Exhibit 3.2 are as follows:

(Text continued on page 71)

Exhibit 2.2. Input file RADNUCL1.DAT for Example 2.

Annotated File:

```
Line
 1   RADNUCL1.DAT  EXAMPLE 2, USER'S MANUAL.  SEE RADNUCL1.009, 5/4/95.
 2   EXAMPLE IS IN USER'S MANUAL. SEE CHAPTER ON INPUT DATA. ONE SITE, LLNL.
 3   NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
      ↖ Column 1   Pages of nuclide additions for this site      Years in which this page of nuclides is added
 4   PAGE  01 OF 01      FOR YEARS 1970 THROUGH 1970 INCLUSIVE.
           ↑     ↑                 ↑            ↑
          NP1   NP2               NYR1         NYR2

 5   FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,1PE10.4)
 6   12345678901234567890123456789012345678901234567890123456789012345678901234567890
 7     NAME    TYPE NID                            GRAMS/YEAR
            Nuclide type    Nuclide ID from FPNUCS.LIB,
                 ↓        ↙ NUCDAT.LIB or SUBNUC.LIB
 8     AM-241   20  36                             1.0000E+00
 9     NI-63    10  09                             1.2500E+01
10     I-125    10  44                             1.3465E-03
11     ZZZZZ    99 999
                 ↑
           Termination signal
```

Comments:

Lines 1–3 and 5–7: User-supplied narrative; for any information desired. Lines are not used in calculations, but must be read, even if blank. Maximum width is 80 columns.

Line 4: Format is 6x, I2, 4x, I2, 16x, I4, 9x, I4. If NP1 = NP2, this is the last page of data for this site. If NYR2 is greater than NYR1, this page of radionuclide additions is added in each year from NYR1 to NYR2, inclusive.

Lines 8, 9 and 10: These show the radionuclide inputs in the year(s) specified in Line 4. The nuclide names are not needed by the code and are listed only for user related purposes. The code reads the type number and the nuclide identification number and uses these to identify the nuclide. Nuclides may be listed in any order; order may vary from page to page.

Line 11: A 99 in columns 11–12 is the termination signal for the page and must be entered at the end of each page.

Actual File:

```
RADNUCL1.DAT  EXAMPLE 2, USER'S MANUAL.  SEE RADNUCL1.009, 5/4/95.
EXAMPLE IS IN USER'S MANUAL. SEE CHAPTER ON INPUT DATA. ONE SITE, LLNL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  01 OF 01       FOR YEARS 1970 THROUGH 1970 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,1PE10.4)
12345678901234567890123456789012345678901234567890123456789012345678901234567890
NAME     TYPE   NID                            GRAMS/YEAR
  AM-241  20  36                               1.0000E+00
  NI-63   10  09                               1.2500E+01
  I-125   10  44                               1.3465E-03
  ZZZZZ   99 999
```

Exhibit 2.3. Output file RADAC4.OUT for Example 2.

SUMMARY OF RESULTS, **GRAMS**, FOR ALL MAIN ACTINIDES, NOT JUST TRU NUCLIDES, FOR END OF YEAR SHOWN
SITE = LLNL   WASTE TYPE = CH

DECAY	0	1	5	160	300	500	1000	10000	100000	1000000
BI-209	0.0000E+00	3.5116E-21	4.1075E-18	4.7910E-12	5.6711E-11	4.1129E-10	5.6813E-09	1.2940E-05	4.2767E-03	1.8822E-01
RA-225	0.0000E+00	1.2023E-21	2.2057E-19	7.4551E-15	4.6500E-14	1.9924E-13	1.3300E-12	2.4080E-10	5.5893E-09	1.3610E-08
AC-225	0.0000E+00	7.1081E-22	1.4542E-19	5.0325E-15	3.1400E-14	1.3456E-13	8.9835E-13	1.6266E-10	3.7757E-09	9.1940E-09
TH-229	0.0000E+00	2.6647E-16	4.2123E-14	1.3754E-09	8.5748E-09	3.6731E-08	2.4515E-07	4.4379E-05	1.0301E-03	2.5083E-03
PA-233	0.0000E+00	4.7817E-11	2.6108E-10	7.5544E-09	1.2751E-08	1.8416E-08	2.6675E-08	3.3300E-08	3.2343E-08	2.4164E-08
U-233	0.0000E+00	2.0315E-10	5.9998E-09	5.9030E-06	1.9350E-05	4.8827E-05	1.5686E-04	2.8723E-03	2.4810E-02	5.4975E-02
NP-237	0.0000E+00	1.5758E-03	7.8537E-03	2.2255E-01	3.7554E-01	5.4229E-01	7.8542E-01	9.8042E-01	9.5225E-01	7.1145E-01
AM-241	1.0000E+00	9.9840E-01	9.9201E-01	7.7369E-01	6.1810E-01	4.4851E-01	2.0116E-01	1.0848E-07	0.0000E+00	0.0000E+00
FR-221	0.0000E+00	2.3273E-25	4.7611E-23	1.6477E-18	1.0281E-17	4.4056E-17	2.9413E-16	5.3258E-14	1.2362E-12	3.0102E-12
AT-217	0.0000E+00	2.5629E-29	5.2432E-27	1.8145E-22	1.1322E-21	4.8517E-21	3.2391E-20	5.8650E-18	1.3614E-16	3.3150E-16
BI-213	0.0000E+00	2.1332E-24	4.3641E-22	1.5103E-17	9.4235E-17	4.0382E-16	2.6960E-15	4.8817E-13	1.1331E-11	2.7592E-11
PO-213	0.0000E+00	3.2003E-33	6.5471E-31	2.2658E-26	1.4137E-25	6.0582E-25	4.0446E-24	7.3236E-22	1.6999E-20	4.1394E-20
TL-209	0.0000E+00	2.1789E-27	4.4575E-25	1.5426E-20	9.6253E-20	4.1247E-19	2.7537E-18	4.9862E-16	1.1574E-14	2.8183E-14
PB-209	0.0000E+00	9.0785E-24	1.8573E-21	6.4275E-17	4.0105E-16	1.7186E-15	1.1474E-14	2.0775E-12	4.8224E-11	1.1743E-10
TOTAL	1.0000E+00	9.9997E-01	9.9987E-01	9.9624E-01	9.9366E-01	9.9085E-01	9.8674E-01	9.8335E-01	9.8237E-01	9.5715E-01

SUMMARY OF RESULTS, **CURIES**, FOR ALL MAIN ACTINIDES, NOT JUST TRU ACTINIDES, FOR END OF YEAR SHOWN
SITE = LLNL   WASTE TYPE = CH

DECAY	0	1	5	160	300	500	1000	10000	100000	1000000
BI-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RA-225	0.0000E+00	4.7147E-17	8.6498E-15	2.9235E-10	1.8235E-09	7.8130E-09	5.2155E-08	9.4429E-06	2.1918E-04	5.3372E-04
AC-225	0.0000E+00	4.1263E-17	8.4415E-15	2.9213E-10	1.8228E-09	7.8112E-09	5.2149E-08	9.4427E-06	2.1918E-04	5.3371E-04
TH-229	0.0000E+00	5.6700E-17	8.9630E-15	2.9266E-10	1.8245E-09	7.8156E-09	5.2163E-08	9.4430E-06	2.1918E-04	5.3372E-04
PA-233	0.0000E+00	9.9267E-07	5.4200E-06	1.5683E-04	2.6472E-04	3.8232E-04	5.5378E-04	6.9130E-04	6.7144E-04	5.0165E-04
U-233	0.0000E+00	1.9671E-12	5.8095E-11	5.7157E-08	1.8736E-07	4.7278E-07	1.5189E-06	2.7812E-05	2.4023E-04	5.3231E-04
NP-237	0.0000E+00	1.1111E-06	5.5377E-06	1.5692E-04	2.6480E-04	3.8238E-04	5.5381E-04	6.9130E-04	6.7144E-04	5.0165E-04
AM-241	3.4330E+00	3.4275E+00	3.4056E+00	2.6561E+00	2.1219E+00	1.5397E+00	6.9057E-01	3.7241E-07	0.0000E+00	0.0000E+00
FR-221	0.0000E+00	4.1263E-17	8.4415E-15	2.9213E-10	1.8228E-09	7.8112E-09	5.2149E-08	9.4427E-06	2.1918E-04	5.3371E-04
AT-217	0.0000E+00	4.1263E-17	8.4415E-15	2.9213E-10	1.8228E-09	7.8112E-09	5.2149E-08	9.4427E-06	2.1918E-04	5.3371E-04
BI-213	0.0000E+00	4.1263E-17	8.4415E-15	2.9213E-10	1.8228E-09	7.8112E-09	5.2149E-08	9.4427E-06	2.1918E-04	5.3371E-04
PO-213	0.0000E+00	4.0371E-17	8.2591E-15	2.8582E-10	1.7834E-09	7.6425E-09	5.1023E-08	9.2387E-06	2.1445E-04	5.2218E-04
TL-209	0.0000E+00	8.9127E-19	1.8234E-16	6.3101E-12	3.9372E-11	1.6872E-10	1.1264E-09	2.0396E-07	4.7343E-06	1.1528E-05
PB-209	0.0000E+00	4.1263E-17	8.4415E-15	2.9213E-10	1.8228E-09	7.8112E-09	5.2149E-08	9.4427E-06	2.1918E-04	5.3371E-04
TOTAL	3.4330E+00	3.4275E+00	3.4056E+00	2.6564E+00	2.1225E+00	1.5405E+00	6.9168E-01	1.4863E-03	3.3366E-03	5.8053E-03

Exhibit 2.3. Output file RADAC4.OUT for Example 2 (continued).

```
SUMMARY OF RESULTS, CURIES, FOR FISSION PRODUCTS, FOR END OF YEAR SHOWN
SITE = LLNL      WASTE TYPE = CH

DECAY          0          1          5        160        300        500       1000      10000     100000    1000000
NI63  7.7123E+02 7.6544E+02 7.4271E+02 2.3103E+02 8.0460E+01 1.7831E+01 4.1227E-01 1.4695E-30 0.0000E+00 0.0000E+00
I125  2.3568E+01 3.3931E-01 1.4579E-08 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

TOTAL 7.9479E+02 7.6578E+02 7.4271E+02 2.3103E+02 8.0460E+01 1.7831E+01 4.1227E-01 1.4695E-30 0.0000E+00 0.0000E+00
```

Exhibit 2.4. Output file ORIGEN2.OUT for Example 2.

5 SUMMARY TABLE: CONCENTRATIONS, **GRAMS**

	CHARGE	1.0YR	5.0YR	160.0YR	300.0YR	500.0YR	1.0KY	10.0KY	100.0KY	1.0MY
HE4	0.000E+00	2.660E-05	1.326E-04	3.756E-03	6.339E-03	9.154E-03	1.326E-02	1.665E-02	1.763E-02	4.318E-02
TL209	0.000E+00	2.994E-27	5.186E-25	1.549E-20	9.645E-20	4.130E-19	2.755E-18	4.986E-16	1.157E-14	2.827E-14
PB209	0.000E+00	1.248E-23	2.161E-21	6.454E-17	4.019E-16	1.721E-15	1.148E-14	2.078E-12	4.822E-11	1.178E-10
BI209	0.000E+00	4.343E-21	4.835E-18	4.814E-12	5.684E-11	4.118E-10	5.685E-09	1.294E-05	4.277E-03	1.917E-01
BI213	0.000E+00	2.931E-24	5.078E-22	1.517E-17	9.443E-17	4.043E-16	2.697E-15	4.882E-13	1.133E-11	2.767E-11
PO213	0.000E+00	0.000E+00	0.000E+00	2.275E-26	1.417E-25	6.066E-25	4.047E-24	7.324E-22	1.700E-20	4.152E-20
AT217	0.000E+00	3.522E-29	6.100E-27	1.822E-22	1.134E-21	4.857E-21	3.241E-20	5.865E-18	1.361E-16	3.325E-16
FR221	0.000E+00	3.198E-25	5.539E-23	1.655E-18	1.030E-17	4.411E-17	2.943E-16	5.326E-14	1.236E-12	3.019E-12
RA225	0.000E+00	1.446E-21	2.505E-19	7.481E-15	4.658E-14	1.994E-13	1.331E-12	2.408E-10	5.589E-09	1.365E-08
AC225	0.000E+00	9.768E-22	1.692E-19	5.053E-15	3.147E-14	1.347E-13	8.988E-13	1.627E-10	3.776E-09	9.222E-09
TH229	0.000E+00	2.665E-16	4.616E-14	1.379E-09	8.584E-09	3.675E-08	2.452E-07	4.438E-05	1.030E-03	2.516E-03
PA233	0.000E+00	4.782E-11	2.667E-10	7.559E-09	1.276E-08	1.842E-08	2.668E-08	3.330E-08	3.234E-08	2.416E-08
U233	0.000E+00	2.032E-10	6.368E-09	5.908E-06	1.936E-05	4.884E-05	1.569E-04	2.872E-03	2.481E-02	5.497E-02
NP237	0.000E+00	1.576E-03	7.854E-03	2.226E-01	3.755E-01	5.423E-01	7.854E-01	9.804E-01	9.523E-01	7.114E-01
AM241	1.000E+00	9.984E-01	9.920E-01	7.737E-01	6.181E-01	4.485E-01	2.012E-01	1.083E-07	0.000E+00	0.000E+00
SF250	0.000E+00	6.815E-15	3.397E-14	9.625E-13	1.624E-12	2.346E-12	3.398E-12	4.253E-12	4.261E-12	4.549E-12
SUMTOT	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.004E+00
TOTAL	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00

7 SUMMARY TABLE: RADIOACTIVITY, **CURIES**

	CHARGE	1.0YR	5.0YR	160.0YR	300.0YR	500.0YR	1.0KY	10.0KY	100.0KY	1.0MY
TL209	0.000E+00	1.225E-18	2.122E-16	6.337E-12	3.946E-11	1.689E-10	1.127E-09	2.040E-07	4.735E-06	1.156E-05
PB209	0.000E+00	5.671E-17	9.823E-15	2.934E-10	1.827E-09	7.822E-09	5.219E-08	9.444E-06	2.192E-04	5.354E-04
BI213	0.000E+00	5.671E-17	9.823E-15	2.934E-10	1.827E-09	7.822E-09	5.219E-08	9.444E-06	2.192E-04	5.354E-04
PO213	0.000E+00	5.548E-17	9.611E-15	2.871E-10	1.787E-09	7.653E-09	5.106E-08	9.240E-06	2.145E-04	5.238E-04
AT217	0.000E+00	5.671E-17	9.823E-15	2.934E-10	1.827E-09	7.822E-09	5.219E-08	9.444E-06	2.192E-04	5.354E-04
FR221	0.000E+00	5.671E-17	9.823E-15	2.934E-10	1.827E-09	7.822E-09	5.219E-08	9.444E-06	2.192E-04	5.354E-04
RA225	0.000E+00	5.671E-17	9.823E-15	2.934E-10	1.827E-09	7.822E-09	5.219E-08	9.444E-06	2.192E-04	5.354E-04
AC225	0.000E+00	5.671E-17	9.823E-15	2.934E-10	1.827E-09	7.822E-09	5.219E-08	9.444E-06	2.192E-04	5.354E-04
TH229	0.000E+00	5.671E-17	9.823E-15	2.934E-10	1.827E-09	7.822E-09	5.219E-08	9.444E-06	2.192E-04	5.354E-04
PA233	0.000E+00	9.928E-07	5.538E-06	1.569E-04	2.648E-04	3.824E-04	5.539E-04	6.914E-04	6.715E-04	5.017E-04
U233	0.000E+00	1.967E-12	6.167E-11	5.721E-08	1.875E-07	4.729E-07	1.519E-06	2.782E-05	2.403E-04	5.324E-04
NP237	0.000E+00	1.111E-06	5.538E-06	1.569E-04	2.648E-04	3.824E-04	5.539E-04	6.914E-04	6.715E-04	5.017E-04
AM241	3.433E+00	3.428E+00	3.406E+00	2.656E+00	2.122E+00	1.540E+00	6.907E-01	3.717E-07	0.000E+00	0.000E+00
SUMTOT	3.433E+00	3.428E+00	3.406E+00	2.657E+00	2.123E+00	1.541E+00	6.918E-01	1.487E-03	3.337E-03	5.819E-03
TOTAL	0.000E+00	3.428E+00	3.406E+00	2.657E+00	2.123E+00	1.541E+00	6.918E-01	1.487E-03	3.337E-03	5.819E-03

Exhibit 2.4. Output file ORIGEN2.OUT for Example 2 (continued).

5 SUMMARY TABLE: CONCENTRATIONS, **GRAMS**

	CHARGE	1.0YR	5.0YR	160.0YR	300.0YR	500.0YR	1.0KY	10.0KY	100.0KY	1.0MY
NI63	1.250E+01	1.241E+01	1.204E+01	3.744E+00	1.304E+00	2.890E-01	6.681E-03	0.000E+00	0.000E+00	0.000E+00
CU63	0.000E+00	9.382E-02	4.621E-01	8.756E+00	1.120E+01	1.221E+01	1.249E+01	1.250E+01	1.250E+01	1.250E+01
TE125	0.000E+00	1.327E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03	1.347E-03
I125	1.347E-03	1.939E-05	8.328E-13	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01	1.250E+01

7 SUMMARY TABLE: RADIOACTIVITY, **CURIES**

	CHARGE	1.0YR	5.0YR	160.0YR	300.0YR	500.0YR	1.0KY	10.0KY	100.0KY	1.0MY
NI63	7.713E+02	7.655E+02	7.428E+02	5.292E+02	8.047E+01	1.783E+01	4.123E-01	0.000E+00	0.000E+00	0.000E+00
I125	2.357E+01	3.393E-01	1.458E-08	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL	7.949E+02	7.659E+02	7.428E+02	2.311E+02	8.047E+01	1.783E+01	4.123E-01	0.000E+00	0.000E+00	0.000E+00

Exhibit 3.1. Input file RADACINP.DAT for Example 3.

Annotated File:

Line

```
1   RADACINP.DAT  FOR EXAMPLE 3, USER'S MANUAL. SEE RADACINP.003. 7/2/95.
2   ISIG(1)=2: INPUT IS IN CURIES.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
3   ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=0  NO VOLUMES READ.
4   ISIG(6)=9: 9 DECAY TIMES IN OUTPUT OU4: 1,2,3,4,5,10,100,300,500Y.
5   LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
6   STARTING YEAR 1970, FINAL YEAR 2130. ONE SITE, ORNL. ONE WASTE TYPE.
```

Column 1 (arrow to "S" of line 6)

Control signals ISIG(x)
x = 1 through 10

```
7    0002 0000 0000 0000 0000 0009 0002 0000 0001 0000
```

Final year (arrow to 2130); **Number of waste types** (arrow to second 0001)

```
8    1970 2130 0001 0001
```

Starting year (arrow to 1970); **Number of sites** (arrow to first 0001)

```
9    ORNL
```

Site (arrow to ORNL)

Column 2 (arrow to first digit of line 10)

```
10   0001 0002 0003 0004 0005 0010 0100
```

Accumulations at these decay times and high-range times will be shown in RADAC4.OUT

Comments:

Line 1–6: User notes and remarks, not used in calculations. All 6 lines must be used, even if left blank.

Line 7: ISIG(9) = 1 indicates output file RADACMAX.OUT is not produced.

Line 8: First year of waste input 1970. Final year of decay is set by high-range decay times.

Line 9: Name of site, up to 4 letters. Format 16(1x, A4). Use two lines if number of sites exceeds 16.

Line 10: The user lists here up to 9 decay times for which results will be shown in output file RADAC4.OUT. The number of decay times selected is given by the value of ISIG(6); the maximum allowable number is 9. Line 10 is not used if ISIG(6) = 0.

Actual File:

```
RADACINP.DAT FOR EXAMPLE 3, USER'S MANUAL. 7/2/95.
ISIG(1)=2: INPUT IS IN CURIES.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=0  NO VOLUMES READ.
ISIG(6)=9: 9 DECAY TIMES IN OUTPUT OU4: 1,2,3,4,5,10,100,300,500.
LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
STARTING YEAR 1970, FINAL YEAR 2130. ONE SITE, LLNL. ONE WASTE TYPE.
 0002 0000 0000 0000 0000 0009 0002 0000 0001 0000
 1970 2130 0001 0001
 ORNL
 0001 0002 0003 0004 0005 0010 0100
```

Exhibit 3.2. Input file RADNUCL1.DAT for Example 3.

Annotated File:

```
RADNUCL1.DAT  EXAMPLE 3, USER'S MANUAL. FOR SITE ORNL  7/2/95.
EXAMPLE IS IN USER'S MANUAL. SEE CHAPTER ON INPUT DATA. ONE SITE.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  01 OF 03      FOR YEARS 1970 THROUGH 1970 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,1pE10.4)
1234567890123456789012345678901234567890123456789012345678901234567890
NAME     TYPE   NID                         CURIES/YEAR  <--Data are in Ci/year
  PU-239  20   31                          3.2700E+01
  U-234   20   24                          2.8424E+02
  RU-106  10   16                          4.0088E+06
  NI-63   10   09                          7.2500E+01
  I-125   10   44                          1.3465E+02
          99
RADNUCL1.DAT  EXAMPLE 3, USER'S MANUAL.  FOR SITE ORNL  7/2/95.
EXAMPLE IS IN USER'S MANUAL. SEE CHAPTER ON INPUT DATA. ONE SITE.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  02 OF 03      FOR YEARS 1971 THROUGH 1971 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
1234567890123456789012345678901234567890123456789012345678901234567890
NAME     TYPE   NID                         CURIES/YEAR
  PU-239  20   31                          8.8820E+01
  CM-243  20   49                          5.4366E+02
  AC-227  20   13                          4.1632E+04
  TC-99   10   15                          3.6000E+00
  NI-63   10   09                          1.2500E+01
  CO-60   10   07                          1.6665E+01
          99
RADNUCL1.DAT  EXAMPLE 3, USER'S MANUAL.  FOR SITE ORNL  7/2/95.
EXAMPLE IS IN USER'S MANUAL. SEE CHAPTER ON INPUT DATA. ONE SITE.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  03 OF 03      FOR YEARS 1975 THROUGH 1975 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,1pE10.4)
1234567890123456789012345678901234567890123456789012345678901234567890
NAME     TYPE   NID                         CURIES/YEAR
  CM-246  20   40                          6.0772E+00
  PU-238  20   30                          1.0800E+04
  FE-59   10   05                          2.7500E+01
  NI-63   10   09                          2.2500E+02
  EU-152  10   27                          5.2240E-01
  CS-137  10   18                          1.3465E+03
          99
          ^
          Termination signal
```

Note: The actual file is the same as above except for the annotations

- **Line 4** shows page numbers and year numbers of radionuclide additions. The three pages are numbered page 01 of 03, page 02 of 03, and page 03 of 03. When the two numbers are the same (page 03 of 03), the program is signalled that the last page of data for the site is being read. The year numbers on each page give the year or years in which this page of radionuclide additions is added to inventory. Inputs can be made in any years beginning with YSTART and going up to a maximum of 60 years after YSTART; for example, 1970 through 2030.
- **Line 11** shows a 99 in columns 11 and 12. This is the termination signal that must appear at the end of each "page," after the list of radionuclides. If there were another site to be read, its pages of data would begin on the next line following this signal. Sites are counted within the program to indicate when the end of the data file has been reached.

5.4.3 Example 3, Output File RADAC4.OUT

Exhibit 3.3 shows output file RADAC4.OUT for Example 3. As mentioned in Sect. 5.2.3, the quantities of radionuclides shown in RADAC4.OUT are the decayed accumulations collected in the actinide and fission product accumulation arrays. Because there are inputs in three different years, this example illustrates both decay and accumulation.

5.5 EXAMPLE 4: MORE THAN ONE SITE

Each of the examples shown thus far has had only one site. Example 4 illustrates the preparation of input files for a problem with two or more sites. The radionuclides used as inputs differ from those used in the preceding examples.

5.5.1 Example 4, File RADACINP.DAT

Exhibit 4.1 shows file RADACINP.DAT for Example 4. This example has three sites and one waste type, as indicated by the third and fourth entries in line 8, NSITES=3 and NWTYPS=1. The three sites are listed as HANF, ORNL, and INEL.

5.5.2 Example 4, File RADNUCL1.DAT

Exhibit 4.2 shows file RADNUCL1.DAT for Example 4. When there is more than one site, the annual radionuclide inputs are read from file RADNUCL1.DAT in site order. First, the data for

(Text continued on page 79)

Exhibit 3.3. Output file RADAC4.OUT for Example 3.

SUMMARY OF RESULTS, **GRAMS**, FOR ACTINIDES AND DAUGHTERS, FOR END OF YEAR SHOWN
SITE = **ORNL** WASTE TYPE = 1

DECAY	0	1	2	3	4	5	10	100	300	500
PB-206	0.0000E+00	1.5125E-13	3.9307E-12	2.4748E-11	8.8515E-11	2.3378E-10	4.3734E-09	3.3350E-05	1.4273E-03	7.2913E-03
PB-207	0.0000E+00	0.0000E+00	1.4507E+01	3.0493E+01	4.5979E+01	6.0979E+01	1.2922E+02	5.0217E+02	5.2467E+02	5.2470E+02
PB-210	0.0000E+00	7.1158E-11	5.7835E-10	1.9519E-09	4.6088E-09	8.9530E-09	6.9267E-08	3.9791E-05	5.1010E-04	1.5015E-03
PO-210	0.0000E+00	3.9980E-13	5.0119E-12	2.0498E-11	5.3942E-11	1.1231E-10	1.0076E-09	6.6714E-07	8.6355E-06	2.5462E-05
RA-223	0.0000E+00	0.0000E+00	7.9025E-01	7.6549E-01	7.4150E-01	7.1827E-01	6.1257E-01	3.4900E-02	5.9930E-05	1.0292E-07
RA-226	0.0000E+00	5.6034E-07	2.2410E-06	5.0415E-06	8.9614E-06	1.4000E-05	5.5962E-05	5.5362E-03	4.8568E-02	1.3134E-01
AC-227	0.0000E+00	5.7540E+02	5.5737E+02	5.3991E+02	5.2299E+02	5.0660E+02	4.3205E+02	2.4615E+01	4.2269E-02	7.2588E-05
TH-227	0.0000E+00	9.4366E-20	1.3148E+00	1.2736E+00	1.2337E+00	1.1950E+00	1.0192E+00	5.8066E-02	9.9709E-05	1.7123E-07
TH-230	0.0000E+00	1.2672E-01	2.5343E-01	3.8015E-01	5.0686E-01	6.3357E-01	1.2673E+00	1.2713E+01	3.8260E+01	6.3812E+01
TH-234	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	8.7696E-19	3.2675E-16	3.1242E-15	8.7128E-15
PA-231	0.0000E+00	7.2100E-12	4.8424E-11	1.4323E-10	2.9163E-10	4.9364E-10	2.3078E-09	2.6428E-07	2.3974E-06	6.6534E-06
U-234	4.5477E+04	4.5477E+04	4.5477E+04	4.5477E+04	4.5476E+04	4.5476E+04	4.5500E+04	4.5791E+04	4.5998E+04	4.6020E+04
U-235	0.0000E+00	1.4895E-02	7.0251E-02	1.2561E-01	1.8098E-01	2.3635E-01	5.1328E-01	5.5051E+00	1.6570E+01	2.7572E+01
U-238	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	6.2749E-08	2.2552E-05	2.1533E-04	6.0038E-04
PU-238	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	6.3069E+02	6.0627E+02	2.9778E+02	6.1340E+01	1.2635E+01
PU-239	5.2592E+02	1.9544E+03	1.9546E+03	1.9548E+03	1.9550E+03	1.9551E+03	1.9559E+03	1.9582E+03	1.9479E+03	1.9367E+03
PU-242	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.4244E-02	2.6885E-01	8.2260E-01	1.3602E+00
AM-243	0.0000E+00	0.0000E+00	6.0713E-04	1.1996E-03	1.7778E-03	2.3420E-03	4.9655E-03	2.2849E-02	2.4647E-02	2.4206E-02
CM-246	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.9779E+01	1.9764E+01	1.9505E+01	1.8942E+01	1.8395E+01
CM-243	0.0000E+00	1.0529E+01	1.0276E+01	1.0029E+01	9.7880E+00	9.5529E+00	8.4591E+00	9.4778E-01	7.3154E-03	5.6463E-05
PA-234M	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.9531E-23	1.1003E-20	1.0520E-19	2.9340E-19
PA-234	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.3208E-23	4.9213E-21	4.7053E-20	1.3122E-19
RN-222	0.0000E+00	3.6020E-12	1.4406E-11	3.2408E-11	5.7606E-11	8.9996E-11	3.5973E-10	3.5588E-08	3.1221E-07	8.4427E-07
PO-218	0.0000E+00	1.9591E-15	7.8351E-15	1.7626E-14	3.1331E-14	4.8948E-14	1.9565E-13	1.9356E-11	1.6981E-10	4.5919E-10
PB-214	0.0000E+00	1.6898E-14	6.7581E-14	1.5203E-13	2.7024E-13	4.2219E-13	1.6876E-12	1.6695E-10	1.4647E-09	3.9607E-09
BI-214	0.0000E+00	1.2547E-14	5.0182E-14	1.1289E-13	2.0067E-13	3.1350E-13	1.2531E-12	1.2397E-10	1.0876E-09	2.9410E-09
PO-214	0.0000E+00	1.7262E-21	6.9038E-21	1.5531E-20	2.7607E-20	4.3130E-20	1.7240E-19	1.7055E-17	1.4962E-16	4.0461E-16
BI-210	0.0000E+00	4.3783E-14	3.5586E-13	1.2010E-12	2.8358E-12	5.5088E-12	4.2620E-11	2.4483E-08	3.1387E-07	9.2389E-07
NP-239	0.0000E+00	0.0000E+00	5.2175E-10	1.0309E-09	1.5278E-09	2.0127E-09	4.2672E-09	1.9636E-08	2.1181E-08	2.0802E-08
TH-231	0.0000E+00	6.0562E-14	2.8564E-13	5.1073E-13	7.3585E-13	9.6099E-13	2.0870E-12	2.2383E-11	6.7371E-11	1.1210E-10
FR-223	0.0000E+00	1.4850E-05	1.4384E-05	1.3934E-05	1.3497E-05	1.3074E-05	1.1150E-05	6.3526E-07	1.0909E-09	1.8733E-12
RN-219	0.0000E+00	0.0000E+00	3.1108E-06	3.0133E-06	2.9189E-06	2.8274E-06	2.4114E-06	1.3738E-07	2.3591E-10	4.0512E-13
PO-215	0.0000E+00	0.0000E+00	1.3728E-09	1.3298E-09	1.2881E-09	1.2477E-09	1.0641E-09	6.0626E-11	1.0411E-13	1.7878E-16
PB-211	0.0000E+00	0.0000E+00	1.6394E-03	1.5881E-03	1.5383E-03	1.4901E-03	1.2708E-03	7.2402E-05	1.2433E-07	2.1351E-10
BI-211	0.0000E+00	0.0000E+00	9.6730E-05	9.3699E-05	9.0763E-05	8.7919E-05	7.4982E-05	4.2719E-06	7.3357E-09	1.2597E-11
PO-211	0.0000E+00	0.0000E+00	1.1571E-09	1.1209E-09	1.0857E-09	1.0517E-09	8.9696E-10	5.1102E-11	8.7752E-14	1.5069E-16
TL-207	0.0000E+00	0.0000E+00	2.1193E-04	2.0529E-04	1.9885E-04	1.9262E-04	1.6428E-04	9.3594E-06	1.6072E-08	2.7600E-11
TL-210	0.0000E+00	1.7357E-19	6.9416E-19	1.5616E-18	2.7758E-18	4.3366E-18	1.7334E-17	1.7149E-15	1.5044E-14	4.0682E-14
TOTAL	4.6003E+04	4.8017E+04	4.8016E+04	4.8014E+04	4.8013E+04	4.8662E+04	4.8655E+04	4.8613E+04	4.8606E+04	4.8605E+04

Exhibit 3.3. Output file RADAC4.OUT for Example 3 (continued).

```
SUMMARY OF RESULTS, CURIES, FOR ACTINIDES AND DAUGHTERS, FOR END OF YEAR SHOWN
SITE = ORNL       WASTE TYPE =  1
```

DECAY	0	1	2	3	4	5	10	100	300	500
PB-206	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-207	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-210	0.0000E+00	5.4339E-09	4.4166E-08	1.4906E-07	3.5195E-07	6.8369E-07	5.2896E-06	3.0386E-03	3.8954E-02	1.1466E-01
PO-210	0.0000E+00	1.7964E-09	2.2519E-08	9.2104E-08	2.4237E-07	5.0462E-07	4.5275E-06	2.9976E-03	3.8801E-02	1.1441E-01
RA-223	0.0000E+00	0.0000E+00	4.0480E+04	3.9212E+04	3.7983E+04	3.6793E+04	3.1379E+04	1.7878E+03	3.0699E+00	5.2719E-03
RA-226	0.0000E+00	5.5416E-07	2.2163E-06	4.9860E-06	8.8627E-06	1.3846E-05	5.5345E-05	5.4752E-03	4.8033E-02	1.2989E-01
AC-227	0.0000E+00	4.1632E+04	4.0328E+04	3.9064E+04	3.7840E+04	3.6654E+04	3.1260E+04	1.7810E+03	3.0583E+00	5.2519E-03
TH-227	0.0000E+00	2.9012E-15	4.0422E+04	3.9155E+04	3.7929E+04	3.6740E+04	3.1334E+04	1.7852E+03	3.0655E+00	5.2643E-03
TH-230	0.0000E+00	2.5586E-03	5.1171E-03	7.6756E-03	1.0234E-02	1.2793E-02	2.5588E-02	2.5669E-01	7.7251E-01	1.2884E+00
TH-234	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0314E-14	7.5689E-12	7.2368E-11	2.0182E-10
PA-231	0.0000E+00	3.4064E-13	2.2879E-12	6.7671E-12	1.3779E-11	2.3322E-11	1.0903E-10	1.2486E-08	1.1327E-07	3.1435E-07
U-234	2.8424E+02	2.8424E+02	2.8424E+02	2.8424E+02	2.8424E+02	2.8424E+02	2.8438E+02	2.8620E+02	2.8750E+02	2.8763E+02
U-235	0.0000E+00	3.2204E-08	1.5189E-07	2.7159E-07	3.9129E-07	5.1101E-07	1.1098E-06	1.1902E-05	3.5825E-05	5.9613E-05
U-238	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.1101E-14	7.5838E-12	7.2412E-11	2.0189E-10
PU-238	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0800E+04	1.0382E+04	5.0992E+03	1.0504E+03	2.1637E+02
PU-239	3.2700E+01	1.2152E+02	1.2153E+02	1.2154E+02	1.2155E+02	1.2156E+02	1.2161E+02	1.2176E+02	1.2111E+02	1.2042E+02
PU-242	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.4402E-05	1.0268E-03	3.1417E-03	5.1947E-03
AM-243	0.0000E+00	0.0000E+00	1.2106E-04	2.3920E-04	3.5449E-04	4.6700E-04	9.9011E-04	4.5561E-03	4.9147E-03	4.8266E-03
CM-246	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	6.0772E+00	6.0727E+00	5.9932E+00	5.8201E+00	5.6521E+00
CM-243	0.0000E+00	5.4366E+02	5.3060E+02	5.1785E+02	5.0541E+02	4.9326E+02	4.3678E+02	4.8939E+01	3.7773E-01	2.9155E-03
PA-234M	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0288E-14	7.5591E-12	7.2274E-11	2.0156E-10
PA-234	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.6408E-17	9.8396E-15	9.4078E-14	2.6237E-13
RN-222	0.0000E+00	5.5416E-07	2.2163E-06	4.9860E-06	8.8627E-06	1.3846E-05	5.5345E-05	5.4752E-03	4.8033E-02	1.2989E-01
PO-218	0.0000E+00	5.5416E-07	2.2163E-06	4.9860E-06	8.8627E-06	1.3846E-05	5.5345E-05	5.4752E-03	4.8033E-02	1.2989E-01
PB-214	0.0000E+00	5.5416E-07	2.2163E-06	4.9860E-06	8.8627E-06	1.3846E-05	5.5345E-05	5.4752E-03	4.8033E-02	1.2989E-01
BI-214	0.0000E+00	5.5416E-07	2.2163E-06	4.9860E-06	8.8627E-06	1.3846E-05	5.5345E-05	5.4752E-03	4.8033E-02	1.2989E-01
PO-214	0.0000E+00	5.5405E-07	2.2159E-06	4.9849E-06	8.8608E-06	1.3843E-05	5.5333E-05	5.4741E-03	4.8023E-02	1.2986E-01
BI-210	0.0000E+00	5.4339E-09	4.4166E-08	1.4906E-07	3.5195E-07	6.8369E-07	5.2896E-06	3.0386E-03	3.8954E-02	1.1466E-01
NP-239	0.0000E+00	0.0000E+00	1.2106E-04	2.3920E-04	3.5449E-04	4.6700E-04	9.9011E-04	4.5561E-03	4.9147E-03	4.8266E-03
TH-231	0.0000E+00	3.2204E-08	1.5189E-07	2.7159E-07	3.9129E-07	5.1101E-07	1.1098E-06	1.1902E-05	3.5825E-05	5.9613E-05
FR-223	0.0000E+00	5.7452E+02	5.5652E+02	5.3908E+02	5.2219E+02	5.0583E+02	4.3139E+02	2.4578E+01	4.2204E-02	7.2477E-05
RN-219	0.0000E+00	0.0000E+00	4.0480E+04	3.9212E+04	3.7983E+04	3.6793E+04	3.1379E+04	1.7878E+03	3.0699E+00	5.2719E-03
PO-215	0.0000E+00	0.0000E+00	4.0480E+04	3.9212E+04	3.7983E+04	3.6793E+04	3.1379E+04	1.7878E+03	3.0699E+00	5.2719E-03
PB-211	0.0000E+00	0.0000E+00	4.0480E+04	3.9212E+04	3.7983E+04	3.6793E+04	3.1379E+04	1.7878E+03	3.0699E+00	5.2719E-03
BI-211	0.0000E+00	0.0000E+00	4.0480E+04	3.9212E+04	3.7983E+04	3.6793E+04	3.1379E+04	1.7878E+03	3.0699E+00	5.2719E-03
PO-211	0.0000E+00	0.0000E+00	1.1051E+02	1.0705E+02	1.0369E+02	1.0045E+02	8.5665E+01	4.8806E+00	8.3808E-03	1.4392E-05
TL-207	0.0000E+00	0.0000E+00	4.0370E+04	3.9105E+04	3.7880E+04	3.6693E+04	3.1293E+04	1.7829E+03	3.0615E+00	5.2575E-03
TL-210	0.0000E+00	1.1637E-10	4.6543E-10	1.0471E-09	1.8612E-09	2.9076E-09	1.1622E-08	1.1498E-06	1.0087E-05	2.7277E-05
TOTAL	3.1694E+02	4.3156E+04	3.2512E+05	3.1496E+05	3.0510E+05	3.0637E+05	2.6253E+05	1.9880E+04	1.4910E+03	6.3254E+02

Exhibit 3.3. Output file RADAC4.OUT for Example 3 (continued).

