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Code Manual for MACCS2: Volume 2, Preprocessor Codes COMIDA2, FGRDCF, IDCF2

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ABSTRACT

This report is a user's guide for the preprocessors developed for the MACCS2 code. MACCS2 represents a major enhancement of its predecessor MACCS, the MELCOR Accident Consequence Code System. MACCS, distributed by government code centers since 1990, was developed to evaluate the impacts of severe accidents at nuclear power plants on the surrounding public. The principal phenomena considered are atmospheric transport and deposition under time-variant meteorology, short- and long-term mitigative actions and exposure pathways, deterministic and stochastic health effects, and economic costs. MACCS2 was developed as a general-purpose tool applicable to diverse reactor and nonreactor facilities licensed by the Nuclear Regulatory Commission or operated by the Department of Energy or the Department of Defense. The preprocessors available for use with the MACCS2 code are COMIDA2, DOSFAC2, FGRDCF, and IDCF2. The COMIDA2 code contains a semidynamic food chain model and generates a file of dose-to-source conversion factors that are used by MACCS2 in calculations of ingestion doses. DOSFAC2, FGRDCF, and IDCF2 generate a file of dose conversion factors that are required for MACCS2 dose calculations. The preprocessors, written in FORTRAN 77, require a 486 or higher IBM-compatible PC.

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Preface

This report is the second part of a two-volume set of code manuals that describe the MACCS2 code and its preprocessors. The operation of the MACCS2 code is described in Volume 1. The operation of the preprocessor codes distributed with MACCS2 is described in this volume.

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1 OVERVIEW OF MACCS2 AND THE MACCS2 PREPROCESSORS

1.1 Overview of MACCS and MACCS2

MACCS was developed at Sandia National Laboratories (SNL) under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC) to estimate the offsite consequences of hypothetical severe accidents at nuclear power plants (NPPs). MACCS2, developed at SNL primarily under the sponsorship of the U.S. Department of Energy (DOE), includes a number of enhancements that improve the code for consequence analyses for nonreactor nuclear facilities.

MACCS models the transport and dispersion of plumes of radioactive material released to the atmosphere. As the plumes travel through the atmosphere, material may be deposited on the ground via wet and dry processes. Seven pathways are modeled through which the general population can be exposed to radiation: cloudshine, groundshine, direct and resuspension inhalation, ingestion of contaminated food and water, and deposition on skin. Emergency response and protective action guides for both the short and long term are also considered as means to mitigate the extent of the exposures. As a final step, the economic costs of mitigative actions are estimated. The user may choose to perform calculations based on a single weather sequence or random sampling of a year of weather data. The set of consequence results generated from the random sampling of a year of weather data is presented in the form of a complementary cumulative distribution function (CCDF).

The MACCS2 package provides a number of enhancements over MACCS, including: (1) a more flexible emergency response model, (2) an expanded library of radionuclides, and (3) a semidynamic food-chain model. In addition, the MACCS2 package includes four preprocessors that are designed to accept input files containing user-defined model parameters.[1] Although the SNL MACCS development team utilized preprocessor codes to generate input data for MACCS, those codes were not designed to accept user input files and as a result they received only limited use outside of SNL. Three of the MACCS2 preprocessors provide the user with access to a number of different databases of dose conversion factors (DCFs). In addition, the new semidynamic food-chain model is contained in a preprocessor. The preprocessors included in the MACCS2 package make possible the treatment of nuclide-specific data tailored to particular applications.

The MACCS2 preprocessors facilitate code use by reducing both the MACCS2 execution time and the amount of user input required by MACCS2. The preprocessors perform calculations that are computationally intensive, require large amounts of input data, and generate data files that can be useful for numerous consequence calculations. For most users, the preprocessor-generated data files included in the MACCS2 package will be sufficient. The preprocessors will only be required when it is necessary to generate data based on assumptions that differ from those used in the preprocessor-generated files included in the MACCS2 distribution package.

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[1] An additional preprocessor for MACCS and MACCS2, not discussed in this document, became available to users in 1997. This preprocessor, SECPOP90 (Humphreys et al., 1997), was developed under the sponsorship of the NRC and generates MACCS and MACCS2 site data files.

1.2 Dose Conversion Factor Preprocessors

The calculation of health effects to the population resulting from exposure to ionizing radiation is based on models of the effects of various dose levels to specific organs. In MACCS2, all doses are expressed in units of equivalent dose using the SI units of sieverts (Sv). In the remainder of this document, for convenience, the term "dose" will always refer to the equivalent dose or effective dose as those terms are defined in ICRP 60 (ICRP, 1991).

The MACCS2 package includes three dose conversion factor preprocessors, DOSFAC2, FGRDCF, and IDCF2. The preprocessors generate DCF files based on the format of the MACCS DCF files and can be used with both MACCS and MACCS2. User guides for FGRDCF and IDCF2 are contained in this document. A complete description of the DOSFAC2 preprocessor is contained in a separate document, the *DOSFAC2 User's Guide* (Young et al., 1997).

DCFs represent a convenient approach to simplifying dose calculations; they relate environmental contamination levels or intakes to resultant doses. Because of the different energy levels and types of radiation emitted by different nuclides, DCFs are calculated for individual nuclides. For each nuclide, DCFs can be calculated for any organ or for an effective dose to the whole body based on the weighted doses received by different organs. In addition, DCFs are required for each exposure pathway of concern. The DCFs available to the analyst determine the type of health effect that can be calculated. Health effect calculations require that DCFs be available for the specific nuclide present in the environment, the specific organ that would be affected, and the human exposure pathway of concern.

The primary pathways by which people may be exposed to ionizing radiation emitted by radionuclides released during a nuclear accident are:

1. external exposure to radionuclides in a released plume (cloudshine),

2. external exposure from radionuclides deposited from the plume onto surfaces (groundshine),

3. internal exposure through the inhalation of radionuclides in the air, and

4. internal exposure through the ingestion of food or water contaminated with radionuclides.

Table 1 lists the types of DCFs that can be processed by the MACCS/MACCS2 code. MACCS/MACCS2 requires that a database of DCFs be available in a MACCS2 input file format. The DCF file format used for MACCS2 is derived from the DCF file format used for MACCS. As a result, for code-to-code comparisons, MACCS and MACCS2 should be exercised using a single DCF file.

Table 1
Dose Conversion Factors Utilized by MACCS2
for the Calculation of Doses to Humans

Dose conversion factor	Unit
Cloudshine	Sv/s per Bq/m^3
Groundshine 8 hour	Sv per Bq/m^2
Groundshine 7 day	Sv per Bq/m^2
Groundshine rate	Sv/s per Bq/m^2
Inhaled acute	Sv/Bq
Inhaled chronic	Sv/Bq
Ingestion	Sv/Bq

Calculational models of external exposure DCFs assume a homogeneous distribution of radioactivity within a large region of a medium. DCFs for groundshine typically assume a smooth, infinite planar source with uniform concentration. Models for internal exposure resulting from the inhalation or ingestion of radionuclides represent different body organs as compartments through which radionuclides are transported. These models have been refined over the years as additional empirical data have become available.

The most recent complete set of models is provided in ICRP 30 (ICRP, 1979). Those models were issued by the ICRP over a period beginning in 1979 and ending in 1982. Subsequently, revised metabolic models for some transuranic elements were issued as ICRP 48 (ICRP, 1986). Furthermore, age-dependent metabolic models for a limited set of fission products were issued as ICRP 56 (ICRP, 1987). However, apart from the EPA's adoption of the ICRP 48 metabolic models as part of Federal Guidance Report (FGR) 11 (Eckerman et al., 1989) regulatory guidance documents issued by government agencies such as the DOE and NRC have continued to specify the use of ICRP 30 DCFs in radiation protection standards.

Prior to MACCS2, the MACCS DCF file was generated by the DOSFAC preprocessor. DOSFAC generated DCFs only for the 60 radionuclides considered important for nuclear power plant analyses. In addition, DOSFAC was not designed to accept user-defined data. DOSFAC2 is an enhanced version of the DOSFAC DCF preprocessor. It allows the user to input values previously built into the code; e.g., values may now be input for relative biological effectiveness, acute dose reduction factors, clearance class, and particle size. However, the limitations of the DCF databases accessed by DOSFAC2 limit the preprocessor to the generation of DCFs for only the 60 radionuclides considered important for nuclear power plant analyses.

Over the past decade, both the U.S. Environmental Protection Agency (EPA) and the Department of Energy have distributed databases of DCFs for an extensive list of radionuclides and organs. The primary problem in expanding the library of DCFs for MACCS2 is that no one source of DCFs provides all of the types of DCFs required to complete all of the MACCS2 health effect calculations for all radionuclides that may be of interest. For example, the EPA has published external and internal DCFs for a large set of nuclides in Federal Guidance Reports 11 and 12 (Eckerman et al., 1989; Eckerman and Ryan, 1993), but because FGR 11 provides only 50-year committed doses for inhalation, acute (or deterministic) health effects cannot be calculated.

The MACCS2 preprocessor FGRDCF provides the user with access to the EPA-recommended DCFs in Federal Guidance Reports 11 and 12. FGRs 11 and 12 provide a database of 500 nuclides for inhalation and ingestion, and a library of 825 nuclides for the cloudshine and groundshine pathways. This database provides sufficient DCF information for the calculation of chronic doses but it does not provide sufficient DCF information for the calculation of acute doses in MACCS2.

The third MACCS2 DCF preprocessor, IDCF2, provides the capability of accessing ingestion and inhalation DCFs required for acute dose calculations that are not available from DOSFAC2 or FGRDCF. IDCF2 is based on the IDCF DCF code (Fetter, 1988) developed for DOE for fusion reactor consequence analyses.

FGRDCF is the preferred source of DCFs because it accesses the EPA-recommended DCF database, which includes a large number of nuclides, and it takes into account revised methodologies issued by the ICRP, such as ICRP 48, and a revised method for calculating external dose rates developed by Oak Ridge National Laboratory (ORNL).

DOSFAC2, developed and implemented under NRC sponsorship, is recommended for commercial reactor assessments, particularly when acute effects must be calculated. IDCF2 provides a source for DCFs unavailable from FGRDCF or DOSFAC2. It is anticipated that IDCF2 would be most useful when it is necessary to calculate acute effects for nuclides not included in the set of 60 considered by DOSFAC2. And, if necessary, the DCFs generated by IDCF2 could be used to augment a DCF file created by DOSFAC2.

An overview of the three DCF preprocessors included in the MACCS2 package and the databases accessed by the preprocessors is provided in Table 2.

Table 2
DCF Preprocessors Distributed in MACCS2 Package

DCF Preprocessor	DCF Database Accessed	Advantages	Disadvantages
DOSFAC2	Accesses DOE/EH-0070 (DOE 1988a) DOSD87 and INDEXR.DAT provided by K.F. Eckerman (ORNL)	Based on NRC DOSFAC code developed specifically for MACCS; allows the calculation of the full range of MACCS2 health effects. Allows ready modification of parameter values.	Contains DCFs for only the 60 nuclides identified as important for commercial nuclear power plant releases.
FGRDCF	Accesses DCFs distributed by the EPA in Federal Guidance Reports 11 and 12	Provides access to the entire library of nuclides available in FGR 11 and 12. Considered preeminent source of DCFs because they are EPA recommended.	Does not provide DCFs required for the calculation of acute health effects modeled by MACCS2.
IDCF2	Accesses DOE/EH-0070 (DOE, 1988a)	Provides internal DCFs for some nuclides not available in DOSFAC2 or FGRDCF. Can provide internal DCFs for 396 radionuclides.	A secondary source of DCFs that can be used to augment the DOSFAC2 list of 60 nuclides when the calculation of acute effects is required.

1.3 Food-chain Preprocessor: COMIDA2

In versions of MACCS prior to MACCS2, the transfer of radionuclides from deposition to incorporation into the edible portion of animal and plant foodstuffs was modeled within the MACCS code. This original MACCS food-chain model has the following limitations, which resulted in the development of a new food-chain model for MACCS2 (in the discussion in this section, the original MACCS food-chain model will be referred to as the MACCS food-chain model and the new model will be referred to as the MACCS2 food-chain model):

1. The MACCS food-chain model requires the user to supply unitless transfer coefficients for each nuclide and crop type to be considered by the code. These coefficients are not readily available in the literature. The derivation of values for the transfer coefficients is labor intensive and the methodology for their development is poorly documented.

2. The entire process by which a dose is received from food has a strong dependence on time and the dose limit criteria are time-dependent. The MACCS food-chain model does not have the capability to handle time dependence in a dynamic way.