SUMMARY OF RESULTS, **CURIES**, FOR FISSION AND ACTIVATION PRODUCTS, FOR END OF YEAR SHOWN
SITE = **ORNL** WASTE TYPE = 1

DECAY	0	1	2	3	4	5	10	100	300	500
FE59	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.7500E+01	1.6693E-11	0.0000E+00	0.0000E+00	0.0000E+00
CO60	0.0000E+00	1.6665E+01	1.4611E+01	1.2810E+01	1.1231E+01	9.8471E+00	5.1014E+00	3.6855E-05	1.2148E-16	4.5668E-28
NI63	7.2500E+01	8.4456E+01	8.3822E+01	8.3193E+01	8.2568E+01	3.0695E+02	2.9560E+02	1.5004E+02	3.2340E+01	7.1669E+00
TC99	0.0000E+00	3.6000E+00	3.6000E+00	3.6000E+00	3.6000E+00	3.6000E+00	3.5999E+00	3.5988E+00	3.5965E+00	3.5941E+00
RU106	4.0088E+06	2.0155E+06	1.0133E+06	5.0944E+05	2.5612E+05	1.2877E+05	4.1362E+03	5.4811E-24	0.0000E+00	0.0000E+00
RH106	0.0000E+00	2.0155E+06	1.0133E+06	5.0944E+05	2.5612E+05	1.2877E+05	4.1362E+03	5.4811E-24	0.0000E+00	0.0000E+00
I125	1.3465E+02	1.9386E+00	2.7910E-02	4.0183E-04	5.7852E-06	8.3291E-08	5.1522E-17	0.0000E+00	0.0000E+00	0.0000E+00
CS137	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.3465E+03	1.1996E+03	1.4994E+02	1.3147E+00	1.2939E-02
BA137M	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.2738E+03	1.1348E+03	1.4184E+02	1.2437E+00	1.2240E-02
SM148	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	9.3084E-31	1.1994E-28	4.4520E-28	7.6277E-28
EU152	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.2240E-01	4.0489E-01	4.1238E-03	1.1964E-07	4.4787E-12
GD152	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.1231E-15	1.8185E-14	1.8329E-14	1.8329E-14
TOTAL	4.0090E+06	4.0310E+06	2.0267E+06	1.0190E+06	5.1234E+05	2.6050E+05	1.0911E+04	4.4543E+02	3.8495E+01	1.0786E+01

Exhibit 4.1. Input data file RADACINP.DAT for Example 4.

Annotated File:

```
Line
 1   RADACINP.DAT FOR EXAMPLE 4, USER'S MANUAL. 7/3/95.
 2   ISIG(1)=2: INPUT IS IN CURIES.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
 3   ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=0  NO VOLUMES READ.
 4   ISIG(6)=9, ISIG(7)=5: 9 DECAY TIMES: 1,10,100,300,500,1K,10K,100K,1MY.
 5   LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
 6   YSTART=1970, YFINAL=2130. 3 LOW-RANGE AND 6 HIGH-RANGE DECAY TIMES.
 7    0002 0000 0000 0000 0000 0009 0006 0000 0001 0000
 8    1970 2130 0003 0001 <----- One waste type      ^
            Three sites                               |
                                         Output file RADACMAX.OUT
 9    HANF ORNL INEL                          is suppressed
10    0001 0010 0100
```

Comments:

Line 7: ISIG(1) = 2, inputs are in curies. ISIG(9) = 1, output file RADACMAX.OUT is omitted.

Line 8: This example has 3 sites and 1 waste type. Initial year 1970. Final year will be set by the high-range decay times.

Line 9: Site names are shown as they will appear in the output tables.

Line 10: File RADAC4.OUT will show results at these and high-range decay times selected by ISIG(7)

Actual File:

```
RADACINP.DAT FOR EXAMPLE 4, USER'S MANUAL. 7/3/95.
ISIG(1)=2: INPUT IS IN CURIES.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=0  NO VOLUMES READ.
ISIG(6)=9, ISIG(7)=5: 9 DECAY TIMES: 1,10,100,300,500,1K,10K,100K,1MY.
LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
YSTART=1970, YFINAL=2130. 3 LOW-RANGE AND 6 HIGH-RANGE DECAY TIMES.
 0002 0000 0000 0000 0000 0009 0006 0000 0001 0000
 1970 2130 0003 0001
 HANF ORNL INEL
 0001 0010 0100
```

Exhibit 4.2. Input data file RADNUCL1.DAT for Example 4.

```
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 1: HANF   7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  01 OF 03        FOR YEARS 1970 THROUGH 1970 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                           CURIES/YEAR
  PU-241  20  33                            3.2700E+01
  U-234   20  24                            2.8424E+02
  SM-151  10  39                            4.9904E-01
  RU-106  10  16                            4.0088E+04
  NI-63   10  09                            7.2500E+01
  ZR-95   13  59                            3.2004E+00
  I-125   10  44                            1.3465E+02
          99
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 1: HANF   7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  02 OF 03        FOR YEARS 1971 THROUGH 1971 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                           CURIES/YEAR
  PU-240  20  32                            2.8820E+01
  CM-243  20  49                            5.4366E+02
  AC-227  20  13                            4.1632E+04
  TC-99   10  15                            3.6000E+00
  SE-79   10  30                            2.0844E-01
  C-14    10  02                            1.2500E+01
  CO-60   10  07                            1.6665E+01
          99
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 1: HANF   7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  03 OF 03        FOR YEARS 1980 THROUGH 1980 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                           CURIES/YEAR
  CM-245  20  39                            2.0772E+00
  PU-238  20  30                            1.0800E+04
  FE-59   10  05                            2.7500E+01
  NI-63   10  09                            2.2500E+02
  EU-152  10  27                            5.2240E-01
  CS-137  10  18                            1.3433E+00
  BA-137M 11  19                            1.2708E+00
          99
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 2: ORNL   7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  01 OF 04        FOR YEARS 1970 THROUGH 1970 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                           CURIES/YEAR
  PU-239  20  31                            3.2700E+01
  U-234   20  24                            1.8424E+00
  U-235   20  25                            1.8000E-02
  TH-232  20  18                            5.5442E-04
  RU-106  10  16                            4.0088E+00
  CE-144  10  20                            1.2500E+01
  I-125   10  44                            1.3465E+02
          99
```

Exhibit 4.2. Input data file RADNUCL1.DAT for Example 4 (continued).

```
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 2: ORNL    7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  02 OF 04      FOR YEARS 1971 THROUGH 1973 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                        CURIES/YEAR
  PU-239  20  31                         8.8820E+01
  RA-225  20  09                         8.0235E+02
  CM-243  20  49                         5.4366E+02
  AC-227  20  13                         4.1632E+04
  TC-99   10  15                         3.6000E+00
  NI-63   10  09                         1.2500E+01
  CO-60   10  07                         1.6665E+01
          99
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 2: ORNL    7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  03 OF 04      FOR YEARS 1977 THROUGH 1977 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                        CURIES/YEAR
  CM-246  20  40                         6.0772E+00
  PU-238  20  30                         1.0800E+04
  FE-59   10  05                         2.7500E+01
  NI-63   10  09                         2.2500E+02
  EU-152  10  27                         5.2240E-01
  CS-137  10  18                         1.3465E+03
          99
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 2: ORNL    7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  04 OF 04      FOR YEARS 1983 THROUGH 1983 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                        CURIES/YEAR
  CM-246  20  40                         6.0772E+00
  PU-238  20  30                         1.0800E+04
  FE-59   10  05                         2.7500E+01
  NI-63   10  09                         2.2500E+02
  SN-126  10  33                         4.6542E+00
  EU-152  10  27                         5.2240E-01
  CS-137  10  18                         1.3465E+03
          99
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 3: INEL    7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  01 OF 02      FOR YEARS 1970 THROUGH 1970 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
123456789012345678901234567890123456789012345678901234567890
NAME    TYPE  NID                        CURIES/YEAR
  PU-239  20  31                         3.2700E+01
  U-232   20  22                         4.0303E+01
  RU-103  10  82                         4.0088E-01
  NI-63   10  09                         7.2500E+01
  I-125   10  44                         1.3465E+02
          99
```

Exhibit 4.2. Input data file RADNUCL1.DAT for Example 4 (continued).

```
RADNUCL1.DAT  EXAMPLE 4, USER'S MANUAL. DATA FOR SITE 3: INEL    7/3/95.
EXAMPLE IS IN USER'S MANUAL. THREE SITES: HANF, ORNL, INEL.
NEXT LINE GIVES PAGE NUMBER, YEARS. FORMAT 6X,I2,4X,I2,16X,I4,9X,I4.
PAGE  02 OF 02      FOR YEARS 1974 THROUGH 1974 INCLUSIVE.
FOR NUCLIDE DATA USE FORMAT (2X,A7,1X,I2,1X,I3,24X,E10.0)
1234567890123456789012345678901234567890123456789012345678901234567890
NAME     TYPE   NID                            CURIES/YEAR
  PU-240  20  32                               8.8820E+01
  U-233   20  23                               4.0737E-02
  CM-243  20  49                               5.4366E+02
  AC-227  20  13                               4.1632E+04
  TC-99   10  15                               3.6000E+00
  NI-63   10  09                               1.2500E+01
  NB-95M  13  60                               9.0045E-01
  CO-58   10  06                               1.1875E+01
          99
          ↑
```

File ends at this point

site 1 are read, then the data for site 2, and so on. The program has capacity for 19 sites in a single run; it reads the nuclide inputs for a site and completes the calculations for that site before it reads the data for the next site. The order in which the site nuclide data are entered must be the same as the order in which the site names are listed in line 9 of file RADACINP.DAT. Example 4, which has three sites, shows how the radionuclide input pages for the sites are sequenced. Note that the final page of data for the final site uses the same terminator signal as any other page; no additional signal is required. No blank lines should be left between pages.

5.5.3 Example 4, Output File RADAC4.OUT

Exhibit 4.3 shows output file RADAC4.OUT for Example 4. Each of the three sites has a set of output tables similar to those shown in the previous examples. Totals for the three sites combined are not shown in file RADAC4.OUT. Total masses, radioactivities, and thermal power for all sites combined are summarized in files RADACMAX.OUT, RADAC2.OUT, and RADAC3.OUT. These files are discussed in Sect. 6.

5.6 EXAMPLE 5: ACCUMULATION OF VOLUMES

Example 5 illustrates the preparation of annual volume data. This example is identical to Example 4 except that annual volume data are provided.

5.6.1 Example 5, File RADACINP.DAT

Exhibit 5.1 shows file RADACINP.DAT for Example 5. The file is identical to that prepared for Example 4 (Exhibit 4.1) except for one small difference; control signal ISIG(4) is 1 instead of 0. As indicated in Table 7, this change causes file VOLUME.DAT to be read.

5.6.2 Example 5, File RADNUCL1.DAT

This file is identical to that used in Example 4, Exhibit 4.2, and is not repeated.

5.6.3 Example 5, File VOLUME.DAT

Exhibit 5.2 shows file VOLUME.DAT for Example 5. This file contains the volumes of type 1 and type 2 wastes added at each site for each calendar year of waste additions. Volumes added annually are given in m^3. The file lists the volume data for each site in turn. The site order must be the order specified in file RADACINP.DAT. For each site, the data are as follows:

(Text continued on page 92)

Exhibit 4.3. Output file RADAC4.OUT for Example 4.

SUMMARY OF RESULTS, **GRAMS**, FOR ACTINIDES AND DAUGHTERS, FOR END OF YEAR SHOWN
SITE = **HANF** WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
PB-206	0.0000E+00	1.5125E-13	4.3734E-09	3.3338E-05	1.4269E-03	7.2895E-03	6.0871E-02	3.1950E+01	3.4156E+03	3.7082E+04
PB-207	0.0000E+00	0.0000E+00	1.2922E+02	5.0217E+02	5.2467E+02	5.2470E+02	5.2471E+02	5.2471E+02	5.2471E+02	5.2471E+02
PB-208	0.0000E+00	0.0000E+00	1.6852E-19	1.8986E-15	6.6285E-14	3.2202E-13	2.6469E-12	2.2048E-09	6.6272E-07	7.7762E-05
PB-210	0.0000E+00	7.1158E-11	6.9266E-08	3.9776E-05	5.0996E-04	1.5012E-03	5.9828E-03	2.4864E-01	1.8886E+00	3.2488E-01
BI-209	0.0000E+00	9.8876E-24	1.9908E-18	1.2586E-13	1.6044E-11	1.4230E-10	2.6592E-09	3.0458E-05	4.0784E-02	2.2674E+00
PO-210	0.0000E+00	3.9980E-13	1.0076E-09	6.6690E-07	8.6330E-06	2.5457E-05	1.0158E-04	4.2255E-03	3.2099E-02	5.5216E-03
RA-223	0.0000E+00	0.0000E+00	6.1257E-01	3.4900E-02	5.9930E-05	1.0291E-07	1.2330E-13	1.0937E-11	3.0110E-10	4.2939E-10
RA-224	0.0000E+00	0.0000E+00	1.3051E-21	9.9984E-19	1.0750E-17	3.0752E-17	1.2420E-16	9.5326E-15	2.2531E-13	2.4321E-12
RA-225	0.0000E+00	4.2629E-24	6.3848E-20	3.6036E-16	1.4497E-14	7.6090E-14	7.0410E-13	7.2391E-10	6.0413E-08	1.6673E-07
RA-226	0.0000E+00	5.6034E-07	5.5959E-05	5.5342E-03	4.8555E-02	1.3131E-01	4.9068E-01	1.9275E+01	1.4585E+02	2.5084E+01
RA-228	0.0000E+00	0.0000E+00	1.8181E-18	7.2353E-16	7.4578E-15	2.1167E-14	8.5004E-14	6.4913E-12	1.5336E-10	1.6553E-09
AC-225	0.0000E+00	2.4321E-24	4.2463E-20	2.4310E-16	9.7892E-15	5.1388E-14	4.7558E-13	4.8901E-10	4.0811E-08	1.1263E-07
AC-227	0.0000E+00	5.7540E+02	4.3205E+02	2.4615E+01	4.2269E-02	7.2584E-05	8.7281E-11	7.7436E-09	2.1317E-07	3.0401E-07
TH-227	0.0000E+00	0.0000E+00	1.0192E+00	5.8066E-02	9.9709E-05	1.7122E-07	2.0489E-13	1.8164E-11	5.0003E-10	7.1309E-10
TH-228	0.0000E+00	0.0000E+00	2.5499E-19	1.9437E-16	2.0893E-15	5.9764E-15	2.4137E-14	1.8525E-12	4.3785E-11	4.7263E-10
TH-229	0.0000E+00	9.9165E-19	1.2040E-14	6.6549E-11	2.6736E-09	1.4029E-08	1.2979E-07	1.3342E-04	1.1134E-02	3.0729E-02
TH-230	0.0000E+00	1.2672E-01	1.2671E+00	1.2709E+01	3.8252E+01	6.3803E+01	1.2746E+02	1.2106E+03	7.2202E+03	1.2206E+03
TH-232	0.0000E+00	0.0000E+00	1.5534E-08	1.8736E-06	1.6971E-05	4.6936E-05	1.8487E-04	1.3874E-02	3.2728E-01	3.5323E+00
PA-231	0.0000E+00	0.0000E+00	7.9307E-13	6.6995E-10	9.6151E-09	2.9704E-08	1.2813E-07	1.1928E-05	3.2653E-04	4.6555E-04
PA-233	0.0000E+00	3.3684E-13	3.4288E-11	1.3903E-09	5.4540E-09	1.0144E-08	2.3418E-08	2.2191E-07	3.9648E-07	2.9631E-07
U-233	0.0000E+00	9.8263E-13	1.1044E-09	5.4052E-07	6.8367E-06	2.1369E-05	9.9299E-05	1.1230E-02	2.7278E-01	6.7351E-01
U-234	4.5477E+04	4.5477E+04	4.5476E+04	4.5780E+04	4.5995E+04	4.6019E+04	4.5967E+04	4.4809E+04	3.4718E+04	2.7070E+03
U-235	0.0000E+00	0.0000E+00	2.6825E-04	1.7999E-02	7.5178E-02	1.3309E-01	2.7646E-01	2.5352E+00	9.6090E+00	1.0173E+01
U-236	0.0000E+00	0.0000E+00	1.1860E-01	1.2984E+00	3.8801E+00	6.4077E+00	1.2497E+01	8.1256E+01	1.2400E+02	1.2075E+02
NP-237	0.0000E+00	1.2197E-05	1.0296E-03	4.0991E-02	1.6065E-01	2.9873E-01	6.8958E-01	6.5336E+00	1.1673E+01	8.7241E+00
PU-238	0.0000E+00	0.0000E+00	6.3069E+02	3.0978E+02	6.3811E+01	1.3145E+01	2.5314E-01	3.3612E-32	0.0000E+00	0.0000E+00
PU-239	0.0000E+00	0.0000E+00	2.0306E+00	9.3826E+00	1.0248E+01	1.0196E+01	1.0052E+01	7.7675E+00	5.8237E-01	3.2105E-12
PU-240	0.0000E+00	1.2645E+02	1.2633E+02	1.2513E+02	1.2250E+02	1.1993E+02	1.1374E+02	4.3800E+01	3.1414E-03	0.0000E+00
PU-241	3.1732E-01	3.0241E-01	1.9608E-01	2.2354E-02	1.9720E-02	1.9401E-02	1.8625E-02	8.9397E-03	5.8006E-06	7.6737E-38
AM-241	0.0000E+00	1.4901E-02	1.2019E-01	3.4030E-01	4.1233E-01	4.6022E-01	5.2027E-01	2.8272E-01	1.8345E-04	2.4268E-36
AM-243	0.0000E+00	0.0000E+00	4.9655E-03	2.2849E-02	2.4647E-02	2.4206E-02	2.3095E-02	9.9180E-03	2.1155E-06	4.1198E-43
CM-245	0.0000E+00	0.0000E+00	1.2095E+01	1.2007E+01	1.1812E+01	1.1621E+01	1.1157E+01	5.3550E+00	3.4746E-03	4.5966E-35
CM-243	0.0000E+00	1.0529E+01	8.4591E+00	9.4778E-01	7.3154E-03	5.6463E-05	2.9552E-10	0.0000E+00	0.0000E+00	0.0000E+00
U-237	9.8125E-09	9.3513E-09	6.0634E-09	6.9126E-10	6.0980E-10	5.9993E-10	5.7595E-10	2.7644E-10	1.7937E-13	2.8026E-45
FR-221	0.0000E+00	7.9631E-28	1.3903E-23	7.9593E-20	3.2051E-18	1.6825E-17	1.5571E-16	1.6011E-13	1.3362E-11	3.6877E-11
AT-217	0.0000E+00	8.7693E-32	1.5310E-27	8.7651E-24	3.5296E-22	1.8528E-21	1.7147E-20	1.7632E-17	1.4715E-15	4.0611E-15
BI-213	0.0000E+00	7.2990E-27	1.2744E-22	7.2956E-19	2.9378E-17	1.5422E-16	1.4273E-15	1.4676E-12	1.2248E-10	3.3802E-10
PO-213	0.0000E+00	1.0950E-35	1.9118E-31	1.0945E-27	4.4074E-26	2.3136E-25	2.1412E-24	2.2017E-21	1.8374E-19	5.0710E-19
TL-209	0.0000E+00	7.4553E-30	1.3016E-25	7.4518E-22	3.0007E-20	1.5752E-19	1.4578E-18	1.4990E-15	1.2510E-13	3.4526E-13
PB-209	0.0000E+00	3.1063E-26	5.4234E-22	3.1048E-18	1.2503E-16	6.5633E-16	6.0741E-15	6.2457E-12	5.2123E-10	1.4385E-09
RN-222	0.0000E+00	3.6020E-12	3.5972E-10	3.5575E-08	3.1212E-07	8.4410E-07	3.1542E-06	1.2390E-04	9.3757E-04	1.6124E-04

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

PO-218	0.0000E+00	1.9591E-15	1.9565E-13	1.9349E-11	1.6976E-10	4.5910E-10	1.7155E-09	6.7389E-08	5.0994E-07	8.7699E-08
PB-214	0.0000E+00	1.6898E-14	1.6875E-12	1.6689E-10	1.4643E-09	3.9599E-09	1.4797E-08	5.8126E-07	4.3984E-06	7.5644E-07
BI-214	0.0000E+00	1.2547E-14	1.2531E-12	1.2392E-10	1.0873E-09	2.9404E-09	1.0987E-08	4.3161E-07	3.2660E-06	5.6168E-07
PO-214	0.0000E+00	1.7262E-21	1.7239E-19	1.7049E-17	1.4958E-16	4.0453E-16	1.5116E-15	5.9379E-14	4.4932E-13	7.7275E-14
BI-210	0.0000E+00	4.3783E-14	4.2620E-11	2.4474E-08	3.1378E-07	9.2371E-07	3.6812E-06	1.5299E-04	1.1621E-03	1.9990E-04
NP-239	0.0000E+00	0.0000E+00	4.2672E-09	1.9636E-08	2.1181E-08	2.0802E-08	1.9848E-08	8.5233E-09	1.8180E-12	0.0000E+00
TH-231	0.0000E+00	0.0000E+00	1.0907E-15	7.3183E-14	3.0567E-13	5.4114E-13	1.1241E-12	1.0308E-11	3.9069E-11	4.1361E-11
FR-223	0.0000E+00	1.4850E-05	1.1150E-05	6.3526E-07	1.0909E-09	1.8732E-12	2.2525E-18	1.9984E-16	5.5015E-15	7.8457E-15
RN-219	0.0000E+00	0.0000E+00	2.4114E-06	1.3738E-07	2.3591E-10	4.0510E-13	4.8536E-19	4.3054E-17	1.1853E-15	1.6903E-15
PO-215	0.0000E+00	0.0000E+00	1.0641E-09	6.0626E-11	1.0411E-13	1.7877E-16	2.1419E-22	1.9000E-20	5.2305E-19	7.4592E-19
PB-211	0.0000E+00	0.0000E+00	1.2708E-03	7.2402E-05	1.2433E-07	2.1349E-10	2.5579E-16	2.2690E-14	6.2464E-13	8.9080E-13
BI-211	0.0000E+00	0.0000E+00	7.4982E-05	4.2719E-06	7.3357E-09	1.2597E-11	1.5092E-17	1.3388E-15	3.6856E-14	5.2559E-14
PO-211	0.0000E+00	0.0000E+00	8.9696E-10	5.1102E-11	8.7752E-14	1.5069E-16	1.8054E-22	1.6015E-20	4.4088E-19	6.2873E-19
TL-207	0.0000E+00	0.0000E+00	1.6428E-04	9.3594E-06	1.6072E-08	2.7598E-11	3.3066E-17	2.9331E-15	8.0747E-14	1.1515E-13
AC-228	0.0000E+00	0.0000E+00	1.8977E-22	7.5521E-20	7.7844E-19	2.2094E-18	8.8726E-18	6.7755E-16	1.6007E-14	1.7278E-13
RN-220	0.0000E+00	0.0000E+00	2.2539E-25	1.7267E-22	1.8566E-21	5.3108E-21	2.1450E-20	1.6463E-18	3.8911E-17	4.2002E-16
PO-216	0.0000E+00	0.0000E+00	5.9701E-28	4.5738E-25	4.9177E-24	1.4067E-23	5.6816E-23	4.3607E-21	1.0307E-19	1.1125E-18
PB-212	0.0000E+00	0.0000E+00	1.4962E-22	1.1462E-19	1.2324E-18	3.5254E-18	1.4239E-17	1.0928E-15	2.5830E-14	2.7882E-13
BI-212	0.0000E+00	0.0000E+00	1.4192E-23	1.0873E-20	1.1690E-19	3.3440E-19	1.3506E-18	1.0366E-16	2.4501E-15	2.6447E-14
PO-212	0.0000E+00	0.0000E+00	7.5082E-34	5.7522E-31	6.1847E-30	1.7692E-29	7.1455E-29	5.4842E-27	1.2962E-25	1.3992E-24
TL-208	0.0000E+00	0.0000E+00	2.5366E-25	1.9433E-22	2.0894E-21	5.9769E-21	2.4140E-20	1.8528E-18	4.3792E-17	4.7270E-16
TL-210	0.0000E+00	1.7357E-19	1.7333E-17	1.7142E-15	1.5040E-14	4.0674E-14	1.5199E-13	5.9704E-12	4.5178E-11	7.7697E-12
TOTAL	4.5477E+04	4.6190E+04	4.6820E+04	4.6778E+04	4.6771E+04	4.6770E+04	4.6768E+04	4.6743E+04	4.6173E+04	4.1706E+04

SUMMARY OF RESULTS, **CURIES**, FOR ACTINIDES AND DAUGHTERS, FOR END OF YEAR SHOWN
SITE = **HANF** WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
PB-206	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-207	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-208	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-210	0.0000E+00	5.4339E-09	5.2895E-06	3.0375E-03	3.8943E-02	1.1464E-01	4.5687E-01	1.8987E+01	1.4422E+02	2.4810E+01
BI-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PO-210	0.0000E+00	1.7964E-09	4.5274E-06	2.9965E-03	3.8790E-02	1.1438E-01	4.5640E-01	1.8986E+01	1.4423E+02	2.4810E+01
RA-223	0.0000E+00	0.0000E+00	3.1379E+04	1.7878E+03	3.0699E+00	5.2716E-03	6.3160E-09	5.6026E-07	1.5424E-05	2.1996E-05
RA-224	0.0000E+00	0.0000E+00	2.0794E-16	1.5930E-13	1.7128E-12	4.8997E-12	1.9789E-11	1.5188E-09	3.5899E-08	3.8750E-07
RA-225	0.0000E+00	1.6717E-19	2.5038E-15	1.4131E-11	5.6852E-10	2.9839E-09	2.7611E-08	2.8388E-05	2.3691E-03	6.5384E-03
RA-226	0.0000E+00	5.5416E-07	5.5342E-05	5.4732E-03	4.8020E-02	1.2986E-01	4.8527E-01	1.9062E+01	1.4425E+02	2.4807E+01
RA-228	0.0000E+00	0.0000E+00	4.2560E-16	1.6937E-13	1.7458E-12	4.9550E-12	1.9898E-11	1.5195E-09	3.5900E-08	3.8750E-07
AC-225	0.0000E+00	1.4118E-19	2.4650E-15	1.4112E-11	5.6826E-10	2.9831E-09	2.7607E-08	2.8387E-05	2.3691E-03	6.5383E-03
AC-227	0.0000E+00	4.1632E+04	3.1260E+04	1.7810E+03	3.0583E+00	5.2517E-03	6.3150E-09	5.6027E-07	1.5424E-05	2.1996E-05
TH-227	0.0000E+00	0.0000E+00	3.1334E+04	1.7852E+03	3.0655E+00	5.2640E-03	6.2992E-09	5.5844E-07	1.5373E-05	2.1923E-05

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

TH-228	0.0000E+00	0.0000E+00	2.0906E-16	1.5935E-13	1.7130E-12	4.8999E-12	1.9789E-11	1.5188E-09	3.5898E-08	3.8749E-07
TH-229	0.0000E+00	2.1100E-19	2.5618E-15	1.4160E-11	5.6888E-10	2.9850E-09	2.7616E-08	2.8388E-05	2.3691E-03	6.5384E-03
TH-230	0.0000E+00	2.5586E-03	2.5584E-02	2.5660E-01	7.7235E-01	1.2882E+00	2.5734E+00	2.4444E+01	1.4578E+02	2.4645E+01
TH-232	0.0000E+00	0.0000E+00	1.7041E-15	2.0554E-13	1.8617E-12	5.1489E-12	2.0280E-11	1.5220E-09	3.5902E-08	3.8749E-07
PA-231	0.0000E+00	0.0000E+00	3.7469E-14	3.1652E-11	4.5427E-10	1.4034E-09	6.0538E-09	5.6353E-07	1.5427E-05	2.1995E-05
PA-233	0.0000E+00	6.9927E-09	7.1182E-07	2.8863E-05	1.1323E-04	2.1058E-04	4.8616E-04	4.6069E-03	8.2309E-03	6.1514E-03
U-233	0.0000E+00	9.5147E-15	1.0694E-11	5.2337E-09	6.6199E-08	2.0691E-07	9.6149E-07	1.0874E-04	2.6413E-03	6.5214E-03
U-234	2.8424E+02	2.8424E+02	2.8423E+02	2.8613E+02	2.8748E+02	2.8763E+02	2.8730E+02	2.8006E+02	2.1700E+02	1.6920E+01
U-235	0.0000E+00	0.0000E+00	5.7998E-10	3.8916E-08	1.6254E-07	2.8776E-07	5.9773E-07	5.4813E-06	2.0776E-05	2.1994E-05
U-236	0.0000E+00	0.0000E+00	7.6751E-06	8.4024E-05	2.5110E-04	4.1467E-04	8.0874E-04	5.2585E-03	8.0249E-03	7.8142E-03
NP-237	0.0000E+00	8.6005E-09	7.2598E-07	2.8903E-05	1.1328E-04	2.1064E-04	4.8623E-04	4.6069E-03	8.2310E-03	6.1515E-03
PU-238	0.0000E+00	0.0000E+00	1.0800E+04	5.3046E+03	1.0927E+03	2.2509E+02	4.3348E+00	5.7557E-31	0.0000E+00	0.0000E+00
PU-239	0.0000E+00	0.0000E+00	1.2626E-01	5.8338E-01	6.3717E-01	6.3398E-01	6.2499E-01	4.8296E-01	3.6210E-02	1.9962E-13
PU-240	0.0000E+00	2.8820E+01	2.8793E+01	2.8519E+01	2.7921E+01	2.7335E+01	2.5923E+01	9.9829E+00	7.1598E-04	0.0000E+00
PU-241	3.2700E+01	3.1163E+01	2.0206E+01	2.3036E+00	2.0321E+00	1.9992E+00	1.9194E+00	9.2124E-01	5.9776E-04	7.9078E-36
AM-241	0.0000E+00	5.1155E-02	4.1262E-01	1.1682E+00	1.4155E+00	1.5799E+00	1.7861E+00	9.7058E-01	6.2977E-04	8.3313E-36
AM-243	0.0000E+00	0.0000E+00	9.9011E-04	4.5561E-03	4.9147E-03	4.8266E-03	4.6052E-03	1.9777E-03	4.2182E-07	8.2677E-44
CM-245	0.0000E+00	0.0000E+00	2.0772E+00	2.0620E+00	2.0286E+00	1.9958E+00	1.9161E+00	9.1966E-01	5.9673E-04	7.8942E-36
CM-243	0.0000E+00	5.4366E+02	4.3678E+02	4.8939E+01	3.7773E-01	2.9155E-03	1.5259E-08	0.0000E+00	0.0000E+00	0.0000E+00
U-237	8.0115E-04	7.6350E-04	4.9505E-04	5.6439E-05	4.9787E-05	4.8981E-05	4.7024E-05	2.2570E-05	1.4645E-08	1.9374E-40
FR-221	0.0000E+00	1.4118E-19	2.4650E-15	1.4112E-11	5.6826E-10	2.9831E-09	2.7607E-08	2.8387E-05	2.3691E-03	6.5383E-03
AT-217	0.0000E+00	1.4118E-19	2.4650E-15	1.4112E-11	5.6826E-10	2.9831E-09	2.7607E-08	2.8387E-05	2.3691E-03	6.5383E-03
BI-213	0.0000E+00	1.4118E-19	2.4650E-15	1.4112E-11	5.6826E-10	2.9831E-09	2.7607E-08	2.8387E-05	2.3691E-03	6.5383E-03
PO-213	0.0000E+00	1.3814E-19	2.4117E-15	1.3807E-11	5.5599E-10	2.9186E-09	2.7011E-08	2.7774E-05	2.3179E-03	6.3971E-03
TL-209	0.0000E+00	3.0496E-21	5.3244E-17	3.0482E-13	1.2274E-11	6.4434E-11	5.9632E-10	6.1317E-07	5.1171E-05	1.4123E-04
PB-209	0.0000E+00	1.4118E-19	2.4650E-15	1.4112E-11	5.6826E-10	2.9831E-09	2.7607E-08	2.8387E-05	2.3691E-03	6.5383E-03
RN-222	0.0000E+00	5.5416E-07	5.5342E-05	5.4732E-03	4.8020E-02	1.2986E-01	4.8527E-01	1.9062E+01	1.4425E+02	2.4807E+01
PO-218	0.0000E+00	5.5416E-07	5.5342E-05	5.4732E-03	4.8020E-02	1.2986E-01	4.8527E-01	1.9062E+01	1.4425E+02	2.4807E+01
PB-214	0.0000E+00	5.5416E-07	5.5342E-05	5.4732E-03	4.8020E-02	1.2986E-01	4.8527E-01	1.9062E+01	1.4425E+02	2.4807E+01
BI-214	0.0000E+00	5.5416E-07	5.5342E-05	5.4732E-03	4.8020E-02	1.2986E-01	4.8527E-01	1.9062E+01	1.4425E+02	2.4807E+01
PO-214	0.0000E+00	5.5405E-07	5.5331E-05	5.4721E-03	4.8010E-02	1.2984E-01	4.8517E-01	1.9058E+01	1.4422E+02	2.4802E+01
BI-210	0.0000E+00	5.4339E-09	5.2895E-06	3.0375E-03	3.8943E-02	1.1464E-01	4.5687E-01	1.8987E+01	1.4422E+02	2.4810E+01
NP-239	0.0000E+00	0.0000E+00	9.9011E-04	4.5561E-03	4.9147E-03	4.8266E-03	4.6052E-03	1.9777E-03	4.2182E-07	8.2677E-44
TH-231	0.0000E+00	0.0000E+00	5.7998E-10	3.8916E-08	1.6254E-07	2.8776E-07	5.9773E-07	5.4813E-06	2.0776E-05	2.1994E-05
FR-223	0.0000E+00	5.7452E+02	4.3139E+02	2.4578E+01	4.2204E-02	7.2473E-05	8.7148E-11	7.7318E-09	2.1285E-07	3.0354E-07
RN-219	0.0000E+00	0.0000E+00	3.1379E+04	1.7878E+03	3.0699E+00	5.2716E-03	6.3160E-09	5.6026E-07	1.5424E-05	2.1996E-05
PO-215	0.0000E+00	0.0000E+00	3.1379E+04	1.7878E+03	3.0699E+00	5.2716E-03	6.3160E-09	5.6026E-07	1.5424E-05	2.1996E-05
PB-211	0.0000E+00	0.0000E+00	3.1379E+04	1.7878E+03	3.0699E+00	5.2716E-03	6.3160E-09	5.6026E-07	1.5424E-05	2.1996E-05
BI-211	0.0000E+00	0.0000E+00	3.1379E+04	1.7878E+03	3.0699E+00	5.2716E-03	6.3160E-09	5.6026E-07	1.5424E-05	2.1996E-05
PO-211	0.0000E+00	0.0000E+00	8.5665E+01	4.8806E+00	8.3808E-03	1.4391E-05	1.7243E-11	1.5295E-09	4.2107E-08	6.0048E-08
TL-207	0.0000E+00	0.0000E+00	3.1293E+04	1.7829E+03	3.0615E+00	5.2572E-03	6.2988E-09	5.5873E-07	1.5382E-05	2.1936E-05
AC-228	0.0000E+00	0.0000E+00	4.2560E-16	1.6937E-13	1.7458E-12	4.9550E-12	1.9898E-11	1.5195E-09	3.5900E-08	3.8750E-07
RN-220	0.0000E+00	0.0000E+00	2.0794E-16	1.5930E-13	1.7128E-12	4.8997E-12	1.9789E-11	1.5188E-09	3.5899E-08	3.8750E-07
PO-216	0.0000E+00	0.0000E+00	2.0794E-16	1.5930E-13	1.7128E-12	4.8997E-12	1.9789E-11	1.5188E-09	3.5899E-08	3.8750E-07
PB-212	0.0000E+00	0.0000E+00	2.0794E-16	1.5930E-13	1.7128E-12	4.8997E-12	1.9789E-11	1.5188E-09	3.5899E-08	3.8750E-07
BI-212	0.0000E+00	0.0000E+00	2.0794E-16	1.5930E-13	1.7128E-12	4.8997E-12	1.9789E-11	1.5188E-09	3.5899E-08	3.8750E-07

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

PO-212	0.0000E+00	0.0000E+00	1.3323E-16	1.0207E-13	1.0974E-12	3.1392E-12	1.2679E-11	9.7311E-10	2.3000E-08	2.4827E-07
TL-208	0.0000E+00	0.0000E+00	7.4712E-17	5.7238E-14	6.1542E-13	1.7604E-12	7.1102E-12	5.4572E-10	1.2898E-08	1.3923E-07
TL-210	0.0000E+00	1.1637E-10	1.1622E-08	1.1494E-06	1.0084E-05	2.7272E-05	1.0191E-04	4.0031E-03	3.0292E-02	5.2095E-03
TOTAL	3.1694E+02	4.3094E+04	2.6287E+05	1.9992E+04	1.4404E+03	5.4873E+02	3.3067E+02	4.8914E+02	1.6610E+03	2.6492E+02

SUMMARY OF RESULTS, **CURIES**, FOR FISSION AND ACTIVATION PRODUCTS, FOR END OF YEAR SHOWN
SITE = **HANF** WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
C14	0.0000E+00	1.2500E+01	1.2486E+01	1.2351E+01	1.2054E+01	1.1766E+01	1.1076E+01	3.7280E+00	6.9599E-05	0.0000E+00
FE59	0.0000E+00	0.0000E+00	2.7500E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
CO60	0.0000E+00	1.6665E+01	5.1014E+00	3.6855E-05	1.2148E-16	4.5668E-28	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
NI63	7.2500E+01	7.1956E+01	2.9224E+02	1.4834E+02	3.1036E+01	6.8779E+00	1.5901E-01	5.6604E-31	0.0000E+00	0.0000E+00
SE79	0.0000E+00	2.0844E-01	2.0842E-01	2.0822E-01	2.0777E-01	2.0733E-01	2.0623E-01	1.8734E-01	7.1710E-02	4.8411E-06
NB95	0.0000E+00	1.3057E-01	4.6423E-17	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ZR95	3.2004E+00	6.1195E-02	2.0910E-17	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
NB95M	0.0000E+00	4.5397E-04	1.5512E-19	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
TC99	0.0000E+00	3.6000E+00	3.5999E+00	3.5988E+00	3.5965E+00	3.5941E+00	3.5883E+00	3.4847E+00	2.6000E+00	1.3902E-01
RU106	4.0088E+04	2.0284E+04	4.4106E+01	1.0421E-25	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RH106	0.0000E+00	2.0284E+04	4.4106E+01	1.0421E-25	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
I125	1.3465E+02	1.9386E+00	5.1522E-17	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
CS137	0.0000E+00	0.0000E+00	1.3433E+00	1.6790E-01	1.3115E-03	1.2908E-05	1.2403E-10	0.0000E+00	0.0000E+00	0.0000E+00
BA137M	0.0000E+00	0.0000E+00	1.2708E+00	1.5884E-01	1.2407E-03	1.2211E-05	1.1734E-10	0.0000E+00	0.0000E+00	0.0000E+00
SM148	0.0000E+00	0.0000E+00	0.0000E+00	1.1207E-28	4.4520E-28	7.6277E-28	1.5567E-27	1.5847E-26	1.5875E-25	1.5878E-24
SM151	4.9904E-01	4.9521E-01	4.6205E-01	2.3101E-01	4.9504E-02	1.0608E-02	2.2550E-04	1.7709E-34	0.0000E+00	0.0000E+00
EU152	0.0000E+00	0.0000E+00	5.2240E-01	5.3207E-03	1.1964E-07	4.4787E-12	3.8397E-23	0.0000E+00	0.0000E+00	0.0000E+00
GD152	0.0000E+00	0.0000E+00	0.0000E+00	1.8143E-14	1.8329E-14	1.8329E-14	1.8329E-14	1.8329E-14	1.8329E-14	1.8329E-14
TOTAL	4.0299E+04	4.0676E+04	4.3295E+02	1.6506E+02	4.6947E+01	2.2456E+01	1.5029E+01	7.4001E+00	2.6718E+00	1.3902E-01

SUMMARY OF RESULTS, **GRAMS**, FOR ACTINIDES AND DAUGHTERS, FOR END OF YEAR SHOWN
SITE = **ORNL** WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
PB-206	0.0000E+00	9.8037E-16	2.8349E-11	3.0032E-07	2.1877E-05	1.4182E-04	1.5100E-03	1.0369E+00	1.1353E+02	1.2347E+03
PB-207	0.0000E+00	0.0000E+00	3.4886E+02	1.5043E+03	1.5740E+03	1.5741E+03	1.5741E+03	1.5741E+03	1.5747E+03	1.5848E+03
PB-208	0.0000E+00	1.1862E-09	5.2391E-07	1.9572E-05	6.4278E-05	1.0898E-04	2.2075E-04	2.2325E-03	2.2350E-02	2.2352E-01
PB-210	0.0000E+00	4.6123E-13	4.4913E-10	4.0012E-07	9.0250E-06	3.3174E-05	1.6209E-04	8.1688E-03	6.2856E-02	1.0821E-02
BI-209	0.0000E+00	0.0000E+00	5.7016E-02	5.7016E-02	5.7016E-02	5.7016E-02	5.7016E-02	5.7016E-02	5.7016E-02	5.7016E-02
PO-210	0.0000E+00	2.5914E-15	6.5327E-12	6.6914E-09	1.5265E-07	5.6232E-07	2.7516E-06	1.3883E-04	1.0683E-03	1.8392E-04

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

RA-223	0.0000E+00	0.0000E+00	1.8978E+00	1.0812E-01	1.8567E-04	3.2231E-07	7.1824E-09	7.1972E-08	4.4985E-07	5.5186E-07
RA-224	0.0000E+00	5.4413E-11	1.7833E-09	3.4796E-09	3.4798E-09	3.4798E-09	3.4798E-09	3.4798E-09	3.4798E-09	3.4797E-09
RA-225	0.0000E+00	2.0460E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RA-226	0.0000E+00	3.6320E-09	3.6326E-07	6.0391E-05	8.9567E-04	2.9639E-03	1.3381E-02	6.3329E-01	4.8542E+00	8.3551E-01
RA-228	0.0000E+00	2.3278E-07	1.5267E-06	2.3684E-06	2.3685E-06	2.3685E-06	2.3685E-06	2.3685E-06	2.3685E-06	2.3684E-06
AC-225	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
AC-227	0.0000E+00	5.7540E+02	1.3385E+03	7.6260E+01	1.3095E-01	2.2733E-04	5.0857E-06	5.0956E-05	3.1849E-04	3.9071E-04
TH-227	0.0000E+00	1.6848E-13	3.1575E+00	1.7989E-01	3.0891E-04	5.3625E-07	1.1968E-08	1.1992E-07	7.4952E-07	9.1948E-07
TH-228	0.0000E+00	1.0861E-08	3.4702E-07	6.7621E-07	6.7624E-07	6.7624E-07	6.7625E-07	6.7625E-07	6.7624E-07	6.7621E-07
TH-230	0.0000E+00	8.2137E-04	8.2742E-03	1.7054E-01	8.5414E-01	1.6714E+00	3.7849E+00	3.9900E+01	2.4031E+02	4.0657E+01
TH-232	5.0540E+03	5.0540E+03	5.0540E+03	5.0540E+03	5.0540E+03	5.0540E+03	5.0540E+03	5.0540E+03	5.0539E+03	5.0537E+03
TH-234	0.0000E+00	0.0000E+00	3.0784E-19	5.8725E-16	6.0403E-15	1.7080E-14	6.8061E-14	4.6895E-12	8.5349E-11	4.6167E-10
PA-231	0.0000E+00	8.0597E-06	8.0594E-05	8.0576E-04	2.4161E-03	4.0250E-03	8.0401E-03	7.8271E-02	4.8780E-01	5.9833E-01
U-234	2.9477E+02	2.9477E+02	3.0929E+02	9.2548E+02	1.4086E+03	1.5074E+03	1.5306E+03	1.4925E+03	1.1564E+03	9.0170E+01
U-235	8.3252E+03	8.3253E+03	8.3264E+03	8.3387E+03	8.3659E+03	8.3930E+03	8.4602E+03	9.5166E+03	1.2818E+04	1.3074E+04
U-238	0.0000E+00	0.0000E+00	2.2592E-08	4.0536E-05	4.1634E-04	1.1769E-03	4.6890E-03	3.2302E-01	5.8789E+00	3.1800E+01
PU-238	0.0000E+00	0.0000E+00	6.1592E+02	6.1973E+02	1.2766E+02	2.6296E+01	5.0642E-01	6.7242E-32	0.0000E+00	0.0000E+00
PU-239	5.2592E+02	1.9544E+03	4.8158E+03	4.8259E+03	4.8010E+03	4.7735E+03	4.7052E+03	3.6308E+03	2.7173E+02	1.4980E-09
PU-242	0.0000E+00	0.0000E+00	8.5479E-03	5.0958E-01	1.6179E+00	2.6938E+00	5.2479E+00	2.9574E+01	3.2926E+01	6.5662E+00
AM-243	0.0000E+00	0.0000E+00	1.3386E-02	6.8384E-02	7.3947E-02	7.2624E-02	6.9293E-02	2.9757E-02	6.3470E-06	1.2359E-42
CM-246	0.0000E+00	0.0000E+00	1.9770E+01	3.9039E+01	3.7912E+01	3.6817E+01	3.4216E+01	9.1533E+00	1.7178E-05	0.0000E+00
CM-243	0.0000E+00	1.0529E+01	2.6007E+01	2.9139E+00	2.2491E-02	1.7359E-04	9.0857E-10	0.0000E+00	0.0000E+00	0.0000E+00
FR-221	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
AT-217	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
BI-213	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PO-213	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
TL-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PA-234M	0.0000E+00	0.0000E+00	1.0366E-23	1.9775E-20	2.0340E-19	5.7516E-19	2.2919E-18	1.5792E-16	2.8741E-15	1.5546E-14
PA-234	0.0000E+00	0.0000E+00	4.6364E-24	8.8447E-21	9.0974E-20	2.5725E-19	1.0251E-18	7.0629E-17	1.2854E-15	6.9532E-15
RN-222	0.0000E+00	2.3347E-14	2.3351E-12	3.8821E-10	5.7575E-09	1.9053E-08	8.6017E-08	4.0709E-06	3.1204E-05	5.3709E-06
PO-218	0.0000E+00	1.2698E-17	1.2700E-15	2.1114E-13	3.1315E-12	1.0363E-11	4.6784E-11	2.2141E-09	1.6972E-08	2.9212E-09
PB-214	0.0000E+00	1.0953E-16	1.0955E-14	1.8212E-12	2.7010E-11	8.9382E-11	4.0353E-10	1.9098E-08	1.4639E-07	2.5196E-08
BI-214	0.0000E+00	8.1330E-17	8.1342E-15	1.3523E-12	2.0056E-11	6.6369E-11	2.9963E-10	1.4181E-08	1.0870E-07	1.8709E-08
PO-214	0.0000E+00	1.1189E-23	1.1191E-21	1.8605E-19	2.7593E-18	9.1309E-18	4.1223E-17	1.9510E-15	1.4954E-14	2.5739E-15
BI-210	0.0000E+00	2.8380E-16	2.7635E-13	2.4620E-10	5.5531E-09	2.0412E-08	9.9734E-08	5.0263E-06	3.8676E-05	6.6585E-06
NP-239	0.0000E+00	0.0000E+00	1.1503E-08	5.8767E-08	6.3548E-08	6.2411E-08	5.9548E-08	2.5572E-08	5.4544E-12	0.0000E+00
TH-231	3.3850E-08	3.3850E-08	3.3854E-08	3.3904E-08	3.4015E-08	3.4126E-08	3.4398E-08	3.8694E-08	5.2119E-08	5.3158E-08
FR-223	0.0000E+00	1.4850E-05	3.4545E-05	1.9681E-06	3.3796E-09	5.8670E-12	1.3125E-13	1.3151E-12	8.2195E-12	1.0083E-11
RN-219	0.0000E+00	0.0000E+00	7.4706E-06	4.2562E-07	7.3088E-10	1.2687E-12	2.8273E-14	2.8331E-13	1.7708E-12	2.1724E-12
PO-215	0.0000E+00	0.0000E+00	3.2968E-09	1.8783E-10	3.2254E-13	5.5989E-16	1.2477E-17	1.2503E-16	7.8146E-16	9.5866E-16
PB-211	0.0000E+00	0.0000E+00	3.9371E-03	2.2431E-04	3.8518E-07	6.6864E-10	1.4900E-11	1.4931E-10	9.3324E-10	1.1449E-09
BI-211	0.0000E+00	0.0000E+00	2.3230E-04	1.3235E-05	2.2727E-08	3.9452E-11	8.7916E-13	8.8097E-12	5.5064E-11	6.7550E-11
PO-211	0.0000E+00	0.0000E+00	2.7789E-09	1.5832E-10	2.7187E-13	4.7193E-16	1.0517E-17	1.0538E-16	6.5869E-16	8.0806E-16
TL-207	0.0000E+00	0.0000E+00	5.0895E-04	2.8996E-05	4.9793E-08	8.6435E-11	1.9262E-12	1.9301E-11	1.2064E-10	1.4800E-10
AC-228	0.0000E+00	2.4297E-11	1.5936E-10	2.4721E-10	2.4722E-10	2.4722E-10	2.4722E-10	2.4722E-10	2.4722E-10	2.4721E-10

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

RN-220	0.0000E+00	9.3971E-15	3.0798E-13	6.0093E-13	6.0097E-13	6.0097E-13	6.0097E-13	6.0097E-13	6.0097E-13	6.0094E-13
PO-216	0.0000E+00	2.4891E-17	8.1578E-16	1.5918E-15	1.5918E-15	1.5918E-15	1.5918E-15	1.5919E-15	1.5918E-15	1.5918E-15
PB-212	0.0000E+00	6.2380E-12	2.0444E-10	3.9891E-10	3.9893E-10	3.9894E-10	3.9894E-10	3.9894E-10	3.9893E-10	3.9892E-10
BI-212	0.0000E+00	5.9170E-13	1.9392E-11	3.7839E-11	3.7841E-11	3.7841E-11	3.7841E-11	3.7841E-11	3.7841E-11	3.7839E-11
PO-212	0.0000E+00	3.1304E-23	1.0260E-21	2.0019E-21	2.0020E-21	2.0020E-21	2.0020E-21	2.0020E-21	2.0020E-21	2.0019E-21
TL-208	0.0000E+00	1.0576E-14	3.4661E-13	6.7631E-13	6.7634E-13	6.7634E-13	6.7635E-13	6.7635E-13	6.7634E-13	6.7631E-13
TL-210	0.0000E+00	1.1250E-21	1.1252E-19	1.8706E-17	2.7744E-16	9.1809E-16	4.1448E-15	1.9616E-13	1.5036E-12	2.5880E-13
TOTAL	1.4200E+04	1.6214E+04	2.0860E+04	2.1387E+04	2.1372E+04	2.1370E+04	2.1368E+04	2.1349E+04	2.1273E+04	2.1118E+04

SUMMARY OF RESULTS, **CURIES**, FOR ACTINIDES AND DAUGHTERS, FOR END OF YEAR SHOWN
SITE = **ORNL** WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
PB-206	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-207	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-208	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-210	0.0000E+00	3.5222E-11	3.4298E-08	3.0555E-05	6.8919E-04	2.5333E-03	1.2378E-02	6.2381E-01	4.8000E+00	8.2638E-01
BI-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PO-210	0.0000E+00	1.1644E-11	2.9353E-08	3.0066E-05	6.8587E-04	2.5266E-03	1.2364E-02	6.2377E-01	4.8001E+00	8.2639E-01
RA-223	0.0000E+00	0.0000E+00	9.7215E+04	5.5386E+03	9.5109E+00	1.6510E-02	3.6792E-04	3.6868E-03	2.3044E-02	2.8269E-02
RA-224	0.0000E+00	8.6696E-06	2.8414E-04	5.5441E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5441E-04
RA-225	0.0000E+00	8.0235E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RA-226	0.0000E+00	3.5920E-09	3.5925E-07	5.9726E-05	8.8580E-04	2.9313E-03	1.3234E-02	6.2632E-01	4.8007E+00	8.2631E-01
RA-228	0.0000E+00	5.4491E-05	3.5739E-04	5.5442E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5441E-04
AC-225	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
AC-227	0.0000E+00	4.1632E+04	9.6847E+04	5.5177E+03	9.4750E+00	1.6448E-02	3.6797E-04	3.6868E-03	2.3044E-02	2.8269E-02
TH-227	0.0000E+00	5.1797E-09	9.7075E+04	5.5306E+03	9.4972E+00	1.6486E-02	3.6793E-04	3.6867E-03	2.3043E-02	2.8269E-02
TH-228	0.0000E+00	8.9047E-06	2.8451E-04	5.5440E-04	5.5443E-04	5.5443E-04	5.5443E-04	5.5443E-04	5.5443E-04	5.5441E-04
TH-230	0.0000E+00	1.6584E-05	1.6706E-04	3.4434E-03	1.7246E-02	3.3748E-02	7.6420E-02	8.0562E-01	4.8521E+00	8.2091E-01
TH-232	5.5442E-04	5.5442E-04	5.5442E-04	5.5442E-04	5.5442E-04	5.5442E-04	5.5442E-04	5.5442E-04	5.5442E-04	5.5439E-04
TH-234	0.0000E+00	0.0000E+00	7.1307E-15	1.3603E-11	1.3992E-10	3.9564E-10	1.5766E-09	1.0863E-07	1.9770E-06	1.0694E-05
PA-231	0.0000E+00	3.8079E-07	3.8077E-06	3.8069E-05	1.1415E-04	1.9016E-04	3.7986E-04	3.6980E-03	2.3047E-02	2.8269E-02
U-234	1.8424E+00	1.8424E+00	1.9331E+00	5.7844E+00	8.8039E+00	9.4216E+00	9.5665E+00	9.3286E+00	7.2279E+00	5.6358E-01
U-235	1.8000E-02	1.8000E-02	1.8002E-02	1.8029E-02	1.8088E-02	1.8147E-02	1.8292E-02	2.0576E-02	2.7715E-02	2.8267E-02
U-238	0.0000E+00	0.0000E+00	7.5973E-15	1.3631E-11	1.4001E-10	3.9578E-10	1.5768E-09	1.0863E-07	1.9770E-06	1.0694E-05
PU-238	0.0000E+00	0.0000E+00	1.0547E+04	1.0612E+04	2.1860E+03	4.5030E+02	8.6720E+00	1.1515E-30	0.0000E+00	0.0000E+00
PU-239	3.2700E+01	1.2152E+02	2.9943E+02	3.0006E+02	2.9851E+02	2.9680E+02	2.9256E+02	2.2575E+02	1.6895E+01	9.3140E-11
PU-242	0.0000E+00	0.0000E+00	3.2646E-05	1.9462E-03	6.1791E-03	1.0288E-02	2.0043E-02	1.1295E-01	1.2575E-01	2.5078E-02
AM-243	0.0000E+00	0.0000E+00	2.6692E-03	1.3636E-02	1.4745E-02	1.4481E-02	1.3817E-02	5.9335E-03	1.2656E-06	2.4663E-43
CM-246	0.0000E+00	0.0000E+00	6.0745E+00	1.1995E+01	1.1649E+01	1.1312E+01	1.0513E+01	2.8124E+00	5.2782E-06	0.0000E+00
CM-243	0.0000E+00	5.4366E+02	1.3429E+03	1.5046E+02	1.1613E+00	8.9636E-03	4.6914E-08	0.0000E+00	0.0000E+00	0.0000E+00
FR-221	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

AT-217	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
BI-213	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PO-213	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
TL-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PA-234M	0.0000E+00	0.0000E+00	7.1214E-15	1.3585E-11	1.3974E-10	3.9513E-10	1.5745E-09	1.0849E-07	1.9744E-06	1.0680E-05
PA-234	0.0000E+00	0.0000E+00	9.2699E-18	1.7684E-14	1.8189E-13	5.1434E-13	2.0495E-12	1.4122E-10	2.5701E-09	1.3902E-08
RN-222	0.0000E+00	3.5920E-09	3.5925E-07	5.9726E-05	8.8580E-04	2.9313E-03	1.3234E-02	6.2632E-01	4.8007E+00	8.2631E-01
PO-218	0.0000E+00	3.5920E-09	3.5925E-07	5.9726E-05	8.8580E-04	2.9313E-03	1.3234E-02	6.2632E-01	4.8007E+00	8.2631E-01
PB-214	0.0000E+00	3.5920E-09	3.5925E-07	5.9726E-05	8.8580E-04	2.9313E-03	1.3234E-02	6.2632E-01	4.8007E+00	8.2631E-01
BI-214	0.0000E+00	3.5920E-09	3.5925E-07	5.9726E-05	8.8580E-04	2.9313E-03	1.3234E-02	6.2632E-01	4.8007E+00	8.2631E-01
PO-214	0.0000E+00	3.5912E-09	3.5918E-07	5.9713E-05	8.8561E-04	2.9307E-03	1.3231E-02	6.2618E-01	4.7997E+00	8.2613E-01
BI-210	0.0000E+00	3.5222E-11	3.4298E-08	3.0555E-05	6.8919E-04	2.5333E-03	1.2378E-02	6.2381E-01	4.8000E+00	8.2638E-01
NP-239	0.0000E+00	0.0000E+00	2.6692E-03	1.3636E-02	1.4745E-02	1.4481E-02	1.3817E-02	5.9335E-03	1.2656E-06	2.4663E-43
TH-231	1.8000E-02	1.8000E-02	1.8002E-02	1.8029E-02	1.8088E-02	1.8147E-02	1.8292E-02	2.0576E-02	2.7715E-02	2.8267E-02
FR-223	0.0000E+00	5.7452E+02	1.3365E+03	7.6144E+01	1.3075E-01	2.2699E-04	5.0779E-06	5.0878E-05	3.1800E-04	3.9011E-04
RN-219	0.0000E+00	0.0000E+00	9.7215E+04	5.5386E+03	9.5109E+00	1.6510E-02	3.6792E-04	3.6868E-03	2.3044E-02	2.8269E-02
PO-215	0.0000E+00	0.0000E+00	9.7215E+04	5.5386E+03	9.5109E+00	1.6510E-02	3.6792E-04	3.6868E-03	2.3044E-02	2.8269E-02
PB-211	0.0000E+00	0.0000E+00	9.7215E+04	5.5386E+03	9.5109E+00	1.6510E-02	3.6792E-04	3.6868E-03	2.3044E-02	2.8269E-02
BI-211	0.0000E+00	0.0000E+00	9.7215E+04	5.5386E+03	9.5109E+00	1.6510E-02	3.6792E-04	3.6868E-03	2.3044E-02	2.8269E-02
PO-211	0.0000E+00	0.0000E+00	2.6540E+02	1.5120E+01	2.5965E-02	4.5073E-05	1.0044E-06	1.0065E-05	6.2909E-05	7.7174E-05
TL-207	0.0000E+00	0.0000E+00	9.6950E+04	5.5235E+03	9.4850E+00	1.6465E-02	3.6691E-04	3.6767E-03	2.2981E-02	2.8192E-02
AC-228	0.0000E+00	5.4491E-05	3.5739E-04	5.5442E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5441E-04
RN-220	0.0000E+00	8.6696E-06	2.8414E-04	5.5441E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5441E-04
PO-216	0.0000E+00	8.6696E-06	2.8414E-04	5.5441E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5441E-04
PB-212	0.0000E+00	8.6696E-06	2.8414E-04	5.5441E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5441E-04
BI-212	0.0000E+00	8.6696E-06	2.8414E-04	5.5441E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5444E-04	5.5441E-04
PO-212	0.0000E+00	5.5546E-06	1.8205E-04	3.5521E-04	3.5523E-04	3.5523E-04	3.5523E-04	3.5523E-04	3.5523E-04	3.5521E-04
TL-208	0.0000E+00	3.1150E-06	1.0209E-04	1.9920E-04	1.9921E-04	1.9921E-04	1.9921E-04	1.9921E-04	1.9921E-04	1.9920E-04
TL-210	0.0000E+00	7.5432E-13	7.5443E-11	1.2542E-08	1.8602E-07	6.1557E-07	2.7791E-06	1.3153E-04	1.0082E-03	1.7352E-04
TOTAL	3.4579E+01	4.3676E+04	7.9075E+05	5.5437E+04	2.5824E+03	7.6811E+02	3.2159E+02	2.4453E+02	7.2574E+01	9.1635E+00

SUMMARY OF RESULTS, **CURIES**, FOR FISSION AND ACTIVATION PRODUCTS, FOR END OF YEAR SHOWN
SITE = **ORNL** WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
FE59	0.0000E+00	0.0000E+00	1.2860E-06	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
CO60	0.0000E+00	1.6665E+01	1.7556E+01	1.2683E-04	3.6443E-16	1.3700E-27	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
NI63	0.0000E+00	1.2500E+01	2.5528E+02	2.4640E+02	5.0858E+01	1.1270E+01	2.6056E-01	9.2755E-31	0.0000E+00	0.0000E+00
TC99	0.0000E+00	3.6000E+00	1.0800E+01	1.0797E+01	1.0789E+01	1.0782E+01	1.0765E+01	1.0454E+01	7.8001E+00	4.1705E-01
RU106	4.0088E+00	2.0284E+00	4.4106E-03	1.0421E-29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RH106	0.0000E+00	2.0284E+00	4.4106E-03	1.0421E-29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

I125	1.3465E+02	1.9386E+00	5.1522E-17	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
SN126	0.0000E+00	0.0000E+00	0.0000E+00	4.6514E+00	4.6445E+00	4.6381E+00	4.6221E+00	4.3425E+00	2.3272E+00	0.0000E+00
SB126	0.0000E+00	0.0000E+00	0.0000E+00	6.5120E-01	6.5023E-01	6.4933E-01	6.4709E-01	6.0796E-01	3.2581E-01	4.5475E-03
SB126M	0.0000E+00	0.0000E+00	0.0000E+00	4.6514E+00	4.6445E+00	4.6381E+00	4.6221E+00	4.3425E+00	2.3272E+00	6.3665E-04
CS137	0.0000E+00	0.0000E+00	1.2563E+03	3.3741E+02	2.6293E+00	2.5877E-02	2.4866E-07	0.0000E+00	0.0000E+00	4.5475E-03
BA137M	0.0000E+00	0.0000E+00	1.1885E+03	3.1919E+02	2.4874E+00	2.4480E-02	2.3523E-07	0.0000E+00	0.0000E+00	0.0000E+00
CE144	1.2500E+01	5.1299E+00	1.6940E-03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PR144	0.0000E+00	5.0686E+00	1.6738E-03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
ND144	0.0000E+00	2.7002E-15	4.5791E-15	4.5797E-15	4.5797E-15	4.5797E-15	4.5797E-15	0.0000E+00	0.0000E+00	0.0000E+00
SM148	0.0000E+00	0.0000E+00	3.4629E-31	2.2414E-28	8.9040E-28	1.5255E-27	3.1134E-27	4.5797E-15	4.5797E-15	4.5797E-15
EU152	0.0000E+00	0.0000E+00	4.4833E-01	1.0766E-02	2.3929E-07	8.9574E-12	7.6795E-23	3.1695E-26	3.1751E-25	3.1757E-24
GD152	0.0000E+00	0.0000E+00	2.5987E-15	3.6281E-14	3.6658E-14	3.6658E-14	3.6658E-14	0.0000E+00	0.0000E+00	0.0000E+00
								3.6658E-14	3.6658E-14	3.6658E-14
TOTAL	1.5116E+02	4.8959E+01	2.7289E+03	9.2376E+02	7.6703E+01	3.2029E+01	2.0917E+01	1.9747E+01	1.2780E+01	4.2678E-01

SUMMARY OF RESULTS, **GRAMS**, FOR ACTINIDES AND DAUGHTERS, FOR END OF YEAR SHOWN
SITE = **INEL** WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
PB-207	0.0000E+00	2.2673E-19	8.9585E+01	4.9992E+02	5.2466E+02	5.2470E+02	5.2471E+02	5.2471E+02	5.2472E+02	5.2512E+02
PB-208	0.0000E+00	2.5302E-03	1.1406E-01	1.0256E+00	1.5912E+00	1.6737E+00	1.6877E+00	1.6878E+00	1.6878E+00	1.6880E+00
BI-209	0.0000E+00	0.0000E+00	2.7140E-08	7.1450E-06	6.7576E-05	1.8856E-04	7.4819E-04	5.7307E-02	1.2184E+00	3.7239E+00
RA-223	0.0000E+00	4.8817E-20	6.7396E-01	3.8398E-02	6.5936E-05	1.1323E-07	6.2678E-12	5.7172E-10	1.5601E-08	2.2236E-08
RA-224	0.0000E+00	7.5580E-05	2.2907E-04	9.9240E-05	1.4469E-05	2.1095E-06	1.7123E-08	2.9363E-14	6.9436E-13	7.4953E-12
RA-225	0.0000E+00	0.0000E+00	5.8278E-10	9.3687E-09	2.8615E-08	4.7485E-08	9.3055E-08	6.1891E-07	7.0334E-07	1.3739E-08
RA-228	0.0000E+00	0.0000E+00	1.7792E-18	2.0845E-15	2.2513E-14	6.4445E-14	2.6041E-13	1.9995E-11	4.7262E-10	5.1016E-09
AC-225	0.0000E+00	0.0000E+00	3.9107E-10	6.3263E-09	1.9328E-08	3.2075E-08	6.2859E-08	4.1809E-07	4.7513E-07	9.2808E-09
AC-227	0.0000E+00	4.9158E-17	4.7535E+02	2.7082E+01	4.6505E-02	7.9859E-05	4.4386E-09	4.0478E-07	1.1045E-05	1.5743E-05
TH-227	0.0000E+00	9.3587E-20	1.1213E+00	6.3885E-02	1.0970E-04	1.8838E-07	1.0443E-11	9.5252E-10	2.5991E-08	3.7047E-08
TH-228	0.0000E+00	1.4866E-02	4.4517E-02	1.9283E-02	2.8114E-03	4.0990E-04	3.3270E-06	5.7063E-12	1.3494E-10	1.4566E-09
TH-229	0.0000E+00	0.0000E+00	1.0846E-04	1.7277E-03	5.2748E-03	8.7524E-03	1.7151E-02	1.1406E-01	1.2962E-01	2.5320E-03
TH-232	0.0000E+00	0.0000E+00	2.1279E-08	5.4302E-06	5.1262E-05	1.4293E-04	5.6638E-04	4.2737E-02	1.0086E+00	1.0886E+01
PA-231	0.0000E+00	7.1494E-12	7.2113E-10	7.2600E-08	6.5508E-07	1.8169E-06	7.2185E-06	6.2347E-04	1.6918E-02	2.4109E-02
U-232	1.8825E+00	1.8645E+00	1.7097E+00	7.1881E-01	1.0480E-01	1.5280E-02	1.2402E-04	2.8993E-42	0.0000E+00	0.0000E+00
U-233	0.0000E+00	0.0000E+00	4.2070E+00	4.2054E+00	4.2017E+00	4.1980E+00	4.1889E+00	4.0272E+00	2.7169E+00	5.3064E-02
U-235	0.0000E+00	1.4895E-02	1.4905E-01	1.5046E+00	4.5236E+00	7.5265E+00	1.4958E+01	1.3195E+02	4.9768E+02	5.2680E+02
U-236	0.0000E+00	0.0000E+00	2.4371E-01	3.8808E+00	1.1840E+01	1.9632E+01	3.8404E+01	2.5038E+02	3.8217E+02	3.7213E+02
PU-239	5.2592E+02	5.2590E+02	5.2717E+02	5.3372E+02	5.3164E+02	5.2860E+02	5.2104E+02	4.0206E+02	3.0092E+01	1.6589E-10
PU-240	0.0000E+00	0.0000E+00	3.8945E+02	3.8575E+02	3.7766E+02	3.6973E+02	3.5064E+02	1.3503E+02	9.6844E-03	0.0000E+00
AM-243	0.0000E+00	0.0000E+00	3.4300E-03	2.2683E-02	2.4653E-02	2.4213E-02	2.3102E-02	9.9208E-03	2.1161E-06	4.1338E-43
CM-243	0.0000E+00	0.0000E+00	9.0993E+00	1.0195E+00	7.8691E-03	6.0737E-05	3.1789E-10	0.0000E+00	0.0000E+00	0.0000E+00
FR-221	0.0000E+00	0.0000E+00	1.2804E-13	2.0713E-12	6.3282E-12	1.0502E-11	2.0581E-11	1.3689E-10	1.5556E-10	3.0386E-12
AT-217	0.0000E+00	0.0000E+00	1.4100E-17	2.2810E-16	6.9689E-16	1.1565E-15	2.2664E-15	1.5075E-14	1.7131E-14	3.3463E-16

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

BI-213	0.0000E+00	0.0000E+00	1.1736E-12	1.8986E-11	5.8005E-11	9.6260E-11	1.8865E-10	1.2547E-09	1.4259E-09	2.7852E-11
PO-213	0.0000E+00	0.0000E+00	1.7607E-21	2.8483E-20	8.7020E-20	1.4441E-19	2.8301E-19	1.8824E-18	2.1391E-18	4.1785E-20
TL-209	0.0000E+00	0.0000E+00	1.1988E-15	1.9392E-14	5.9247E-14	9.8321E-14	1.9268E-13	1.2816E-12	1.4564E-12	2.8449E-14
PB-209	0.0000E+00	0.0000E+00	4.9947E-12	8.0799E-11	2.4686E-10	4.0966E-10	8.0283E-10	5.3399E-09	6.0683E-09	1.1853E-10
NP-239	0.0000E+00	0.0000E+00	2.9477E-09	1.9493E-08	2.1186E-08	2.0808E-08	1.9853E-08	8.5257E-09	1.8185E-12	0.0000E+00
TH-231	0.0000E+00	6.0562E-14	6.0604E-13	6.1175E-12	1.8393E-11	3.0602E-11	6.0820E-11	5.3651E-10	2.0235E-09	2.1419E-09
FR-223	0.0000E+00	1.2686E-24	1.2268E-05	6.9893E-07	1.2002E-09	2.0610E-12	1.1455E-16	1.0446E-14	2.8505E-13	4.0629E-13
RN-219	0.0000E+00	1.9216E-25	2.6530E-06	1.5115E-07	2.5955E-10	4.4571E-13	2.4673E-17	2.2505E-15	6.1411E-14	8.7533E-14
PO-215	0.0000E+00	8.4801E-29	1.1708E-09	6.6702E-11	1.1454E-13	1.9669E-16	1.0888E-20	9.9316E-19	2.7101E-17	3.8628E-17
PB-211	0.0000E+00	1.0127E-22	1.3982E-03	7.9658E-05	1.3679E-07	2.3489E-10	1.3003E-14	1.1861E-12	3.2364E-11	4.6131E-11
BI-211	0.0000E+00	5.9754E-24	8.2496E-05	4.7000E-06	8.0708E-09	1.3859E-11	7.6720E-16	6.9981E-14	1.9096E-12	2.7218E-12
PO-211	0.0000E+00	7.1479E-29	9.8685E-10	5.6223E-11	9.6546E-14	1.6579E-16	9.1775E-21	8.3713E-19	2.2843E-17	3.2560E-17
TL-207	0.0000E+00	1.3091E-23	1.8074E-04	1.0297E-05	1.7682E-08	3.0365E-11	1.6809E-15	1.5332E-13	4.1837E-12	5.9633E-12
AC-228	0.0000E+00	0.0000E+00	1.8571E-22	2.1758E-19	2.3499E-18	6.7266E-18	2.7181E-17	2.0871E-15	4.9331E-14	5.3249E-13
RN-220	0.0000E+00	1.3053E-08	3.9561E-08	1.7139E-08	2.4988E-09	3.6432E-10	2.9571E-12	5.0711E-18	1.1992E-16	1.2944E-15
PO-216	0.0000E+00	3.4574E-11	1.0479E-10	4.5397E-11	6.6188E-12	9.6501E-13	7.8327E-15	1.3432E-20	3.1764E-19	3.4287E-18
PB-212	0.0000E+00	8.6647E-06	2.6262E-05	1.1377E-05	1.6588E-06	2.4184E-07	1.9630E-09	3.3663E-15	7.9603E-14	8.5928E-13
BI-212	0.0000E+00	8.2188E-07	2.4910E-06	1.0792E-06	1.5734E-07	2.2940E-08	1.8620E-10	3.1931E-16	7.5507E-15	8.1506E-14
PO-212	0.0000E+00	4.3482E-17	1.3179E-16	5.7094E-17	8.3241E-18	1.2136E-18	9.8507E-21	1.6893E-26	3.9947E-25	4.3121E-24
TL-208	0.0000E+00	1.4690E-08	4.4523E-08	1.9288E-08	2.8122E-09	4.1002E-10	3.3280E-12	5.7071E-18	1.3496E-16	1.4568E-15
TOTAL	5.2780E+02	5.2780E+02	1.4989E+03	1.4590E+03	1.4563E+03	1.4561E+03	1.4557E+03	1.4501E+03	1.4414E+03	1.4404E+03

SUMMARY OF RESULTS, **CURIES**, FOR ACTINIDES AND DAUGHTERS, FOR END OF YEAR SHOWN
SITE = **INEL**   WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
PB-207	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PB-208	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
BI-209	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RA-223	0.0000E+00	2.5006E-15	3.4524E+04	1.9669E+03	3.3776E+00	5.8000E-03	3.2107E-07	2.9286E-05	7.9914E-04	1.1391E-03
RA-224	0.0000E+00	1.2042E+01	3.6498E+01	1.5812E+01	2.3053E+00	3.3611E-01	2.7281E-03	4.6785E-09	1.1063E-07	1.1942E-06
RA-225	0.0000E+00	0.0000E+00	2.2854E-05	3.6740E-04	1.1222E-03	1.8621E-03	3.6492E-03	2.4271E-02	2.7581E-02	5.3876E-04
RA-228	0.0000E+00	0.0000E+00	4.1650E-16	4.8796E-13	5.2701E-12	1.5086E-11	6.0960E-11	4.6807E-09	1.1064E-07	1.1942E-06
AC-225	0.0000E+00	0.0000E+00	2.2701E-05	3.6724E-04	1.1220E-03	1.8620E-03	3.6490E-03	2.4270E-02	2.7581E-02	5.3875E-04
AC-227	0.0000E+00	3.5567E-15	3.4393E+04	1.9595E+03	3.3648E+00	5.7780E-03	3.2114E-07	2.9287E-05	7.9915E-04	1.1391E-03
TH-227	0.0000E+00	2.8772E-15	3.4474E+04	1.9641E+03	3.3727E+00	5.7916E-03	3.2107E-07	2.9284E-05	7.9908E-04	1.1390E-03
TH-228	0.0000E+00	1.2188E+01	3.6498E+01	1.5809E+01	2.3050E+00	3.3606E-01	2.7277E-03	4.6784E-09	1.1063E-07	1.1942E-06
TH-229	0.0000E+00	0.0000E+00	2.3078E-05	3.6762E-04	1.1224E-03	1.8623E-03	3.6494E-03	2.4271E-02	2.7581E-02	5.3876E-04
TH-232	0.0000E+00	0.0000E+00	2.3344E-15	5.9570E-13	5.6235E-12	1.5680E-11	6.2132E-11	4.6882E-09	1.1064E-07	1.1942E-06
PA-231	0.0000E+00	3.3778E-13	3.4071E-11	3.4301E-09	3.0950E-08	8.5842E-08	3.4105E-07	2.9456E-05	7.9932E-04	1.1391E-03
U-232	4.0303E+01	3.9917E+01	3.6604E+01	1.5389E+01	2.2437E+00	3.2713E-01	2.6552E-03	6.2071E-41	0.0000E+00	0.0000E+00
U-233	0.0000E+00	0.0000E+00	4.0736E-02	4.0720E-02	4.0684E-02	4.0649E-02	4.0560E-02	3.8995E-02	2.6307E-02	5.1381E-04

Exhibit 4.3. Output file RADAC4.OUT for Example 4 (continued).