3. The MACCS food-chain model does not have the capability of modeling radionuclide decay and ingrowth.

Input parameter values for the MACCS food-chain model were originally derived for only six nuclides. Values for additional nuclides have not been developed because the calculations required are labor intensive and the methodology for their derivation is inadequately defined. In addition, the modeling of the ingrowth and decay of radionuclides could increase in importance as the original list of nuclides included in the food-chain model is expanded.

Another major disadvantage of the MACCS food-chain model is that it is essentially a static model divided into two discrete submodels: the growing season submodel and the long-term submodel. The growing season submodel is used to determine doses received from radionuclides deposited onto the surface of growing plants. The long-term submodel determines the dose received from the material deposited onto the surface of the soil. Any deposition that occurred during the growing season is modeled as if it had been deposited in the middle of the growing season. If the deposition occurred outside of the growing season, the growing season dose is assumed to be zero.

The new food-chain preprocessor developed for MACCS2 is based on the COMIDA food-chain model. The COMIDA code was developed by Abbott and Rood (1993, 1994) of the Idaho National Engineering and Environmental Laboratory (INEEL) specifically for MACCS2, and those two references contain the code's documentation. The COMIDA code estimates nuclide concentrations in agricultural food products following an acute fallout event.

COMIDA was designed as a general-purpose replacement for the MACCS food-chain model. COMIDA is a dynamic food-chain model that models the transfer of radionuclides into the edible portion of plants as a function of plant growth. The input parameter values are typically directly available in the literature and do not require labor-intensive calculations. In addition, COMIDA accounts for linear decay chains up to four nuclides in length, and can consider ingrowth after deposition.

COMIDA models transport through the human food chain and calculates the respective nuclide concentration in nine foodstuffs (grains, leafy vegetables, roots, fruits, legumes, milk, beef, poultry, and “other animal”), based on an initial unit deposition. All COMIDA calculations are performed for one user-specified accident day in the year, or "fallout" date, and foodstuff concentration data can be calculated for up to 50 years following the accident, reported as both 1-year or cumulative (0 to N yrs) values.

COMIDA2, developed at Sandia National Laboratories, serves as an interface program between COMIDA and MACCS2. COMIDA2 exercises COMIDA a number of times to generate the information needed for the MACCS2 run. It automatically loops on multiple fallout dates, translates the COMIDA-calculated foodstuff concentrations into units of dose broken down by crop category, and writes a binary file of dose-to-source ratios for use by MACCS2. A full description of COMIDA2 is provided in Section 2 of this document.

2 COMIDA2 MODEL DESCRIPTION AND USER'S GUIDE

The INEEL-developed COMIDA program estimates concentrations in food resulting from a single accident date, whereas MACCS2, which selects dates based on Monte Carlo sampling, needs to have date-dependent concentration data available for each accident date selected. Although it would have been possible to have MACCS2 perform all the COMIDA calculations for every execution by calling it as a subroutine, this is a very inefficient process that would have greatly increased the MACCS2 run time. A significant reduction in computing time was achieved by implementing COMIDA as part of a preprocessor to MACCS2.

COMIDA2 serves as an interface shell between MACCS2 and COMIDA that builds on the modeling capabilities of COMIDA. Three functional capabilities added to the INEEL-developed COMIDA characterize COMIDA2: (1) the ability to consider multiple accident dates in the year (up to nine in a single run); (2) calculation of projected and accumulated doses (per unit deposition), considering food consumption rates, agricultural productivity, and processing losses; and (3) a free-format User Input file processed according to the conventions of MACCS2, which specifies the additional input data required by the newly added code features.

In developing COMIDA2, no changes to the calculational algorithms of Abbott and Rood have been made. In order to verify that this is the case, the output of the four sample problems (for spring, winter, summer, and fall), listed in Abbott and Rood (1993) can be reproduced exactly with a single execution of COMIDA2.

Providing data for multiple accident dates allows MACCS2 to consider the variability in ingestion dose due to seasonality effects. Furthermore, by expanding the scope of the food-chain calculations to include projected and accumulated doses (per unit deposition), in addition to the foodstuff concentrations, substantial efficiency gains are achieved.

As a result of the fact that doses, and not concentrations, are stored by COMIDA2 for use by MACCS2, the calculation framework allows an expansion in the number of nuclides that can be considered in a single run of MACCS2. Whereas the MACCS food-chain model allows a maximum of 10 nuclides at a time to be considered, the COMIDA2 preprocessor allows the simultaneous consideration of up to 50 nuclides and their progeny. Furthermore, as a result of the chosen architecture, the run time of MACCS2 is minimized.

2.1 New Model Features Implemented in COMIDA2

The MACCS2 food-chain tasks performed by COMIDA2 include (1) calculation of data for multiple release dates, (2) calculation of the resulting individual and societal doses per unit deposit, (3) reconciling differences between COMIDA's discrete harvesting and continuous harvesting models, and (4) accounting for decay and ingrowth that occurs between harvest and consumption. These tasks are discussed in this section.

2.1.1 Consideration of Multiple Accident Dates

COMIDA can consider multiple nuclides in a single execution, but only one postulated accident date. For use with MACCS2, where accidents can be postulated to occur on any day of the year, it was necessary for the food-chain preprocessor to produce a MACCS2 input file that contained food transfer data for a number of potential accident dates throughout the year so that seasonality effects could be reflected in the consequence estimates. COMIDA2 thus exercises COMIDA for a series of user-specified accident dates and consolidates the COMIDA output for the different dates into a single binary file of dose-to-source ratios used by MACCS2.

There are practical limitations of storage space and execution that constrain the number of accident dates that can be considered with COMIDA2. COMIDA2 and MACCS2 are configured to accommodate a maximum of 50 food ingestion nuclides and 9 accident dates. The only constraint on the user specification of the Julian accident dates is that they be monotononically increasing. When MACCS2 is exercised in conjunction with COMIDA2 for an accident occurring on a specific day in the year, it utilizes the COMIDA2 dataset generated for the closest available date, spanning the year's end as necessary. For example, if the MACCS2 accident date was Julian day 365 and COMIDA2 results were generated for Julian days 300 and 63, MACCS2 would select the COMIDA2 results for Julian day 63. In cases where the two nearest COMIDA2 datasets are equally close to the MACCS2 accident day, MACCS2 will select the date that occurs earliest in the year. For example, if COMIDA2 results are available for Julian days 120 and 160, and the MACCS2 accident date is Julian day 140, the MACCS2 calculations will utilize the COMIDA2 results for Julian day 120.

2.1.2 Calculation of Both Individual and Societal Doses

The ingestion pathway model in MACCS2 requires data relating to both individual and societal doses from ingestion. COMIDA2 converts COMIDA's instantaneous foodstuff concentrations for vegetable crops (Bq/kg) and time-integrated foodstuff concentrations for animal crops (Bq-day/kg) to measures of individual dose and societal dose. By performing this conversion in the MACCS2 food-chain preprocessor COMIDA2, rather than in MACCS2 itself, great economies of storage space and execution time are achieved.

In addition to the binary file of dose-to-source ratios used by MACCS2, the COMIDA2 List Output file provides an extensive set of tables so that the dose-to-source ratios generated can be examined and compared with the results of other food-chain models without the need for exercising MACCS2.

In order to calculate an individual dose, the user must define the individual's annual consumption rate (kg/yr) for nine foodstuffs: (1) grains, (2) leafy vegetables, (3) roots, (4) fruits, (5) legumes, (6) beef, (7) milk, (8) poultry, and (9) "other" animal crop. COMIDA2 then calculates the individual's food dose per unit deposition by assuming that the individual is self-sufficient in food production. That is, that the entire diet is locally produced.

The calculation of the individual dose D_i (Sv) for a given spatial element and area A can be represented by the following equation:

$$D_i = A \sum_{k=1}^{N} \left[\sum_{j=1}^{F} (GC_k DS_k CR_j) \right]$$

where

N = number of nuclides;
F = number of foodstuffs;
GC_k = the ground concentration of nuclide k;
DS_k = the COMIDA2 individual dose-to-source ratio for nuclide k; and
CR_j = the individual consumption rate for the foodstuff j.

As indicated by the above equation, the amount of radioactive material ingested is calculated by multiplying (1) the contamination level in each foodstuff category by (2) the foodstuff category's annual consumption rate. For example, if the time-integrated milk concentration for the year is estimated to be 10^3 Bq-year/kg and the maximally exposed individual (MEI) consumes 10^2 kg/year of milk, then 10^5 Bq are consumed via milk in that annual exposure period. Carrying through the example to dose calculation, if the ingestion DCF for that nuclide is 10^{-8} Sv/Bq, then the individual dose-to-source ratio for milk ingestion over that period would be 10^{-3} Sv/(Bq/m^2).

MACCS2 calculations are often performed for a number of organs. For example, the FGR 11 and 12 organ list includes gonad, breast, lung, red marrow, bone surface, thyroid, remainder, and effective. In order to economize on run time and storage space, COMIDA2 only calculates individual dose-to-source ratios for two organs: thyroid and effective. These two organs are used because the projected individual dose is used in MACCS2 only to determine protective actions related to food interdiction, and the current EPA PAGs (EPA 1992) are based on thyroid and effective doses. Societal dose-to-source ratios (see Section 3.2.2) are generated for all of the organs included in the DCF file used by COMIDA2 (see Section 3.5.1), because it is the societal dose that MACCS2 utilizes in the food ingestion dose calculations.

In order to minimize the size of the COMIDA2 List Output file, dose-to-source ratios for both individual and societal doses on the COMIDA2 List Output file are only tabulated for effective dose and thyroid. Nevertheless, the binary data file includes societal dose-to-source ratios for all organs for which DCFs are available. To reiterate, MACCS2 allows the reporting of projected individual doses for just two organs: effective and thyroid. The societal ingestion dose calculated in MACCS2, however, is available for all of the organs considered in the MACCS2 calculations.

The individual dose calculations in COMIDA2 are based on the approach outlined on pp. 33-34 of Abbott and Rood (1993). The COMIDA2 individual dose information is combined with the MACCS2 ground contamination data. The subsequent individual dose level calculated by MACCS2 is compared with interdiction criteria input by the MACCS2 user to determine if agricultural interdiction is to be implemented by the code.

Societal dose is a measure of the total dose to a population. A societal ingestion dose results from the ingestion of noninterdicted foodstuffs, i.e., foodstuffs for which an individual dose below the interdiction level was calculated. The societal dose is a function of the level of contamination and the agricultural productivity of the contaminated land. The COMIDA2 user is required to specify agricultural productivity data which define the quantity of contaminated food available for consumption and the size of the affected population. The percentage of the MACCS2 user-defined grid defined as farmland is specified in the MACCS2 Site Input file. The COMIDA2 model assumes that the area of farmland specified within the user-defined grid produces foodstuffs in proportion to the user-defined consumption rates for the foodstuff categories.

The calculation of the societal dose, D_s (person-Sv), for a given spatial element and area A may be represented by the following equation:

$$D_S = A\sum_{k=1}^{N}\left[\sum_{j=1}^{C}(GC_k DS_k AP_j)\right]$$

where

N = number of nuclides;
C = number of crop categories;
DS_k = the COMIDA2 societal dose-to-source ratio for nuclide k; and
AP_j = the agricultural productivity for the crop category j.

2.1.3 Consideration of Modeling Differences for Animal and Vegetable Foodstuffs

Food interdiction is modeled in MACCS2 as a function of the projected annual individual doses from successive years of agricultural production. The MACCS2 food interdiction model requires the user to specify annual dose limits for effective dose and thyroid. The dose criteria evaluated are for the total dose from both animal and vegetable crops. Because of differences between COMIDA's calculational methods for animal versus vegetable foodstuffs, COMIDA2 must reconcile the two types of results so that they can be combined to yield estimates of projected doses from successive annual exposure periods. The approach to reconciling those differences is described in the following two subsections.

2.1.3.1 Accounting for Discrete versus Continuous Harvesting

COMIDA models vegetable crops as being harvested once per year. Animal crops are modeled as being continuously harvested. COMIDA provides vegetable crop foodstuff concentrations as instantaneous concentrations (Bq/kg) and animal crop concentrations as time-integrated concentrations (Bq-day/kg). COMIDA2 incorporates a calculational "fix" to reconcile these differences.

The vegetable crop foodstuff concentrations reported by COMIDA are the instantaneous concentrations estimated to be present in the edible portion of the foodstuff at the time of its harvest. The time of harvest is specified in the COMIDA .VAR input file as variable TEC, with a single Julian day specified as the harvest day for all five of the human-consumed vegetable crops. The delay between the date of the fallout event and the crop harvest can range from a minimum of zero (if the fallout day is the same as the harvest day) to a maximum of 364 days (if the fallout day occurs the day after the harvest day).

Whereas vegetable crops are harvested once a year, animal crops are modeled by COMIDA as being continuously produced and consumed throughout the year. As a result, the animal crop foodstuff concentrations reported by COMIDA are reported as time-integrated concentrations for annual integration periods, each period having a duration of 365 days. These annual "consumption" periods are modeled by COMIDA as beginning on the Julian day of the fallout event. For example, if the fallout occurs on Julian day 200, the time-integrated concentrations reported by COMIDA for animal products are reported for successive 365-day periods, with each period beginning on Julian day 200.

COMIDA2 dose calculations are based on the consumption of contaminated foodstuffs for incremental 365-day (yearly) periods after the accident. In order to reconcile the difference in the way vegetable and animal concentrations are calculated, an algorithm was developed for COMIDA2 which divides each year's crop inventories, as reported by COMIDA, into two components: (1) that which is consumed in the 365-day period following the accident and (2) that which is "left over" for consumption in the subsequent 365-day period, also referenced to the time of the accident.

As illustration of the sensitivity of vegetable crop concentrations to the relationship between the time of fallout and the time of harvest, consider the following example. Assume that the fallout day occurs the day after the vegetable crop harvest time, TEC. The human-consumed vegetable crops are then harvested after a delay of 364 days. If there is a holdup time (i.e., time between harvest and consumption) of just 1 day, the dose to humans from the ingestion of vegetable crops in the first 365-day period following the accident should be zero. The animal product concentrations, however, have much less sensitivity to small shifts in the fallout day.

2.1.3.2 Consideration of Holdup Time—"Leftover" Food

COMIDA models holdup time for animal products, allowing a different holdup time for each of the four animal crops. Radioactive decay and ingrowth are modeled to occur within the contaminated food crops during this holdup period. In contrast, COMIDA does not model holdup time for the vegetable crops. As a result, new coding incorporated into COMIDA2 is used to account for vegetable crop holdup time.

COMIDA2 implements a user-specified holdup time for the five vegetable crops consumed by humans. The user specifies a holdup time (in days) for each of the five crops. Allowable values must be in the range between 0 and 60 days. The total foodstuff inventories, CTOTAL, at harvest

are decayed (with ingrowth) for the holdup time specified for each crop. For calculating the "effective" time of harvest relative to the time of the accident (for the purpose of allocating the crops between "current" year and the amount that is "left over" for the next year), the code adds the holdup time (variable HOLDUPTM) to the time of harvest (variable TEC).

For the leftover animal products, COMIDA2 implements a simple ratio of the time-integrated foodstuff concentrations reported by COMIDA. For example, if the holdup time for animal products is 30 days, then the code calculates the first year's dose from animal products by multiplying the COMIDA time-integrated animal product concentrations by a fudge factor of 335/365 because 30/365 of the year's production will be left over for the next year. In calculating the second-year dose, the code adds the leftover term (30/365 of the first year's concentration) to 335/365 times the second year's animal concentrations.

2.2 Development of Individual and Societal Dose Input Parameter Values

This section provides guidance for the development of and recommended values for COMIDA2 individual and societal dose input parameter values. As discussed in Section 3.2.2, COMIDA2 must provide MACCS2 with sufficient information to allow the calculation of both an individual dose for the food interdiction model and a societal dose for the ingestion model.

2.2.1 Individual Dose Input Parameter Data

The primary input parameter for the individual dose calculations is CONSUM_RATES, as discussed in Section 3.5.1. CONSUM_RATES defines the individual annual consumption rate of each food category. Numerous sources are available in the literature for foodstuff consumption rates, broken down by food category. Food consumption rates vary widely, depending on the age of the individual and other factors. One of the most widely cited sources for consumption rates is NRC Regulatory Guide 1.109, which specifies consumption rates for a maximally exposed individual consuming a total of 940 kg of food per year (including 310 kg of milk). However, most published data for the food consumption of an average adult total less than half that amount, indicating a high degree of conservatism in the regulatory guide.

COMIDA2 accepts the input of only one set of food consumption parameters. The user must decide what type of individual to consider, and provide the corresponding parameters. Since the foodstuff interdiction models use the projected individual dose in determining the acceptability of food production, conservatively overestimating an individual's consumption rate, everything else being equal, could result in underestimates of societal food doses and overestimates of farm-associated economic costs. However, if no interdiction occurs, that effect would not be present. The sample problems distributed with COMIDA2 utilize food consumption data for an average adult in the United States, obtained from Kennedy and Strenge (1992).

2.2.2 Societal Dose Input Parameter Data

If commercial farmland production is allowed on land with a given level of contamination, the resultant societal dose is proportional to the agricultural productivity of the land in question. The primary input parameter for the societal dose calculations, PRODUC_RATES (discussed in Section 3.5.1), defines the farmland annual productivity of edible product (kg/m^2) for nine foodstuffs. In addition, for each foodstuff, the user supplies a unitless factor to account for a reduction in contamination as a result of processing losses.

Calculation of the societal ingestion dose is a more complex problem than the individual dose calculations. Very few individuals in the United States consume only locally grown food. Over the past decades, agribusiness has evolved as a result of the conversion of farmland to large-scale commercial enterprises and improvements in transportation and food distribution. In many areas of the country, most of the locally consumed food is produced at distant locations, with source locations shifting over the course of the year.

It would be exceedingly difficult to attempt, for example, to track the movement of contaminated foodstuffs through the U.S. production and distribution systems. A simple approach to the calculation of societal dose from food ingestion entails estimating the annual average productivity of U.S. farmland; that is, the number of kilograms of each foodstuff produced from a square meter of farmland in an average year.

Examination of agricultural data in the 1993 *Statistical Abstract of the United States* revealed that many agricultural statistics follow a cyclic pattern. The drivers for these cycles are probably year-to-year changes in weather in combination with U.S. and global business cycles. One statistic, however, which appears to follow a straight line is the land in farms, which has declined from 1,028 million acres in 1982 to 980 million acres in 1992 (estimated).

The variabilities of the other agricultural statistics are larger than the variability of the land in farms. For example, on average, the harvested acreage is only about one-fourth to one-third of the land in farms, having values that varied between 298 and 352 million acres over the period between 1980 and 1990.

Because we are only interested in calculating the potential dose received by the U.S. population, the derivation of the productivity values must also include a consideration of the fraction of harvested acreage that is devoted to exports. Between 1980 and 1990, the harvested acreage going to exports, as a fraction of the total harvested acreage, varied cyclically between a minimum of 23.7% (in 1985) and a maximum of 39.7% (1989). On average, however, between 1980 and 1990, roughly 67% of harvested acreage was for domestic consumption and 33% was exported.

After considering the available aggregate statistics, we have derived a simple method of estimating the productivity of average farmland. It entails calculating the U.S. per capita land in farms devoted to domestic consumption. If land in farms is taken to be 980 million acres (4.0 million square kilometers), and 67% of that area is used for domestic consumption, then 2.7 million square kilometers of the land in farms is devoted to domestic consumption. With the 1990 census

population of 248.7 million persons, the per capita land in domestic farm production is thus 0.011 square kilometer per capita (or 11,000 m^2 of farmland to feed a person). An alternative way of stating the relationship is as a reciprocal; that one square kilometer of average farmland can support 91 people (i.e., 1 / 0.011).

Because there are large uncertainties in agricultural productivity, due to both regional differences and variations from year to year as a result of weather and economic factors, it is desirable to simplify the analysis by using a round number for the number of people fed by a square kilometer of farmland. Rounding off 91 people to 100 is well within the year-to-year variations in the national average statistics and it simplifies the preparation of the COMIDA2 input files. An aggregate agricultural productivity figure of 100 persons/km^2 is also exactly the same as the assumption used by Abbott and Wenzel (1994) in their estimate of the societal dose resulting from ingestion of food after potential releases from the international thermonuclear experimental reactor (ITER). A productivity figure of 100 persons/km^2 indicates that, on average, 10^4 m^2 of farmland in the United States feeds one U.S. resident.

The next step in the derivation is to define individual annual food consumption rates. For the purpose of illustration, we present the COSYMA default values for human consumption rates as tabulated by Abbott et al. (1993) to derive an example of agricultural productivity data that can be used in MACCS2 to estimate societal dose. Our analysis is based on the assumption that 10^4 m^2 of farmland feed one person. These results are shown in Table 3.

Table 3
ITER COSYMA-Based Consumption Rates

Foodstuff	Annual consumption rate (kg)[a]	Annual productivity (kg/m^2)[b]
Milk	115	0.0115
Beef	75	0.0075
Poultry	0	0.0
Leafy Veg.	15	0.0015
Other Veg.	15	0.0015
Legumes	15	0.0015
Root Veg.	85	0.0085
Grains	85	0.0085

[a] Foodstuff annual consumption rates sum to a total individual annual consumption rate of 405 kg produced per 10^4 m^2.

[b] Foodstuff annual productivity rates sum to a total annual productivity rate of 0.0405 kg/m^2.

The annual consumption rates presented here differ from the consumption rates of Kennedy and Strenge (1992). The COSYMA-based ITER parameter values are presented because they are used in the INEL analyses of fusion reactors previously cited. The COSYMA-based ITER values yield a total food consumption rate of 405 kg, 13% higher than the total food consumption rate, 355 kg, used for the COMIDA2 sample problems. Considering the numerous uncertainties, differences of this magnitude can be considered unimportant. However, the lack of data for poultry consumption in the COSYMA-based ITER values resulted in the use of an alternative source of data for the COMIDA2 sample problems which did provide data for poultry consumption. Inclusion of poultry in the MACCS2 calculational framework, as opposed to its exclusion, allows a better understanding of the relative importance of the various foodstuff categories.

For all of the vegetable crops, the derived productivity values are much smaller than the nominal values found in the literature. For example, NUREG/CR-5512 (Kennedy and Strenge, 1982) gives crop yields (kilograms wet weight/square meter) of 2.0 for leafy vegetables, 4.0 for other vegetables, 2.0 for fruit, and 1.0 for grains—values more than two orders of magnitude larger than our derivation. However, we do not believe that the NUREG/CR-5512 crop yield data can be used as agricultural productivity parameters for COMIDA2 to generate realistic estimates of societal food dose because (1) sizable quantities of vegetable crops are wasted or fed to animals, (2) most farmland is fallow in any given year, and (3) large quantities of food are exported.

With a total farmland area of approximately 4×10^6 km^2, a nominal agricultural productivity of 1 kg/m^2 (the lowest value from NUREG/CR-5512) would yield a total annual agricultural production of 4×10^{12} kg or approximately 15 metric tons of food per U.S. resident. Clearly, societal doses from food ingestion cannot be calculated using agricultural productivity values of such high magnitude.

While the 100 persons/km^2-farmland assumption is consistent with aggregate agricultural statistics for the United States, it suffers from a weakness that results in overestimating the importance of animal products: Inherent in the derivation is the assumption that the fraction of farmland devoted to the production of each foodstuff is proportional to the quantity of the foodstuff consumed by the representative individual, as defined by the market basket. This simplifying assumption ignores the important fact that the production of animal product foodstuffs requires much larger areas (probably by more than an order of magnitude) than the production of equal quantities (on a mass basis) of vegetable foodstuffs. This inefficiency is due to the fact that crops must be grown to feed the animals, and the ratio of animal feed to resultant animal mass can be large.

In preparing the COMIDA2 sample problems, owing to a lack of suitable agricultural productivity data, we assumed in effect that farmland is allocated to the various crops in proportion to the market basket of the representative individual. For example, if an individual consumes roughly equal quantities of grain and beef, then the calculational method we derived indicates that equal portions of farmland are devoted to (1) grain consumed by humans and (2) beef consumed by humans.

Since this is clearly not the case, with a vastly larger fraction of farmland devoted to the production of human-consumed beef than human-consumed grain, our derived values for the agricultural productivity of animal products are overestimates, possibly by more than an order of magnitude. And, if the agricultural productivity of animal products is an overestimate, then the relative importance of the animal foodstuffs, compared with the vegetable foodstuffs, is similarly an overestimate.

At this time, despite the acknowledged weakness of the data derived in this manner, there is no ready source of alternative information that can be used with MACCS2 to calculate societal doses. It is stressed, however, that users are encouraged to make their own critical assessments of the code's sample problem data, and to revise such data as appropriate for their particular application.

An alternative approach to the use of the 100 persons/km^2-farmland assumption, but one that is likely to be quite demanding in terms of resources, is to perform an agricultural census of a study area surrounding the facility being evaluated. The agricultural productivity of each foodstuff is simply the amount produced in the region divided by the area of the region. Because agricultural production is subject to large variations due to weather and the economic cycle, several years of data would probably be required.