U-235	0.0000E+00	3.2204E-08	3.2227E-07	3.2531E-06	9.7805E-06	1.6273E-05	3.2341E-05	2.8530E-04	1.0760E-03	1.1390E-03
U-236	0.0000E+00	0.0000E+00	1.5772E-05	2.5115E-04	7.6623E-04	1.2705E-03	2.4853E-03	1.6203E-02	2.4732E-02	2.4082E-02
PU-239	3.2700E+01	3.2699E+01	3.2778E+01	3.3185E+01	3.3056E+01	3.2866E+01	3.2397E+01	2.4999E+01	1.8710E+00	1.0314E-11
PU-240	0.0000E+00	0.0000E+00	8.8764E+01	8.7920E+01	8.6076E+01	8.4270E+01	7.9918E+01	3.0776E+01	2.2073E-03	0.0000E+00
AM-243	0.0000E+00	0.0000E+00	6.8394E-04	4.5231E-03	4.9158E-03	4.8280E-03	4.6065E-03	1.9782E-03	4.2194E-07	8.2677E-44
CM-243	0.0000E+00	0.0000E+00	4.6984E+02	5.2643E+01	4.0632E-01	3.1362E-03	1.6414E-08	0.0000E+00	0.0000E+00	0.0000E+00
FR-221	0.0000E+00	0.0000E+00	2.2701E-05	3.6724E-04	1.1220E-03	1.8620E-03	3.6490E-03	2.4270E-02	2.7581E-02	5.3875E-04
AT-217	0.0000E+00	0.0000E+00	2.2701E-05	3.6724E-04	1.1220E-03	1.8620E-03	3.6490E-03	2.4270E-02	2.7581E-02	5.3875E-04
BI-213	0.0000E+00	0.0000E+00	2.2701E-05	3.6724E-04	1.1220E-03	1.8620E-03	3.6490E-03	2.4270E-02	2.7581E-02	5.3875E-04
PO-213	0.0000E+00	0.0000E+00	2.2211E-05	3.5931E-04	1.0978E-03	1.8217E-03	3.5701E-03	2.3746E-02	2.6985E-02	5.2711E-04
TL-209	0.0000E+00	0.0000E+00	4.9035E-07	7.9324E-06	2.4235E-05	4.0218E-05	7.8818E-05	5.2424E-04	5.9575E-04	1.1637E-05
PB-209	0.0000E+00	0.0000E+00	2.2701E-05	3.6724E-04	1.1220E-03	1.8620E-03	3.6490E-03	2.4270E-02	2.7581E-02	5.3875E-04
NP-239	0.0000E+00	0.0000E+00	6.8394E-04	4.5231E-03	4.9158E-03	4.8280E-03	4.6065E-03	1.9782E-03	4.2194E-07	8.2677E-44
TH-231	0.0000E+00	3.2204E-08	3.2227E-07	3.2531E-06	9.7805E-06	1.6273E-05	3.2341E-05	2.8530E-04	1.0760E-03	1.1390E-03
FR-223	0.0000E+00	4.9082E-17	4.7463E+02	2.7041E+01	4.6434E-02	7.9737E-05	4.4318E-09	4.0416E-07	1.1028E-05	1.5719E-05
RN-219	0.0000E+00	2.5006E-15	3.4524E+04	1.9669E+03	3.3776E+00	5.8000E-03	3.2107E-07	2.9286E-05	7.9914E-04	1.1391E-03
PO-215	0.0000E+00	2.5006E-15	3.4524E+04	1.9669E+03	3.3776E+00	5.8000E-03	3.2107E-07	2.9286E-05	7.9914E-04	1.1391E-03
PB-211	0.0000E+00	2.5006E-15	3.4524E+04	1.9669E+03	3.3776E+00	5.8000E-03	3.2107E-07	2.9286E-05	7.9914E-04	1.1391E-03
BI-211	0.0000E+00	2.5006E-15	3.4524E+04	1.9669E+03	3.3776E+00	5.8000E-03	3.2107E-07	2.9286E-05	7.9914E-04	1.1391E-03
PO-211	0.0000E+00	6.8267E-18	9.4250E+01	5.3697E+00	9.2207E-03	1.5834E-05	8.7651E-10	7.9951E-08	2.1817E-06	3.1096E-06
TL-207	0.0000E+00	2.4938E-15	3.4429E+04	1.9615E+03	3.3683E+00	5.7841E-03	3.2019E-07	2.9206E-05	7.9696E-04	1.1360E-03
AC-228	0.0000E+00	0.0000E+00	4.1650E-16	4.8796E-13	5.2701E-12	1.5086E-11	6.0960E-11	4.6807E-09	1.1064E-07	1.1942E-06
RN-220	0.0000E+00	1.2042E+01	3.6498E+01	1.5812E+01	2.3053E+00	3.3611E-01	2.7281E-03	4.6785E-09	1.1063E-07	1.1942E-06
PO-216	0.0000E+00	1.2042E+01	3.6498E+01	1.5812E+01	2.3053E+00	3.3611E-01	2.7281E-03	4.6785E-09	1.1063E-07	1.1942E-06
PB-212	0.0000E+00	1.2042E+01	3.6498E+01	1.5812E+01	2.3053E+00	3.3611E-01	2.7281E-03	4.6785E-09	1.1063E-07	1.1942E-06
BI-212	0.0000E+00	1.2042E+01	3.6498E+01	1.5812E+01	2.3053E+00	3.3611E-01	2.7281E-03	4.6785E-09	1.1063E-07	1.1942E-06
PO-212	0.0000E+00	7.7154E+00	2.3384E+01	1.0131E+01	1.4770E+00	2.1535E-01	1.7479E-03	2.9975E-09	7.0882E-08	7.6514E-07
TL-208	0.0000E+00	4.3267E+00	1.3114E+01	5.6812E+00	8.2831E-01	1.2077E-01	9.8022E-04	1.6810E-09	3.9750E-08	4.2909E-07
TOTAL	7.3003E+01	1.5706E+02	2.7737E+05	1.6052E+04	1.6503E+02	1.1993E+02	1.1242E+02	5.6029E+01	2.1543E+00	4.1463E-02

SUMMARY OF RESULTS, **CURIES**, FOR FISSION AND ACTIVATION PRODUCTS, FOR END OF YEAR SHOWN
SITE = **INEL** WASTE TYPE = 1

DECAY	0	1	10	100	300	500	1000	10000	100000	1000000
NI63	7.2500E+01	7.1956E+01	7.9186E+01	4.0194E+01	8.8675E+00	1.9651E+00	4.5431E-02	1.6173E-31	0.0000E+00	0.0000E+00
NB95	0.0000E+00	0.0000E+00	1.7573E-20	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
NB95M	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
TC99	0.0000E+00	0.0000E+00	3.5999E+00	3.5989E+00	3.5965E+00	3.5941E+00	3.5883E+00	3.4847E+00	2.6000E+00	1.3902E-01
RU103	4.0088E-01	6.3683E-04	4.1028E-29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
RH103M	0.0000E+00	5.7410E-04	3.6986E-29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
I125	1.3465E+02	1.9386E+00	5.1522E-17	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
SM147	0.0000E+00	0.0000E+00	1.1875E+01	1.1875E+01	1.1875E+01	1.1875E+01	1.1875E+01	1.1875E+01	1.1875E+01	1.1875E+01
TOTAL	2.0755E+02	7.3896E+01	9.4661E+01	5.5668E+01	2.4339E+01	1.7434E+01	1.5509E+01	1.5360E+01	1.4475E+01	1.2014E+01

Exhibit 5.1. Input data file RADACINP.DAT for Example 5.

Annotated File:

```
Line
 1   RADACINP.DAT FOR EXAMPLE 5, USER'S MANUAL. 7/3/95.
 2   ISIG(1)=2: INPUT IS IN CURIES.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
 3   ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=1 VOLUMES ARE READ.
 4   ISIG(6)=9, ISIG(7)=5: 9 DECAY TIMES: 1,10,100,300,500,1K,10K,100K,1MY.
 5   LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
 6   YSTART=1970, YFINAL=2130. 3 LOW-RANGE AND 6 HIGH-RANGE DECAY TIMES.
 7    0002 0000 0000 0001 0000 0009 0006 0000 0001 0000
 8    1970 2130 0003 0001
 9    HANF ORNL INEL
10    0001 0010 0100
```

Three sites

File VOLUME.DAT is read

Output file RADACMAX.OUT is suppressed

Comments:

Line 7: ISIG(1) = 2, inputs are in curies. ISIG(9) = 1, output file RADACMAX.OUT is omitted. ISIG(4) = 1; volume data are read. Annual and accumulated volumes will be shown in output files RADAC2.OUT and RADAC3.OUT.

Line 8: This example has 3 sites and 1 waste type. Initial year 1970. Final year will be set by the high-range decay times.

Line 9: Site names are shown as they will appear in the output tables.

Line 10: File RADAC4.OUT will show results at these and high-range decay times selected by ISIG(7)

Actual File:

```
RADACINP.DAT FOR EXAMPLE 5, USER'S MANUAL. 7/3/95.
ISIG(1)=2: INPUT IS IN CURIES.  ISIG(2)=0 ; NO PROMPT FOR ISIG(3).
ISIG(3)=0, ISIG(5)=0, SEE USER'S MANUAL. ISIG(4)=1  VOLUMES ARE READ.
ISIG(6)=9, ISIG(7)=5: 9 DECAY TIMES: 1,10,100,300,500,1K,10K,100K,1MY.
LINE 8 (16I5) GIVES THE FOLLOWING DATA: YSTART, YFINAL, NSITES, NWTYPS.
YSTART=1970, YFINAL=2130. 3 LOW-RANGE AND 6 HIGH-RANGE DECAY TIMES.
 0002 0000 0000 0001 0000 0009 0006 0000 0001 0000
 1970 2130 0003 0001
 HANF ORNL INEL
 0001 0010 0100
```

Exhibit 5.2. File VOLUME.DAT for Example 5.

```
FILE VOLUME.DAT FOR EXAMPLE 5. THREE SITES IN THIS FILE.
1234567890123456789012345678901234567890
HANF       0011
1970       8.25                    0.0
1971       12.32                   0.0
1972       0.0                     0.0
1973       0.0                     0.0
1974       0.0                     0.0
1975       0.0                     0.0
1976       0.0                     0.0
1977       0.0                     0.0
1978       0.0                     0.0
1979       0.0                     0.0
1980       4.54                    0.0
FILE VOLUME.DAT  FOR EXAMPLE 5.
1234567890123456789012345678901234567890
ORNL       0011
1970       0.56                    0.0
1971       5.55                    0.0
1972       5.55                    0.0
1973       4.98                    0.0
1974       0.0                     0.0
1975       0.0                     0.0
1976       0.0                     0.0
1977       8.04                    0.0
1978       0.0                     0.0
1979       0.0                     0.0
1980       0.0                     0.0
FILE VOLUME.DAT  FOR EXAMPLE 5.
1234567890123456789012345678901234567890
INEL       0011
1970       12.80                   0.0
1971       0.0                     0.0
1972       0.0                     0.0
1973       0.0                     0.0
1974       10.20                   0.0
1975       0.0                     0.0
1976       0.0                     0.0
1977       0.0                     0.0
1978       0.0                     0.0
1979       0.0                     0.0
1980       0.0                     0.0
```

Number of years of data (This must be the same for all sites)

Volumes of Type 1 waste, m^3

Volumes of Type 2 waste, m^3

File ends here. No termination signal is needed.

Lines 1–2:

The first two lines give alphanumeric narrative information selected by the user. Format is A80. These data are for the user's convenience and are not used in the calculation.

Line 3:

This line gives the site name and the number of years (NYRS) of volume data to be read for each site. The number given here must be the same for all sites. Format for this line is A7, 3X, I4. Some of the volumes may be zero.

Lines 4 to NYRS+3:

Each of these lines gives a calendar year and two annual volumes, representing the m^3 of type 1 and type 2 wastes added in that year. Format for each line is I4, 6X, E10.0, 10X, E10.0.

This completes the volume data for the first site. The data for the succeeding sites are then entered in the same form. The file does not use a terminator line.

5.6.4 Example 5, Output Files

The sites, years, and radionuclide inputs are the same for Example 5 as they were for Example 4. Because output file RADAC4.OUT does not show accumulated volumes, this file is the same for Example 5 as it was for Example 4, and is not repeated. The calculated year-by-year volume results are given in output files RADAC2.OUT and RADAC3.OUT. Exhibit 5.3 shows file RADAC3.OUT for Example 5. Annual and accumulated volumes in m^3 given in this file are for all sites combined. File RADAC2.OUT gives results for each site individually. Throughout the code, volumes are accumulated by simple addition; decay is assumed to have no effect.

5.7 FURTHER DETAILS ON RADACINP.DAT

Line 8 of RADACINP.DAT contains YSTART, YFINAL, NSITES, and NWTYPS in format 16I5. As mentioned in Sect. 5.2.1, YSTART is the first calendar year of waste input; it is the first year that appears in the year-by-year output tabulations.

The definition of YFINAL is slightly more complicated, because it depends on whether extended decay times (times greater than 160 years) are being called for. If extended decay times are not being called for, the maximum allowable decay time is 160 years, and ISIG(7), which is the calling

(Text continued on page 95)

Exhibit 5.3. File RADAC3.OUT for Example 5.

SUMMARY FOR TABLE 3.1 OF IDB REPORT, CONTACT HANDLED TRU WASTE TOTAL OF ALL SITES

END OF YEAR	VOLUME, M3		TOTAL MASS, KG		RADIOACTIVITY, KCI		THERMAL POWER, KW	
	ANNUAL	CUMUL	ANNUAL	CUMUL	ANNUAL	CUMUL	ANNUAL	CUMUL
1970	21.6	21.6	60.2	60.2	41.08	41.08	0.01	0.01
1971	17.9	39.5	2.7	62.9	85.34	127.79	0.08	0.49
1972	5.6	45.0	2.0	64.9	43.10	714.60	0.04	16.85
1973	5.0	50.0	2.0	67.0	43.10	1008.97	0.04	24.53
1974	10.2	60.2	1.0	67.9	42.29	1298.00	0.05	32.02
1975	0.0	60.2	0.0	67.9	0.00	1538.25	0.00	39.24
1976	0.0	60.2	0.0	67.9	0.00	1488.87	0.00	38.00
1977	8.0	68.3	0.7	68.6	12.41	1455.33	0.36	37.17
1978	0.0	68.3	0.0	68.6	0.00	1409.72	0.00	36.01
1979	0.0	68.3	0.0	68.6	0.00	1365.72	0.00	34.89
1980	4.5	72.8	0.6	69.2	11.06	1334.23	0.36	34.16
1981	0.0	72.8	0.0	69.2	0.00	1292.94	0.00	33.11
1982	0.0	72.8	0.0	69.2	0.00	1252.99	0.00	32.09
1983	0.0	72.8	0.7	69.9	12.41	1227.98	0.36	31.47
1984	0.0	72.8	0.0	69.9	0.00	1190.32	0.00	30.51
1985	0.0	72.8	0.0	69.9	0.00	1153.86	0.00	29.58
1986	0.0	72.8	0.0	69.9	0.00	1118.54	0.00	28.68
1987	0.0	72.8	0.0	69.9	0.00	1084.32	0.00	27.80
1988	0.0	72.8	0.0	69.9	0.00	1051.16	0.00	26.96
1989	0.0	72.8	0.0	69.9	0.00	1019.04	0.00	26.14
1990	0.0	72.8	0.0	69.9	0.00	987.92	0.00	25.34
1991	0.0	72.8	0.0	69.9	0.00	957.76	0.00	24.58
1992	0.0	72.8	0.0	69.9	0.00	928.54	0.00	23.83
1993	0.0	72.8	0.0	69.9	0.00	900.24	0.00	23.11
1994	0.0	72.8	0.0	69.9	0.00	872.81	0.00	22.41
1995	0.0	72.8	0.0	69.9	0.00	846.23	0.00	21.73
1996	0.0	72.8	0.0	69.9	0.00	820.48	0.00	21.07
1997	0.0	72.8	0.0	69.9	0.00	795.53	0.00	20.44
1998	0.0	72.8	0.0	69.9	0.00	771.36	0.00	19.82
1999	0.0	72.8	0.0	69.9	0.00	747.94	0.00	19.22
2000	0.0	72.8	0.0	69.9	0.00	725.25	0.00	18.64
2001	0.0	72.8	0.0	69.9	0.00	703.26	0.00	18.08
2002	0.0	72.8	0.0	69.9	0.00	681.95	0.00	17.54
2003	0.0	72.8	0.0	69.9	0.00	661.30	0.00	17.01
2004	0.0	72.8	0.0	69.9	0.00	641.30	0.00	16.50
2005	0.0	72.8	0.0	69.9	0.00	621.92	0.00	16.00
2006	0.0	72.8	0.0	69.9	0.00	603.13	0.00	15.52
2007	0.0	72.8	0.0	69.9	0.00	584.93	0.00	15.06
2008	0.0	72.8	0.0	69.9	0.00	567.30	0.00	14.61
2009	0.0	72.8	0.0	69.9	0.00	550.21	0.00	14.17
2010	0.0	72.8	0.0	69.9	0.00	533.65	0.00	13.75
2011	0.0	72.8	0.0	69.9	0.00	517.61	0.00	13.34
2012	0.0	72.8	0.0	69.9	0.00	502.06	0.00	12.94
2013	0.0	72.8	0.0	69.9	0.00	486.99	0.00	12.56
2014	0.0	72.8	0.0	69.9	0.00	472.39	0.00	12.19
2015	0.0	72.8	0.0	69.9	0.00	458.25	0.00	11.82
2016	0.0	72.8	0.0	69.9	0.00	444.54	0.00	11.47
2017	0.0	72.8	0.0	69.9	0.00	431.25	0.00	11.13
2018	0.0	72.8	0.0	69.9	0.00	418.38	0.00	10.81
2019	0.0	72.8	0.0	69.9	0.00	405.90	0.00	10.49
2020	0.0	72.8	0.0	69.9	0.00	393.81	0.00	10.18
2021	0.0	72.8	0.0	69.9	0.00	382.09	0.00	9.88
2022	0.0	72.8	0.0	69.9	0.00	370.74	0.00	9.59
2023	0.0	72.8	0.0	69.9	0.00	359.74	0.00	9.31

Exhibit 5.3. RADAC3.OUT, Example 5 (continued).

2024	0.0	72.8	0.0	69.9	0.00	349.07	0.00	9.03
2025	0.0	72.8	0.0	69.9	0.00	338.74	0.00	8.77
2026	0.0	72.8	0.0	69.9	0.00	328.72	0.00	8.51
2027	0.0	72.8	0.0	69.9	0.00	319.01	0.00	8.27
2028	0.0	72.8	0.0	69.9	0.00	309.61	0.00	8.03
2029	0.0	72.8	0.0	69.9	0.00	300.49	0.00	7.79
2030	0.0	72.8	0.0	69.9	0.00	291.65	0.00	7.57
2040	0.0	72.8	0.0	69.9	0.00	216.94	0.00	5.65
2050	0.0	72.8	0.0	69.9	0.00	162.24	0.00	4.25
2060	0.0	72.8	0.0	69.9	0.00	122.11	0.00	3.22
2070	0.0	72.8	0.0	69.9	0.00	92.61	0.00	2.46
2080	0.0	72.8	0.0	69.9	0.00	70.88	0.00	1.90
2090	0.0	72.8	0.0	69.9	0.00	54.81	0.00	1.49
2100	0.0	72.8	0.0	69.9	0.00	42.89	0.00	1.18
2110	0.0	72.8	0.0	69.9	0.00	34.00	0.00	0.95
2120	0.0	72.8	0.0	69.9	0.00	27.33	0.00	0.77
2130	0.0	72.8	0.0	69.9	0.00	22.30	0.00	0.64
2270	0.0	72.8	0.0	69.9	0.00	4.32	0.00	0.14
2470	0.0	72.8	0.0	69.9	0.00	1.50	0.00	0.05
2970	0.0	72.8	0.0	69.9	0.00	0.80	0.00	0.02
11970	0.0	72.8	0.0	69.9	0.00	0.82	0.00	0.02
101970	0.0	72.8	0.0	69.9	0.00	1.75	0.00	0.04
1001970	0.0	72.8	0.0	69.9	0.00	0.27	0.00	0.01

signal for extended decay times, will be 0. In that case, YFINAL indicates the final calendar year of the output tabulations. The maximum allowable difference between YSTART and YFINAL will be 160 years.

If extended decay times are being called for, ISIG(7) will indicate the number of extended decay times desired, as explained in Table 7. In this case, it is not practical to make YFINAL equal to YSTART plus the maximum decay time desired, because the latter can be as much as 1,000,000 years. The value entered for YFINAL should be set at YSTART+160. When extended decay times are used [that is, ISIG(7) > 0], the code will use ISIG(7), rather than YFINAL, to determine the final year of decay time shown in the output tabulations. Whenever ISIG(7) >0, YFINAL should be set at YSTART+160.

5.8 FURTHER INFORMATION ON FILE RADNUCL1.DAT

The DO loop structure for reading this file is explained and shown schematically in Sect. 3. The file contains the annual inputs of type 1 waste for all the sites. The data are listed for the sites in order; that is, the data for site 1 are listed, then the data for site 2, and so on. The form of the data is the same for each site. The program does not read the entire file at one pass; it reads one site at a time, performs the decay calculations, and writes the results for that site. Then it reads the data for the next site. The DO 600 loop controls this sequence. In general terms, the data required for a given site are the curies of each radionuclide added in each year. The sequence in which the site data are ordered in this file must be the same as the sequence in which the sites are listed in file RADACINP.DAT. Instead of curies, grams can be used as input. This is done by setting ISIG(1) = 1 in file RADACINP.DAT, as described in Table 7.

The input data for a given site are given in a series of "pages." A "page" contains the list of annual inputs added to inventory in a particular year or in each year of a series of consecutive years, NYR1 through NYR2, inclusive. The maximum number of years of input is 60. The program is written so that a "page" of data can list up to 300 radionuclides. This allows for future expansion of the radionuclide libraries. The data on each "page" are as follows:

Lines 1-3:

Three lines of narrative description containing any information desired by the user. The statements controlling the reading of these three lines of data are as follows:

```
      READ(LL,867)RECORD
      READ(LL,867)RECORD
      READ(LL,867)RECORD
  867 FORMAT (A80)
```

The alphanumeric information in the three lines of data read by the above statements is at the choice of the user and is not used in the calculations. All three lines must be used, even if blank. As indicated above, the format is A80 for each line.

Line 4:

This line gives the page numbers and year numbers for this page of data. The read and format statements are as follows:

```
      READ(LL,900)NP1,NP2,NYR1,NYR2
      IF(NP1.GE.NP2) NSTOP=1
  900 FORMAT (6X,I2,4X,I2,16X,I4,9X,I4)

      NP1   =  page number of data for this site.
      NP2   =  total number of pages of data for this site.
      NYR1  =  first calendar year for which the annual
               additions shown on this page of data are
               effective.
      NYR2  =  final calendar year for which the annual
               additions shown on this page of data are
               effective (may be equal to NYR1).
```

For this site, the page of data being read is page NP1 of NP2 pages. The list of annual radionuclide additions on the page being read is effective for each year from NYR1 to NYR2, inclusive. Thus, if a site has the same list of annual nuclide additions in two or more consecutive years, the user can put this list on one page and use NYR1 and NYR2 to specify the years for which this annual list is effective. For the first page of data for a site, NP1 is 1; for the second page, NP1 is 2, etc, regardless of how many years are covered by the period NYR1 through NYR2. NP2 is the same for each page of a given site but may vary from site to site. If the annual additions for a given site are identical for each year of the study, a single "page" will suffice for that site. It is permissible to have some years in which no waste is added, and it is not necessary to fill out pages of data for such years. However, the file must contain at least one page of data for each site listed in RADACINP.DAT. If a site has no radionuclide additions in any years, a dummy page showing a zero entry should be used. The final year of waste additions must not exceed YSTART + 60. The user can minimize NP2, the number of pages required for a site, by taking advantage of any consecutive years for which the annual additions are identical as to composition and quantity. However, the user does not have to minimize the number of pages; separate pages can be used for years that have identical annual additions if the user finds this more convenient.

Lines 5-7:

Three lines of user-supplied narrative are read by the following:

```
      READ (LL,867) RECORD
      READ (LL,867) RECORD
      READ (LL,867) RECORD
  867 FORMAT (A80)
```

As in lines 1-3, the information in these three lines is at the choice of the user and is not used in the calculations. All three lines must be used, even if blank.

Lines 8 through N+7:

Where N represents the number of radionuclides listed on this page, these lines give the list of radionuclides and the curies or grams of each radionuclide added annually in years NYR1 through NYR2. The read and format statements are as follows:

```
      READ(LL,901) NAME48,NTYP48,NID48,CUR48

  901 FORMAT(2X,A7,1X,I2,1X,I3,24X,E10.0)
```

The list of radionuclides, identifiers, and annual quantities is read iteratively in the DO 60 loop of the program. CUR48 represents the quantity, whether curies or grams. The list of radionuclides can vary from page to page for a given site. Definitions are as follows:

```
NAME48  =  name of radionuclide.
NTYP48  =  a two-digit number identifying the type of
           radionuclide.  These identifiers are as
           follows:

10      =  parent fission product or activation product.
```

11	=	daughter (subordinate) fission product or activation product.
13	=	parent fission product of a chain of several radioactive daughters.
20	=	actinide (principal actinides only).
NID48	=	the radionuclide identification number.
CUR48	=	the curies or grams of this radionuclide added each year for years NYR1 through NYR2 inclusive.

Subordinate (type 21) actinides are not accepted as inputs. If a type 21 actinide is entered, the code will ignore it and proceed to the next nuclide input. The code assumes that any principal (type 20) actinides entered as input are always accompanied by their subordinate actinide daughters, in amounts corresponding to secular equilibrium. Thus, the output tabulations will show the presence of these subordinate actinide daughters as part of the input in the same year in which their parents are entered, even though the daughters are not part of file RADNUCL1.DAT. However, by setting ISIG(8) = 1, the user can omit the automatic addition of subordinate actinides in year 1. If the user wishes to include the subordinate actinides in file RADNUCL1.DAT for reference purposes, this is permissible, but the user should be aware that the code will calculate the amounts of the subordinate actinides internally, and that these amounts may differ from those input by the user.

The treatment of short-lived daughter (type 11) fission products is similar to that described for subordinate actinides. If a type 11 fission product is entered, the code will ignore it and proceed to the next nuclide input. Type 11 daughter fission products will appear as outputs only if their type 10 or type 13 parents are present, in which case the quantity of the daughter will be determined by secular equilibrium with the parent, adjusted for branching ratio.

Line N+8:

This is the termination line for each page of data. Termination is signalled by putting 99 in the position normally occupied by NTYP48. In the examples, ZZZZZ was put in the position normally occupied by NAME48, but any symbol can be used here, including a blank. The ZZZZZ was used as an extra memory aid for the user, but the only termination signal recognized by the code is the 99 in columns 11 through 12.

After the page termination signal, the next line in the file is line 1 of the next page of data for this site. On the final page of data for a given site, the numbers NP1 and NP2 will be equal; this is how the program is signalled that it is reading the final page for that site. The next line of the file is line 1 of the data for the next site. Each site follows the same pattern. The order in which radionuclides are listed does not have to be the same from page to page or from site to site. Also, fission products, activation products, and actinides do not have to be in any particular order and can be intermingled if desired.

No special signal is needed to indicate when the final site has been read. The program determines this automatically through the structure of the DO 600 loop, as described in Sect. 3. That is, the sites are counted as they are read. The user should be aware that when NP1 and NP2 are equal, this is the signal that the final page of data for a given site is being read.

To assist the user in preparing actinide inputs, a list of the actinides not available in RADAC is given in Table 8.

5.9 INPUT DATA FILE RADNUCL2.DAT

This file is not needed unless the problem calls for two waste types, that is, unless NWTYPS = 2 in file RADACINP.DAT. If NWTYPS = 2, files RADNUCL1.DAT and RADNUCL2.DAT must both be provided. RADNUCL2.DAT gives the annual radionuclide inputs of type 2 waste for all sites. The form, sequence, and termination procedures of the data are the same as for the type 1 waste, file RADNUCL1.DAT. The sequence in which the sites are listed must be the same as for the type 1 waste and is the sequence in which the sites are listed in file RADACINP.DAT.

When assembling files RADNUCL1.DAT and RADNUCL2.DAT, there must be at least one "page" of data for each site listed in lines 9 through 10 of RADACINP.DAT. For each site that has no inputs, a dummy "page" showing a zero input must appear in the file.

The order in which radionuclides are listed on a page does not have to be the same from page to page or from site to site. Also, the radionuclide order does not have to be the same for type 2 waste as it is for type 1 waste.

6. OUTPUT FILES

6.1 RADACMAX.OUT

RADACMAX.OUT is the most detailed output file produced by the code. Outputs are tabulated site by site, radionuclide by radionuclide, and year by year. For each site, and for each waste type, the file contains six tables:

Table 8. Some of the actinides and daughters not currently available in RADAC[a,b]

Actinide or daughter	Half-life (s)	Decay constant (s^{-1})
^{206}Tl	2.5200E+02	2.7506E-03
^{204}Pb	4.4181E+24	1.5689E-25
^{208}Bi	1.1613E+13	5.9686E-14
^{210m}Bi	9.4673E+13	7.3215E-15
^{211m}Po	2.5000E+01	2.7726E-02
^{233}Th	1.3260E+03	5.2274E-04
^{232}Pa	1.1320E+05	6.1232E-06
^{235}Pa	1.4460E+03	4.7935E-04
^{231}U	3.6290E+05	1.9100E-06
^{239}U	1.4120E+03	4.9090E-04
^{241}U	1.0000E+00	6.9315E-01
^{236m}Np	8.1000E+04	8.5574E-06
^{245}Pu	3.8160E+04	1.8164E-05
^{239}Am	4.2840E+04	1.6180E-05
^{240}Am	1.8290E+05	3.7898E-06
^{244}Am	3.6360E+04	1.9063E-05
^{244m}Am	1.5600E+03	4.4433E-04
^{249}Cm	3.8490E+03	1.8009E-04
^{251}Bk	3.4200E+03	2.0267E-04
^{248}Cf	2.8814E+07	2.4056E-08
^{253}Cf	1.5390E+06	4.5039E-07
^{254}Cf	5.2272E+06	1.3260E-07
^{255}Cf	5.4000E+03	1.2836E-04
^{254m}Es	1.4148E+05	4.8993E-06
^{255}Es	3.3696E+06	2.0571E-07

[a]This is a partial list of the actinides and daughters that are not yet available in the actinide data file NUCDAT.LIB.

[b]Products of spontaneous fission are not calculated by RADAC.

1. principal actinides, grams;
2. principal actinides, curies;
3. subordinate actinides, grams;
4. subordinate actinides, curies;
5. fission and activation products, curies; and
6. summary table: volumes, grams, curies, and watts.

The first five tables for each site give accumulated quantities, radionuclide by radionuclide, for all the time points of the study period. The first time point is the end of the starting year, YSTART. The next 60 time points are in 1-year steps, and the next 10 are in 10-year steps. The year at this point is YSTART+160. If YFINAL is less than this, the tables will end at YFINAL. If the extended decay time option has been chosen, the tabulated radionuclide-by-radionuclide quantities will be shown for each of the extended decay times selected.

The sixth table is a summary table for the site. This table is similar to the summary table in the annual IDB report. It gives the annual additions and year-end accumulations of volume (m^3), mass (kg), radioactivity (kCi), and thermal power (kW) for each year, but does not show the radionuclide-by-radionuclide breakdown.

For each site there is a complete set of tables as described above. If there are two waste types, there is a complete separate set of tables for each type.

The detailed accumulation tables are listed in floating point notation with five significant figures. The summary tables give volumes and masses (m^3 and kg) as fixed-point numbers with one digit after the decimal point; radioactivity and thermal power (kCi and kW) are given with two digits after the decimal point.

As discussed in Sect. 5.2 and Table 7, production of file RADACMAX.OUT can be suppressed by setting ISIG(9) = 1. This is frequently useful because the file can occupy considerable space on the user's computer, and the amount of detail it presents is not always needed.

6.2 RADAC2.OUT

This is an abbreviated version of the detailed output. It omits the five detailed tables listed in Sect. 6.1 and shows only the summary table for each site. The summary tables (site by site and total of all sites) are as described in Sect. 6.1. There is a separate set of summary tables for each waste type.

6.3 RADAC3.OUT

This is the minimum output summary file. It is similar to RADAC2.OUT except that it omits the site-by-site summary tables and gives only the summary for all sites combined. A separate table is given for each waste type. An example of this file is given in Exhibit 5.3, Sect. 5.6.

6.4 RADAC4.OUT

This output is produced only if the user-specified decay time option is chosen by setting ISIG(6) >0, as described in Sect. 5 and Table 7. It is also produced whenever the extended decay time option is chosen, because the user-specified decay time option is automatically activated whenever the extended decay time option is selected. The output gives the accumulated quantities of each radionuclide in each of the years selected by the user. Fission and activation products are given in curies; actinides and their daughters are given in both grams and curies. The other output files, RADACMAX.OUT, RADAC2.OUT, and RADAC3.OUT, are produced regardless of the value of ISIG(6).

7. VERIFICATION AND VALIDATION

7.1 SCOPE

Most of the verification and validation work reported here was based on comparisons of the results of the RADAC code with those of the LIBGEN/WINPRO/SAS and ORIGEN2 codes. The LIBGEN/WINPRO/SAS code system uses the ORIGEN2 decay module in an accumulation mode, and thus provides a means for testing the accumulation feature of RADAC.