2.3 COMIDA2 Sample Problems

The distribution diskette contains four sample problems for COMIDA2, identified as BASECASE, PATHWAY, SAMP_A, and SAMP_D.

BASECASE: The sample problem provided with COMIDA by INEEL is described in Abbott and Rood (1993). It models a single deposited nuclide, ^{93}Mo, which decays to ^{97m}Nb. The results are generated for fall, winter, spring, and summer fallout dates. This problem utilizes DCFs from Federal Guidance Reports 11 and 12.

SAMP_A: This sample problem represents a set of input files generated independently of the COMIDA guidance document provided by INEEL that is reproduced in Appendix A of this volume. Much of the input utilized for this sample problem was obtained from Kennedy and Strenge (1992). This problem utilizes DCFs from the DOSFAC-produced DOSDATA.INP file that was distributed with MACCS 1.5.11.1.

SAMP-D: A set of input files identical to SAMP_A except that the DCFs of FGR 11 and 12 are used.

PATHWAY: A set of input files used to perform a comparison against the PATHWAY code. This comparison is discussed in Section 2.6.5. The DCF file utilized was that from FGR 11 and 12. The time of harvest for vegetable crops (PATHWAY.PAR input variable TEC) was changed from a value of Julian day 280 (October 7) to the vegetable harvest date used in PATHWAY, Julian day 200 (July 19). (Because of the semidesert conditions at the Nevada Test Site, the area used in the

PATHWAY analyses, local vegetable crops are harvested much earlier than is the case for most other U.S. locations.)

2.3.1 Running COMIDA2

COMIDA2 is exercised by invoking the DOS batch file RUNCOM2.BAT. The four sample problems can be rerun by entering the following commands at the DOS prompt or by executing the included RUNEM.BAT DOS command file:

RUNCOM2 BASECASE
RUNCOM2 PATHWAY
RUNCOM2 SAMP_A
RUNCOM2 SAMP_D

2.4 Input and Output Files

This section describes the COMIDA and COMIDA2 input files required and output files produced by each program. In each execution of COMIDA2, a number of associated files are used to obtain the input data needed, and to store the output generated by the code's execution. A naming convention is used to maintain the association between the files used for each execution of the code. All of the files used for a single COMIDA2 execution have an identical DOS filename, which can be up to 8 characters in length.

2.4.1 .PAR file

This file contains the COMIDA input data that are not nuclide specific. The contents of this file are described on pages 54-56 of Abbott and Rood (1993). Aside from the following exceptions, COMIDA2 utilizes this information in exactly the same manner as COMIDA:

a. The accident time TI is not processed; COMIDA2 obtains the accident times (Julian day in year) from the ACCDATES array described in Section 3.5.1.

b. The variables controlling the number of years to be considered, NTIMES and KYEAR, are not processed, being overridden by the value of LASTACUM described in Section 3.5.1.

2.4.2 .VAR file

This file contains the COMIDA input data that are nuclide specific. The contents of this file are described on page 57 of Abbott and Rood (1993). Aside from the following exceptions, COMIDA2 utilizes this information in exactly the same manner as COMIDA:

a. The number of nuclides to be considered, NNUC, is limited to a maximum of 50. As per the original COMIDA, each of the specified nuclides can have up to three progeny, as a linear chain, with the branch ratios for each decay step being hardwired to one. In checking for exceedance of the 50-nuclide limit of COMIDA2, the number of defined progeny, NPROG, is not considered. Only initially deposited nuclides, and not ingrown daughter products, count toward the limit.

b. All of the nuclide names specified on the .VAR file must be included in the dose factor file specified for COMIDA2 as input variable DCF_FILE (see Section 3.5.1). The DCF file must include all of the specified nuclides: both initially deposited, and any progeny which are defined on the .VAR file.

2.4.3 .CNC file

This file contains foodstuff concentration data for every year of the calculations, and every accident date. In contrast to the original COMIDA, which offered the capability of skipping the printing of concentration results for intermediate years of the calculations, COMIDA2 automatically stores foodstuff concentration data.

Because this file is large, after verifying the correct installation of the code, the user may wish to have the RUNCOM2.BAT file automatically delete the .CNC file after each COMIDA2 execution. This is readily accomplished by adding a **DEL %1.CNC** statement after the **DEL COMIDA2.TMP** statement in the RUNCOM2.BAT file. Subsequently, whenever there is a need to examine the year-by-year foodstuff concentrations, the RUNCOM2.BAT file can be restored to its initial configuration, and thereby make the .CNC file available for analysis.

2.4.4 .DMP file

This file of intermediate results is likely to be of use only for purposes of debugging. Its contents are exactly the same as the COMIDA.DMP file written by the original COMIDA code. In the RUNCOM2.BAT file distributed with COMIDA2, the .DMP file is automatically deleted after every execution. If problems are encountered with COMIDA2 execution, it may be necessary to modify the RUNCOM2.BAT file so that the file is preserved for debugging purposes. Under normal circumstances, the file contains no useful information.

2.4.5 .INP file

This file contains the input parameters that are needed to control the code enhancements implemented during the development of COMIDA2, principally the ability to consider multiple accident dates and the calculation of doses.

2.4.6 .LST file

This file contains an echo of the .INP file as well as a series of tables showing the results of the dose calculations.

2.4.7 .BIN file

This is a FORTRAN sequential-access unformatted (binary) file which is written by COMIDA2 for processing by MACCS2. The user should not attempt to modify this file with any type of editor.

2.5 COMIDA2 User's Guide

The COMIDA2 program incorporates the MACCS2 free-format input processor for processing input variables. Consequently, the error-handling facilities of COMIDA2 in processing this information follow the same approach as used in MACCS2. If the software cannot obtain a valid set of input data (that is, values of the proper type and within the specified allowable range), an error message will be issued and further execution terminated. For information regarding the operation of the MACCS2 free-format input processor, refer to Section 2.2.1 of Volume 1 of this report. The MACCS2 free-format input processor is not used for the data files processed by the original COMIDA code, the .PAR and .VAR files.

2.5.1 COMIDA2 Input Parameters

This section describes all of the COMIDA2 input parameters that must be provided on the .INP file. It does not describe the nuclide-specific data of the .VAR file and the non-nuclide-specific data of the .PAR file. For information regarding the contents of the .VAR and .PAR file, refer to the COMIDA manual (Abbott and Rood, 1993, 1994).

Variable Name: **DCF_FILE**
Variable Type: Character, Scalar
Allowed Range: 1 <= length <= 40
Purpose: Identifies the DCF file to be used for the COMIDA2 calculations. This filename can include a directory path; the file need not be in the current directory. The DCF file that is specified in the CHRONC input file for MACCS2 must be the same DCF file specified for COMIDA2.

If MACCS2 detects a discrepancy in the two-line headers of the two DCF files, an error message will be printed and MACCS2 execution terminated. If it is impossible to obtain the same DCF file that was used for the COMIDA2 run (because of accidental deletion), the user can manually edit the two-line header of the MACCS2 DCF file so that it matches the two-line header shown as part of the MACCS2 error message. The user is then

responsible for ensuring that the two DCF files used for COMIDA2 and MACCS2 contain identical data.

Example Usage:
*
DCF_FILE001 'DOSDATA.INP' (MACCS 1.5.11.1 INPUT FILE)

Variable Name: **NUMDATES**
Variable Type: Integer, Scalar
Allowed Range: 1 <= value <= 9
Purpose: Specifies the total number of accident dates to utilize.
Example Usage:
*
NUMDATES001 9

Variable Name: **ACCDATES**
Variable Type: Integer, Array
Allowed Range: 1 <= value <= 365
Purpose: Defines the accident dates, or "fallout" dates, to be utilized. A total of NUMDATES values must be supplied as a row of data on the input file.
Example Usage:
*
ACCDATES001 1 61 121 151 181 201 241 271 301

Variable Name: **LASTACUM**
Variable Type: Integer, Scalar
Allowed Range: 1 <= value <= 50 years
Purpose: Specifies the duration of the ingestion dose exposure period. In MACCS2, the accumulated societal dose will be calculated starting with the year that the land satisfies the human consumption criteria DOSEMILK and DOSEOTHR, with the exposure period ending in the LASTACUM year after the accident. If a value of 30 is specified, the maximum number of years considered is thirty.
Example Usage:
*
LASTACUM001 10

Variable Name: **CROPNAME**
Variable Type: Character, Array
Allowed Range: 4 <= length <= 9

Purpose: Defines the nine food categories for which the original COMIDA program calculates nuclide concentrations. These names are defined by COMIDA and thus should not be modified by the user in the following variable input blocks. The names must be specified exactly as shown below in column one of the following data blocks.

Variable Name: CONSUM_RATES

Variable Type: Real, Array

Allowed Range: 0.0 <= value <= 1000.0 kg/yr

Purpose: Defines the specific food category consumption rate for an average individual. Corresponds to an average adult annual food intake. Nine values must be supplied in column two of the data block.

Example Usage:

```
*
* Average individual's consumption rate of foodstuffs (kg/year)
* Taken from Kennedy and Strenge (1992, NUREG/CR-5512, Vol. 1)
*
*                 CROPNAME        CONSUM_RATES
*
CONSUMPT001       'GRAINS'          69.
CONSUMPT002       'LEAFY_VEG'       11.
CONSUMPT003       'ROOTS'           25.5   (50% of NUREG/CR-5512's "other veg.")
CONSUMPT004       'FRUITS'          46.
CONSUMPT005       'LEGUMES'         25.5   (50% of NUREG/CR-5512's "other veg.")
CONSUMPT006       'BEEF'            59.
CONSUMPT007       'MILK'           100.    (includes all milk products)
CONSUMPT008       'POULTRY'         9.
CONSUMPT009       'OTHER'           10.    ("Other Meat" of COMIDA is used for eggs)
```

Variable Name: PRODUC_RATES

Variable Type: Real, Array

Allowed Range: 0.0 <= value <= 1000.0 kg/m^2

Purpose: Defines the agricultural productivity for a specific food category. Nine values must be supplied in column two of the data block.

Example Usage:

```
*
* Farmland's annual productivity of finished edible product (kg/square meter)
*
* Note: These values are much lower than the commonly cited figures for productivity of
        vegetable crops. The agricultural productivity values below are based on the assumption
        that it requires an average of 1 km^2 of farmland to feed 100 people. Therefore, the
        productivity values are 1E-4 (one ten-thousandth) of the individual's consumption rates
        specified above.
```

```
*
*                  CROPNAME          PRODUC_RATES
*
AGPRODUC001        'GRAINS'           69.0E-4
AGPRODUC002        'LEAFY_VEG'        11.0E-4
AGPRODUC003        'ROOTS'            25.5E-4
AGPRODUC004        'FRUITS'           46.0E-4
AGPRODUC005        'LEGUMES'          25.5E-4
AGPRODUC006        'BEEF'             59.0E-4
AGPRODUC007        'MILK'            100.0E-4
AGPRODUC008        'POULTRY'          9.0E-4
AGPRODUC009        'OTHER'            10.0E-4     (egg production)
```

Variable Name: **PROCLOSS**

Variable Type: Real, Array

Allowed Range: 0.0 <= value <= 1.0 (unitless)

Purpose: Defines unitless factors applied in the COMIDA2 dose calculation to account for the reduction in contamination levels (radionuclide losses) as a result of processing foodstuffs prior to consumption. Values for each food category must be supplied in column two of the data block.

Example Usage:

```
*
* Processing Losses Applied to Each Crop Category (unitless)
*  (A value of 0.0 means that all of the radioactive material is lost during processing.  A
*  value of 1.0 means that none of the radioactive material is lost during processing. )
*
* Note:  The foodstuff concentrations reported in the .CNC file are not affected by the values
* provided in the .INP file.  While some references provide element-specific loss factors for
* each foodstuff category, COMIDA2 does not offer that flexibility.
*
* The values below are taken from F.W. Boone, Y.C. Ng, and J. M. Palms, "Terrestrial Pathways
* of Radionuclide Particulates," Health Physics, Vol. 41, No. 5, pp. 735-747 (November 1981).
*
*                  CROPNAME          PROCLOSS
*
PROCLOSS001        'GRAINS'          0.25
PROCLOSS002        'LEAFY_VEG'       0.8
PROCLOSS003        'ROOTS'           0.8
PROCLOSS004        'FRUITS'          0.65     (taken as average of 0.5 and 0.8)
PROCLOSS005        'LEGUMES'         0.75     (taken as average of 0.5 and 1.0)
PROCLOSS006        'BEEF'            0.9
PROCLOSS007        'MILK'            1.0
PROCLOSS008        'POULTRY'         0.9
PROCLOSS009        'OTHER'           1.0      (eggs)
```

Variable Name:	**HOLDUPTM**
Variable Type:	Real, Array
Allowed Range:	0.0 <= value <= 60.0 (days)
Purpose:	Defines the holdup time for each of the five vegetable crops consumed by humans. Five values must be supplied in column two of the data block.

Example Usage:

*		
*	**CROPNAME**	**HOLDUPTM**
*		
HOLDUPTM001	'GRAINS'	0.
HOLDUPTM002	'LEAFY_VEG'	0.
HOLDUPTM003	'ROOTS'	0.
HOLDUPTM004	'FRUITS'	0.
HOLDUPTM005	'LEGUMES'	0.

2.6 The SAMP_A Test Case

This section reviews the development of input parameter values for the SAMP_A COMIDA2 test case. This case was developed in order to compare COMIDA2 output with the output of other food-chain models and accident consequence studies. The results of these comparisons are presented in this section.

2.6.1 SAMP_A.VAR File

The file SAMP_A.VAR is almost exactly the same as the file COMIDA.VAR described in the COMIDA manual (see Abbott and Rood, 1993). An examination of the data in that file indicated that it was based largely on the assumptions implemented in PATHWAY (see Whicker and Kirchner, 1987; Whicker et al., 1990). Since the purpose of the exercise was to validate COMIDA2 results against PATHWAY and other codes, only the minimum necessary changes were made to the files provided by INEL.

During the preparation of SAMP_A, the only change that was made to the original INEL file, COMIDA.VAR as listed on page A-1 of the COMIDA manual, was the correction of the "other" meat animal consumption rates for vegetable crops so that it became identical with the COMIDA.VAR file's feed consumption rates for poultry. In SAMP_A, a laying hen was thus assumed to consume 95 grams/day of grains, 10 grams/day of legumes, and 10 grams/day of soil.

2.6.2 SAMP_A.PAR File

The data file SAMP_A.PAR was developed by SNL independently of efforts toward the preparation of Appendix A of this volume. Appendix A was prepared by Mike Abbott of INEL and that information was not available during the preparation of SAMP_A.PAR. Because of Mr. Abbott's extensive experience with food-chain modeling, his recommendations should be given

great weight in choosing appropriate input data for COMIDA2. Nevertheless, the parameter values of SAMP_A.PAR are considered by the authors to be a reasonably defensible source of parameter values for risk assessments and a good starting point for sensitivity studies, etc.

The nuclide-specific data in SAMP_A.PAR file were developed using just two reference sources, a description of the PATHWAY code (Whicker and Kirchner, 1987), and NUREG/CR-5512 (Kennedy and Strenge, 1992).

Foliar absorption rates, soil leach rates, and soil absorption and desorption rates were obtained from Whicker and Kirchner (1987). The values given in that article for the concentration ratio, COMIDA variable CRC, were not used because crop-specific values were not given. A single value was given for each element. The CRC values of SAMP_A were obtained from NUREG/CR-5512, which provides crop-specific values for leafy vegetables, root vegetables, fruit, and grain. NUREG/CR-5512 does not include concentration ratio values for legumes, hay, and pasture. Thus, for the COMIDA variables CRC(5), CRCH, and CRCP, parameter values were taken to be the same as NUREG/CR-5512 values for leafy vegetables, ordinarily considered the "reference" crop.

Whicker and Kirchner (1987) do not include tabulated data for the animal product transfer factors, which are ordinarily expressed in units of days per kilogram for the various animal products. They gave instead the equations used to calculate those parameters. NUREG/CR-5512 provides animal product transfer factors for beef, poultry, milk, and eggs. Those values were used directly to obtain data for the COMIDA input variables TCB, TCP, TCM, and TCO, respectively.

The soil leach rate constant, COMIDA variable ZKL, in accordance with PATHWAY, was set to zero for the relatively short-lived nuclides, taken here as those with half-lives less than 2 years. For ^{235}U, because NUREG/CR-5512 appears to have assumed a soluble form, ZKL was set to the value used in PATHWAY for cesium, 6.6E-6/d (corresponding to the middle value of the three used in PATHWAY). The same value, 6.6E-5/d, was used for curium because of its W clearance class. For americium and cerium, ZKL was set to the value used in PATHWAY for plutonium, 6.7E-7/d. For ^{129}I, the high leach rate used in PATHWAY for strontium, 6.6E-5/d, was used because of iodine's high solubility.

2.6.3 SAMP_A.INP File

The consumption and productivity rate values applied in the COMIDA2 SAMP_A.INP file are based on the derivation discussed in Section 2.2 of this document. The data used for illustrating the example usage in Section 2.5 represent the input data contained in SAMP_A.INP.

2.6.4 Comparison with KfK[2] Results

COMIDA2 results from the SAMP_A sample problem were compared with the IG-91/X and IB-90/X results prepared by KfK for COSYMA (see Steinhauer, 1992). The two sets of results are

[2] The Kernforschungszentrum Karlsruhe, now the Forschungszentrum Karlsruhe.

from two versions of COSYMA used in 1990 and 1991. The comparison was performed by exercising COMIDA2 with two accident dates: Julian days 1 and 181.

The IG-91X and IG-90BX analyses present dose calculations for ^{131}I, ^{134}Cs, and ^{137}Cs in units of $Sv/(Bq/m^2)$ for an exposure period of 100 years and a dose commitment period of 50 years. The COMIDA2 calculations were performed for a 10-year exposure period and a 50-year dose commitment period. Previous studies such as Whicker and Kirchner (1987) have indicated that the residual ingestion dose after 4 years is insignificant.

The main exceptions to this premise would be long-lived nuclides that are taken up by the roots, such as ^{90}Sr. Root uptake for the nuclides evaluated here is relatively unimportant. In addition, ^{131}I and ^{134}Cs have short half-lives, making both 10-year and 100-year exposure periods essentially of an effective infinite duration. Even for ^{137}Cs, the difference in exposure periods is probably unimportant because the SAMP_A results indicate that approximately 99 percent of the dose is delivered in the first 4 years.

A minor difference between the MACCS2 and KfK DCFs was accounted for, with the COMIDA2 results adjusted so that they are on the same basis as the KfK results. The COSYMA DCFs (Sv-effective/Bq ingested) were

^{131}I	1.32E-8
^{134}Cs	1.92E-8
^{137}Cs	1.33E-8.

The COMIDA2 DCFs used in SAMP_A were

^{131}I	1.434E-8
^{134}Cs	1.975E-8
^{137}Cs	1.355E-8.

The COSYMA DCFs were adjusted to match the COMIDA2 DCFs, using ^{131}I as an example, by multiplying the COSYMA results by a factor of 1.086 (i.e., 1.434 / 1.32).

Results from both KfK analyses are presented to portray some of the "model uncertainty" associated with two sets of results generated by the same team of researchers in two successive years. These results are shown in Table 4.

Table 4
Comparison of COMIDA2-based SAMP_A Results with KfK Results

Results for Summer Accident, July 1 [Sv-effective/(Bq/m^2-deposit)]			
Nuclide	COMIDA2	IG-91/AX[a]	IG-90/BX[a]
^{131}I	6.9E-9	4.1E-9	1.0E-8
^{134}Cs	9.0E-8	3.5E-7	6.0E-7
^{137}Cs	7.2E-8	3.0E-7	5.2E-7
Results for Winter Accident, January 1 [Sv-effective/(Bq/m^2)-deposit]			
Nuclide	COMIDA2	IG-91/AX[a]	IG-90/BX[a]
^{131}I	3.2E-10	9.8E-10	1.1E-16
^{134}Cs	6.8E-9	1.2E-8	1.9E-9
^{137}Cs	5.2E-9	1.4E-8	1.8E-8

[a] Values are adjusted so DCFs match the DCFs applied in the COMIDA2 calculations.

2.6.5 Comparison with PATHWAY Results

Whicker and Kirchner (1987, Table 9) provide a set of PATHWAY results for individual intake predictions for eight fallout dates spanning the period March 1 to October 7. PATHWAY was used to estimate the total food ingestion of an adult male that would occur if there were a unit deposition (1 Bq/m^2) of each of twenty nuclides considered by that version of the code.

To facilitate a comparison against COMIDA2 results, the integrated intakes calculated by PATHWAY have been converted to units of dose by applying the ingestion DCFs of Federal Guidance Report 11. In our PATHWAY sample problem (included in the COMIDA2 distribution archive as PATHWAY.LST), COMIDA2 was exercised for the same eight fallout dates using an exposure period of 4 years (PATHWAY used a 4.2-year period). The results of the comparison are given in Table 5. In general, the two sets of results are in good agreement, with most values deviating by less than a factor of two.

Table 5
Comparison of COMIDA2 and PATHWAY Results

	Total individual dose per unit deposition as a function of fallout date [Sv-effective/(Bq/m2)]							
	Julian day							
	60	**76**	**115**	**139**	**175**	**205**	**243**	**280**
COMIDA2/^{90}Sr	6.70E-09	9.90E-09	1.50E-08	1.80E-08	2.80E-08	6.90E-09	6.40E-09	6.40E-09
PATHWAY/^{90}Sr	9.60E-09	9.20E-09	2.30E-08	2.30E-08	4.20E-08	7.70E-09	6.20E-09	6.90E-09
COMIDA2/^{106}Ru	2.60E-10	4.50E-10	7.90E-10	1.10E-09	2.70E-09	3.50E-10	3.00E-10	2.80E-10
PATHWAY/^{106}Ru	1.10E-09	1.30E-09	1.90E-09	2.20E-09	5.00E-09	1.00E-09	1.20E-09	1.70E-09
COMIDA2/^{131}I	3.60E-10	4.20E-10	2.20E-09	2.00E-09	2.00E-09	1.90E-09	1.90E-09	1.70E-09
PATHWAY/^{131}I	3.00E-10	2.90E-10	4.80E-10	7.10E-10	1.30E-09	1.40E-09	7.90E-09	5.30E-10
COMIDA2/^{136}Cs	1.70E-10	2.30E-10	8.70E-10	7.80E-10	8.00E-10	7.30E-10	7.20E-10	6.20E-10
PATHWAY/^{136}Cs	3.00E-10	3.30E-10	3.60E-10	4.30E-10	5.80E-10	4.90E-10	3.30E-10	3.70E-10
COMIDA2/^{137}Cs	9.60E-09	1.80E-08	2.90E-08	3.10E-08	3.50E-08	1.30E-08	1.00E-08	9.20E-09
PATHWAY/^{137}Cs	2.70E-08	2.70E-08	4.10E-08	3.50E-08	4.50E-08	1.90E-08	2.20E-08	3.20E-08
COMIDA2/^{239}Pu	7.10E-12	5.00E-10	1.20E-09	2.10E-09	6.10E-09	6.30E-12	6.40E-12	6.60E-12
PATHWAY/^{239}Pu	5.60E-10	8.40E-10	2.90E-09	4.10E-09	1.10E-08	8.40E-10	6.60E-10	6.90E-10

2.6.6 Comparison with Rocky Flats Plant TRAC Results

COMIDA2 results were compared with data utilized in TRAC, a computer code that was developed for site-specific dose assessments at the Rocky Flats Plant (RFP). For its food-chain calculations, TRAC utilizes a table (in Restrepo, [3] Table 2.2.3-6) of dose-to-source ratios that can be directly compared with the results available on COMIDA2 .LST files. The SAMP_A test case generated by COMIDA2 (included in the distribution package archive as SAMP_A.LST) was used for the comparison. Fifty-year committed effective doses from both codes were compared utilizing a 1-year exposure period. Results for both codes are for a 1-year exposure period.

Since SAMP_A.LST presents results for nine fallout dates spread throughout the year, it was necessary to select a COMIDA2 fallout date for comparison. Restrepo (personal communication) suggested that a code-to-code comparison should use a COMIDA2 fallout date that was just prior to harvest in order to compare the TRAC data against the maximal dose calculated by COMIDA2.

[3] L.F. Restrepo, "Dosimetric Modeling in the Terrain Responsive Atmospheric Code (TRAC)," paper presented at the Annual Meeting of the Health Physics Society, June 25-29, 1989, Albuquerque, NM.

The SAMP_A fallout date just prior to harvest was Julian day 271. The two sets of results are presented in Table 6.