In addition, considerable work was done on verifying the integer-array arithmetic code modules developed for use in the RADAC system. Verification of these code modules and of the IBAT codes in which they are used (IBATFIX.FOR and IBATFLT.FOR) was considered essential because all of the integer-array codes in the RADAC system are in-house codes and because the function they serve (the precise calculation of yield factors) is basic to RADAC's actinide decay capability.

7.2 COMPARISONS WITH LIBGEN/WINPRO/SAS

The RADAC program has been tested against the LIBGEN/WINPRO/SAS system of codes, which was developed by the IDB group at ORNL as a way of extending ORIGEN2 to include the accumulation of products (Storch 1989). In the examples run thus far, RADAC gave results very close to those of LIBGEN/WINPRO/SAS. In an example based on the contact-handled TRU waste in the 1992 IDB report (DOE 1992b), the total curies accumulated at the end of year 1991 were 1887.51 kilocuries for LIBGEN/WINPRO/SAS and 1887.67 kilocuries for RADAC. Total thermal power at the end of 1991 was 36.06 kW for LIBGEN/WINPRO/SAS and 36.07 kW for RADAC (DOE 1994a).

Another comparison with LIBGEN/WINPRO/SAS was based on a simulated low-level waste composition designed to be typical of low-level wastes at DOE sites. Waste accumulation was assumed to occur from 1970 to 1993. The annual rates of waste addition, in terms of volumes (m^3) and radioactivity (Ci), are shown in Table 9. The radionuclide composition of the added waste, which was the same in each year, is shown in Table 10. The results of decay and accumulation calculations by both codes through the end of year 2030 are shown in Table 11. It can be seen that very close agreement was obtained. It is not surprising that the results of volume accumulations, being based on simple addition of the annual quantities, were identical. The agreement between the two codes in regard to accumulated radioactivity and thermal power, however, is striking, considering the variety of radionuclides represented in the mixture. The results of this test give confidence that RADAC is properly performing the basic functions of accumulation and decay.

The LIBGEN/WINPRO/SAS calculations for this example were made by Lynn Tharp. Data for the example were supplied by Alan Icenhour (Icenhour 1995).

7.3 COMPARISONS WITH ORIGEN2

7.3.1 High-Level Waste Examples

The applicability of RADAC to the decay of HLW has been tested using two examples based on projected HLW canister compositions. Because no accumulation was involved, these examples were tests only of the decay modules of the two codes. The first of these examples was based on a projected canister of Idaho National Engineering Laboratory HLW immobilized in a glass-ceramic composition. Data on the radionuclide composition of this HLW were taken from a 1992 DOE report on waste characteristics; both actinides and fission products were present (DOE 1992a). The same source gave the results of ORIGEN2 decay calculations at decay times ranging from 1 year to 1 million years. Table 12 shows the results of ORIGEN2 and RADAC decay calculations. The ORIGEN2 results are documented in DOE 1992a. The RADAC calculations were generated on

(Text continued on page 110)

TABLE 9. Input data used in LLW example for LIBGEN/WINPRO/SAS and RADAC: annual added volumes and radioactivity[a]

Year	Annual added volume (m^3)	Annual added radioactivity (Ci)
1970	1.8100E+04	1.9960E+04
1971	1.1620E+04	6.7690E+03
1972	1.3360E+04	2.5100E+03
1973	1.3120E+04	3.4740E+03
1974	1.1080E+04	9.3130E+03
1975	1.0170E+04	6.9080E+04
1976	8.1010E+03	2.2460E+02
1977	1.4710E+04	6.0870E+02
1978	1.5490E+04	1.2660E+02
1979	1.8230E+04	1.0150E+03
1980	1.9570E+04	2.4620E+02
1981	2.0140E+04	5.5610E+02
1982	2.2420E+04	5.0790E+02
1983	2.6650E+04	2.2610E+02
1984	2.6080E+04	3.9130E+02
1985	3.0540E+04	1.5770E+03
1986	3.0070E+04	1.6940E+03
1987	2.8160E+04	1.5460E+03
1988	3.0183E+04	7.9750E+02
1989	2.6810E+04	3.6090E+02
1990	2.6571E+04	3.1520E+02
1991	2.3827E+04	2.9880E+02
1992	1.3000E+04	1.1000E+02
1993	6.5900E+02	4.6000E+02
Totals	4.5866E+05	1.2217E+05

[a]Radionuclide mixture compositions are given in Table 10.

Table 10. Input data used in LLW example for LIBGEN/WINPRO/SAS and RADAC: radionuclide mixture composition[a]

Nuclide	Type	ID	Curie fraction
H-3	10	1	2.698298E-01
C-14	10	2	2.499981E-04
CL-36	10	69	2.522236E-08
CO-60	10	7	3.316493E-01
NI-59	10	8	2.967336E-03
NI-63	10	9	3.462377E-01
SE-79	10	30	4.080087E-09
SR-90	10	10	1.231148E-02
Y-90	11	11	1.231148E-02
NB-94	10	79	1.404539E-05
TC-99	10	15	2.334305E-06
CS-137	10	18	1.234016E-02
BA-137M	11	19	1.167869E-02
EU-152	10	27	4.253182E-06
EU-154	10	28	6.602323E-06
TH-232	20	18	2.472780E-07
U-234	20	24	8.654730E-06
U-235	20	25	2.472780E-07
U-236	20	26	2.472780E-07
U-238	20	27	1.854585E-05
NP-237	20	28	1.423043E-04
PU-238	20	30	6.231406E-05
PU-239	20	31	4.500460E-05
PU-240	20	32	1.384757E-05
PU-241	20	33	7.764529E-05
AM-241	20	36	2.794241E-05
CM-244	20	45	6.627051E-09
Total			1.000000E+00

[a]This radionuclide composition was assumed to apply in each year of waste addition.

Table 11. Comparison of LIBGEN/WINPRO/SAS and RADAC accumulation-decay calculations for LLW

End of year	LIBGEN/WINPRO/SAS			RADAC		
	Accumulated volume (10^3 m^3)	Accumulated radioactivity (10^3 Ci)	Accumulated thermal power (W)	Accumulated volume (10^3 m^3)	Accumulated radioactivity (10^3 Ci)	Accumulated thermal power (W)[a]
1970	18.100	19.960	105.844	18.100	19.960	105.900
1971	29.720	25.548	129.103	29.720	25.548	129.100
1972	43.080	26.591	127.034	43.080	26.591	127.000
1973	56.200	28.592	130.371	56.200	28.592	130.400
1974	67.280	36.369	164.319	67.280	36.369	164.300
1975	77.450	103.509	511.193	77.450	103.507	511.200
1976	85.551	97.890	451.585	85.551	97.889	451.600
1977	100.261	93.201	401.300	100.261	93.200	401.300
1978	115.751	88.503	354.625	115.751	88.503	354.700
1979	133.981	85.142	318.374	133.981	85.141	318.400
1980	153.551	81.358	282.497	153.551	81.357	282.500
1981	173.691	78.235	252.650	173.691	78.235	252.700
1982	196.111	75.361	226.199	196.111	75.360	226.200
1983	222.761	72.470	201.486	222.761	72.470	201.500
1984	248.841	69.999	180.663	248.841	69.999	180.700
1985	279.381	68.931	168.665	279.381	68.930	168.700
1986	309.451	68.103	158.763	309.451	68.103	158.800
1987	337.611	67.232	149.295	337.611	67.231	149.300
1988	367.794	65.712	137.021	367.794	65.712	137.000
1989	394.604	63.891	123.926	394.604	63.890	123.900
1990	421.175	62.170	112.175	421.175	62.170	112.200
1991	445.002	60.567	101.757	445.002	60.567	101.800
1992	458.002	58.898	91.595	458.002	58.898	91.600
1993	458.661	57.699	84.512	458.661	57.699	84.500
1994	458.661	56.129	75.840	458.661	56.129	75.800
1995	458.661	54.666	68.205	458.661	54.666	68.200

Table 11. (continued)

End of year	LIBGEN/WINPRO/SAS Accumulated volume (10^3 m^3)	LIBGEN/WINPRO/SAS Accumulated radioactivity (10^3 Ci)	LIBGEN/WINPRO/SAS Accumulated thermal power (W)	RADAC Accumulated volume (10^3 m^3)	RADAC Accumulated radioactivity (10^3 Ci)	RADAC Accumulated thermal power (W)[a]
1996	458.661	53.300	61.481	458.661	53.300	61.500
1997	458.661	52.021	55.555	458.661	52.021	55.600
1998	458.661	50.822	50.331	458.661	50.822	50.300
1999	458.661	49.695	45.722	458.661	49.695	45.700
2000	458.661	48.634	41.654	458.661	48.634	41.700
2001	458.661	47.633	38.059	458.661	47.633	38.100
2002	458.661	46.687	34.881	458.661	46.687	34.900
2003	458.661	45.791	32.069	458.661	45.791	32.100
2004	458.661	44.940	29.578	458.661	44.940	29.600
2005	458.661	44.132	27.370	458.661	44.132	27.400
2006	458.661	43.362	25.409	458.661	43.362	25.400
2007	458.661	42.628	23.666	458.661	42.628	23.700
2008	458.661	41.927	22.115	458.661	41.927	22.100
2009	458.661	41.257	20.732	458.661	41.257	20.700
2010	458.661	40.614	19.497	458.661	40.614	19.500
2011	458.661	39.998	18.393	458.661	39.998	18.400
2012	458.661	39.406	17.404	458.661	39.406	17.400
2013	458.661	38.837	16.516	458.661	38.837	16.500
2014	458.661	38.288	15.717	458.661	38.288	15.700
2015	458.661	37.759	14.997	458.661	37.759	15.000
2016	458.661	37.249	14.345	458.661	37.249	14.300
2017	458.661	36.756	13.756	458.661	36.756	13.800
2018	458.661	36.279	13.220	458.661	36.279	13.200
2019	458.661	35.817	12.732	458.661	35.817	12.700
2020	458.661	35.369	12.286	458.661	35.369	12.300
2021	458.661	34.935	11.878	458.661	34.935	11.900

Table 11. (continued)

End of year	LIBGEN/WINPRO/SAS Accumulated volume (10^3 m^3)	LIBGEN/WINPRO/SAS Accumulated radioactivity (10^3 Ci)	LIBGEN/WINPRO/SAS Accumulated thermal power (W)	RADAC Accumulated volume (10^3 m^3)	RADAC Accumulated radioactivity (10^3 Ci)	RADAC Accumulated thermal power (W)[a]
2022	458.661	34.513	11.503	458.661	34.513	11.500
2023	458.661	34.104	11.158	458.661	34.104	11.200
2024	458.661	33.705	10.839	458.661	33.705	10.800
2025	458.661	33.317	10.543	458.661	33.318	10.500
2026	458.661	32.940	10.268	458.661	32.940	10.300
2027	458.661	32.572	10.012	458.661	32.572	10.000
2028	458.661	32.213	9.772	458.661	32.213	9.800
2029	458.661	31.863	9.547	458.661	31.863	9.500
2030	458.661	31.521	9.335	458.661	31.521	9.300

[a]In RADAC, accumulated thermal power is rounded to the nearest tenth of a watt.

Table 12. Comparison of ORIGEN2 and RADAC decay calculations based on INEL HLW canister[a]

Decay time (years)	Calculated radioactivity of fission and activation products (Ci)	
	ORIGEN2	RADAC
0	1.086E+05	1.085E+05
1	8.912E+04	8.911E+04
10	5.338E+04	5.336E+04
100	6.383E+03	6.381E+03
1,000	3.810E+00	3.809E+00
10,000	3.619E+00	3.618E+00
100,000	2.843E+00	2.842E+00
1,000,000	6.676E−01	6.675E−01

Decay time (years)	Calculated radioactivity of actinides and daughter products (Ci)	
	ORIGEN2	RADAC
0	2.982E+02	2.981E+02
1	2.875E+02	2.874E+02
10	2.148E+02	2.148E+02
100	5.095E+01	5.093E+01
1,000	3.358E+00	3.357E+00
10,000	1.027E+00	1.027E+00
100,000	2.486E−01	2.458E−01
1,000,000	4.437E−02	4.447E−02

[a]The projected INEL HLW canister composition is documented in *Characteristics of Potential Repository Wastes*, DOE/RW-0184-R1, Vol. 3, July 1992 (DOE 1992a). Radioactivities shown are for a canister containing 1,825 kg of a glass-ceramic-HLW composition.

May 12, 1995. As Table 12 shows, the two codes gave virtually identical results for fission and activation products. For actinides and actinide daughters, the results were again virtually identical except at 100,000 years, when RADAC was lower by about 1%. For decay codes, this is a high degree of verification.

The second example was based on a projected canister of SRS HLW immobilized in borosilicate glass. The composition of the HLW glass and the results of the ORIGEN2 calculations are documented in DOE 1992a. The RADAC calculations were made on July 28, 1995. Table 13 shows the results of the calculations by the two codes. The results show strikingly close agreement over the entire range of decay times, except at 100,000 years, when the actinide curies given by RADAC were again about 1% lower. Because this difference in actinide curies at 100,000 years was present in both the INEL and the Savannah River canisters, an effort was made to determine its cause. Study of the detailed outputs of ORIGEN2 and RADAC showed that the curies of ^{226}Ra and its short-lived daughters (see Fig. 3) were slightly less in RADAC than in ORIGEN2. However, the total difference between the two codes was only about 0.3 Ci for the INEL canister and 0.5 Ci for the Savannah River canister, so the differences in ^{226}Ra and its short-lived daughters can probably be considered negligible.

7.3.2 Short-Chain Fission and Activation Products

Table 14 shows the results of decay calculations made for short-chain fission and activation products by use of ORIGEN2 and RADAC. The decay times used in this series of runs range from 1 year to 1 million years. The nuclides used as inputs include essentially all of those listed in Table 6 as belonging to type 10. These decay either to stable daughters or to daughters of type 11, which have such short half-lives that they can be considered to be in secular equilibrium with their parents. The feed of the parent in each case was 1.0 g. Comparison of the ORIGEN2 and RADAC results shows excellent agreement over the entire range of decay times. Agreement of the two codes was expected in this instance, because the half-lives used in RADAC were essentially all taken from the ORIGEN2 decay library or from other sources using the same data. In a number of cases, there were slight differences between ORIGEN2 and RADAC in the curies of the input nuclide. Because the nuclide inputs were one gram in all cases, the differences were caused by differences in the way the two codes calculate curies per gram using Avogadro's number, half-life, and atomic mass number. However, these differences were small enough in all cases to be considered negligible.

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Table 13. Comparison of ORIGEN2 and RADAC decay calculations based on SRS HLW-glass canister[a]

Decay time (years)	Calculated radioactivity of fission and activation products (Ci)	
	ORIGEN2	RADAC
0	2.312E+05	2.311E+05
1	2.054E+05	2.052E+05
10	1.433E+05	1.432E+05
100	1.716E+04	1.716E+04
1,000	6.605E+00	6.604E+00
10,000	6.320E+00	6.319E+00
100,000	4.958E+00	4.958E+00
1,000,000	1.591E+00	1.591E+00

Decay time (years)	Calculated radioactivity of actinides and daughter products (Ci)	
	ORIGEN2	RADAC
0	3.294E+03	3.295E+03
1	3.203E+03	3.203E+03
10	2.531E+03	2.531E+03
100	7.697E+02	7.696E+02
1,000	3.564E+01	3.564E+01
10,000	1.382E+01	1.382E+01
100,000	4.212E+00	4.161E+00
1,000,000	8.560E-01	8.578E-01

[a]The projected SRS HLW canister composition is documented in *Characteristics of Potential Repository Wastes*, DOE/RW-0184-R1, Vol. 3, July 1992 (DOE 1992a) and in a 1988 Savannah River report (Baxter 1988). Radioactivities shown are for a canister containing 1,682 kg of a HLW-glass composition.

Table 14. Results of ORIGEN2 and RADAC decay calculations for short-chain fission and activation products[a]

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	1	2	5	10	0	1	2	5	10
H-3	9.654E+03	9.127E+03	8.629E+03	7.292E+03	5.507E+03	9.651E+03	9.124E+03	8.626E+03	7.290E+03	5.506E+03
C-14	4.459E+00	4.458E+00	4.458E+00	4.456E+00	4.454E+00	4.458E+00	4.457E+00	4.457E+00	4.455E+00	4.452E+00
NA-22	6.248E+03	4.787E+03	3.667E+03	1.649E+03	4.353E+02	6.246E+03	4.785E+03	3.666E+03	1.649E+03	4.352E+02
NA-24	8.709E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.706E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SI-32	1.719E+01	1.718E+01	1.716E+01	1.710E+01	1.701E+01	1.719E+01	1.717E+01	1.715E+01	1.710E+01	1.701E+01
P-32	0.000E+00	1.718E+01	1.716E+01	1.710E+01	1.701E+01	0.000E+00	1.717E+01	1.715E+01	1.710E+01	1.701E+01
S-35	4.241E+04	2.388E+03	1.345E+02	2.400E-02	1.358E-08	4.240E+04	2.387E+03	1.344E+02	2.400E-02	1.358E-08
CL-36	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.299E-02
K-40	6.986E-06	6.986E-06	6.986E-06	6.986E-06	6.986E-06	6.984E-06	6.984E-06	6.984E-06	6.984E-06	6.984E-06
CA-45	1.781E+04	3.767E+03	7.968E+02	7.537E+00	3.189E-03	1.781E+04	3.766E+03	7.966E+02	7.536E+00	3.189E-03
SC-46	3.389E+04	1.652E+03	8.050E+01	9.320E-03	2.563E-09	3.388E+04	1.651E+03	8.048E+01	9.318E-03	2.563E-09
V-50	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13
CR-51	9.244E+04	9.947E+00	1.070E-03	1.334E-15	1.924E-35	9.241E+04	9.944E+00	1.070E-03	1.333E-15	0.000E+00
MN-54	7.741E+03	3.443E+03	1.531E+03	1.348E+02	2.346E+00	7.739E+03	3.442E+03	1.531E+03	1.347E+02	2.346E+00
FE-55	2.501E+03	1.916E+03	1.467E+03	6.595E+02	1.739E+02	2.500E+03	1.915E+03	1.467E+03	6.593E+02	1.739E+02
FE-59	4.920E+04	1.774E+02	6.389E-01	2.988E-08	1.814E-20	4.919E+04	1.772E+02	6.385E-01	2.986E-08	1.812E-20
CO-60	1.131E+03	9.917E+02	8.695E+02	5.860E+02	3.036E+02	1.131E+03	9.914E+02	8.692E+02	5.858E+02	3.035E+02
NI-59	7.577E-02	7.577E-02	7.577E-02	7.577E-02	7.577E-02	7.575E-02	7.575E-02	7.575E-02	7.575E-02	7.575E-02
NI-63	6.171E+01	6.124E+01	6.078E+01	5.942E+01	5.723E+01	6.169E+01	6.123E+01	6.077E+01	5.941E+01	5.721E+01
ZN-65	8.241E+03	2.918E+03	1.033E+03	4.588E+01	2.555E-01	8.239E+03	2.917E+03	1.033E+03	4.587E+01	2.554E-01
SE-75	1.454E+04	1.757E+03	2.123E+02	3.743E-01	9.636E-06	1.454E+04	1.756E+03	2.122E+02	3.743E-01	9.636E-06
SE-79	6.969E-02	6.969E-02	6.969E-02	6.969E-02	6.968E-02	6.967E-02	6.967E-02	6.967E-02	6.967E-02	6.966E-02
KR-81	2.104E-02	2.104E-02	2.104E-02	2.104E-02	2.104E-02	2.103E-02	2.103E-02	2.103E-02	2.103E-02	2.103E-02
KR-85	3.925E+02	3.679E+02	3.449E+02	2.841E+02	2.056E+02	3.924E+02	3.678E+02	3.448E+02	2.840E+02	2.055E+02
RB-86	8.141E+04	1.041E-01	1.332E-07	2.785E-25	0.000E+00	8.139E+04	1.041E-01	1.331E-07	2.784E-25	0.000E+00
RB-87	8.754E-08	8.754E-08	8.754E-08	8.754E-08	8.754E-08	8.751E-08	8.751E-08	8.751E-08	8.751E-08	8.751E-08
SR-89	2.907E+04	1.932E+02	1.284E+00	3.772E-07	4.896E-18	2.906E+04	1.932E+02	1.284E+00	3.771E-07	4.895E-18
SR-90	1.365E+02	1.332E+02	1.301E+02	1.211E+02	1.076E+02	1.364E+02	1.332E+02	1.301E+02	1.211E+02	1.075E+02

Table 14. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	1	2	5	10	0	1	2	5	10
Y-90	0.000E+00	1.333E+02	1.301E+02	1.212E+02	1.076E+02	0.000E+00	1.332E+02	1.301E+02	1.211E+02	1.075E+02
Y-91	2.454E+04	3.240E+02	4.278E+00	9.848E-06	3.953E-15	2.453E+04	3.239E+02	4.277E+00	9.846E-06	3.952E-15
NB-94	1.874E-01	1.874E-01	1.874E-01	1.874E-01	1.874E-01	1.874E-01	1.874E-01	1.874E-01	1.873E-01	1.873E-01
MO-93	1.099E+00	1.099E+00	1.099E+00	1.098E+00	1.097E+00	1.099E+00	1.099E+00	1.099E+00	1.098E+00	1.097E+00
TC-99	1.696E-02	1.696E-02	1.696E-02	1.696E-02	1.696E-02	1.696E-02	1.696E-02	1.696E-02	1.695E-02	1.695E-02
RU-106	3.316E+03	1.678E+03	8.490E+02	1.100E+02	3.648E+00	3.315E+03	1.677E+03	8.488E+02	1.100E+02	3.647E+00
RH-106	0.000E+00	1.678E+03	8.490E+02	1.100E+02	3.648E+00	0.000E+00	1.677E+03	8.488E+02	1.100E+02	3.647E+00
PD-107	5.145E-04	5.145E-04	5.145E-04	5.145E-04	5.145E-04	5.144E-04	5.144E-04	5.144E-04	5.144E-04	5.144E-04
AG-108	0.000E+00	2.308E+00	2.295E+00	2.258E+00	2.197E+00	0.000E+00	2.307E+00	2.295E+00	2.257E+00	2.197E+00
AG-108M	2.607E+01	2.593E+01	2.579E+01	2.537E+01	2.469E+01	2.607E+01	2.592E+01	2.578E+01	2.536E+01	2.468E+01
AG-109M	0.000E+00	1.497E+03	8.673E+02	1.688E+02	1.103E+01	0.000E+00	1.496E+03	8.671E+02	1.687E+02	1.102E+01
AG-110	0.000E+00	2.295E+01	8.332E+00	3.988E-01	2.516E-03	0.000E+00	2.294E+01	8.330E+00	3.987E-01	2.515E-03
AG-110M	4.752E+03	1.725E+03	6.265E+02	2.998E+01	1.892E-01	4.751E+03	1.725E+03	6.263E+02	2.997E+01	1.891E-01
CD-109	2.583E+03	1.497E+03	8.673E+02	1.688E+02	1.103E+01	2.582E+03	1.496E+03	8.671E+02	1.687E+02	1.102E+01
IN-113M	0.000E+00	1.114E+03	1.235E+02	1.683E-01	2.818E-06	0.000E+00	1.113E+03	1.234E+02	1.681E-01	2.815E-06
SN-113	1.004E+04	1.113E+03	1.234E+02	1.682E-01	2.816E-06	1.004E+04	1.113E+03	1.234E+02	1.681E-01	2.815E-06
SN-119M	4.480E+03	1.594E+03	5.673E+02	2.556E+01	1.458E-01	4.479E+03	1.594E+03	5.671E+02	2.556E+01	1.458E-01
SN-121	9.668E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.665E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-121M	5.915E+01	5.833E+01	5.753E+01	5.519E+01	5.149E+01	5.913E+01	5.832E+01	5.751E+01	5.517E+01	5.147E+01
SN-123	8.222E+03	1.158E+03	1.631E+02	4.558E-01	2.527E-05	8.220E+03	1.158E+03	1.631E+02	4.557E-01	2.526E-05
SN-123M	3.815E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.814E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-125	1.750E+04	2.520E+02	3.628E+00	1.083E-05	6.697E-15	1.750E+04	2.520E+02	3.627E+00	1.083E-05	6.696E-15
I-129	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04
XE-133	1.872E+05	2.046E-16	2.094E-37	0.000E+00	0.000E+00	1.872E+05	2.045E-16	0.000E+00	0.000E+00	0.000E+00
CS-134	1.294E+03	9.249E+02	6.608E+02	2.411E+02	4.489E+01	1.294E+03	9.246E+02	6.606E+02	2.410E+02	4.488E+01
CS-135	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03
CS-137	8.702E+01	8.503E+01	8.309E+01	7.753E+01	6.907E+01	8.700E+01	8.501E+01	8.307E+01	7.751E+01	6.905E+01
BA-137M	0.000E+00	8.044E+01	7.860E+01	7.334E+01	6.534E+01	0.000E+00	8.042E+01	7.858E+01	7.332E+01	6.532E+01
CE-141	2.850E+04	1.183E+01	4.909E-03	3.509E-13	4.322E-30	2.849E+04	1.182E+01	4.907E-03	3.508E-13	4.321E-30

Table 14. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	1	2	5	10	0	1	2	5	10
CE-142	2.401E-08	2.401E-08	2.401E-08	2.401E-08	2.401E-08	2.400E-08	2.400E-08	2.400E-08	2.400E-08	2.400E-08
SM-151	2.632E+01	2.612E+01	2.592E+01	2.532E+01	2.437E+01	2.631E+01	2.611E+01	2.591E+01	2.532E+01	2.436E+01
EU-154	2.700E+02	2.491E+02	2.298E+02	1.805E+02	1.206E+02	2.700E+02	2.491E+02	2.298E+02	1.804E+02	1.206E+02
EU-155	4.653E+02	4.046E+02	3.518E+02	2.313E+02	1.150E+02	4.651E+02	4.045E+02	3.517E+02	2.313E+02	1.150E+02
GD-153	3.528E+03	1.239E+03	4.354E+02	1.888E+01	1.011E-01	3.527E+03	1.239E+03	4.353E+02	1.887E+01	1.010E-01
TB-160	1.129E+04	3.405E+02	1.027E+01	2.814E-04	7.012E-12	1.129E+04	3.404E+02	1.026E+01	2.813E-04	7.010E-12
YB-169	2.414E+04	8.878E+00	3.265E-03	1.623E-13	1.091E-30	2.414E+04	8.876E+00	3.264E-03	1.623E-13	1.091E-30
HF-175	1.066E+04	2.865E+02	7.699E+00	1.494E-04	2.092E-12	1.066E+04	2.865E+02	7.697E+00	1.493E-04	2.092E-12
TA-182	6.241E+03	6.905E+02	7.640E+01	1.037E-01	1.718E-06	6.240E+03	6.903E+02	7.638E+01	1.034E-01	1.715E-06
IR-192	9.192E+03	3.006E+02	9.827E+00	3.435E-04	1.284E-11	9.190E+03	3.005E+02	9.824E+00	3.434E-04	1.283E-11
TOTAL	4.858E+07	5.225E+04	2.624E+04	1.255E+04	7.488E+03	4.857E+07	5.230E+04	2.629E+04	1.260E+04	7.541E+03

Table continues. Results at higher decay times shown on next page.

Table 14. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	20	50	80	100	0	20	50	80	100
H-3	9.654E+03	3.142E+03	5.832E+02	1.083E+02	3.524E+01	9.651E+03	3.141E+03	5.831E+02	1.082E+02	3.523E+01
C-14	4.459E+00	4.448E+00	4.432E+00	4.416E+00	4.405E+00	4.458E+00	4.447E+00	4.431E+00	4.415E+00	4.404E+00
NA-22	6.248E+03	3.034E+01	1.026E-02	3.469E-06	1.684E-08	6.246E+03	3.032E+01	1.025E-02	3.467E-06	1.683E-08
NA-24	8.709E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.706E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SI-32	1.719E+01	1.683E+01	1.630E+01	1.579E+01	1.546E+01	1.719E+01	1.683E+01	1.630E+01	1.578E+01	1.545E+01
P-32	0.000E+00	1.683E+01	1.630E+01	1.579E+01	1.546E+01	0.000E+00	1.683E+01	1.630E+01	1.578E+01	1.545E+01
S-35	4.241E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.240E+04	4.350E-21	0.000E+00	0.000E+00	0.000E+00
CL-36	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.300E-02	3.299E-02	3.299E-02	3.299E-02	3.299E-02
K-40	6.986E-06	6.986E-06	6.986E-06	6.986E-06	6.986E-06	6.984E-06	6.984E-06	6.984E-06	6.984E-06	6.984E-06
CA-45	1.781E+04	5.711E-10	3.279E-30	0.000E+00	0.000E+00	1.781E+04	5.710E-10	3.278E-30	0.000E+00	0.000E+00
SC-46	3.389E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.388E+04	1.938E-22	0.000E+00	0.000E+00	0.000E+00
V-50	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13
CR-51	9.244E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.241E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
MN-54	7.741E+03	7.111E-04	1.980E-14	5.512E-25	5.063E-32	7.739E+03	7.109E-04	1.979E-14	5.510E-25	5.062E-32
FE-55	2.501E+03	1.210E+01	4.067E-03	1.367E-06	6.609E-09	2.500E+03	1.209E+01	4.064E-03	1.366E-06	6.606E-09
FE-59	4.920E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.919E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CO-60	1.131E+03	8.148E+01	1.575E+00	3.045E-02	2.193E-03	1.131E+03	8.145E+01	1.575E+00	3.044E-02	2.193E-03
NI-59	7.577E-02	7.576E-02	7.574E-02	7.572E-02	7.571E-02	7.575E-02	7.574E-02	7.572E-02	7.570E-02	7.569E-02
NI-63	6.171E+01	5.307E+01	4.234E+01	3.377E+01	2.905E+01	6.169E+01	5.306E+01	4.233E+01	3.376E+01	2.904E+01
ZN-65	8.241E+03	7.918E-06	2.358E-19	7.024E-33	0.000E+00	8.239E+03	7.916E-06	2.358E-19	7.022E-33	0.000E+00
SE-75	1.454E+04	6.390E-15	0.000E+00	0.000E+00	0.000E+00	1.454E+04	6.388E-15	0.000E+00	0.000E+00	0.000E+00
SE-79	6.969E-02	6.968E-02	6.965E-02	6.963E-02	6.962E-02	6.967E-02	6.966E-02	6.963E-02	6.961E-02	6.960E-02
KR-81	2.104E-02	2.104E-02	2.104E-02	2.103E-02	2.103E-02	2.103E-02	2.103E-02	2.103E-02	2.103E-02	2.103E-02
KR-85	3.925E+02	1.077E+02	1.548E+01	2.225E+00	6.106E-01	3.924E+02	1.077E+02	1.548E+01	2.225E+00	6.104E-01
RB-86	8.141E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.139E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RB-87	8.754E-08	8.754E-08	8.754E-08	8.754E-08	8.754E-08	8.751E-08	8.751E-08	8.751E-08	8.751E-08	8.751E-08
SR-89	2.907E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.906E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SR-90	1.365E+02	8.477E+01	4.151E+01	2.033E+01	1.263E+01	1.364E+02	8.475E+01	4.150E+01	2.032E+01	1.262E+01

Table 14. (continued)

Nuclide	ORIGEN2 0	ORIGEN2 20	ORIGEN2 50	ORIGEN2 80	ORIGEN2 100	RADAC 0	RADAC 20	RADAC 50	RADAC 80	RADAC 100
Y-90	0.000E+00	8.479E+01	4.152E+01	2.033E+01	1.263E+01	0.000E+00	8.475E+01	4.150E+01	2.032E+01	1.262E+01
Y-91	2.454E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.453E+04	6.368E-34	0.000E+00	0.000E+00	0.000E+00
NB-94	1.874E-01	1.873E-01	1.871E-01	1.869E-01	1.868E-01	1.874E-01	1.873E-01	1.871E-01	1.869E-01	1.867E-01
MO-93	1.099E+00	1.095E+00	1.088E+00	1.082E+00	1.078E+00	1.099E+00	1.095E+00	1.088E+00	1.082E+00	1.077E+00
TC-99	1.696E-02	1.696E-02	1.696E-02	1.696E-02	1.695E-02	1.696E-02	1.695E-02	1.695E-02	1.695E-02	1.695E-02
RU-106	3.316E+03	4.014E-03	5.346E-12	7.121E-21	8.620E-27	3.315E+03	4.013E-03	5.345E-12	7.119E-21	8.617E-27
RH-106	0.000E+00	4.014E-03	5.346E-12	7.121E-21	8.620E-27	0.000E+00	4.013E-03	5.345E-12	7.119E-21	8.617E-27
PD-107	5.145E-04	5.145E-04	5.145E-04	5.145E-04	5.145E-04	5.144E-04	5.144E-04	5.144E-04	5.144E-04	5.144E-04
AG-108	0.000E+00	2.081E+00	1.766E+00	1.500E+00	1.345E+00	0.000E+00	2.080E+00	1.766E+00	1.499E+00	1.344E+00
AG-108M	2.607E+01	2.338E+01	1.985E+01	1.685E+01	1.511E+01	2.607E+01	2.337E+01	1.984E+01	1.684E+01	1.510E+01
AG-109M	0.000E+00	4.708E-02	3.665E-09	2.852E-16	5.199E-21	0.000E+00	4.707E-02	3.664E-09	2.851E-16	5.198E-21
AG-110	0.000E+00	1.001E-07	6.315E-21	6.429E-34	0.000E+00	0.000E+00	1.001E-07	6.313E-21	3.981E-34	0.000E+00
AG-110M	4.752E+03	7.529E-06	4.748E-19	2.994E-32	0.000E+00	4.751E+03	7.527E-06	4.746E-19	2.993E-32	0.000E+00
CD-109	2.583E+03	4.708E-02	3.665E-09	2.852E-16	5.199E-21	2.582E+03	4.707E-02	3.664E-09	2.851E-16	5.198E-21
IN-113M	0.000E+00	7.898E-16	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.891E-16	0.000E+00	0.000E+00	0.000E+00
SN-113	1.004E+04	7.893E-16	0.000E+00	0.000E+00	0.000E+00	1.004E+04	7.891E-16	0.000E+00	0.000E+00	0.000E+00
SN-119M	4.480E+03	4.748E-06	1.638E-19	5.653E-33	0.000E+00	4.479E+03	4.747E-06	1.638E-19	5.651E-33	0.000E+00
SN-121	9.668E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.665E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-121M	5.915E+01	4.482E+01	2.956E+01	1.950E+01	1.478E+01	5.913E+01	4.481E+01	2.955E+01	1.949E+01	1.477E+01
SN-123	8.222E+03	7.768E-14	0.000E+00	0.000E+00	0.000E+00	8.220E+03	7.765E-14	0.000E+00	0.000E+00	0.000E+00
SN-123M	3.815E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.814E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-125	1.750E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.750E+04	2.562E-33	0.000E+00	0.000E+00	0.000E+00
I-129	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04
XE-133	1.872E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.872E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CS-134	1.294E+03	1.556E+00	6.490E-05	2.707E-09	3.279E-12	1.294E+03	1.556E+00	6.491E-05	2.707E-09	3.256E-12
CS-135	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03
CS-137	8.702E+01	5.482E+01	2.741E+01	1.370E+01	8.633E+00	8.700E+01	5.480E+01	2.740E+01	1.370E+01	8.631E+00
BA-137M	0.000E+00	5.186E+01	2.593E+01	1.296E+01	8.167E+00	0.000E+00	5.184E+01	2.592E+01	1.296E+01	8.165E+00

Calculated radioactivity (Ci) at decay times shown (years)

Table 14. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	20	50	80	100	0	20	50	80	100
CE-141	2.850E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.849E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CE-142	2.401E-08	2.401E-08	2.401E-08	2.401E-08	2.401E-08	2.400E-08	2.400E-08	2.400E-08	2.400E-08	2.400E-08
SM-151	2.632E+01	2.256E+01	1.791E+01	1.421E+01	1.218E+01	2.631E+01	2.255E+01	1.790E+01	1.421E+01	1.218E+01
EU-154	2.700E+02	5.387E+01	4.800E+00	4.278E-01	8.534E-02	2.700E+02	5.386E+01	4.799E+00	4.276E-01	8.531E-02
EU-155	4.653E+02	2.842E+01	4.292E-01	6.480E-03	3.959E-04	4.651E+02	2.842E+01	4.291E-01	6.478E-03	3.958E-04
GD-153	3.528E+03	2.892E-06	6.786E-20	1.593E-33	0.000E+00	3.527E+03	2.891E-06	6.784E-20	1.592E-33	0.000E+00
TB-160	1.129E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.129E+04	4.352E-27	0.000E+00	0.000E+00	0.000E+00
YB-169	2.414E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.414E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
HF-175	1.066E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.066E+04	4.104E-28	0.000E+00	0.000E+00	0.000E+00
TA-182	6.241E+03	4.713E-16	0.000E+00	0.000E+00	0.000E+00	6.240E+03	4.712E-16	0.000E+00	0.000E+00	0.000E+00
IR-192	9.192E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.190E+03	1.792E-26	0.000E+00	0.000E+00	0.000E+00
TOTAL	4.858E+07	3.919E+03	8.919E+02	3.016E+02	1.873E+02	4.857E+07	3.918E+03	8.916E+02	3.015E+02	1.872E+02

Table continues. Results at higher decay times shown on next page.