Table 6
Total Individual Dose from First-Year Exposure
COMIDA2 versus TRAC Dose-to-Source Ratios [Sv/(Bq/m^2)]

Nuclide[a]	TRAC	COMIDA2
^{89}Sr (D)	1.1E-09	1.1E-09
^{131}I (D)	1.9E-08	7.0E-09
^{133}I (D)	3.5E-09	2.0E-10
^{137}Cs (D)	8.9E-10	1.0E-07
^{238}Pu (Y)	1.7E-12	.2E-08
^{239}Pu (Y)	1.8E-12	2.3E-08
^{240}Pu (Y)	1.8E-12	2.3E-08
^{241}Pu (Y)	3.0E-14	1.5E-09
^{241}Am (W)	1.8E-09	1.6E-06

[a] The notation in parentheses indicates the clearance class used in the analyses.

The data used in TRAC were generated using a calculation method based on Regulatory Guide 1.109 (NRC, 1977). The NRC model is an equilibrium-type model intended to be used for estimating doses resulting from routine emissions from nuclear power plants. In addition, the NRC Regulatory Guide ingestion model considers the pathways of direct contamination of vegetation and root uptake. The TRAC methodology considered only root uptake. It did not consider direct contamination of vegetation, contamination of vegetation via resuspension or rainsplash, or soil ingestion by grazing animals.

For insoluble materials such as plutonium oxide, root uptake is quite small. It appears that the dominant pathways for such elements through vegetable foodstuffs are direct contamination of vegetation and indirect contamination with soil after cloud passage. Similarly, for animal products, the consideration of soil directly consumed by grazing animals or contamination of stored feed appears to be important. The TRAC derivation of dose-to-source ratios did not consider these soil pathways, which are, however, considered in PATHWAY and COMIDA2.

The COMIDA2 results for plutonium are four orders of magnitude higher than the TRAC dose-to-source ratios. For americium, the COMIDA2 results are three orders of magnitude higher than those of TRAC. For iodine and cesium, the COMIDA2 and TRAC results are within two orders of magnitude. For strontium, the two results are identical; this is explained by the fact that of all the elements being compared here, strontium has the highest uptake by roots.

The difference in results from TRAC and COMIDA2 can be explained as being due to the differences in modeling approaches. By neglecting an important mechanism of food-chain transport, the TRAC results for plutonium and americium significantly underestimate dose.

2.6.7 Comparison with RSAC-5 Results

RSAC-5 (Wenzel, 1994) was used to generate dose-to-source ratios by defining a test case where a unit concentration (1 Bq/m^2) of various radionuclides was deposited on the ground after just 200 meters of travel. The RSAC-5 program defaults for "acute" ingestion calculation were used to perform the calculations. The only parameter actually required from the user to control these calculations is the delay that elapses between deposition and the beginning of crop harvesting.

Values for the harvest delay, RSAC-5 input variable THD, must be between 0 and 60. A harvest delay period of 30 days, the midpoint value, was specified for the RSAC-5 input variable THD. COMIDA2 results from the SAMP_A test case for Julian day 271 were used for this comparison. RSAC-5 implements a default 7-day harvest period and the default harvest duration was utilized.

In the SAMP_A test case, the Julian day 271 results precede the crop harvest times by slightly less than a month and are thus the best choice for this comparison. Fifty-year committed effective doses from both codes were compared assuming a 1-year exposure period. The results are shown in Table 7.

Table 7
Total Individual Dose from First-Year Exposure
COMIDA2 versus RSAC-5 Dose-to-Source Ratios [$Sv/(Bq/m^2)$]

Nuclide[a]	RSAC-5	COMIDA2
^{89}Sr (D)	1.2E-08	1.1E-09
^{90}Sr (D)	4.6E-07	7.5E-08
^{106}Ru (D)	3.2E-08	9.3E-09
^{131}I (D)	1.2E-07	7.0E-09
^{133}I (D)	4.3E-10	2.0E-10
^{134}Cs (D)	1.5E-06	1.2E-07
^{137}Cs (D)	1.1E-06	9.7E-08
^{239}Pu (Y)	2.7E-06	2.2E-08

[a] The notation in parentheses indicates the clearance class used in the analyses.

The RSAC-5 results are generally higher than the COMIDA2 results, with the biggest difference being for ^{239}Pu. Examination of the RSAC-5 default data for plutonium concentration ratios for vegetation and plant-to-animal transfer factors revealed that the two models were being exercised with identical or very similar parameter values. The RSAC-5 dose results for ^{239}Pu are two orders of magnitude higher than the COMIDA2 results.

2.6.8 Comparison with KfK Actinide Study

Because of the difference between the RSAC-5 and COMIDA2 results for ^{239}Pu, additional sources of data were reviewed in order to gain a perspective on the variability that can result from the use of different models. A good discussion pertinent to the ^{239}Pu ingestion dose predictions of interest is provided in a KfK-sponsored study by Steinhauer (1985).

The purpose of the KfK study was to determine the relative importance of actinides, in comparison with fission and activation products, from postulated severe accidents at a German breeder reactor. Two different food-chain models were used to calculate the resulting ingestion doses from the actinides—the German BSU model and the UK FOOD-MARC model (Simmonds et al., 1979 and Simmonds, 1985). The BSU model was developed in 1982 by G. Schwarz and H. Bastek of Brenk Systemplanung, Aachen, Germany (Steinhauer, 1985). At the time of the KfK study, both models could arguably be state of the art, with neither code clearly superior to the other.

COMIDA2 results from SAMP_A.LST for fallout dates of Julian days 271 (to obtain a peak) and 1 are used for the summer and winter fallout dates, respectively. There is an important difference between the BSU and the FOOD-MARC results for summer in that the BSU results are for an accident immediately prior to harvest, while the FOOD-MARC results are for the first of July, 60 days prior to the harvesting of vegetable crops. The winter results shown for COMIDA2 and FOOD-MARC are both for the first of January. The exposure period for all of the results shown was 1 year. The ingestion food-chain results are shown in Table 8.

Table 8
Total Individual Dose from First-Year Exposure
COMIDA2 versus KfK Actinide Study Dose-to-Source Ratios [Sv/(Bq/m^2)]

Nuclide	COMIDA2		BSU	FOOD-MARC	
	Summer	Winter	Summer	Summer	Winter
^{239}Pu (Y)	2.2E-08	1.7E-12	1.7E-07	4.8E-09	3.5E-09
^{241}Am (W)	1.5E-06	1.6E-10	1.2E-05	3.3E-07	2.5E-07
^{244}Cm (W)	8.4E-07	2.2E-10	6.5E-06	1.8E-07	1.4E-07

2.6.9 Comparison of "Old" versus "New" Food Model

Sample problem E, distributed with MACCS2, is a series of calculations for the release of 1 TBq quantities of eight nuclides: ^{89}Sr, ^{90}Sr, ^{131}I, ^{133}I, ^{134}Cs, ^{137}Cs, ^{239}Pu, and ^{241}Pu. Sample problem E utilizes the source term-looping capability of ATMOS so that a single execution of the code is used to generate results for eight source terms.

The weather conditions for all cases are D-stability and 5 m/s wind. The releases were point sources and occur at ground level with no sensible heat. The duration of release is specified to be 600 s, thereby eliminating any application of the plume-meander expansion factor on sigma-y. No precipitation occurred and the dry deposition velocity was set to 0.003 m/s.

All of the mitigative action models were turned off. The emergency phase was given a 1-day duration; there was no intermediate phase, and the long-term phase was given a duration of 30 years for the resuspension and groundshine pathways.

Of the 1E12 Bq released, 15.7%, or 1.57E11 Bq, was deposited within the 80.5-km region and thus was available for uptake through the food chain. The farmland fraction for the calculations is set to 100%. The fallout date is midsummer, Julian day 181.

MACCS2 was used to compare the food ingestion results obtained for the "old" versus the "new" food ingestion models, comparing results obtained using the NUREG-1150 food-chain input data with those obtained from the COMIDA2 results of the SAMP_A test case. In SAMP_A, the ingestion calculations were performed for an exposure period of 10 years, but extending that period would result in a negligible increase in the ingestion dose. The 80.5-km (50-mile) collective ingestion doses from the two approaches are compared in Table 9.

Table 9
Comparison of COMIDA2 with NUREG-1150 Food-Chain Data
80.5-km Collective Ingestion Dose (person-Sv)

Nuclide	Old Model of NUREG-1150	New Model of COMIDA2
^{89}Sr	2.61E-2	5.17E-3
^{90}Sr	7.86E+0	4.59E-1
^{131}I	5.29E-2	9.51E-2
^{133}I	4.65E-6	2.85E-3
^{134}Cs	5.70E+0	1.25E+0
^{137}Cs	4.72E+0	9.84E-1

No clear pattern of deviation, that is, higher versus lower, can be observed from these data but most of the results differ by less than a factor of ten. The results for ^{133}I (half-life of 20.8 h) differ by three orders of magnitude. The ^{133}I discrepancy in resultant ingestion dose is judged to be of minor importance because of results by Charles et al. (1983) indicating that ^{133}I contributes much less than 1% of the total ingestion dose that could result from a severe light water reactor accident in the United Kingdom.

Because the NUREG-1150 food-chain data were derived in a manner that was wholly unique to that study, and the documents that describe it (Jow et al., 1990; Sprung et al., 1990) make no comparison with other calculational methods, it is not possible to provide detailed explanations for the discrepancies observed in the two sets of results.

2.7 Summary of COMIDA2 Comparison Efforts

A comparison of COMIDA2 output with other food pathway model results indicates, overall, a high degree of agreement. Typically differences are less than an order of magnitude compared with a code of comparable sophistication. When COMIDA2 results were compared with those of less sophisticated models, however, there were differences of several orders of magnitude in some cases. Nevertheless, none of the comparisons has raised serious questions regarding COMIDA2 results and in one instance, a large difference in results was explained as being due to a shortcoming of the model against which the COMIDA2 results were being compared.

The development of a full understanding of the reasons for all the differences observed between code outputs was not possible within the resource limitations of this project. However, code errors were identified and corrected during this process and COMIDA2 results compared particularly well against the PATHWAY and COSYMA results.

Code-to-code comparisons are most useful when the analyst develops a full understanding of the modeling and input parameter assumptions implemented in each code. Unfortunately, this type of exercise can be very demanding in terms of resources. An understanding of the reasons for significant differences in the output obtained from different models is nevertheless important in ensuring the appropriate application of code output, and an understanding of the phenomenon to be modeled is very important in selecting an appropriate model. These comparisons, for example, indicate the importance of choosing food pathway models that are appropriate for the released nuclides and their progeny.

3 FGRDCF

The FGRDCF code incorporates the data of Federal Guidance Reports 11 (Eckerman et al., 1989) and 12 (Eckerman and Ryman, 1993). These reports were prepared by an organization at Oak Ridge National Laboratory that has a long history of providing dose conversion factor data to the ICRP, EPA, DOE, and NRC. ORNL's work on this subject sponsored by those agencies is continuing.

According to FGR 11, the inhalation and ingestion DCFs it presents are for the most part identical to the values listed in ICRP 30 (ICRP, 1979). However, FGR 11 utilized the revised metabolic models of ICRP 48 (ICRP, 1986) for the following transuranic elements: Np, Pu, Am, Cm, Bk, Cf, Es, Fm, and Md. In addition, FGR 11 provides inhalation and ingestion DCFs for a few radionuclides (^{82}Sr, ^{95}Tc, ^{95m}Tc, ^{116}Sb, ^{246}Pu, and ^{250}Cm), which are not considered in ICRP 30, but for which nuclear decay data were presented in ICRP 38 (ICRP, 1983).

The dose-rate factors of DOE/EH-0070 (DOE, 1988a) are largely identical to the widely used data of Kocher (1981). DOE/EH-0070 describes the areas in which there are differences, primarily relating to the calculation of external dose-rate factors to the skin. DOE Order 5400.5 (DOE, 1993) specifies that dose calculations for routine emissions from DOE facilities be performed using the DCFs of DOE/EH-0070 and DOE/EH-0071 (DOE, 1988b).

However, a DOE/EH guidance memo by Pelletier[4] states that FGR 12 is appropriate for use by DOE and its contractors as an alternative to the DOE/EH-0070 values. The dose commitments tabulated in FGR 11 are identical to those of DOE/EH-0071. Furthermore, in discussing the parameter values which are "appropriate to evaluate actual and potential doses in the environs of DOE facilities," DOE Order 5400.5 states,

> *Such information shall be updated as necessary to document significant changes that could affect dose calculations. Dose evaluation models which are codified, approved, or accepted by regulatory or other authorities shall be used where appropriate ...*

FGR 12, which provides FGRDCF with external dose-rate factors for 825 radionuclides, is based on improvements to the methodology of Kocher (1981), yielding greater accuracy in the human "phantom" dose calculations. The methodology of FGR 12, according to the EPA, supersedes all sources of DCF data based on the 1981 Kocher file. However, since FGR 12 includes DCFs for a smaller set of organs than is considered by DOSFAC2 and IDCF2, those two DCF preprocessors continue to use the data of the prior Kocher methodology, as revised per DOE/EH-0070. Consequently, the only avenue for the use of FGR 12 dose-rate factors with MACCS or MACCS2 is through the use of FGRDCF-generated DCF files.