Table 14. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	120	160	300	500	0	120	160	300	500
H-3	9.654E+03	1.145E+01	1.212E+00	4.686E-04	6.243E-09	9.651E+03	1.146E+01	1.214E+00	4.693E-04	6.252E-09
C-14	4.459E+00	4.395E+00	4.373E+00	4.300E+00	4.197E+00	4.458E+00	4.393E+00	4.372E+00	4.299E+00	4.196E+00
NA-22	6.248E+03	8.170E-11	1.925E-15	1.222E-31	0.000E+00	6.246E+03	8.168E-11	1.924E-15	1.221E-31	0.000E+00
NA-24	8.709E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.706E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SI-32	1.719E+01	1.513E+01	1.450E+01	1.249E+01	1.009E+01	1.719E+01	1.513E+01	1.449E+01	1.248E+01	1.009E+01
P-32	0.000E+00	1.513E+01	1.450E+01	1.249E+01	1.009E+01	0.000E+00	1.513E+01	1.449E+01	1.248E+01	1.009E+01
S-35	4.241E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.240E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CL-36	3.300E-02	3.300E-02	3.299E-02	3.298E-02	3.297E-02	3.300E-02	3.299E-02	3.298E-02	3.297E-02	3.296E-02
K-40	6.986E-06	6.986E-06	6.986E-06	6.986E-06	6.986E-06	6.984E-06	6.984E-06	6.984E-06	6.984E-06	6.984E-06
CA-45	1.781E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.781E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SC-46	3.389E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.388E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
V-50	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13
CR-51	9.244E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.241E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
MN-54	7.741E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.739E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
FE-55	2.501E+03	3.195E-11	7.468E-16	4.612E-32	0.000E+00	2.500E+03	3.194E-11	7.467E-16	4.612E-32	0.000E+00
FE-59	4.920E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.919E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CO-60	1.131E+03	1.580E-04	8.197E-07	8.246E-15	3.100E-26	1.131E+03	1.579E-04	8.194E-07	8.243E-15	3.099E-26
NI-59	7.577E-02	7.569E-02	7.567E-02	7.558E-02	7.545E-02	7.575E-02	7.567E-02	7.565E-02	7.555E-02	7.542E-02
NI-63	6.171E+01	2.499E+01	1.848E+01	6.437E+00	1.427E+00	6.169E+01	2.498E+01	1.848E+01	6.436E+00	1.426E+00
ZN-65	8.241E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.239E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE-75	1.454E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.454E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE-79	6.969E-02	6.960E-02	6.957E-02	6.947E-02	6.932E-02	6.967E-02	6.958E-02	6.955E-02	6.945E-02	6.930E-02
KR-81	2.104E-02	2.103E-02	2.103E-02	2.102E-02	2.100E-02	2.103E-02	2.102E-02	2.102E-02	2.101E-02	2.100E-02
KR-85	3.925E+02	1.675E-01	1.262E-02	1.478E-06	3.576E-12	3.924E+02	1.675E-01	1.261E-02	1.477E-06	3.575E-12
RB-86	8.141E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.139E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RB-87	8.754E-08	8.754E-08	8.754E-08	8.754E-08	8.754E-08	8.751E-08	8.751E-08	8.751E-08	8.751E-08	8.751E-08
SR-89	2.907E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.906E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SR-90	1.365E+02	7.844E+00	3.027E+00	1.081E-01	9.256E-04	1.364E+02	7.842E+00	3.027E+00	1.081E-01	9.254E-04

Table 14. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	120	160	300	500	0	120	160	300	500
Y-90	0.000E+00	7.846E+00	3.028E+00	1.081E-01	9.259E-04	0.000E+00	7.842E+00	3.027E+00	1.081E-01	9.254E-04
Y-91	2.454E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.453E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NB-94	1.874E-01	1.867E-01	1.864E-01	1.855E-01	1.843E-01	1.874E-01	1.866E-01	1.864E-01	1.855E-01	1.842E-01
MO-93	1.099E+00	1.073E+00	1.065E+00	1.036E+00	9.956E-01	1.099E+00	1.073E+00	1.065E+00	1.036E+00	9.953E-01
TC-99	1.696E-02	1.695E-02	1.695E-02	1.694E-02	1.693E-02	1.696E-02	1.695E-02	1.695E-02	1.694E-02	1.693E-02
RU-106	3.316E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.315E+03	1.043E-32	0.000E+00	0.000E+00	0.000E+00
RH-106	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.043E-32	0.000E+00	0.000E+00	0.000E+00
PD-107	5.145E-04	5.145E-04	5.145E-04	5.145E-04	5.145E-04	5.144E-04	5.144E-04	5.144E-04	5.144E-04	5.144E-04
AG-108	0.000E+00	1.206E+00	9.691E-01	4.514E-01	1.515E-01	0.000E+00	1.205E+00	9.688E-01	4.512E-01	1.515E-01
AG-108M	2.607E+01	1.355E+01	1.089E+01	5.072E+00	1.703E+00	2.607E+01	1.354E+01	1.089E+01	5.070E+00	1.702E+00
AG-109M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.476E-26	0.000E+00	0.000E+00	0.000E+00
AG-110	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
AG-110M	4.752E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.751E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CD-109	2.583E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.582E+03	9.476E-26	0.000E+00	0.000E+00	0.000E+00
IN-113M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-113	1.004E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.004E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+0
SN-119M	4.480E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.479E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-121	9.668E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.665E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-121M	5.915E+01	1.120E+01	6.428E+00	9.221E-01	5.754E-02	5.913E+01	1.119E+01	6.427E+00	9.218E-01	5.752E-02
SN-123	8.222E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.220E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-123M	3.815E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.814E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-125	1.750E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.750E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-129	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04	1.766E-04
XE-133	1.872E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.872E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CS-134	1.294E+03	3.916E-15	5.664E-21	0.000E+00	0.000E+00	1.294E+03	3.915E-15	5.663E-21	0.000E+00	0.000E+00
CS-135	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.152E-03	1.151E-03	1.151E-03
CS-137	8.702E+01	5.438E+00	2.158E+00	8.496E-02	8.361E-04	8.700E+01	5.437E+00	2.158E+00	8.494E-02	8.360E-04
BA-137M	0.000E+00	5.145E+00	2.042E+00	8.038E-02	7.910E-04	0.000E+00	5.143E+00	2.041E+00	8.035E-02	7.908E-04

Table 14. (continued)

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	120	160	300	500	0	120	160	300	500
CE-141	2.850E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.849E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CE-142	2.401E-08	2.401E-08	2.401E-08	2.401E-08	2.401E-08	2.400E-08	2.400E-08	2.400E-08	2.400E-08	2.400E-08
SM-151	2.632E+01	1.044E+01	7.675E+00	2.611E+00	5.595E-01	2.631E+01	1.044E+01	7.673E+00	2.610E+00	5.593E-01
EU-154	2.700E+02	1.702E-02	6.776E-04	8.522E-09	8.511E-16	2.700E+02	1.702E-02	6.774E-04	8.520E-09	8.509E-16
EU-155	4.653E+02	2.418E-05	9.029E-08	2.867E-16	2.076E-28	4.651E+02	2.418E-05	9.023E-08	2.865E-16	2.074E-28
GD-153	3.528E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.527E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TB-160	1.129E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.129E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
YB-169	2.414E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.414E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
HF-175	1.066E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.066E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TA-182	6.241E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.240E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
IR-192	9.192E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.190E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL	4.858E+07	1.354E+02	9.076E+01	4.659E+01	2.967E+01	4.857E+07	1.354E+02	9.074E+01	4.658E+01	2.966E+01

Table continues. Results at higher decay times shown on next page.

Table 14. (continued)

Nuclide	ORIGEN2 0	ORIGEN2 1,000	ORIGEN2 10,000	ORIGEN2 100,000	ORIGEN2 1,000,000	RADAC 0	RADAC 1,000	RADAC 10,000	RADAC 100,000	RADAC 1,000,000
	Calculated radioactivity (Ci) at decay times shown (years)									
H-3	9.654E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.651E+03	4.050E-21	0.000E+00	0.000E+00	0.000E+00
C-14	4.459E+00	3.951E+00	1.330E+00	2.483E-05	0.000E+00	4.458E+00	3.950E+00	1.329E+00	2.482E-05	0.000E+00
NA-22	6.248E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.246E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NA-24	8.709E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.706E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SI-32	1.719E+01	5.919E+00	4.019E-04	0.000E+00	0.000E+00	1.719E+01	5.918E+00	4.017E-04	0.000E+00	0.000E+00
P-32	0.000E+00	5.920E+00	4.020E-04	0.000E+00	0.000E+00	0.000E+00	5.918E+00	4.017E-04	0.000E+00	0.000E+00
S-35	4.241E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.240E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CL-36	3.300E-02	3.293E-02	3.225E-02	2.622E-02	3.300E-03	3.300E-02	3.292E-02	3.224E-02	2.621E-02	3.299E-03
K-40	6.986E-06	6.986E-06	6.986E-06	6.986E-06	6.982E-06	6.984E-06	6.984E-06	6.984E-06	6.984E-06	6.980E-06
CA-45	1.781E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.781E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SC-46	3.389E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.388E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
V-50	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13	1.788E-13
CR-51	9.244E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.241E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
MN-54	7.741E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.739E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
FE-55	2.501E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.500E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
FE-59	4.920E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.919E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CO-60	1.131E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.131E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NI-59	7.577E-02	7.512E-02	6.948E-02	3.186E-02	1.308E-05	7.575E-02	7.510E-02	6.946E-02	3.185E-02	1.308E-05
NI-63	6.171E+01	3.298E-02	0.000E+00	0.000E+00	0.000E+00	6.169E+01	3.297E-02	1.174E-31	0.000E+00	0.000E+00
ZN-65	8.241E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.239E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE-75	1.454E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.454E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SE-79	6.969E-02	6.895E-02	6.264E-02	2.398E-02	1.619E-06	6.967E-02	6.893E-02	6.262E-02	2.397E-02	1.618E-06
KR-81	2.104E-02	2.097E-02	2.036E-02	1.512E-02	7.738E-04	2.103E-02	2.096E-02	2.035E-02	1.512E-02	7.736E-04
KR-85	3.925E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.924E+02	3.257E-26	0.000E+00	0.000E+00	0.000E+00
RB-86	8.141E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.139E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RB-87	8.754E-08	8.754E-08	8.754E-08	8.754E-08	8.754E-08	8.751E-08	8.751E-08	8.751E-08	8.751E-08	8.751E-08
SR-89	2.907E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.906E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SR-90	1.365E+02	6.279E-09	0.000E+00	0.000E+00	0.000E+00	1.364E+02	6.278E-09	0.000E+00	0.000E+00	0.000E+00

Table 14. (continued)

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	1,000	10,000	100,000	1,000,000	0	1,000	10,000	100,000	1,000,000
Y-90	0.000E+00	6.281E-09	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.278E-09	0.000E+00	0.000E+00	0.000E+00
Y-91	2.454E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.453E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NB-94	1.874E-01	1.811E-01	1.332E-01	6.164E-03	2.775E-16	1.874E-01	1.811E-01	1.332E-01	6.163E-03	2.775E-16
MO-93	1.099E+00	9.017E-01	1.516E-01	2.730E-09	0.000E+00	1.099E+00	9.014E-01	1.515E-01	2.730E-09	0.000E+00
TC-99	1.696E-02	1.690E-02	1.642E-02	1.225E-02	6.549E-04	1.696E-02	1.690E-02	1.641E-02	1.225E-02	6.547E-04
RU-106	3.316E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.315E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RH-106	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
PD-107	5.145E-04	5.145E-04	5.140E-04	5.091E-04	4.625E-04	5.144E-04	5.143E-04	5.138E-04	5.089E-04	4.623E-04
AG-108	0.000E+00	9.894E-03	4.605E-24	0.000E+00	0.000E+00	0.000E+00	9.892E-03	4.607E-24	0.000E+00	0.000E+00
AG-108M	2.607E+01	1.111E-01	5.174E-23	0.000E+00	0.000E+00	2.607E+01	1.111E-01	5.176E-23	0.000E+00	0.000E+00
AG-109M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
AG-110	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
AG-110M	4.752E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.751E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CD-109	2.583E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.582E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
IN-113M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-113	1.004E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.004E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-119M	4.480E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.479E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-121	9.668E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.665E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-121M	5.915E+01	5.597E-05	0.000E+00	0.000E+00	0.000E+00	5.913E+01	5.596E-05	0.000E+00	0.000E+00	0.000E+00
SN-123	8.222E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.220E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SN-123M	3.815E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.814E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-125	1.750E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.750E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-129	1.766E-04	1.766E-04	1.765E-04	1.758E-04	1.690E-04	1.766E-04	1.766E-04	1.765E-04	1.758E-04	1.689E-04
XE-133	1.872E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.872E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CS-134	1.294E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.294E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CS-135	1.152E-03	1.152E-03	1.148E-03	1.118E-03	8.522E-04	1.152E-03	1.151E-03	1.148E-03	1.117E-03	8.519E-04
CS-137	8.702E+01	8.035E-09	0.000E+00	0.000E+00	0.000E+00	8.700E+01	8.033E-09	0.000E+00	0.000E+00	0.000E+00
BA-137M	0.000E+00	7.601E-09	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.599E-09	0.000E+00	0.000E+00	0.000E+00

Table 14. (continued)

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	1,000	10,000	100,000	1,000,000	0	1,000	10,000	100,000	1,000,000
CE-141	2.850E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.849E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CE-142	2.401E-08	2.401E-08	2.401E-08	2.401E-08	2.401E-08	2.400E-08	2.400E-08	2.400E-08	2.400E-08	2.400E-08
SM-151	2.632E+01	1.189E-02	0.000E+00	0.000E+00	0.000E+00	2.631E+01	1.189E-02	9.337E-33	0.000E+00	0.000E+00
EU-154	2.700E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.700E+02	2.682E-33	0.000E+00	0.000E+00	0.000E+00
EU-155	4.653E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.651E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
GD-153	3.528E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.527E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TB-160	1.129E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.129E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
YB-169	2.414E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.414E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
HF-175	1.066E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.066E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TA-182	6.241E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.240E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
IR-192	9.192E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.190E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL	4.858E+07	1.726E+01	1.818E+00	1.174E-01	6.234E-03	4.857E+07	1.725E+01	1.818E+00	1.174E-01	6.232E-03

[a]The quantities at zero years show the nuclide feeds in curies. Feed of each parent nuclide is 1.0 g. Daughter nuclides have zero feeds. The parent nuclides listed in this table are of type 10. Their decay chains are relatively simple.

7.3.3 Long-Chain Fission and Activation Products

A set of decay runs similar to those reported in Table 14 was made for type-13 fission and activation products, which have more complicated decay chains than those of type 10. The results of these runs are shown in Table 15. Again, the feed of each parent nuclide was 1.0 g; and again, very good agreement was obtained between the results of ORIGEN2 and RADAC. Because one of the integer-array Bateman (IBAT) codes was used to develop yield factors for some of these fission and activation products, these results provide some degree of verification of the algorithms used in the IBAT codes. This includes the algorithm for the summation of different paths to the same "to" nuclide.

7.3.4 Actinides

This section shows the results of ORIGEN2 and RADAC runs on ^{244}Pu, ^{249}Bk, ^{243}Cm, ^{246}Cm, and ^{239}Pu. The results of RADAC are compared with those of ORIGEN2 using a single actinide as input in each case. The five actinides listed were chosen as representative of the four actinide decay series and of long-lived TRU nuclides found in typical DOE-defense TRU wastes. Also, they have decay chains long enough to test the decay capabilities of the codes. Comparisons of the results of the two codes for each actinide are given in the subsections that follow.

7.3.4.1 Actinide ^{244}Pu (see Fig. 5)

Table 16 shows ORIGEN2 and RADAC results for an input of 1 gram of ^{244}Pu. For decay times from 10 to 160 years, the agreement between ORIGEN2 and RADAC results for nuclides from ^{232}Th to ^{244}Pu is within 1 or 2 in the fourth significant figure except for ^{240}Np, which was not shown in the ORIGEN2 results. This occurred because the ORIGEN2 decay library does not include ^{240}Np. When the ORIGEN2 decay library was modified to show ^{240}Np, ORIGEN2 showed the same curie quantities for ^{240}Np as those shown by RADAC. From 10 to 160 years, ORIGEN2 does not report curies for nuclides from ^{208}Tl to ^{228}Th because their quantities are below the cut-off point. At 300 years and above, differences appear in the curies shown by the two codes. These differences are essentially all in nuclides from ^{208}Tl to ^{228}Th, and become negligible above 1,000 years. The agreement at 100,000 years is excellent. At 1 million years, the differences in the results shown by the two codes is less than 1%. Overall, ORIGEN2 and RADAC show good to excellent agreement for the ^{244}Pu chain.

(Text continued on page 133)

Table 15. Results of ORIGEN2 and RADAC decay calculations for long-chain fission and activation products[a]

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	1	2	5	10	0	1	2	5	10
ZR-93	2.514E-03	2.514E-03	2.514E-03	2.514E-03	2.514E-03	2.513E-03	2.513E-03	2.513E-03	2.513E-03	2.513E-03
ZR-95	2.149E+04	4.109E+02	7.858E+00	5.493E-05	1.404E-13	2.149E+04	4.108E+02	7.856E+00	5.492E-05	1.404E-13
NB-93M	0.000E+00	1.187E-04	2.314E-04	5.372E-04	9.535E-04	0.000E+00	1.186E-04	2.313E-04	5.370E-04	9.532E-04
NB-95	0.000E+00	8.765E+02	1.741E+01	1.220E-04	3.117E-13	0.000E+00	8.766E+02	1.741E+01	1.219E-04	3.117E-13
NB-95M	0.000E+00	3.049E+00	5.829E-02	4.075E-07	1.042E-15	0.000E+00	3.048E+00	5.828E-02	4.074E-07	1.041E-15
RU-103	3.229E+04	5.135E+01	8.185E-02	3.281E-10	3.320E-24	3.228E+04	5.127E+01	8.145E-02	3.265E-10	3.303E-24
RH-103M	0.000E+00	4.629E+01	7.379E-02	2.958E-10	2.993E-24	0.000E+00	4.622E+01	7.343E-02	2.944E-10	2.978E-24
SB-125	1.033E+03	8.043E+02	6.262E+02	2.956E+02	8.458E+01	1.033E+03	8.041E+02	6.260E+02	2.955E+02	8.456E+01
TE-125M	0.000E+00	1.930E+02	1.527E+02	7.212E+01	2.064E+01	0.000E+00	1.930E+02	1.527E+02	7.210E+01	2.063E+01
TE-127	0.000E+00	9.060E+02	8.880E+01	8.363E-02	7.568E-07	0.000E+00	9.057E+02	8.878E+01	8.361E-02	7.566E-07
TE-127M	9.436E+03	9.249E+02	9.066E+01	8.538E-02	7.726E-07	9.434E+03	9.247E+02	9.064E+01	8.536E-02	7.724E-07
I-131	1.240E+05	2.623E-09	5.549E-23	0.000E+00	0.000E+00	1.240E+05	2.622E-09	5.547E-23	0.000E+00	0.000E+00
XE-131M	0.000E+00	1.647E-06	9.456E-16	0.000E+00	0.000E+00	0.000E+00	1.647E-06	9.453E-16	0.000E+00	0.000E+00
CE-144	3.191E+03	1.310E+03	5.375E+02	3.715E+01	4.325E-01	3.190E+03	1.309E+03	5.373E+02	3.714E+01	4.324E-01
PR-144	0.000E+00	1.294E+03	5.311E+02	3.671E+01	4.273E-01	0.000E+00	1.294E+03	5.309E+02	3.670E+01	4.272E-01
ND-144	0.000E+00	6.894E-13	9.723E-13	1.156E-12	1.169E-12	0.000E+00	6.892E-13	9.720E-13	1.155E-12	1.169E-12
PM-147	9.274E+02	7.121E+02	5.467E+02	2.475E+02	6.604E+01	9.271E+02	7.119E+02	5.466E+02	2.474E+02	6.602E+01
SM-147	0.000E+00	5.279E-09	9.332E-09	1.667E-08	2.112E-08	0.000E+00	5.278E-09	9.330E-09	1.666E-08	2.111E-08
EU-152	1.730E+02	1.644E+02	1.562E+02	1.341E+02	1.039E+02	1.730E+02	1.644E+02	1.562E+02	1.340E+02	1.039E+02
GD-152	0.000E+00	3.016E-13	5.882E-13	1.365E-12	2.424E-12	0.000E+00	3.015E-13	5.881E-13	1.365E-12	2.423E-12
TOTAL	1.926E+05	7.729E+03	2.756E+03	8.233E+02	2.760E+02	1.925E+05	7.695E+03	2.755E+03	8.231E+02	2.760E+02

[a] Table continues. Results at higher decay times shown on next page.

Table 15. (continued)

Nuclide	ORIGEN2					RADAC				
	Calculated radioactivity (Ci) at decay times shown (years)									
	0	20	50	80	100	0	20	50	80	100
ZR-93	2.514E-03	2.514E-03	2.514E-03	2.514E-03	2.514E-03	2.513E-03	2.513E-03	2.513E-03	2.513E-03	2.513E-03
ZR-95	2.149E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.149E+04	9.172E-31	0.000E+00	0.000E+00	0.000E+00
NB-93M	0.000E+00	1.526E-03	2.201E-03	2.347E-03	2.373E-03	0.000E+00	1.526E-03	2.201E-03	2.347E-03	2.373E-03
NB-95	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.036E-30	0.000E+00	0.000E+00	0.000E+00
NB-95M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.804E-33	0.000E+00	0.000E+00	0.000E+00
RU-103	3.229E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.228E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RH-103M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SB-125	1.033E+03	6.925E+00	3.802E-03	2.087E-06	1.400E-08	1.033E+03	6.924E+00	3.801E-03	2.087E-06	1.399E-08
TE-125M	0.000E+00	1.690E+00	9.277E-04	5.093E-07	3.415E-09	0.000E+00	1.689E+00	9.275E-04	5.092E-07	3.414E-09
TE-127	0.000E+00	6.196E-17	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.194E-17	0.000E+00	0.000E+00	0.000E+00
TE-127M	9.436E+03	6.326E-17	0.000E+00	0.000E+00	0.000E+00	9.434E+03	6.324E-17	0.000E+00	0.000E+00	0.000E+00
I-131	1.240E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.240E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
XE-131M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CE-144	3.191E+03	5.861E-05	1.459E-16	3.631E-28	6.669E-36	3.190E+03	5.860E-05	1.458E-16	3.630E-28	0.000E+00
PR-144	0.000E+00	5.791E-05	1.441E-16	3.588E-28	0.000E+00	0.000E+00	5.789E-05	1.441E-16	3.587E-28	0.000E+00
ND-144	0.000E+00	1.169E-12	1.169E-12	1.169E-12	1.169E-12	0.000E+00	1.169E-12	1.169E-12	1.169E-12	1.169E-12
PM-147	9.274E+02	4.704E+00	1.699E-03	6.134E-07	3.111E-09	9.271E+02	4.701E+00	1.698E-03	6.131E-07	3.109E-09
SM-147	0.000E+00	2.262E-08	2.274E-08	2.274E-08	2.274E-08	0.000E+00	2.261E-08	2.273E-08	2.273E-08	2.273E-08
EU-152	1.730E+02	6.243E+01	1.353E+01	2.933E+00	1.058E+00	1.730E+02	6.241E+01	1.353E+01	2.932E+00	1.058E+00
GD-152	0.000E+00	3.880E-12	5.595E-12	5.967E-12	6.033E-12	0.000E+00	3.879E-12	5.594E-12	5.966E-12	6.031E-12
TOTAL	1.926E+05	7.575E+01	1.354E+01	2.938E+00	1.063E+00	1.925E+05	7.573E+01	1.354E+01	2.937E+00	1.063E+00

Table continues. Results at higher decay times shown on next page.

Table 15. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	120	160	300	500	0	120	160	300	500
ZR-93	2.514E-03	2.514E-03	2.513E-03	2.513E-03	2.513E-03	2.513E-03	2.513E-03	2.513E-03	2.513E-03	2.512E-03
ZR-95	2.149E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.149E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NB-93M	0.000E+00	2.383E-03	2.387E-03	2.390E-03	2.388E-03	0.000E+00	2.382E-03	2.386E-03	2.387E-03	2.387E-03
NB-95	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NB-95M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RU-103	3.229E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.228E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RH-103M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SB-125	1.033E+03	9.384E-11	4.219E-15	2.570E-30	0.000E+00	1.033E+03	9.382E-11	4.217E-15	2.569E-30	0.000E+00
TE-125M	0.000E+00	2.290E-11	1.029E-15	6.270E-31	0.000E+00	0.000E+00	2.289E-11	1.029E-15	6.268E-31	0.000E+00
TE-127	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TE-127M	9.436E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.434E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-131	1.240E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.240E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
XE-131M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CE-44	3.191E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.190E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
PR144	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ND-144	0.000E+00	1.169E-12	1.169E-12	1.169E-12	1.169E-12	0.000E+00	1.169E-12	1.169E-12	1.169E-12	1.169E-12
PM-147	9.274E+02	1.577E-11	4.055E-16	3.496E-32	0.000E+00	9.271E+02	1.576E-11	4.054E-16	3.495E-32	0.000E+00
SM-147	0.000E+00	2.274E-08	2.274E-08	2.274E-08	2.274E-08	0.000E+00	2.273E-08	2.273E-08	2.273E-08	2.273E-08
SM-148	0.000E+00	5.281E-26	7.382E-26	1.474E-25	2.526E-25	0.000E+00	5.279E-26	7.380E-26	1.474E-25	2.525E-25
EU-152	1.730E+02	3.818E-01	4.971E-02	3.960E-05	1.482E-09	1.730E+02	3.818E-01	4.972E-02	3.961E-05	1.483E-09
GD-152	0.000E+00	6.057E-12	6.068E-12	6.070E-12	6.070E-12	0.000E+00	6.055E-12	6.067E-12	6.068E-12	6.068E-12
TOTAL	1.926E+05	3.867E-01	5.461E-02	4.943E-03	4.901E-03	1.925E+05	3.867E-01	5.462E-02	4.939E-03	4.899E-03

Table continues. Results at higher decay times shown on next page.

Table 15. (continued)

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	1,000	10,000	100,000	1,000,000	0	1,000	10,000	100,000	1,000,000
ZR-93	2.514E-03	2.513E-03	2.502E-03	2.402E-03	1.598E-03	2.513E-03	2.512E-03	2.502E-03	2.402E-03	1.597E-03
ZR-95	2.149E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.149E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NB-93M	0.000E+00	2.387E-03	2.377E-03	2.282E-03	1.518E-03	0.000E+00	2.386E-03	2.377E-03	2.282E-03	1.518E-03
NB-95	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
NB-95M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RU-103	3.229E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.228E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
RH-103M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SB-125	1.033E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.033E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TE-125M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TE-127	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TE-127M	9.436E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.434E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
I-131	1.240E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.240E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
XE-131M	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CE-144	3.191E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.190E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
PR-144	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ND-144	0.000E+00	1.169E-12	1.169E-12	1.169E-12	1.169E-12	0.000E+00	1.169E-12	1.169E-12	1.169E-12	1.169E-12
PM-147	9.274E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.271E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SM-147	0.000E+00	2.274E-08	2.274E-08	2.274E-08	2.274E-08	0.000E+00	2.273E-08	2.273E-08	2.273E-08	2.273E-08
SM-148	0.000E+00	5.156E-25	5.248E-24	5.258E-23	5.259E-22	0.000E+00	5.154E-25	5.247E-24	5.256E-23	5.257E-22
EU-152	1.730E+02	1.271E-20	0.000E+00	0.000E+00	0.000E+00	1.730E+02	1.271E-20	0.000E+00	0.000E+00	0.000E+00
GD-152	0.000E+00	6.070E-12	6.070E-12	6.070E-12	6.070E-12	0.000E+00	6.068E-12	6.068E-12	6.068E-12	6.068E-12
TOTAL	1.926E+05	4.899E-03	4.880E-03	4.685E-03	3.116E-03	1.925E+05	4.898E-03	4.878E-03	4.683E-03	3.115E-03

[a]The quantities at zero years show the nuclide feeds in curies. Feed of each parent nuclide is 1.0 g. Daughter nuclides have zero feeds. The parent nuclides listed in this table are of type 13; their decay chains are more complex than those of the nuclides listed in Table 14.

Table 16. Results of ORIGEN2 and RADAC calculations for decay of actinide $^{244}Pu^{a}$

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	10	20	30	40	0	10	20	30	40
TL-208	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.566E-26	3.012E-25	1.515E-24	4.523E-24
PB-212	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.358E-26	8.383E-25	4.217E-24	1.259E-23
BI-212	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.358E-26	8.383E-25	4.217E-24	1.259E-23
PO-212	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.792E-26	5.371E-25	2.702E-24	8.066E-24
PO-216	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.358E-26	8.383E-25	4.217E-24	1.259E-23
RN-220	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.358E-26	8.383E-25	4.217E-24	1.259E-23
RA-224	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.358E-26	8.383E-25	4.217E-24	1.259E-23
RA-228	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.742E-26	1.315E-24	5.731E-24	1.585E-23
AC-228	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	9.742E-26	1.315E-24	5.731E-24	1.585E-23
TH-228	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.385E-26	8.407E-25	4.225E-24	1.261E-23
TH-232	0.000E+00	4.571E-25	3.656E-24	1.234E-23	2.924E-23	0.000E+00	4.570E-25	3.656E-24	1.233E-23	2.923E-23
U-236	0.000E+00	2.779E-15	1.112E-14	2.500E-14	4.443E-14	0.000E+00	2.779E-15	1.111E-14	2.500E-14	4.443E-14
U-240	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05
NP-240	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.952E-08	1.952E-08	1.952E-08	1.952E-08
NP-240M	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05
PU-240	0.000E+00	1.877E-08	3.753E-08	5.627E-08	7.499E-08	0.000E+00	1.877E-08	3.753E-08	5.626E-08	7.498E-08
PU-244	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05
TOTAL	1.774E-05	5.320E-05	5.322E-05	5.324E-05	5.326E-05	1.774E-05	5.322E-05	5.323E-05	5.325E-05	5.327E-05

Table continues. Results at higher decay times shown on next page.

Table 16. (continued)

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	50	60	80	100	0	50	60	80	100
TL-208	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.027E-23	1.971E-23	5.362E-23	1.141E-22
PB-212	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.857E-23	5.486E-23	1.492E-22	3.175E-22
BI-212	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.857E-23	5.486E-23	1.492E-22	3.175E-22
PO-212	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.831E-23	3.515E-23	9.561E-23	2.034E-22
PO-216	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.857E-23	5.486E-23	1.492E-22	3.175E-22
RN-220	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.857E-23	5.486E-23	1.492E-22	3.175E-22
RA-224	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.857E-23	5.486E-23	1.492E-22	3.175E-22
RA-228	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.432E-23	6.385E-23	1.670E-22	3.470E-22
AC-228	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.432E-23	6.385E-23	1.670E-22	3.470E-22
TH-228	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.860E-23	5.491E-23	1.493E-22	3.176E-22
TH-232	0.000E+00	5.709E-23	9.862E-23	2.336E-22	4.561E-22	0.000E+00	5.708E-23	9.860E-23	2.336E-22	4.560E-22
U-236	0.000E+00	6.940E-14	9.990E-14	1.775E-13	2.771E-13	0.000E+00	6.939E-14	9.989E-14	1.775E-13	2.771E-13
U-240	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05
NP-240	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.952E-08	1.952E-08	1.952E-08	1.952E-08
NP-240M	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05
PU-240	0.000E+00	9.369E-08	1.124E-07	1.497E-07	1.869E-07	0.000E+00	9.368E-08	1.124E-07	1.496E-07	1.869E-07
PU-244	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05
TOTAL	1.774E-05	5.328E-05	5.330E-05	5.333E-05	5.337E-05	1.774E-05	5.329E-05	5.331E-05	5.335E-05	5.338E-05

Table continues. Results at higher decay times shown on next page.

Table 16. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	120	160	300	500	0	120	160	300	500
TL-208	0.000E+00	0.000E+00	0.000E+00	3.583E-21	2.027E-20	0.000E+00	2.089E-22	5.328E-22	3.891E-21	1.882E-20
PB-212	0.000E+00	0.000E+00	0.000E+00	9.974E-21	5.642E-20	0.000E+00	5.813E-22	1.483E-21	1.083E-20	5.239E-20
BI-212	0.000E+00	0.000E+00	0.000E+00	9.974E-21	5.642E-20	0.000E+00	5.813E-22	1.483E-21	1.083E-20	5.239E-20
PO-212	0.000E+00	0.000E+00	0.000E+00	6.390E-21	3.615E-20	0.000E+00	3.725E-22	9.500E-22	6.938E-21	3.356E-20
PO-216	0.000E+00	0.000E+00	0.000E+00	9.974E-21	5.642E-20	0.000E+00	5.813E-22	1.483E-21	1.083E-20	5.239E-20
RN-220	0.000E+00	0.000E+00	0.000E+00	9.974E-21	5.642E-20	0.000E+00	5.813E-22	1.483E-21	1.083E-20	5.239E-20
RA-224	0.000E+00	0.000E+00	0.000E+00	9.974E-21	5.642E-20	0.000E+00	5.813E-22	1.483E-21	1.083E-20	5.239E-20
RA-228	0.000E+00	0.000E+00	0.000E+00	9.966E-21	5.642E-20	0.000E+00	6.256E-22	1.566E-21	1.114E-20	5.328E-20
AC-228	0.000E+00	0.000E+00	0.000E+00	9.966E-21	5.642E-20	0.000E+00	6.256E-22	1.566E-21	1.114E-20	5.328E-20
TH-228	0.000E+00	0.000E+00	0.000E+00	9.974E-21	5.642E-20	0.000E+00	5.816E-22	1.483E-21	1.083E-20	5.239E-20
TH-232	0.000E+00	7.877E-22	1.865E-21	1.225E-20	5.641E-20	0.000E+00	7.876E-22	1.865E-21	1.225E-20	5.641E-20
U-236	0.000E+00	3.988E-13	7.079E-13	2.477E-12	6.831E-12	0.000E+00	3.987E-13	7.078E-13	2.476E-12	6.831E-12
U-240	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05
NP-240	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.952E-08	1.952E-08	1.952E-08	1.952E-08
NP-240M	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05	0.000E+00	1.772E-05	1.772E-05	1.772E-05	1.772E-05
PU-240	0.000E+00	2.240E-07	2.981E-07	5.548E-07	9.150E-07	0.000E+00	2.240E-07	2.980E-07	5.547E-07	9.149E-07
PU-244	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05	1.774E-05
TOTAL	1.774E-05	5.341E-05	5.348E-05	5.374E-05	5.410E-05	1.774E-05	5.342E-05	5.349E-05	5.375E-05	5.411E-05

Table continues. Results at higher decay times shown on next page.

Table 16. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	1,000	10,000	100,000	1,000,000	0	1,000	10,000	100,000	1,000,000
TL-208	0.000E+00	1.565E-19	1.286E-16	3.850E-14	4.544E-12	0.000E+00	1.542E-19	1.281E-16	3.849E-14	4.505E-12
PB-212	0.000E+00	4.355E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.293E-19	3.566E-16	1.071E-13	1.254E-11
BI-212	0.000E+00	4.355E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.293E-19	3.566E-16	1.071E-13	1.254E-11
PO-212	0.000E+00	2.790E-19	2.293E-16	6.866E-14	8.103E-12	0.000E+00	2.750E-19	2.285E-16	6.864E-14	8.034E-12
PO-216	0.000E+00	4.355E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.293E-19	3.566E-16	1.071E-13	1.254E-11
RN-220	0.000E+00	4.355E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.293E-19	3.566E-16	1.071E-13	1.254E-11
RA-224	0.000E+00	4.355E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.293E-19	3.566E-16	1.071E-13	1.254E-11
RA-228	0.000E+00	4.355E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.329E-19	3.569E-16	1.071E-13	1.254E-11
AC-228	0.000E+00	4.355E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.329E-19	3.569E-16	1.071E-13	1.254E-11
TH-228	0.000E+00	4.355E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.293E-19	3.566E-16	1.071E-13	1.254E-11
TH-232	0.000E+00	4.454E-19	3.578E-16	1.072E-13	1.265E-11	0.000E+00	4.454E-19	3.578E-16	1.072E-13	1.254E-11
U-236	0.000E+00	2.685E-11	2.012E-09	4.743E-08	5.099E-07	0.000E+00	2.685E-11	2.012E-09	4.743E-08	5.099E-07
U-240	0.000E+00	1.772E-05	1.772E-05	1.771E-05	1.757E-05	0.000E+00	1.772E-05	1.772E-05	1.770E-05	1.757E-05
NP-240	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.951E-08	1.951E-08	1.950E-08	1.935E-08
NP-240M	0.000E+00	1.772E-05	1.772E-05	1.771E-05	1.757E-05	0.000E+00	1.772E-05	1.772E-05	1.770E-05	1.757E-05
PU-240	0.000E+00	1.783E-06	1.158E-05	1.771E-05	1.757E-05	0.000E+00	1.783E-06	1.158E-05	1.771E-05	1.757E-05
PU-244	1.774E-05	1.774E-05	1.774E-05	1.773E-05	1.759E-05	1.774E-05	1.774E-05	1.774E-05	1.773E-05	1.759E-05
TOTAL	1.774E-05	5.497E-05	6.476E-05	7.089E-05	7.082E-05	1.774E-05	5.498E-05	6.478E-05	7.090E-05	7.083E-05

[a]Feed is 1.0 g of ^{244}Pu. Quantities shown at zero years are the feeds in curies.