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[4] R.F. Pelletier, memo from its Director to the attention of the DOE Office of Environmental Guidance, dated January, 10, 1994, subject: "Two EPA Radiation Reference Documents," Office of Environment and Health, Department of Energy, Washington, DC.

3.1 Purpose of FGRDCF

FGRDCF is intended as the primary tool for the calculation of DCFs for DOE applications. Users, however, need to be aware that FGRDCF does not offer the capability of calculating the "acute" dose conversion factors needed for the MACCS2 early fatality and early injury deterministic health effects models.

Furthermore, since FGRDCF does not include organ-specific dose commitments for the full set of organs considered in LMF-132 (Abrahamson et al., 1991), MACCS2 calculations using FGRDCF need to utilize cancer risk factors based on effective dose; for example, the 0.05/Sv and 0.1/Sv cancer fatality risk factors of ICRP 60 for low and high exposures, respectively. In addition, the ICRP 60 risk factor of 0.07/Sv for cancer incidence from low exposures could be specified as the "cancer injury" risk factor. However, if it is necessary to use the organ-specific risk factors of LMF-132, DCF files generated by DOSFAC2 or IDCF2 would need to be obtained and utilized with MACCS2.

The described limitations of FGRDCF are not expected to be important for most DOE applications of MACCS2. One important reason is that DOE no longer operates large-scale production reactors. As a result, source terms from DOE facilities do not approach the magnitude of the source terms addressed by the NRC in its assessments of severe accidents at commercial power plants.

There may be no need to calculate "acute" doses for DOE applications because exposure levels are likely to be so low that deterministic health effects would not be expected to occur.[5] For that reason, and the fact that DOE risk assessments commonly utilize ICRP 60 cancer risk factors, for most DOE applications the limitations of FGRDCF are not expected to hamper the use of the FGRDCF-generated DCF files.

3.2 FGRDCF Development History

FGRDCF is an adaptation of the READEM program included in the FGR 11 and 12 data library package distributed by the Radiation Shielding Information Center (1994). In order to make the data usable with both MACCS and MACCS2, FGRDCF incorporates additional calculations for the 8-hour and 1-week groundshine parameters used by MACCS. This allows FGRDCF (and DOSFAC2 as well), to be used for both MACCS and MACCS2 calculations. In contrast, the DCF files generated by IDCF2 can only be used with MACCS2 and are unusable with MACCS.

The READEM and CHAIN utility programs developed by ORNL are included in the archive and can be used independently of FGRDCF to examine the FGR 11 and 12 databases of DCFs and decay data. To execute READEM and CHAIN, just type the name of the program at the DOS prompt.

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[5] A notable exception would be assessments of risks to workers at nearby DOE facilities, where deterministic health effects could be of possible concern.

3.3 FGRDCF User's Guide

The user input file for FGRDCF is identified by an **.SEL** extension. Execution of FGRDCF is controlled through user modification of the "Select" file, which specifies the list of nuclides and clearances classes for which DCFs are to be generated.

FGRDCF is distributed with two sample Select files: DOSD60.SEL and DOSD825.SEL. DOSD60.SEL embodies a list of the 60 nuclides used in MACCS and the default clearance classes for those nuclides as tabulated on page D-4 of NUREG/CR-4691, Volume 2 (Jow et al., 1990). DOSD825.SEL incorporates a list of the 825 nuclides for which external dose-rate factors are supplied in Federal Guidance Report 12. Those 825 nuclides are the same as those that appear in the INDEXR.DAT file distributed with MACCS2. The default clearance classes used for DOSD825.SEL are based on the default clearance classes used in RSAC-5 (Wenzel, 1994). For elements not addressed in RSAC-5, a clearance class was chosen that would yield the highest inhalation effective dose. The provided Select files can be modified to generate alternative sets of DCFs.

3.3.1 .SEL File Format

The format of the .SEL file is as follows:

```
Kr-87
Kr-88           Including:Rb-88
Rb-86      D
Sr-91      D    Including:Y-91m
Sr-92      D
Zr-95      W
Zr-97      W    Including:Nb-97m , Including:Nb-97
C-11       c    (labeled organic, hydrocarbons)
C-14       c       ""
Co-60      Y
H-3        V    (vapor)
```

where the nuclide and clearance specification is processed one record at a time. The first seven characters of the record are reserved for the nuclide name, three columns are skipped, and a one-character clearance class code is read.

Any trailing text on the record, in column twelve and beyond, is not processed. FGRDCF defines implicit daughters according to the criteria discussed in Section 3.4. As a result, user modification of the "Including:" text fields or comments such as "(vapor)" will have no effect on code operation.

Allowable values for the clearance class code are D, W, Y, C, V, or a blank, as illustrated above using either upper-case or lower-case letters as shown in the example. D, W, and Y refer to the clearance classes for days, weeks, or years, respectively. C and V represent the organic compound and vapor form labels applied in FGR 11.

Nuclide names are specified as mixed-case, always beginning with an upper-case letter. The .SEL file is processed one record at a time until the end of the file is reached. The number of nuclides considered is equal to the number of records in the .SEL file. The nuclides can appear in a random order, as shown above. Because naming schemes for nuclides can vary, especially for isomers, and the special codes for vapor, organic forms, etc. may not be obvious, users are advised to use the READEM and CHAIN utility programs to determine the radiological half-life and decay scheme of any nuclide for which uncertainty exists as to its assigned name in the FGR 11 and 12 database and the available clearance classes (and their codes).

The FGRDCF sample problems can be exercised by using the RUNFGR.BAT file as follows:

RUNFGR DOSD60 (to generate DCFs for 60 nuclides)

or

RUNFGR DOSD825 (to generate DCFs for 825 nuclides)

To rerun FGRDCF for an alternative set of nuclides, or clearance classes, prepare a Select file containing the new selections, e.g., NEW.SEL. FGRDCF can then be run by typing

FGRDCF NEW

and the DCF file will be written to NEW.INP.

3.3.2 Clearance Classes

The conventional designations D, W, and Y are used in the Select file to specify clearance class. An ASCII blank character in the clearance class field is used to signify nuclides that have no clearance class definition. The lack of a clearance class signifies that no inhalation and ingestion DCFs are available for the nuclide in FGR 11. FGR 11 does not include DCFs for noble gases. It also omits aerosols and non-noble gases with short half-lives. In order to determine if FGR 11 data are available for a particular nuclide, refer to FGR 11 or exercise the READEM program.

Some nuclides which have unique chemical forms, e.g., ^{3}H and ^{14}C, have special codes, as previously shown, to distinguish between elemental forms and various compounds. Those special codes can be identified by exercising READEM; the special codes cannot be determined by examination of FGR 11.

3.3.3 Implicit Daughters

FGRDCF is set up so that it considers the dose contribution of "implicit daughters" in calculating the DCFs. A nuclide is an implicit daughter if three conditions are satisfied:

1. it is an immediate daughter product (parent goes to daughter),
2. it has a half-life less than 90 minutes, and
3. its half-life is less than one-tenth the half-life of its parent.

The most common example of a nuclide for which the implicit daughter concept is useful is ^{137}Cs (30 yr), which decays with a branch ratio of 0.95 to ^{137m}Ba (2.552 m). Because ^{137}Cs is a low-energy beta-emitter, its external dose-rate factors are zero; nevertheless, ^{137}Cs is commonly regarded as a principal contributor to long-term groundshine doses from reactor source terms. The resultant groundshine is due to the ^{137m}Ba decay. Since the two nuclides are almost always in secular equilibrium, computational expense can be minimized by "adding in" the dose from the daughter together with that from the parent.

The user of MACCS2 must ensure that the resultant doses are not double counted. If, for example, the nuclide list of MACCS2 includes both ^{137}Cs and ^{137m}Ba, and ^{137m}Ba is an implicit daughter, the long-term dose from the ^{137}Cs will be double counted.

The treatment of inhalation clearance class for implicit daughters is as follows. If the implicit daughter is found on the Select file list, the clearance class specified in the Select file will be used. If the implicit daughter is not on the Select file list but another isotope of the element is found on the list, the clearance class for the first isotope encountered on the Select file is used for the implicit daughter. If a clearance class for the element cannot be found, an error message will be printed by FGRDCF and the user requested to add the implicit daughter to the Select file list.

On the DCF files generated by FGRDCF (and DOSFAC2 as well), the clearance class of each nuclide is readily apparent in the list of nuclide names that appears at the beginning of the .INP file that was generated. Also, text fields such as "Including:Ba-137m" give a clear indication of the implicit daughters that were included as sums with the DCFs of the parent nuclide. The presentation of this information on the DCF file appears as follows:

```
      3 NUCLIDES DEFINED IN THIS FILE:
Sr-91     D     Including:Y-91m
Zr-97     W     Including:Nb-97m , Including:Nb-97
Ru-103    Y     Including:Rh-103m
```

which specifies that the D, W, and Y clearance classes are used for ^{91}Sr, ^{97}Zr, and ^{103}Ru, respectively. It also shows the implicit daughters used for the three nuclides.

MACCS2 reads the DCF file and examines the list of implicit daughters for each of the nuclides being used in its calculations (NUCNAM). If a nuclide appears as both an explicit nuclide in the list of radioactive nuclides on the ATMOS User Input file, and as an implicit daughter as defined by

the DCF file used for the MACCS2 calculations, MACCS2 will generate a warning message to the console and the List Output file, but the calculation will be allowed to proceed.

In order to avoid double counting in the MACCS2 dose calculations, the following rule should always be observed. If the DCF file defines a nuclide as an implicit daughter of another, e.g., ^{137m}Ba resulting from ^{137}Cs decay, the daughter nuclide should not appear on the list of radionuclides considered in the MACCS2 calculations, the NUCNAM array. Implicit daughters can be excluded from the MACCS2 calculations by adding them to the list of pseudostable nuclides, the NAMSTB array. For additional information on the specification of the NUCNAM and NAMSTB arrays, see Section 5.4 of Volume 1 of this report.

3.3.4 Organ List

When COMIDA2 and MACCS2 are exercised using a DCF file generated by FGRDCF, those two programs utilize an abbreviated list of nine organs that is built in and cannot be modified by the user.

COMIDA2 and MACCS2 detect the use of an FGRDCF file by examining the first seven characters of the DCF file's header record, the file being eye-readable ASCII text. If the DCF file was generated by FGRDCF, the first of the two header records will begin with the letters **FGRDCF**.

When COMIDA2 and MACCS2 determine that an FGRDCF file is being used, as specified by variable DCF_FILE (see Section 6.2 of Volume 1 of this report), the list of available organs in MACCS2 is set to the following:

L-GONADS
L-BREAST
L-LUNGS
L-RED MARR
L-BONE SUR
L-THYROID
L-REMAINDER
L-EFFECTIVE
L-SKIN(FGR)

with those names based on the nomenclature of FGR 11 and 12, prefixed by the **L-** used by MACCS2 to refer to 50-year committed "lifetime" doses. The organ **L-SKIN(FGR)** is based on the skin dose of FGR 12, and it differs substantially from the "acute" skin dose used in MACCS and MACCS2 for the sole purpose of calculating early injury health effects from material deposited on the skin, such as skin erythema and transepidermal injury. In contrast to the "acute" skin dose, the doses calculated for L-SKIN(FGR) are intended to be used for comparison against ICRP, EPA, or NRC criteria for radiation protection, to the extent that such criteria are implemented by the DOE.

If an FGRDCF file is to be used with MACCS, the user must ensure that the spelling of the organ names in the ORGNAM array defined in the EARLY User Input file matches the spelling used by FGRDCF. The **L-** prefix is not used with MACCS. An example of how the FGRDCF organ names can be used with MACCS is the following specification of the ORGNAM array (as defined on page 52 of NUREG/CR-4691, Vol. 1; Chanin et al., 1990). When this is done, lifetime (50-year) committed doses are available for calculating cancer health effects as well as consequence measures such as population dose and centerline dose.

```
ODORGNAM001     'SKIN', 'GONADS', 'BREAST', 'LUNGS',
ODORGNAM002     'RED MARR', 'BONE SUR', 'THYROID',
ODORGNAM003     'REMAINDER', 'EFFECTIVE', 'SKIN(FGR)'
```

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4 IDCF2

The IDCF code, developed by Fetter (1988), performs its calculations for 22 distinct organs as shown in Table 10. In order to simplify IDCF2, this list was left unchanged. Fetter chose this list to correspond with ICRP 30. Clearance classes for the nuclides considered in IDCF2 were chosen by Fetter as corresponding to the oxide chemical form.