7.3.4.2 Actinide ^{249}Bk (see Fig. 2)

At a decay time of 10 years, Table 17 shows that differences in the results reported by ORIGEN2 and RADAC are negligible for the first 6 members of the chain, ^{249}Bk through ^{237}U, but are appreciable from ^{233}U to ^{209}Tl. For ^{233}U, the difference is about 7% at 10 years, but is less than 2% at 20 years. The fairly large differences for nuclides from about the 7th member to the end of the decay chain at the smaller decay times and the gradual diminution of these differences as decay times increase are typical of the differences in the decay patterns exhibited by the two codes. For example, comparing ^{209}Tl results, the codes differ by 6% at 20 years, by 3% at 40 years, by 1.4% at 80 years, by 0.4% at 300 years, and by 0.2% at 500 years. In all these cases, the curies shown by ORIGEN were higher than those shown by RADAC. At 1,000 years, the difference rose to 2% and then dropped to 0.5% at 10,000 years, 0.3% at 100,000 years, and 0.2% at 1 million years. Overall, the agreement between the codes is very good for the first 6 members of the chain at 10 years and becomes very good for all members at 120 years. At 10,000 years and above, agreement between the codes is excellent.

7.3.4.3 Actinide ^{243}Cm (see Fig. 4)

As Table 18 shows, the two codes are in good agreement through the first seven chain members (i.e., from ^{243}Cm through ^{231}Pa). At a decay time of 10 years, the curies shown by ORIGEN2 for ^{231}Pa are about 0.25% higher than those shown by RADAC. For actinides further down the chain, the agreement becomes less good. At 10 years, the difference in the codes is about 5% for the final radioactive member, ^{207}Tl. As in the ^{249}Bk example, agreement becomes better as the decay time increases. For the final member, the difference between the codes diminishes to 2.4% at 20 years, 1.6% at 30 years, 1.2% at 40 years, and continues to decrease to 0.04% at 1,000 years. At 10,000 years, there is an increase to 0.6%, which is followed by a decrease to 0.1% at 100,000 years, and exact agreement at 1 million years. There was one exception to this. At all decay times, the codes showed a noticeable difference in the ratio of ^{211}Po to ^{211}Bi. This difference was traced to the fact that ORIGEN2 uses 0.0028 as the branching ratio from ^{211}Bi to ^{211}Po, whereas RADAC uses 0.00273, the value given by Browne 1986. When the branching ratio in the ORIGEN2 library was changed temporarily to 0.00273, the curies of ^{211}Po shown by the codes became equal. With this minor and easily remedied exception, the two codes show excellent agreement on the decay of ^{243}Cm.

(Text continued on page 142)

Table 17. Results of ORIGEN2 and RADAC calculations for decay of actinide $^{249}Bk^{a}$

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	10	20	30	40	0	10	20	30	40
TL-209	0.000E+00	0.000E+00	4.155E-21	4.902E-20	2.729E-19	0.000E+00	4.746E-23	3.915E-21	4.716E-20	2.652E-19
PB-209	0.000E+00	0.000E+00	1.924E-19	2.269E-18	1.263E-17	0.000E+00	2.197E-21	1.813E-19	2.183E-18	1.228E-17
BI-213	0.000E+00	0.000E+00	1.924E-19	2.269E-18	1.263E-17	0.000E+00	2.197E-21	1.813E-19	2.183E-18	1.228E-17
PO-213	0.000E+00	0.000E+00	1.882E-19	2.220E-18	1.236E-17	0.000E+00	2.150E-21	1.774E-19	2.136E-18	1.201E-17
AT-217	0.000E+00	2.569E-21	1.924E-19	2.269E-18	1.263E-17	0.000E+00	2.197E-21	1.813E-19	2.183E-18	1.228E-17
FR-221	0.000E+00	2.569E-21	1.924E-19	2.269E-18	1.263E-17	0.000E+00	2.197E-21	1.813E-19	2.183E-18	1.228E-17
RA-225	0.000E+00	2.569E-21	1.924E-19	2.269E-18	1.263E-17	0.000E+00	2.254E-21	1.835E-19	2.201E-18	1.235E-17
AC-225	0.000E+00	2.569E-21	1.924E-19	2.269E-18	1.263E-17	0.000E+00	2.197E-21	1.813E-19	2.183E-18	1.228E-17
TH-229	0.000E+00	2.569E-21	1.924E-19	2.269E-18	1.263E-17	0.000E+00	2.340E-21	1.868E-19	2.227E-18	1.246E-17
PA-233	0.000E+00	2.063E-12	3.666E-11	1.826E-10	5.504E-10	0.000E+00	1.972E-12	3.588E-11	1.801E-10	5.448E-10
U-233	0.000E+00	1.716E-17	6.236E-16	4.798E-15	1.972E-14	0.000E+00	1.599E-17	6.121E-16	4.747E-15	1.957E-14
U-237	0.000E+00	1.330E-08	5.181E-08	1.057E-07	1.685E-07	0.000E+00	1.329E-08	5.179E-08	1.057E-07	1.684E-07
NP-237	0.000E+00	2.063E-12	3.666E-11	1.826E-10	5.504E-10	0.000E+00	2.062E-12	3.666E-11	1.826E-10	5.503E-10
PU-241	0.000E+00	5.424E-04	2.114E-03	4.313E-03	6.874E-03	0.000E+00	5.423E-04	2.114E-03	4.312E-03	6.873E-03
AM-241	0.000E+00	2.707E-06	2.276E-05	7.294E-05	1.605E-04	0.000E+00	2.707E-06	2.276E-05	7.293E-05	1.604E-04
AM-245	0.000E+00	8.718E-06	3.197E-09	1.172E-12	4.298E-16	0.000E+00	8.715E-06	3.195E-09	1.172E-12	4.296E-16
CM-245	0.000E+00	2.896E-03	6.145E-03	9.328E-03	1.245E-02	0.000E+00	2.896E-03	6.144E-03	9.327E-03	1.244E-02
BK-249	1.639E+03	6.011E-01	2.204E-04	8.081E-08	2.963E-11	1.639E+03	6.010E-01	2.204E-04	8.080E-08	2.963E-11
CF-249	0.000E+00	4.027E+00	3.949E+00	3.872E+00	3.796E+00	0.000E+00	4.026E+00	3.949E+00	3.871E+00	3.796E+00
TOTAL	1.639E+03	4.631E+00	3.958E+00	3.886E+00	3.816E+00	1.639E+03	4.631E+00	3.957E+00	3.885E+00	3.815E+00

[a] Table continues. Results at higher decay times shown on next page.

Table 17. (continued)

Nuclide	ORIGEN2 0	ORIGEN2 50	ORIGEN2 60	ORIGEN2 80	ORIGEN2 100	RADAC 0	RADAC 50	RADAC 60	RADAC 80	RADAC 100
	Calculated radioactivity (Ci) at decay times shown (years)									
TL-209	0.000E+00	1.013E-18	2.919E-18	1.511E-17	5.291E-17	0.000E+00	9.900E-19	2.863E-18	1.490E-17	5.233E-17
PB-209	0.000E+00	4.690E-17	1.351E-16	6.993E-16	2.450E-15	0.000E+00	4.583E-17	1.326E-16	6.897E-16	2.423E-15
BI-213	0.000E+00	4.690E-17	1.351E-16	6.993E-16	2.450E-15	0.000E+00	4.583E-17	1.326E-16	6.897E-16	2.423E-15
PO-213	0.000E+00	4.589E-17	1.322E-16	6.842E-16	2.397E-15	0.000E+00	4.484E-17	1.297E-16	6.748E-16	2.370E-15
AT-217	0.000E+00	4.690E-17	1.351E-16	6.993E-16	2.450E-15	0.000E+00	4.583E-17	1.326E-16	6.897E-16	2.423E-15
FR-221	0.000E+00	4.690E-17	1.351E-16	6.993E-16	2.450E-15	0.000E+00	4.583E-17	1.326E-16	6.897E-16	2.423E-15
RA-225	0.000E+00	4.690E-17	1.351E-16	6.993E-16	2.450E-15	0.000E+00	4.605E-17	1.331E-16	6.916E-16	2.428E-15
AC-225	0.000E+00	4.690E-17	1.351E-16	6.993E-16	2.450E-15	0.000E+00	4.583E-17	1.326E-16	6.897E-16	2.423E-15
TH-229	0.000E+00	4.690E-17	1.351E-16	6.993E-16	2.450E-15	0.000E+00	4.636E-17	1.338E-16	6.945E-16	2.436E-15
PA-233	0.000E+00	1.268E-09	2.471E-09	6.893E-09	1.492E-08	0.000E+00	1.258E-09	2.455E-09	6.860E-09	1.486E-08
U-233	0.000E+00	5.779E-14	1.373E-13	5.235E-13	1.445E-12	0.000E+00	5.746E-14	1.366E-13	5.217E-13	1.441E-12
U-237	0.000E+00	2.362E-07	3.063E-07	4.483E-07	5.883E-07	0.000E+00	2.360E-07	3.061E-07	4.481E-07	5.880E-07
NP-237	0.000E+00	1.268E-09	2.471E-09	6.893E-09	1.492E-08	0.000E+00	1.268E-09	2.471E-09	6.892E-09	1.492E-08
PU-241	0.000E+00	9.635E-03	1.250E-02	1.829E-02	2.400E-02	0.000E+00	9.634E-03	1.249E-02	1.829E-02	2.400E-02
AM-241	0.000E+00	2.891E-04	4.605E-04	9.323E-04	1.571E-03	0.000E+00	2.891E-04	4.605E-04	9.322E-04	1.571E-03
AM-245	0.000E+00	1.576E-19	5.778E-23	7.769E-30	0.000E+00	0.000E+00	1.575E-19	5.776E-23	7.765E-30	1.044E-36
CM-245	0.000E+00	1.550E-02	1.849E-02	2.429E-02	2.986E-02	0.000E+00	1.550E-02	1.849E-02	2.429E-02	2.985E-02
BK-249	1.639E+03	1.087E-14	3.984E-18	5.356E-25	7.201E-32	1.639E+03	1.086E-14	3.983E-18	5.355E-25	7.200E-32
CF-249	0.000E+00	3.722E+00	3.649E+00	3.507E+00	3.371E+00	0.000E+00	3.721E+00	3.648E+00	3.507E+00	3.371E+00
TOTAL	1.639E+03	3.747E+00	3.680E+00	3.551E+00	3.427E+00	1.639E+03	3.747E+00	3.680E+00	3.550E+00	3.426E+00

Table continues. Results at higher decay times shown on next page.

Table 17. (continued)

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	120	160	300	500	0	120	160	300	500
TL-209	0.000E+00	1.452E-16	6.948E-16	1.889E-14	2.450E-13	0.000E+00	1.439E-16	6.901E-16	1.882E-14	2.445E-13
PB-209	0.000E+00	6.723E-15	3.217E-14	8.743E-13	1.134E-11	0.000E+00	6.661E-15	3.195E-14	8.713E-13	1.132E-11
BI-213	0.000E+00	6.723E-15	3.217E-14	8.743E-13	1.134E-11	0.000E+00	6.661E-15	3.195E-14	8.713E-13	1.132E-11
PO-213	0.000E+00	6.577E-15	3.147E-14	8.554E-13	1.110E-11	0.000E+00	6.517E-15	3.126E-14	8.525E-13	1.107E-11
AT-217	0.000E+00	6.723E-15	3.217E-14	8.743E-13	1.134E-11	0.000E+00	6.661E-15	3.195E-14	8.713E-13	1.132E-11
FR-221	0.000E+00	6.723E-15	3.217E-14	8.743E-13	1.134E-11	0.000E+00	6.661E-15	3.195E-14	8.713E-13	1.132E-11
RA-225	0.000E+00	6.723E-15	3.217E-14	8.743E-13	1.134E-11	0.000E+00	6.673E-15	3.199E-14	8.719E-13	1.132E-11
AC-225	0.000E+00	6.723E-15	3.217E-14	8.743E-13	1.134E-11	0.000E+00	6.661E-15	3.195E-14	8.713E-13	1.132E-11
TH-229	0.000E+00	6.723E-15	3.217E-14	8.743E-13	1.134E-11	0.000E+00	6.691E-15	3.206E-14	8.728E-13	1.133E-11
PA-233	0.000E+00	2.760E-08	7.080E-08	4.909E-07	2.084E-06	0.000E+00	2.751E-08	7.064E-08	4.904E-07	2.082E-06
U-233	0.000E+00	3.264E-12	1.148E-11	1.589E-10	1.189E-09	0.000E+00	3.257E-12	1.146E-11	1.588E-10	1.189E-09
U-237	0.000E+00	7.241E-07	9.810E-07	1.728E-06	2.474E-06	0.000E+00	7.238E-07	9.801E-07	1.727E-06	2.474E-06
NP-237	0.000E+00	2.760E-08	7.080E-08	4.909E-07	2.084E-06	0.000E+00	2.759E-08	7.079E-08	4.909E-07	2.084E-06
PU-241	0.000E+00	2.954E-02	4.001E-02	7.051E-02	1.010E-01	0.000E+00	2.954E-02	4.001E-02	7.050E-02	1.010E-01
AM-241	0.000E+00	2.368E-03	4.389E-03	1.488E-02	3.485E-02	0.000E+00	2.367E-03	4.389E-03	1.488E-02	3.484E-02
AM-245	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.401E-43	0.000E+00	0.000E+00	0.000E+00
CM-245	0.000E+00	3.520E-02	4.523E-02	7.440E-02	1.035E-01	0.000E+00	3.519E-02	4.522E-02	7.439E-02	1.035E-01
BK-249	1.639E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.639E+03	9.681E-39	0.000E+00	0.000E+00	0.000E+00
CF-249	0.000E+00	3.241E+00	2.994E+00	2.270E+00	1.528E+00	0.000E+00	3.240E+00	2.994E+00	2.270E+00	1.528E+00
TOTAL	1.639E+03	3.308E+00	3.084E+00	2.430E+00	1.768E+00	1.639E+03	3.307E+00	3.083E+00	2.429E+00	1.767E+00

Table continues. Results at higher decay times shown on next page.

Table 17. (continued)

Nuclide	ORIGEN2 0	ORIGEN2 1,000	ORIGEN2 10,000	ORIGEN2 100,000	ORIGEN2 1,000,000	RADAC 0	RADAC 1,000	RADAC 10,000	RADAC 100,000	RADAC 1,000,000
	Calculated radioactivity (Ci) at decay times shown (years)									
TL-209	0.000E+00	6.683E-12	3.918E-08	4.030E-06	1.123E-05	0.000E+00	6.555E-12	3.897E-08	4.019E-06	1.119E-05
PB-209	0.000E+00	3.094E-10	1.814E-06	1.866E-04	5.197E-04	0.000E+00	3.035E-10	1.804E-06	1.861E-04	5.182E-04
BI-213	0.000E+00	3.094E-10	1.814E-06	1.866E-04	5.197E-04	0.000E+00	3.035E-10	1.804E-06	1.861E-04	5.182E-04
PO-213	0.000E+00	3.027E-10	1.775E-06	1.825E-04	5.085E-04	0.000E+00	2.969E-10	1.765E-06	1.820E-04	5.070E-04
AT-217	0.000E+00	3.094E-10	1.814E-06	1.866E-04	5.197E-04	0.000E+00	3.035E-10	1.804E-06	1.861E-04	5.182E-04
FR-221	0.000E+00	3.094E-10	1.814E-06	1.866E-04	5.197E-04	0.000E+00	3.035E-10	1.804E-06	1.861E-04	5.182E-04
RA-225	0.000E+00	3.094E-10	1.814E-06	1.866E-04	5.197E-04	0.000E+00	3.035E-10	1.804E-06	1.861E-04	5.182E-04
AC-225	0.000E+00	3.094E-10	1.814E-06	1.866E-04	5.197E-04	0.000E+00	3.035E-10	1.804E-06	1.861E-04	5.182E-04
TH-229	0.000E+00	3.094E-10	1.814E-06	1.866E-04	5.197E-04	0.000E+00	3.036E-10	1.804E-06	1.861E-04	5.182E-04
PA-233	0.000E+00	1.212E-05	3.443E-04	6.523E-04	4.875E-04	0.000E+00	1.190E-05	3.437E-04	6.524E-04	4.875E-04
U-233	0.000E+00	1.531E-08	7.427E-06	2.082E-04	5.168E-04	0.000E+00	1.499E-08	7.399E-06	2.077E-04	5.168E-04
U-237	0.000E+00	3.363E-06	1.914E-06	1.242E-09	0.000E+00	0.000E+00	3.362E-06	1.914E-06	1.242E-09	1.643E-41
NP-237	0.000E+00	1.212E-05	3.443E-04	6.523E-04	4.875E-04	0.000E+00	1.190E-05	3.437E-04	6.524E-04	4.876E-04
PU-241	0.000E+00	1.373E-01	7.812E-02	5.069E-05	6.706E-37	0.000E+00	1.372E-01	7.811E-02	5.068E-05	6.705E-37
AM-241	0.000E+00	8.425E-02	8.139E-02	5.069E-05	7.065E-37	0.000E+00	8.450E-02	8.229E-02	5.340E-05	7.064E-37
AM-245	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CM-245	0.000E+00	1.380E-01	7.799E-02	5.060E-05	6.694E-37	0.000E+00	1.380E-01	7.798E-02	5.060E-05	6.693E-37
BK-249	1.639E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.639E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CF-249	0.000E+00	5.685E-01	1.056E-08	0.000E+00	0.000E+00	0.000E+00	5.685E-01	1.058E-08	0.000E+00	0.000E+00
TOTAL	1.639E+03	9.281E-01	2.382E-01	3.157E-03	5.650E-03	1.639E+03	9.282E-01	2.391E-01	3.156E-03	5.637E-03

[a]Feed is 1.0 g of ^{249}Bk. Quantities shown at zero years are the feeds in curies.

Table 18. Results of ORIGEN2 and RADAC calculations for decay of actinide $^{243}Cm^{a}$

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	10	20	30	40	0	10	20	30	40
TL-207	0.000E+00	3.668E-16	5.264E-15	2.400E-14	6.856E-14	0.000E+00	3.492E-16	5.140E-15	2.363E-14	6.773E-14
PB-211	0.000E+00	3.679E-16	5.278E-15	2.407E-14	6.875E-14	0.000E+00	3.502E-16	5.154E-15	2.369E-14	6.792E-14
BI-211	0.000E+00	3.679E-16	5.278E-15	2.407E-14	6.875E-14	0.000E+00	3.502E-16	5.154E-15	2.369E-14	6.792E-14
PO-211	0.000E+00	1.030E-18	1.478E-17	6.740E-17	1.925E-16	0.000E+00	9.806E-19	1.443E-17	6.634E-17	1.902E-16
PO-215	0.000E+00	3.679E-16	5.278E-15	2.407E-14	6.875E-14	0.000E+00	3.502E-16	5.154E-15	2.369E-14	6.792E-14
RN-219	0.000E+00	3.679E-16	5.278E-15	2.407E-14	6.875E-14	0.000E+00	3.502E-16	5.154E-15	2.369E-14	6.792E-14
FR-223	0.000E+00	5.074E-18	7.283E-17	3.321E-16	9.482E-16	0.000E+00	5.059E-18	7.273E-17	3.317E-16	9.474E-16
RA-223	0.000E+00	3.679E-16	5.278E-15	2.407E-14	6.875E-14	0.000E+00	3.502E-16	5.154E-15	2.369E-14	6.792E-14
AC-227	0.000E+00	3.677E-16	5.278E-15	2.406E-14	6.871E-14	0.000E+00	3.666E-16	5.270E-15	2.404E-14	6.865E-14
TH-227	0.000E+00	3.628E-16	5.205E-15	2.374E-14	6.780E-14	0.000E+00	3.514E-16	5.126E-15	2.349E-14	6.725E-14
TH-231	0.000E+00	6.749E-11	2.501E-10	5.230E-10	8.665E-10	0.000E+00	6.748E-11	2.501E-10	5.229E-10	8.664E-10
PA-231	0.000E+00	4.859E-15	3.666E-14	1.170E-13	2.629E-13	0.000E+00	4.847E-15	3.662E-14	1.169E-13	2.627E-13
U-235	0.000E+00	6.749E-11	2.501E-10	5.230E-10	8.665E-10	0.000E+00	6.748E-11	2.501E-10	5.229E-10	8.664E-10
NP-239	0.000E+00	1.033E-04	1.842E-04	2.475E-04	2.971E-04	0.000E+00	1.033E-04	1.841E-04	2.475E-04	2.970E-04
PU-239	0.000E+00	1.317E-02	2.349E-02	3.159E-02	3.793E-02	0.000E+00	1.317E-02	2.349E-02	3.158E-02	3.792E-02
AM-243	0.000E+00	1.033E-04	1.842E-04	2.475E-04	2.971E-04	0.000E+00	1.033E-04	1.841E-04	2.475E-04	2.970E-04
CM-243	5.164E+01	4.049E+01	3.175E+01	2.490E+01	1.952E+01	5.163E+01	4.049E+01	3.175E+01	2.489E+01	1.952E+01
TOTAL	5.164E+01	4.051E+01	3.177E+01	2.493E+01	1.956E+01	5.163E+01	4.050E+01	3.177E+01	2.492E+01	1.956E+01

[a] Table continues. Results at higher decay times shown on next page.

Table 18. (continued)

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	50	60	80	100	0	50	60	80	100
TL-207	0.000E+00	1.517E-13	2.859E-13	7.520E-13	1.545E-12	0.000E+00	1.502E-13	2.835E-13	7.475E-13	1.537E-12
PB-211	0.000E+00	1.521E-13	2.867E-13	7.541E-13	1.549E-12	0.000E+00	1.506E-13	2.843E-13	7.496E-13	1.542E-12
BI-211	0.000E+00	1.521E-13	2.867E-13	7.541E-13	1.549E-12	0.000E+00	1.506E-13	2.843E-13	7.496E-13	1.542E-12
PO-211	0.000E+00	4.259E-16	8.027E-16	2.112E-15	4.338E-15	0.000E+00	4.218E-16	7.960E-16	2.099E-15	4.317E-15
PO-215	0.000E+00	1.521E-13	2.867E-13	7.541E-13	1.549E-12	0.000E+00	1.506E-13	2.843E-13	7.496E-13	1.542E-12
RN-219	0.000E+00	1.521E-13	2.867E-13	7.541E-13	1.549E-12	0.000E+00	1.506E-13	2.843E-13	7.496E-13	1.542E-12
FR-223	0.000E+00	2.098E-15	3.953E-15	1.040E-14	2.137E-14	0.000E+00	2.096E-15	3.950E-15	1.040E-14	2.136E-14
RA-223	0.000E+00	1.521E-13	2.867E-13	7.541E-13	1.549E-12	0.000E+00	1.506E-13	2.843E-13	7.496E-13	1.542E-12
AC-227	0.000E+00	1.520E-13	2.864E-13	7.538E-13	1.548E-12	0.000E+00	1.519E-13	2.862E-13	7.533E-13	1.548E-12
TH-227	0.000E+00	1.500E-13	2.827E-13	7.437E-13	1.528E-12	0.000E+00	1.490E-13	2.811E-13	7.505E-13	1.540E-12
TH-231	0.000E+00	1.265E-09	1.708E-09	2.687E-09	3.751E-09	0.000E+00	1.265E-09	1.708E-09	2.687E-09	3.751E-09
PA-231	0.000E+00	4.876E-13	8.014E-13	1.727E-12	3.086E-12	0.000E+00	4.872E-13	8.008E-13	1.726E-12	3.085E-12
U-235	0.000E+00	1.265E-09	1.708E-09	2.687E-09	3.751E-09	0.000E+00	1.265E-09	1.708E-09	2.687E-09	3.751E-09
NP-239	0.000E+00	3.358E-04	3.661E-04	4.082E-04	4.338E-04	0.000E+00	3.358E-04	3.661E-04	4.082E-04	4.337E-04
PU-239	0.000E+00	4.289E-02	4.679E-02	5.222E-02	5.555E-02	0.000E+00	4.289E-02	4.678E-02	5.221E-02	5.554E-02
AM-243	0.000E+00	3.358E-04	3.661E-04	4.082E-04	4.338E-04	0.000E+00	3.358E-04	3.661E-04	4.082E-04	4.337E-04
CM-243	5.164E+01	1.531E+01	1.200E+01	7.379E+00	4.537E+00	5.163E+01	1.530E+01	1.200E+01	7.378E+00	4.536E+00
TOTAL	5.164E+01	1.535E+01	1.205E+01	7.432E+00	4.593E+00	5.163E+01	1.535E+01	1.205E+01	7.431E+00	4.593E+00

Table continues. Results at higher decay times shown on next page.

Table 18. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	120	160	300	500	0	120	160	300	500
TL-207	0.000E+00	2.722E-12	6.384E-12	3.439E-11	1.167E-10	0.000E+00	2.711E-12	6.359E-12	3.431E-11	1.166E-10
PB-211	0.000E+00	2.730E-12	6.402E-12	3.448E-11	1.170E-10	0.000E+00	2.719E-12	6.377E-12	3.440E-11	1.169E-10
BI-211	0.000E+00	2.730E-12	6.402E-12	3.448E-11	1.170E-10	0.000E+00	2.719E-12	6.377E-12	3.440E-11	1.169E-10
PO-211	0.000E+00	7.644E-15	1.792E-14	9.655E-14	3.276E-13	0.000E+00	7.612E-15	1.785E-14	9.633E-14	3.274E-13
PO-215	0.000E+00	2.730E-12	6.402E-12	3.448E-11	1.170E-10	0.000E+00	2.719E-12	6.377E-12	3.440E-11	1.169E-10
RN-219	0.000E+00	2.730E-12	6.402E-12	3.448E-11	1.170E-10	0.000E+00	2.719E-12	6.377E-12	3.440E-11	1.169E-10
FR-223	0.000E+00	3.765E-14	8.822E-14	4.754E-13	1.615E-12	0.000E+00	3.763E-14	8.818E-14	4.753E-13	1.614E-12
RA-223	0.000E+00	2.730E-12	6.402E-12	3.448E-11	1.170E-10	0.000E+00	2.719E-12	6.377E-12	3.440E-11	1.169E-10
AC-227	0.000E+00	2.728E-12	6.393E-12	3.445E-11	1.170E-10	0.000E+00	2.727E-12	6.390E-12	3.444E-11	1.170E-10
TH-227	0.000E+00	2.692E-12	6.314E-12	3.401E-11	1.154E-10	0.000E+00	2.711E-12	6.339E-12	3.406E-11	1.155E-10
TH-231	0.000E+00	4.867E-09	7.181E-09	1.550E-08	2.739E-08	0.000E+00	4.866E-09	7.180E-09	1.550E-08	2.739E-08
PA-231	0.000E+00	4.907E-12	9.993E-12	4.348E-11	1.339E-10	0.000E+00	4.904E-12	9.989E-12	4.347E-11	1.339E-10
U-235	0.000E+00	4.867E-09	7.181E-09	1.550E-08	2.739E-08	0.000E+00	4.866E-09	7.180E-09	1.550E-08	2.739E-08
NP-239	0.000E+00	4.491E-04	4.635E-04	4.668E-04	4.584E-04	0.000E+00	4.491E-04	4.634E-04	4.667E-04	4.584E-04
PU-239	0.000E+00	5.758E-02	5.956E-02	6.052E-02	6.022E-02	0.000E+00	5.757E-02	5.955E-02	6.052E-02	6.021E-02
AM-243	0.000E+00	4.491E-04	4.635E-04	4.668E-04	4.584E-04	0.000E+00	4.491E-04	4.634E-04	4.667E-04	4.584E-04
CM-243	5.164E+01	2.789E+00	1.054E+00	3.502E-02	2.703E-04	5.163E+01	2.789E+00	1.054E+00	3.501E-02	2.702E-04
TOTAL	5.164E+01	2.848E+00	1.115E+00	9.648E-02	6.141E-02	5.163E+01	2.848E+00	1.115E+00	9.646E-02	6.140E-02

Table continues. Results at higher decay times shown on next page.

Table 18. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	1,000	10,000	100,000	1,000,000	0	1,000	10,000	100,000	1,000,000
TL-207	0.000E+00	5.386E-10	5.342E-08	1.462E-06	2.083E-06	0.000E+00	5.383E-10	5.307E-08	1.461E-06	2.083E-06
PB-211	0.000E+00	5.401E-10	5.357E-08	1.466E-06	2.089E-06	0.000E+00	5.398E-10	5.322E-08	1.465E-06	2.089E-06
BI-211	0.000E+00	5.401E-10	5.357E-08	1.466E-06	2.089E-06	0.000E+00	5.398E-10	5.322E-08	1.465E-06	2.089E-06
PO-211	0.000E+00	1.512E-12	1.500E-10	4.105E-09	5.850E-09	0.000E+00	1.512E-12	1.490E-10	4.102E-09	5.849E-09
PO-215	0.000E+00	5.401E-10	5.357E-08	1.466E-06	2.089E-06	0.000E+00	5.398E-10	5.322E-08	1.465E-06	2.089E-06
RN-219	0.000E+00	5.401E-10	5.357E-08	1.466E-06	2.089E-06	0.000E+00	5.398E-10	5.322E-08	1.465E-06	2.089E-06
FR-223	0.000E+00	7.453E-12	7.392E-10	2.023E-08	2.883E-08	0.000E+00	7.452E-12	7.345E-10	2.022E-08	2.883E-08
RA-223	0.000E+00	5.401E-10	5.357E-08	1.466E-06	2.089E-06	0.000E+00	5.398E-10	5.322E-08	1.465E-06	2.089E-06
AC-227	0.000E+00	5.401E-10	5.357E-08	1.466E-06	2.089E-06	0.000E+00	5.400E-10	5.322E-08	1.465E-06	2.089E-06
TH-227	0.000E+00	5.327E-10	5.283E-08	1.446E-06	2.060E-06	0.000E+00	5.329E-10	5.249E-08	1.445E-06	2.060E-06
TH-231	0.000E+00	5.684E-08	5.207E-07	1.974E-06	2.089E-06	0.000E+00	5.683E-08	5.206E-07	1.973E-06	2.089E-06
PA-231	0.000E+00	5.763E-10	5.354E-08	1.465E-06	2.089E-06	0.000E+00	5.762E-10	5.353E-08	1.465E-06	2.089E-06
U-235	0.000E+00	5.684E-08	5.207E-07	1.974E-06	2.089E-06	0.000E+00	5.683E-08	5.206E-07	1.973E-06	2.089E-06
NP-239	0.000E+00	4.374E-04	1.878E-04	4.007E-08	0.000E+00	0.000E+00	4.373E-04	1.878E-04	4.006E-08	8.408E-45
PU-239	0.000E+00	5.937E-02	4.588E-02	3.440E-03	1.896E-14	0.000E+00	5.936E-02	4.587E-02	3.439E-03	1.896E-14
AM-243	0.000E+00	4.374E-04	1.878E-04	4.007E-08	0.000E+00	0.000E+00	4.373E-04	1.878E-04	4.006E-08	8.408E-45
CM-243	5.164E+01	1.415E-09	0.000E+00	3.457E-03	2.298E-05	5.163E+01	1.414E-09	0.000E+00	0.000E+00	0.000E+00
TOTAL	5.164E+01	6.024E-02	4.625E-02	3.457E-03	2.298E-05	5.163E+01	6.023E-02	4.625E-02	3.456E-03	2.298E-05

[a]Feed is 1.0 g of ^{243}Cm. Quantities shown at zero years are the feeds in curies.

7.3.4.4 Actinide ^{246}Cm (see Fig. 3)

Table 19 shows that ORIGEN2 and RADAC give essentially identical results at 10 years for the first three nuclides of the chain, ^{246}Cm, ^{242}Pu, and ^{238}U. For the next three nuclides, ^{234}Th, ^{234m}Pa , and ^{234}Pa, the ORIGEN2 results are about 1.9% higher than those of RADAC. These differences diminish to about 0.9% at 20 years, 0.6% at 30 years, and 0.5% at 40 years. Over the same time span, the differences shown by the two codes for ^{234}U diminish from 1.5% to 0.4%, and essential agreement of the codes has extended to ^{230}Th. As the decay time increases from 40 years to 100 years, the difference in the results of the two codes for ^{230}Th diminishes from about 0.48% to 0.37%. At a decay time of 100 years, substantial differences between the codes appear for ^{226}Ra and its daughters. As the decay time increases through the range 120 to 500 years, the differences in the curies shown by the two codes for ^{226}Ra and its daughters essentially disappear, dropping to 0.06% for the final member at 500 years. At decay times from 1,000 to 1 million years, agreement between the codes is excellent. The reason ^{210}Tl does not appear in the ORIGEN2 results is that it was not in the ORIGEN2 decay library used in these runs. When it was temporarily added to the library, the two codes showed the same agreement for ^{210}Tl as they do for its parent, ^{214}Bi.

7.3.4.5 Actinide ^{239}Pu (see Fig. 4)

At a decay time of 10 years, Table 20 shows that ORIGEN2 and RADAC are in essentially perfect agreement through the first three chain members, ^{239}Pu, ^{235}U, and ^{231}Th. For the fourth and fifth members, ^{231}Pa and ^{227}Ac, the two codes show differences of only 0.23% and 0.28%, respectively. For the sixth member, ^{223}Ra, the curies calculated by ORIGEN2 are 3.9% higher than those of RADAC. This ratio persists through the remaining members of the chain, which are all short-lived daughters of ^{223}Ra, and which show the same activity as their parent. The differences between the two codes for the entire chain, therefore, can be largely traced to the difference in ^{223}Ra. As the decay time increases from 10 to 100 years, the difference in the curies of ^{223}Ra shown by the two codes diminishes steadily to 1.9%, 1.3%, and 1.0% at 20, 30, and 40 years, respectively, and continues to decrease to 0.8%, 0.7%, 0.5%, and 0.2% at 50, 60, 80, and 100 years. At 120 years, the difference rises to 0.4%. From 120 to 1,000 years, the difference diminishes to 0.5%, and then rises to 0.6% at 10,000 years. At 100,000 and 1 million years, the results of the two codes are essentially identical, except for ^{211}Po. The reason the codes differ slightly on the curies of ^{211}Po has already been discussed in Sect. 7.3.4.3.

(Text continued on page 151)

Table 19. Results of ORIGEN2 and RADAC calculations for decay of actinide ^{246}Cm[a]

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	10	20	30	40	0	10	20	30	40
TL-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.574E-31	5.152E-30	3.939E-29	1.665E-28
PB-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.650E-29	2.311E-27	2.553E-26	1.385E-25
PB-214	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.498E-28	2.453E-26	1.876E-25	7.928E-25
BI-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.650E-29	2.311E-27	2.553E-26	1.385E-25
BI-214	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.498E-28	2.453E-26	1.876E-25	7.928E-25
PO-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.717E-29	1.981E-27	2.301E-26	1.281E-25
PO-214	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.496E-28	2.453E-26	1.875E-25	7.926E-25
PO-218	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.498E-28	2.453E-26	1.876E-25	7.928E-25
RN-222	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.498E-28	2.453E-26	1.876E-25	7.928E-25
RA-226	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.498E-28	2.453E-26	1.876E-25	7.928E-25
TH-230	0.000E+00	0.000E+00	1.357E-23	7.246E-23	2.310E-22	0.000E+00	8.739E-25	1.424E-23	7.253E-23	2.299E-22
TH-234	0.000E+00	4.267E-15	1.706E-14	3.836E-14	6.817E-14	0.000E+00	4.186E-15	1.690E-14	3.812E-14	6.784E-14
PA-234M	0.000E+00	4.267E-15	1.706E-14	3.836E-14	6.817E-14	0.000E+00	4.181E-15	1.687E-14	3.807E-14	6.775E-14
PA-234	0.000E+00	5.547E-18	2.218E-17	4.987E-17	8.862E-17	0.000E+00	5.442E-18	2.197E-17	4.955E-17	8.819E-17
U-234	0.000E+00	3.979E-20	3.204E-19	1.083E-18	2.569E-18	0.000E+00	3.919E-20	3.179E-19	1.078E-18	2.559E-18
U-238	0.000E+00	4.267E-15	1.706E-14	3.836E-14	6.817E-14	0.000E+00	4.266E-15	1.706E-14	3.836E-14	6.816E-14
PU-242	0.000E+00	5.500E-06	1.099E-05	1.647E-05	2.195E-05	0.000E+00	5.499E-06	1.099E-05	1.647E-05	2.195E-05
CM-246	3.073E-01	3.069E-01	3.064E-01	3.060E-01	3.055E-01	3.073E-01	3.068E-01	3.064E-01	3.059E-01	3.055E-01
TOTAL	3.073E-01	3.069E-01	3.064E-01	3.060E-01	3.055E-01	3.073E-01	3.068E-01	3.064E-01	3.059E-01	3.055E-01

[a] Table continues. Results at higher decay times shown on next page.

Table 19. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	50	60	80	100	0	50	60	80	100
TL-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.088E-28	1.267E-27	5.338E-27	1.628E-26
PB-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.096E-25	1.468E-24	7.687E-24	2.741E-23
PB-214	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.211E-23	0.000E+00	2.423E-24	6.032E-24	2.542E-23	7.751E-23
BI-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.096E-25	1.468E-24	7.687E-24	2.741E-23
BI-214	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.211E-23	0.000E+00	2.423E-24	6.032E-24	2.542E-23	7.751E-23
PO-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.788E-25	1.394E-24	7.396E-24	2.658E-23
PO-214	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.211E-23	0.000E+00	2.422E-24	6.031E-24	2.541E-23	7.750E-23
PO-218	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.212E-23	0.000E+00	2.423E-24	6.032E-24	2.542E-23	7.751E-23
RN-222	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.212E-23	0.000E+00	2.423E-24	6.032E-24	2.542E-23	7.751E-23
RA-226	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.212E-23	0.000E+00	2.423E-24	6.032E-24	2.542E-23	7.751E-23
TH-230	0.000E+00	5.653E-22	1.173E-21	3.707E-21	9.047E-21	0.000E+00	5.621E-22	1.167E-21	3.691E-21	9.014E-21
TH-234	0.000E+00	1.065E-13	1.532E-13	2.721E-13	4.248E-13	0.000E+00	1.060E-13	1.527E-13	2.715E-13	4.240E-13
PA-234M	0.000E+00	1.065E-13	1.532E-13	2.721E-13	4.248E-13	0.000E+00	1.059E-13	1.525E-13	2.711E-13	4.234E-13
PA-234	0.000E+00	1.384E-16	1.992E-16	3.538E-16	5.522E-16	0.000E+00	1.379E-16	1.986E-16	3.529E-16	5.511E-16
U-234	0.000E+00	5.020E-18	8.674E-18	2.056E-17	4.013E-17	0.000E+00	5.004E-18	8.652E-18	2.052E-17	4.007E-17
U-238	0.000E+00	1.065E-13	1.532E-13	2.721E-13	4.248E-13	0.000E+00	1.065E-13	1.532E-13	2.721E-13	4.248E-13
PU-242	0.000E+00	2.742E-05	3.288E-05	4.377E-05	5.463E-05	0.000E+00	2.741E-05	3.287E-05	4.376E-05	5.463E-05
CM-246	3.073E-01	3.051E-01	3.046E-01	3.037E-01	3.028E-01	3.073E-01	3.050E-01	3.046E-01	3.037E-01	3.028E-01
TOTAL	3.073E-01	3.051E-01	3.046E-01	3.038E-01	3.029E-01	3.073E-01	3.050E-01	3.046E-01	3.037E-01	3.028E-01

Table continues. Results at higher decay times shown on next page.

Table 19. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	120	160	300	500	0	120	160	300	500
TL-210	0.000E+00	2.966E-26	1.585E-25	3.882E-24	4.913E-23	0.000E+00	4.046E-26	1.700E-25	3.891E-24	4.910E-23
PB-210	0.000E+00	1.522E-26	3.349E-25	1.162E-20	1.758E-19	0.000E+00	7.675E-23	3.825E-22	1.176E-20	1.750E-19
PB-214	0.000E+00	1.412E-22	7.549E-22	1.848E-20	2.340E-19	0.000E+00	1.926E-22	8.094E-22	1.853E-20	2.338E-19
BI-210	0.000E+00	1.523E-26	3.350E-25	1.162E-20	1.758E-19	0.000E+00	7.675E-23	3.825E-22	1.176E-20	1.750E-19
BI-214	0.000E+00	1.412E-22	7.549E-22	1.848E-20	2.340E-19	0.000E+00	1.926E-22	8.094E-22	1.853E-20	2.338E-19
PO-210	0.000E+00	1.523E-26	3.350E-25	1.162E-20	1.758E-19	0.000E+00	7.482E-23	3.754E-22	1.165E-20	1.740E-19
PO-214	0.000E+00	1.412E-22	7.547E-22	1.848E-20	2.339E-19	0.000E+00	1.926E-22	8.093E-22	1.852E-20	2.338E-19
PO-218	0.000E+00	1.413E-22	7.550E-22	1.849E-20	2.340E-19	0.000E+00	1.926E-22	8.094E-22	1.853E-20	2.338E-19
RN-222	0.000E+00	1.413E-22	7.550E-22	1.849E-20	2.340E-19	0.000E+00	1.926E-22	8.094E-22	1.853E-20	2.338E-19
RA-226	0.000E+00	1.413E-22	7.550E-22	1.849E-20	2.340E-19	0.000E+00	1.926E-22	8.094E-22	1.853E-20	2.338E-19
TH-230	0.000E+00	1.875E-20	5.919E-20	7.283E-19	5.584E-18	0.000E+00	1.869E-20	5.904E-20	7.273E-19	5.579E-18
TH-234	0.000E+00	6.111E-13	1.084E-12	3.786E-12	1.041E-11	0.000E+00	6.101E-13	1.083E-12	3.783E-12	1.041E-11
PA-234M	0.000E+00	6.111E-13	1.084E-12	3.786E-12	1.041E-11	0.000E+00	6.093E-13	1.081E-12	3.778E-12	1.040E-11
PA-234	0.000E+00	7.944E-16	1.410E-15	4.921E-15	1.354E-14	0.000E+00	7.931E-16	1.408E-15	4.918E-15	1.353E-14
U-234	0.000E+00	6.931E-17	1.641E-16	1.076E-15	4.947E-15	0.000E+00	6.922E-17	1.639E-16	1.076E-15	4.945E-15
U-238	0.000E+00	6.111E-13	1.084E-12	3.786E-12	1.041E-11	0.000E+00	6.110E-13	1.084E-12	3.785E-12	1.041E-11
PU-242	0.000E+00	6.546E-05	8.702E-05	1.615E-04	2.652E-04	0.000E+00	6.545E-05	8.701E-05	1.615E-04	2.652E-04
CM-246	3.073E-01	3.019E-01	3.002E-01	2.941E-01	2.856E-01	3.073E-01	3.019E-01	3.001E-01	2.940E-01	2.856E-01
TOTAL	3.073E-01	3.020E-01	3.003E-01	2.942E-01	2.859E-01	3.073E-01	3.020E-01	3.002E-01	2.942E-01	2.858E-01

Table continues. Results at higher decay times shown on next page.

Table 19. (continued)

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	1,000	10,000	100,000	1,000,000	0	1,000	10,000	100,000	1,000,000
TL-210	0.000E+00	0.000E+00	7.135E-17	2.932E-13	3.945E-11	0.000E+00	1.498E-21	7.135E-17	2.930E-13	3.935E-11
PB-210	0.000E+00	6.136E-18	3.397E-13	1.396E-09	1.878E-07	0.000E+00	6.136E-18	3.351E-13	1.394E-09	1.874E-07
PB-214	0.000E+00	7.136E-18	3.397E-13	1.396E-09	1.878E-07	0.000E+00	7.134E-18	3.398E-13	1.395E-09	1.874E-07
BI-210	0.000E+00	6.137E-18	3.397E-13	1.396E-09	1.878E-07	0.000E+00	6.136E-18	3.351E-13	1.394E-09	1.874E-07
BI-214	0.000E+00	7.136E-18	3.397E-13	1.396E-09	1.878E-07	0.000E+00	7.134E-18	3.398E-13	1.395E-09	1.874E-07
PO-210	0.000E+00	6.137E-18	3.397E-13	1.396E-09	1.878E-07	0.000E+00	6.119E-18	3.351E-13	1.394E-09	1.874E-07
PO-214	0.000E+00	7.135E-18	3.397E-13	1.396E-09	1.878E-07	0.000E+00	7.132E-18	3.397E-13	1.395E-09	1.874E-07
PO-218	0.000E+00	7.138E-18	3.398E-13	1.397E-09	1.879E-07	0.000E+00	7.134E-18	3.398E-13	1.395E-09	1.874E-07
RN-222	0.000E+00	7.138E-18	3.398E-13	1.397E-09	1.879E-07	0.000E+00	7.134E-18	3.398E-13	1.395E-09	1.874E-07
RA-226	0.000E+00	7.138E-18	3.398E-13	1.397E-09	1.879E-07	0.000E+00	7.134E-18	3.398E-13	1.395E-09	1.874E-07
TH-230	0.000E+00	8.794E-17	6.759E-13	1.490E-09	1.879E-07	0.000E+00	8.790E-17	6.758E-13	1.490E-09	1.878E-07
TH-234	0.000E+00	4.065E-11	2.751E-09	4.999E-08	2.704E-07	0.000E+00	4.064E-11	2.751E-09	4.998E-08	2.703E-07
PA-234M	0.000E+00	4.065E-11	2.751E-09	4.999E-08	2.704E-07	0.000E+00	4.059E-11	2.747E-09	4.992E-08	2.700E-07
PA-234	0.000E+00	5.285E-14	3.576E-12	6.498E-11	3.515E-10	0.000E+00	5.284E-14	3.576E-12	6.498E-11	3.514E-10
U-234	0.000E+00	3.885E-14	2.867E-11	6.246E-09	2.096E-07	0.000E+00	3.885E-14	2.867E-11	6.245E-09	2.095E-07
U-238	0.000E+00	4.065E-11	2.751E-09	4.999E-08	2.704E-07	0.000E+00	4.065E-11	2.750E-09	4.998E-08	2.703E-07
PU-242	0.000E+00	5.115E-04	2.857E-03	3.179E-03	6.340E-04	0.000E+00	5.114E-04	2.856E-03	3.179E-03	6.339E-04
CM-246	3.073E-01	2.654E-01	7.100E-02	1.334E-07	0.000E+00	3.073E-01	2.654E-01	7.099E-02	1.332E-07	0.000E+00
TOTAL	3.073E-01	2.659E-01	7.386E-02	3.180E-03	6.369E-04	3.073E-01	2.659E-01	7.385E-02	3.179E-03	6.368E-04

[a]Feed is 1.0 g of ^{246}Cm. Quantities shown at zero years are the feeds in curies.

Table 20. Results of ORIGEN2 and RADAC calculations for decay of actinide $^{239}Pu^{a}$

Nuclide	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
	0	10	20	30	40	0	10	20	30	40
TL-207	0.000E+00	6.359E-15	4.716E-14	1.483E-13	3.285E-13	0.000E+00	6.121E-15	4.629E-14	1.464E-13	3.253E-13
PB-211	0.000E+00	6.377E-15	4.729E-14	1.487E-13	3.295E-13	0.000E+00	6.138E-15	4.642E-14	1.468E-13	3.263E-13
BI-211	0.000E+00	6.377E-15	4.729E-14	1.487E-13	3.295E-13	0.000E+00	6.138E-15	4.642E-14	1.468E-13	3.263E-13
PO-211	0.000E+00	1.785E-17	1.324E-16	4.164E-16	9.225E-16	0.000E+00	1.719E-17	1.300E-16	4.111E-16	9.135E-16
PO-215	0.000E+00	6.377E-15	4.729E-14	1.487E-13	3.295E-13	0.000E+00	6.138E-15	4.642E-14	1.468E-13	3.263E-13
RN-219	0.000E+00	6.377E-15	4.729E-14	1.487E-13	3.295E-13	0.000E+00	6.138E-15	4.642E-14	1.468E-13	3.263E-13
FR-223	0.000E+00	8.793E-17	6.525E-16	2.051E-15	4.543E-15	0.000E+00	8.768E-17	6.515E-16	2.049E-15	4.539E-15
RA-223	0.000E+00	6.377E-15	4.729E-14	1.487E-13	3.295E-13	0.000E+00	6.138E-15	4.642E-14	1.468E-13	3.263E-13
AC-227	0.000E+00	6.372E-15	4.728E-14	1.486E-13	3.292E-13	0.000E+00	6.354E-15	4.721E-14	1.485E-13	3.289E-13
TH-227	0.000E+00	6.289E-15	4.664E-14	1.466E-13	3.249E-13	0.000E+00	6.132E-15	4.607E-14	1.454E-13	3.227E-13
TH-231	0.000E+00	6.124E-10	1.225E-09	1.837E-09	2.448E-09	0.000E+00	6.123E-10	1.224E-09	1.836E-09	2.448E-09
PA-231	0.000E+00	6.486E-14	2.592E-13	5.830E-13	1.036E-12	0.000E+00	6.471E-14	2.589E-13	5.825E-13	1.035E-12
U-235	0.000E+00	6.124E-10	1.225E-09	1.837E-09	2.448E-09	0.000E+00	6.123E-10	1.224E-09	1.836E-09	2.448E-09
PU-239	6.218E-02	6.217E-02	6.215E-02	6.213E-02	6.211E-02	6.218E-02	6.216E-02	6.214E-02	6.212E-02	6.211E-02
TOTAL	6.218E-02	6.217E-02	6.215E-02	6.213E-02	6.211E-02	6.218E-02	6.216E-02	6.214E-02	6.212E-02	6.211E-02

[a] Table continues. Results at higher decay times shown on next page.

Table 20. (continued)

	Calculated radioactivity (Ci) at decay times shown (years)									
	ORIGEN2					RADAC				
Nuclide	0	50	60	80	100	0	50	60	80	100
TL-207	0.000E+00	6.016E-13	9.773E-13	2.062E-12	3.622E-12	0.000E+00	5.967E-13	9.705E-13	2.052E-12	3.607E-12
PB-211	0.000E+00	6.033E-13	9.801E-13	2.068E-12	3.632E-12	0.000E+00	5.984E-13	9.732E-13	2.058E-12	3.617E-12
BI-211	0.000E+00	6.033E-13	9.801E-13	2.068E-12	3.632E-12	0.000E+00	5.984E-13	9.732E-13	2.058E-12	3.617E-12
PO-211	0.000E+00	1.689E-15	2.744E-15	5.791E-15	1.017E-14	0.000E+00	1.676E-15	2.725E-15	5.762E-15	1.013E-14
PO-215	0.000E+00	6.033E-13	9.801E-13	2.068E-12	3.632E-12	0.000E+00	5.984E-13	9.732E-13	2.058E-12	3.617E-12
RN-219	0.000E+00	6.033E-13	9.801E-13	2.068E-12	3.632E-12	0.000E+00	5.984E-13	9.732E-13	2.058E-12	3.617E-12
FR-223	0.000E+00	8.317E-15	1.351E-14	2.852E-14	5.009E-14	0.000E+00	8.311E-15	1.350E-14	2.851E-14	5.007E-14
RA-223	0.000E+00	6.033E-13	9.801E-13	2.068E-12	3.632E-12	0.000E+00	5.984E-13	9.732E-13	2.058E-12	3.617E-12
AC-227	0.000E+00	6.027E-13	9.790E-13	2.067E-12	3.630E-12	0.000E+00	6.022E-13	9.783E-13	2.066E-12	3.628E-12
TH-227	0.000E+00	5.949E-13	9.666E-13	2.040E-12	3.582E-12	0.000E+00	5.915E-13	9.617E-13	2.060E-12	3.617E-12
TH-231	0.000E+00	3.060E-09	3.672E-09	4.894E-09	6.116E-09	0.000E+00	3.060E-09	3.671E-09	4.893E-09	6.115E-09
PA-231	0.000E+00	1.619E-12	2.331E-12	4.142E-12	6.469E-12	0.000E+00	1.618E-12	2.329E-12	4.139E-12	6.466E-12
U-235	0.000E+00	3.060E-09	3.672E-09	4.894E-09	6.116E-09	0.000E+00	3.060E-09	3.671E-09	4.893E-09	6.115E-09
PU-239	6.218E-02	6.210E-02	6.208E-02	6.204E-02	6.201E-02	6.218E-02	6.209E-02	6.207E-02	6.203E-02	6.200E-02
TOTAL	6.218E-02	6.210E-02	6.208E-02	6.204E-02	6.201E-02	6.218E-02	6.209E-02	6.207E-02	6.203E-02	6.200E-02

Table continues. Results at higher decay times shown on next page.

Table 20. (continued)

Nuclide	ORIGEN2 0	ORIGEN2 120	ORIGEN2 160	ORIGEN2 300	ORIGEN2 500	RADAC 0	RADAC 120	RADAC 160	RADAC 300	RADAC 500
	Calculated radioactivity (Ci) at decay times shown (years)									
TL-207	0.000E+00	5.676E-12	1.130E-11	4.708E-11	1.414E-10	0.000E+00	5.655E-12	1.126E-11	4.698E-11	1.413E-10
PB-211	0.000E+00	5.692E-12	1.134E-11	4.721E-11	1.418E-10	0.000E+00	5.671E-12	1.129E-11	4.711E-11	1.417E-10
BI-211	0.000E+00	5.692E-12	1.134E-11	4.721E-11	1.418E-10	0.000E+00	5.671E-12	1.129E-11	4.711E-11	1.417E-10
PO-211	0.000E+00	1.594E-14	3.174E-14	1.322E-13	3.970E-13	0.000E+00	1.588E-14	3.163E-14	1.319E-13	3.967E-13
PO-215	0.000E+00	5.692E-12	1.134E-11	4.721E-11	1.418E-10	0.000E+00	5.671E-12	1.129E-11	4.711E-11	1.417E-10
RN-219	0.000E+00	5.692E-12	1.134E-11	4.721E-11	1.418E-10	0.000E+00	5.671E-12	1.129E-11	4.711E-11	1.417E-10
FR-223	0.000E+00	7.848E-14	1.562E-13	6.508E-13	1.956E-12	0.000E+00	7.844E-14	1.561E-13	6.506E-13	1.956E-12
RA-223	0.000E+00	5.692E-12	1.134E-11	4.721E-11	1.418E-10	0.000E+00	5.671E-12	1.129E-11	4.711E-11	1.417E-10
AC-227	0.000E+00	5.687E-12	1.132E-11	4.716E-11	1.418E-10	0.000E+00	5.684E-12	1.131E-11	4.715E-11	1.417E-10
TH-227	0.000E+00	5.613E-12	1.118E-11	4.656E-11	1.398E-10	0.000E+00	5.662E-12	1.125E-11	4.673E-11	1.402E-10
TH-231	0.000E+00	7.337E-09	9.777E-09	1.829E-08	3.040E-08	0.000E+00	7.336E-09	9.775E-09	1.829E-08	3.040E-08
PA-231	0.000E+00	9.312E-12	1.654E-11	5.802E-11	1.606E-10	0.000E+00	9.308E-12	1.654E-11	5.800E-11	1.606E-10
U-235	0.000E+00	7.337E-09	9.777E-09	1.829E-08	3.040E-08	0.000E+00	7.336E-09	9.775E-09	1.829E-08	3.040E-08
PU-239	6.218E-02	6.197E-02	6.190E-02	6.165E-02	6.130E-02	6.218E-02	6.196E-02	6.189E-02	6.164E-02	6.129E-02
TOTAL	6.218E-02	6.197E-02	6.190E-02	6.165E-02	6.130E-02	6.218E-02	6.196E-02	6.189E-02	6.164E-02	6.129E-02

Table continues. Results at higher decay times shown on next page.

Table 20. (continued)

Nuclide	ORIGEN2 0	ORIGEN2 1,000	ORIGEN2 10,000	ORIGEN2 100,000	ORIGEN2 1,000,000	RADAC 0	RADAC 1,000	RADAC 10,000	RADAC 100,000	RADAC 1,000,000
TL-207	0.000E+00	6.047E-10	5.482E-08	1.487E-06	2.118E-06	0.000E+00	5.967E-10	5.447E-08	1.486E-06	2.118E-06
PB-211	0.000E+00	6.064E-10	5.498E-08	1.491E-06	2.124E-06	0.000E+00	5.984E-10	5.462E-08	1.490E-06	2.124E-06
BI-211	0.000E+00	6.064E-10	5.498E-08	1.491E-06	2.124E-06	0.000E+00	5.984E-10	5.462E-08	1.490E-06	2.124E-06
PO-211	0.000E+00	1.698E-12	1.539E-10	4.176E-09	5.948E-09	0.000E+00	1.676E-12	1.529E-10	4.173E-09	5.947E-09
PO-215	0.000E+00	6.064E-10	5.498E-08	1.491E-06	2.124E-06	0.000E+00	5.984E-10	5.462E-08	1.490E-06	2.124E-06
RN-219	0.000E+00	6.064E-10	5.498E-08	1.491E-06	2.124E-06	0.000E+00	5.984E-10	5.462E-08	1.490E-06	2.124E-06
FR-223	0.000E+00	8.365E-12	7.587E-10	2.058E-08	2.932E-08	0.000E+00	8.260E-12	7.538E-10	2.056E-08	2.931E-08
RA-223	0.000E+00	6.064E-10	5.498E-08	1.491E-06	2.124E-06	0.000E+00	5.984E-10	5.462E-08	1.490E-06	2.124E-06
AC-227	0.000E+00	6.062E-10	5.498E-08	1.491E-06	2.124E-06	0.000E+00	5.986E-10	5.462E-08	1.490E-06	2.124E-06
TH-227	0.000E+00	5.981E-10	5.422E-08	1.471E-06	2.095E-06	0.000E+00	5.912E-10	5.388E-08	1.470E-06	2.095E-06
TH-231	0.000E+00	6.037E-08	5.321E-07	2.007E-06	2.124E-06	0.000E+00	6.036E-08	5.321E-07	2.006E-06	2.124E-06
PA-231	0.000E+00	6.372E-10	5.495E-08	1.491E-06	2.124E-06	0.000E+00	6.370E-10	5.494E-08	1.491E-06	2.124E-06
U-235	0.000E+00	6.037E-08	5.321E-07	2.007E-06	2.124E-06	0.000E+00	6.036E-08	5.321E-07	2.006E-06	2.124E-06
PU-239	6.218E-02	6.042E-02	4.662E-02	3.489E-03	1.924E-14	6.218E-02	6.041E-02	4.662E-02	3.489E-03	1.923E-14
TOTAL	6.218E-02	6.042E-02	4.662E-02	3.507E-03	2.337E-05	6.218E-02	6.041E-02	4.662E-02	3.506E-03	2.336E-05

Column heads: Calculated radioactivity (Ci) at decay times shown (years).

[a]Feed is 1.0 g of ^{239}Pu. Quantities shown at zero years are the feeds in curies.

The overall impression received from Table 20 is that ORIGEN2 and RADAC show very good agreement for the ^{239}Pu chain, excellent agreement for the first five members of the chain, and excellent agreement for all members at decay times of 100,000 and 1 million years.

7.4 VERIFICATION OF INTEGER-ARRAY ARITHMETIC SUBROUTINES

This section shows the results of some example problems designed to demonstrate the precision of the integer-array arithmetic subroutine package used in IBATFIX.FOR and IBATFLT.FOR.

7.4.1 Division Subroutine

Exhibit 6.1 shows the division of 1.0 by 7.0 in terms of arrays consisting of 60 integers of 3 digits each. The arrays use a modified floating-point notation. The decimal point is located between the third and fourth integers, so there are 57 integers of 3 digits each following the decimal point. The first integer of the array shows the exponent of 1000 by which the value of the array is multiplied. In this notation, the numerator is 1.0, the denominator is 7.0, and the quotient is 142.857142857 · · · · ·, with an exponent of -1, meaning that the value shown is multiplied by 1000^{-1}. The validity of the result is obvious from the fact that the repeating decimal 142857 continues all the way to the final digit.

As the exhibit shows, the division was checked by multiplying the quotient by the denominator, giving a result that is very close to 1, as it should be. Incidentally, this serves as a check on the multiplication subroutine.

Exhibit 6.2 shows a similar example in which 1.0 is divided by 61.0. In this case, the period of the repeating decimal in the quotient is 60 digits. The rounding routine in the program has rounded the final integer upward to 869 because the next integer following would have been 852. Again, the quotient has been multiplied by the divisor, and the result is very close to 1. In this case, because there are 171 zeros following the 1.0, the error in the result is not more than 10^{-171}.

7.4.2 Calculation of e^x

Exhibit 6.3 shows the results of calculating e^{+1} and e^{-1}. These results illustrate the ability of the subroutine package to perform a lengthy series calculation involving all four of the basic operations of arithmetic. The standard power series for e^x shown in the exhibit can be found in handbooks such as Peirce 1929. The results for e^{+1} and e^{-1} were multiplied together, giving a result very close to 1.0,

(Text continued on page 155)

Exhibit 6.1. Example of division routine.

Subroutine DIV divides one array by another. In this example, the numerator is 1.0 and the denominator is 7.0. Both are expressed as arrays of 60 integers of 3 digits each. The single digit on the left is the exponent of the array to the base 1000.

Numerator:

```
0  000 001.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
           000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
           000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
           000 000 000 000 000 000 000 000 000 000 000 000
```

Denominator:

```
0  000 007.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
           000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
           000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
           000 000 000 000 000 000 000 000 000 000 000 000
```

Results (quotient):

```
-1  000 142.857 142 857 142 857 142 857 142 857 142 857 142 857 142 857
            142 857 142 857 142 857 142 857 142 857 142 857 142 857 142
            857 142 857 142 857 142 857 142 857 142 857 142 857 142 857
            142 857 142 857 142 857 142 857 142 857 142 857
```

Check by multiplying quotient by denominator. The result is equal to the numerator within an error of 1.0×10^{-173}:

```
-1  000 999.999 999 999 999 999 999 999 999 999 999 999 999 999 999 999
            999 999 999 999 999 999 999 999 999 999 999 999 999 999 999
            999 999 999 999 999 999 999 999 999 999 999 999 999 999 999
            999 999 999 999 999 999 999 999 999 999 999 999
```

Exhibit 6.2. Second example of division routine.

In this example, subroutine DIV divides 1.0 by 61.0.

Numerator:

```
 0   000 001.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000
```

Denominator:

```
 0   000 061.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000
```

Quotient:

```
-1   000 016.393 442 622 950 819 672 131 147 540 983 606 557 377 049 180
             327 868 852 459 016 393 442 622 950 819 672 131 147 540 983
             606 557 377 049 180 327 868 852 459 016 393 442 622 950 819
             672 131 147 540 983 606 557 377 049 180 327 869
```

Check by multiplying quotient by the denominator:

```
 0   000 001.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000
```

When dividing 1 by 61, the quotient has an unusually long repeating period, 60 digits long. The repeating part starts with 016 and ends with 459. The program has rounded the final integer to 869.

Exhibit 6.3. Calculation of e^x and e^{-x} with $x = 1$.

Program EMX2C calculates e^x and e^{-x} by power series summation. The series used is Peirce 759:

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

The series in each case was calculated with x = 1 and x = -1, and the calculations were carried out until the term being added or subtracted had an absolute value less than 10 to the -170 power. This occurred at the 109th term. The summations at that point were as follows:

e^{+1}:

```
0  000 002.718 281 828 459 045 235 360 287 471 352 662 497 757 247 093
               699 959 574 966 967 627 724 076 630 353 547 594 571 382 178
               525 166 427 427 466 391 932 003 059 921 817 413 596 629 043
               572 900 334 295 260 595 630 738 132 328 627 946
```

e^{-1}:

```
0  000 000.367 879 441 171 442 321 595 523 770 161 460 867 445 811 131
               031 767 834 507 836 801 697 461 495 744 899 803 357 147 274
               345 919 643 746 627 325 276 843 995 208 246 975 792 790 129
               008 626 653 589 494 098 783 092 194 367 377 338
```

These are multiplied together by subroutine MULT with the following result:

```
0  000 001.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
               000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
               000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
               000 000 000 000 000 000 000 000 000 000 000 001
```

Note that this example demonstrates all four of the basic arithmetical operations.

The National Bureau of Standards *Handbook of Mathematical Functions* gives values of these functions to 20 significant figures, as follows:

e^{+1} = **2.718281828459045235360287**

e^{-1} = **0.3678794411714423215955238**

and these agree with the calculations shown here.

which verifies to some extent the precision of the results of the series calculations. The fact that these results agree with the values given by the National Bureau of Standards is not of much use in establishing precision, as the handbook values are given to only twenty significant figures. However, the agreement of the results to twenty figures does indicate that there are no gross programming errors in the routine.

There are two principal points of interest in this example. First, it demonstrates the ability of the integer-array arithmetic package to handle a lengthy series calculation without excessive accumulation of round-off errors. Second, the calculation of e^{-x} plays an important part in the evaluation of the Bateman equations.

Exhibit 6.4 shows the results of calculating e^{+10} and e^{-10}. As stated in the exhibit, the precision of the series calculation tends to suffer as the absolute value of the exponent increases. However, the precision achieved here is ample for calculating actinide decay, even for long chains. Again, the values given by the Bureau of Standards agree with those attained here, but are given to only twenty significant figures.

The precision attainable by integer-array arithmetic is limited only by the size of the array. By using larger array sizes, we have found that the last integer of e^{+10} shown in Exhibit 6.4 should be 275 rather than 273, and the last integer of e^{-10} should be 909 rather than 911.

7.4.3 Other Series Calculations

A number of test programs were created in which a small master program was combined with the complete package of integer-array arithmetic subroutines to perform various combinations of series calculations. Exhibit 6.5 shows the results of one such program, EMX2F2. This program uses power series to calculate arctan(x) and sin(arctan x) and then squares the latter to obtain a result that can be predicted in advance on trigonometric grounds. By considering a right-angled triangle whose sides are 1, 2, and $\sqrt{5}$, it can easily be shown that the square of sin(arctan 0.5) must be exactly 1/5. The result shown in the exhibit is within 1.0 E-170 of this value. This demonstrates the ability of the integer-array arithmetic subroutine package to perform a lengthy series of calculations without excessive accumulation of round-off errors.

Exhibit 6.6 shows the results of the same test program using x = 1/7. In a right triangle whose sides are 1, 7, and $\sqrt{50}$, the smaller acute angle has a tangent of 1/7, and it can readily be shown that the square of the sine of this angle must be exactly 1/50, or 0.02. The result obtained by the program

(Text continued on page 159)

Exhibit 6.4. Calculation of e^{+10} and e^{-10}.

The calculation of e^{+10} and e^{-10} in this example uses the same procedure as that used in the previous example for e^{+1} and e^{-1}. It provides a more difficult test of precision because the increase in the exponent of e causes an increase in the number of terms required to reach the point at which the term being added has an absolute value less than 10^{-170}.

e^{+10}:

```
1   0 22.026 465 794 806 716 516 957 900 645 284 244 366 353 512 618
          556 781 074 235 426 355 225 202 818 570 792 575 199 120 968
          164 525 895 451 555 501  92 457 836 652 423 291 606 522 895
          166 222 480 137 728 972 873 485 577 837 847 273
```

e^{-10}:

```
1   0 0.000 000 045 399 929 762 484 851 535 591 515 560 550 610 237
         918 088 866 564 969 259 071 305 650 999 421 614 302 281 652
         525 004 545 947 782 321 708 055 089 686 028 492 945 199 117
         244 520 388 837 183 347 709 414 567 560 990 911
```

Product of e^{+10} and e^{-10}

```
0   0 1.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
         000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
         000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
         000 000 000 000 000 000 000 000 000 039 273 026
```

The deviation of this product from the desired value of 1.0 indicates that there has been some loss of precision in the calculation.

The values given by the Bureau of Standards handbook to 20 significant figures are as follows:

e^{+10} = **22026.46579480671651695790**

e^{-10} = **0.00004539992976248485153559152**

To the number of significant figures given, the handbook values agree exactly with the values calculated here.

Exhibit 6.5. Example of precision of integer-array arithmetic.

Program EMX2F2 uses integer-array arithmetic to calculate arctan(x), sin(arctan x), and the square of sin(arctan x) with a precision of 170 decimal places. This example shows results of calculations with x=0.5:

The first series, Peirce 779, calculates arctan 0.5. The result, given in radians, is:

```
  -1      0 463.647 609 000 806 116 214 256 231 461 214 402 028 537 054 286
                120 263 810 933 088 720 197 864 165 741 705 300 600 283 984
                887 892 556 529 852 251 190 837 513 505 818 181 625 011 155
                471 530 569 944 105 620 719 336 266 164 879 761
```

In the notation used in the program, the first term is the exponent of 1000. Thus arctan 0.5 = 0.4636476....., etc., to about 170 decimal places. The final term of the summation, shown below, is less than 1.0E-170, showing that the desired degree of convergence has been reached. This is term 286:

```
  -1      0 000.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
                000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
                000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
                000 000 000 000 000 000 000 000 000 000 000 000
```

The second series, Peirce 772, calculates sin(arctan 0.5). After 49 terms:

```
  -1      0 447.213 595 499 957 939 281 834 733 746 255 247 088 123 671 922
                305 144 854 179 449 082 104 185 127 560 979 882 882 881 675
                756 454 993 901 635 230 154 756 700 850 653 544 889 414 772
                717 272 024 306 690 541 773 355 634 638 375 068

        or:     sin(arctan 0.5) = 0.447213595...., etc.
```

The 49th term of the second series, shown below, is 4.33607E-185, again demonstrating that convergence has been reached:

```
 -62      0  43.360 670 762 434 613 375 505 863 746 298 967 387 067 774 007
                369 301 962 002 524 388 360 589 619 752 794 169 796 380 030
                354 078 828 648 575 515 875 687 716 970 051 358 347 838 353
                072 941 248 024 554 382 226 790 874 218 529 436
```

The program then squares sin(arctan 0.5), giving the final result:

```
  -1      0 199.999 999 999 999 999 999 999 999 999 999 999 999 999 999 999
                999 999 999 999 999 999 999 999 999 999 999 999 999 999 999
                999 999 999 999 999 999 999 999 999 999 999 999 999 999 999
                999 999 999 999 999 999 999 999 999 999 999 316

          = 0.19999....   to 170 decimal places.
```

The exact trigonometric answer, which was known in advance, was 1/5. The result obtained by the above calculations is within 1.0E-170 of that. This demonstrates the precision of the integer-array arithmetic package used in EMX2F2 for handling lengthy power-series calculations. The same package is used in the yield factor calculations performed by IBATFLT.

Exhibit 6.6. Second example using trigonometric series.

This program calculates arctan(x) and sin(arctan(x)) with tan(x) = 1/7 and uses this to calculate the square root of 2.

Converged result for arctan x:

```
-1   000 141.897 054 604 163 922 812 851 617 102 553 083 007 781 758 728
             464 072 378 130 029 363 441 626 759 931 160 944 191 861 634
             246 518 117 522 682 874 061 098 365 238 175 210 862 376 753
             011 721 287 856 090 962 076 101 506 654 275 681
   NLOOP =   103
```

Final term of converged summation:

```
-1   000 000.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000
```

Converged result for sin(arctan x):

```
-1   000 141.421 356 237 309 504 880 168 872 420 969 807 856 967 187 537
             694 807 317 667 973 799 073 247 846 210 703 885 038 753 432
             764 157 273 501 384 623 091 229 702 492 483 605 585 073 721
             264 412 149 709 993 583 141 322 266 592 751 030
   NLOOP =   040
```

Final term of converged summation:

```
-62  000 113.307 679 717 416 489 907 090 041 212 313 881 911 932 385 871
             080 127 652 849 579 656 368 584 643 225 550 421 941 928 334
             898 586 579 198 892 927 588 895 537 747 277 771 351 198 084
             360 667 017 593 162 866 749 606 857 898 486 768
```

Sin(arctan x) multiplied by 10 gives the square root of 2:

```
0    000 001.414 213 562 373 095 048 801 688 724 209 698 078 569 671 875
             376 948 073 176 679 737 990 732 478 462 107 038 850 387 534
             327 641 572 735 013 846 230 912 297 024 924 836 055 850 737
             212 644 121 497 099 935 831 413 222 665 927 510
```

This is the square of 10 * sin(arctan x). It should be equal to 2:

```
0    000 002.000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
             000 000 000 000 000 000 000 000 000 000 000 012
```

was within 1.0 E−170 of this, again demonstrating the ability of the integer-array arithmetic package to handle series calculations with high precision.

7.5 SUMMARY OF RESULTS OF VERIFICATION AND VALIDATION

The results of the verification and validation studies described here can be summarized as follows:

1. The proper functioning of the accumulation feature of RADAC has been amply confirmed by the results of test examples run on RADAC and LIBGEN/WINPRO/SAS.
2. The results of decay calculations performed by RADAC have been compared with the results of ORIGEN2 on the same problems. For fission and activation products, decay calculations were made on 86 individual nuclides over a decay-time range of 1 to 1 million years. The results shown by RADAC and ORIGEN2 in these tests were essentially identical; disagreements, if any, were in fourth significant figure. For actinides, decay calculations for five long-chain actinides were made for a decay-time range of 10 to 1 million years. These runs show agreement between ORIGEN2 and RADAC that varied from poor to excellent depending on the decay time and the position of the nuclide in the decay chain. The preponderance of these results, however, showed agreement in the good to excellent range.
3. The ability of the integer-array arithmetic package used in the IBAT codes to perform lengthy series calculations with very high precision was demonstrated by examples.

8. CONCLUSIONS

Our principal conclusion from this work is that the use of integer-array arithmetic is a practical and effective way of dealing with the precision difficulties posed by the Bateman equations.

Our second conclusion is that the yield factor method, using stored yield factors that have been previously calculated off-line, is an efficient way of utilizing the high precision afforded by integer-array arithmetic.

Our final conclusion is that the RADAC code, which combines the advantages of these techniques, has been validated to the point where it is ready for testing by a limited group of users.

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