Table 10
Organs for Which DCFs are Available from IDCF2

Adrenals	Ovaries
Brain	Pancreas
GI:LLI (lower large intestine)	Marrow
GI:SI (small intestine)	Skeleton
GI:ST (stomach)	Spleen
GI:ULI (upper large intestine)	Testes
Kidneys	Thyroid
Liver	Bladder
Lungs	others
Muscle	Whole body
Total body	EDE

While in most cases assuming an oxide form is conservative, there are important exceptions, for example, intakes of plutonium nitrates yield higher doses than intakes of plutonium oxide. Because Fetter's purpose was the evaluation of fusion reactor facilities, nonoxide chemical forms may have seemed of little importance. In any event, users of IDCF2 are cautioned that the architecture of IDCF and IDCF2 does not permit the selection of alternative clearance classes for other chemical

forms. That limitation of the code, in contrast to DOSFAC2 and FGRDCF, which do allow selection of clearance classes, is expected to weigh against the use of IDCF2.

Rood and Abbott (1991) compared the results of IDCF with DCFs used by the DOE (DOE/EH-0071), the Soviet Union, and the United Kingdom. The dose conversion factors generated by IDCF were judged in that study to compare reasonably well with those from other sources, although in some cases IDCF values deviated from the other sources by more than a factor of two. A comparison of inhalation DCFs from IDCF and DOE/EH-0071 found that the two sets of data differed by more than a factor of two for approximately 8 percent of the nuclides appearing in both datasets. In no instances did the two sets of DCF values differ by more than a factor of ten.

4.1 Purpose of IDCF2

IDCF2 can be used to generate a MACCS2 DCF file, which can then be used to calculate deterministic health effects for nuclides not available in the database used by DOSFAC2. The DCFs of IDCF2 are calculated for a library of 396 nuclides chosen by Fetter for fusion reactor applications. Appendix D of this volume lists the nuclides for which DCFs are available from IDCF2.

4.2 IDCF2 Development History--Code Modifications

IDCF2 is a modified version of the IDCF code written by Fetter (1988, 1991). An intermediate code developed for MACCS2 and given limited distribution was named IDCFMAX. IDCFMAX is being superseded by IDCF2. The IDCF2 modifications to Fetter's original code consist primarily of the following: (1) user control of output data, (2) minor mathematical changes, (3) machine-independent routines for enhanced portability, and (4) a revised format for the DCF file that makes IDCF2 consistent with DOSFAC2 and FGRDCF.

The original IDCF code, as provided by Fetter, included some built-in options and system dependencies. The original IDCF code was modified at SNL in order to increase its portability to diverse computer systems and to allow the use of its DCFs by MACCS2 in a fashion consistent with other sources of DCFs such as DOSFAC, DOSFAC2, and FGRDCF. Code modifications incorporated into IDCF2 are described in Appendix C.

4.3 IDCF2 DCF File Format

IDCF2 generates two data files which are no longer used in MACCS2—filenames IDCFINH.DAT and IDCFING.DAT. MACCS2 no longer utilizes those files because it was modified to obtain its DCF data in the format used by MACCS. The revised file format increases the computational efficiency of MACCS2 because the storage requirements for the DCF data are greatly reduced. Another reason for making this revision was to allow the possibility of exercising MACCS and MACCS2 using the same DCF file as input, to facilitate the verification and validation of MACCS2.

In implementing this change, however, IDCF2 does not provide two columns of data that are used by MACCS, but not by MACCS2—the 8-hour and 1-week integrated groundshine dose factors in columns 31-50 of the DCF file. For this reason, the dose conversion factor files generated by IDCF2 can only be used with MACCS2, and they cannot be used with MACCS.

4.4 IDCF2 User's Guide

Running IDCF2 requires the following three library files, as prepared by Steve Fetter for the INEEL version of IDCF:

DECAYLIB -- DECAYLIB.DAT is the currently used version of this file. It contains the decay-chain data for 396 radionuclides, which are listed in Appendix C.1 of this volume. The name of this file is built into the code.

SAFLIB -- this file, now named SAFLIB.DAT, contains data for the specific absorbed fractions for the standard man. The name of this file is built into the code.

ICRPLIB.DAT contains the biological data from ICRP 30. The name of this file is built into the code.

IDCF2 only allows the user to define the list of radionuclides for which DCFs are to be generated. All other calculational parameters are built into the code. The IDCF2 sample problem, TEST.INP, generates DCFs for the MACCS list of 60 nuclides. This sample problem can be executed by entering the following command at the DOS prompt while in the IDCF2 directory:

RUNIDCF2 TEST

To create DCF files for alternative sets of nuclides, the file TEST.INP can be edited. The format of this file is self-explanatory. It is processed according to the conventions of the MACCS and MACCS2 free-format input processor.

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APPENDIX A

COMIDA INPUT PARAMETERS AND SAMPLE INPUT FILES

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A.1 Introduction

The primary description of the COMIDA food chain model and the general development of its input parameters are given in Abbott and Rood (1993, 1994). The purpose of this appendix is to provide (1) methods, data, and data sources for determination of site-specific values for input parameters, (2) recommended values for "generic" U.S. or major regional site analyses, and (3) sample COMIDA.VAR and COMIDA.PAR input files for some important ingestion dose radionuclides. It is emphasized that the "recommended" values presented here are generally only appropriate for accident evaluations at an unknown site. Site-specific values may often differ greatly from these generic values and should be used whenever possible. When data were available, an effort was made to provide values or sources of information for different geographical regions or for important environmental conditions (e.g., soil type) that are known to significantly affect terrestrial transport.

Most of the values presented here are "best estimate" or "expected" values for specific environmental conditions. Ranges of values are provided for animal consumption rates, and ranges for some of the other parameters (e.g., soil-to-plant concentration ratios) may be obtained from the referenced literature. Also, information is provided on whether the parameter has a direct or inverse effect on food concentrations. Using this information, the user can decide on the general level of conservatism desired by either (1) selecting a value for a different environmental condition (e.g., a higher concentration ratio for sand) or (2) investigating the ranges of values in the referenced literature. The "generic site" values recommended here may be considered best estimates for average temperate climate conditions across the United States.

A.2 COMIDA.VAR Input Parameters

The COMIDA.VAR file contains the nuclide-specific, element-specific, and element/crop-specific input parameters (Table A-1). An example COMIDA.VAR is given in Section A.4.

A.2.1 NNUC, NUC, NPROG, THALF, and NCUTOFF

The first three lines of input in the COMIDA.VAR file are the number of nuclides modeled (NNUC), the names of the nuclides, including progeny (NUC), the number of progeny being simulated (NPROG), and the half-life of each nuclide (THALF). The number of nuclides modeled (NNUC) does not include decay chain members that are modeled as progeny in COMIDA. The

parameters NUC, NPROG, and THALF are listed for a single parent/progeny decay chain (e.g., 'Sr-90' 1, 'Y-90') and then repeated for each additional decay chain after the remaining COMIDA.VAR parameters are entered (see Section A.4). NCUTOFF is the number of nuclide half-lives for which COMIDA calculates annual concentrations. After the time NCUTOFF, COMIDA assumes that decay has reduced initial concentrations to relatively insignificant levels and assumes the remaining annual concentrations are zero to speed processing time. An NCUTOFF value of 10 will result in zero annual concentration output when concentrations have been reduced to less than 1/1000 of initial values.

Table A-1. Description of input parameters in the COMIDA.VAR file

Card	Record	Code Variable	Code Variable	Type	Description
1	1	---	NNUC	INTEGER	Number of nuclides in simulation
NOTE: Cards 2 through 10 are repeated NNUC number of times					
2	1	---	NUC(1)	CHARACTER	Character array identification for parent nuclide (J=1)
2	2	---	NPROG	INTEGER	Number of progeny (3 maximum)
2	3 to NPROG+3		NUC(J)	CHARACTER	Character array identification for NPROG number of progeny nuclides (J=2 to J=4)
3	1 to 4	---	THALF(J) REAL		Half-life for parent (J=1) and NPROG (J=2 to J=4) number of progeny (d)
4	1 to 4	Kl	ZKL(J)	REAL	Leach rate constant for parent (J=1) and NPROG (J=2 to J=4) number of progeny (d^{-1})
5	1	Kad	ZKAD	REAL	Adsorption rate constant for parent nuclide in fixed soil (d^{-1})
5	2	Kde	ZKDE	REAL	Desorption rate constant for parent nuclide in fixed soil (d^{-1})
5	3	---	NCUTOFF	INTEGER	Number of half-lives to compute concentrations for (unitless)
NOTE: Cards 6 through 10 are repeated NPROG number of times.					
6	1 to 5	CR	CRC(I,J)	REAL	Concentration ratio for crop I[a] and decay chain member J[a]
7	1 to 5	Kab	ZKABC(I,J)	REAL	Foliar absorption rate constant for crop I[a] and decay chain member J[b] (d^{-1})
8	1	CR	CRP(J)	REAL	Concentration ratio for pasture grass for decay chain member J[b]
8	2	CR	CRH(J)	REAL	Concentration ratio for hay for decay chain member J[b]
9	1	Kab	ZKABP(J) REAL		Foliar absorption rate constant for pasture for decay chain member J[b] (d^{-1}).
9	2	Kab	ZKABH(J) REAL		Foliar absorption rate constant for hay for decay chain member J[b] (d^{-1})
10	1	TC	TCB(J)	REAL	Beef transfer coefficient for decay chain member J[b] (d kg^{-1})
10	2	TC	TCM(J)	REAL	Milk transfer coefficient for decay chain member J[b] (d L^{-1})
10	3	TC	TCP(J)	REAL	Poultry transfer coefficient for decay chain member J[b] (d kg^{-1})
10	4	TC	TCO(J)	REAL	Other animal transfer coefficient for decay chain member J[b] (d kg^{-1})

(a) The value of I indicates the crop type: 1=grains, 2=leafy vegetables, 3=root crops, 4=fruits, 5=legumes.

(b) The value of J indicates the decay chain member: J=1,the parent, J=2, the first progeny member, J=3, the second progeny member, J=4, the third progeny member.

MACCS2 calculations should include all nuclides that are potentially important ingestion dose contributors and exclude those nuclides that give insignificant ingestion doses, in order to keep the run times and level of output at an efficient level. The important food-chain contributors can be determined by using the COMIDA2 preprocessor as a screening tool and selecting only those nuclides that contribute to some cumulative fraction (e.g., 99.9%) of the ingestion dose. This will

normally be limited to a few or several nuclides. As an example, for highly enriched (>93%) uranium fuels that have been cooled from 7 days to 3 years, the *fission products* that usually account for a significant fraction of the food-chain dose include: ^{131}I, ^{90}Sr/Y, ^{137}Cs, ^{144}Ce/Pr, ^{91}Y, ^{95}Zr/Nb, ^{89}Sr, ^{134}Cs, ^{140}Ba/La, and ^{147}Pm [results from RSAC-5 (Wenzel, 1994) assuming 2250 MWd burnup and 1% release]. Other fission products that may be important, depending on the nature of the source term, include ^{99}Mo/Tc, ^{103}Ru, ^{106}Ru/Rh, ^{127m}Te, ^{129m}Te, ^{132}Te, ^{129}I, ^{131}I, ^{135}I, ^{136}Cs, and ^{143}Pr. These results do not include activation products or actinides which, if present, should also be screened using the COMIDA2 preprocessor.

Progeny that require days or years of buildup time after deposition of a pure parent (e.g., ^{90}Sr$\rightarrow^{90}$Y, ^{95}Zr$\rightarrow^{95}$Nb, ^{241}Pu$\rightarrow^{241}$Am) should be modeled as progeny in COMIDA. Short-lived progeny that rapidly reach secular equilibrium with a long-lived parent (e.g., ^{137}Cs $\rightarrow^{137m}$Ba, ^{106}Ru $\rightarrow^{106}$Rh) do not need to be explicitly modeled since the parent internal dose conversion factor adequately accounts for the contribution of the progeny. Also, since COMIDA does not currently handle branching to multiple progeny, only those progeny with a branching ratio of approximately 1 should be modeled.

A.2.2 ZKL- Leach Rate Constant

This parameter controls the rate at which radionuclides are transported from the labile soil compartment into deep soil where root uptake does not occur. An element-specific value for any decay chain member (*J*) may be calculated using a formulation given by Baes and Sharp (1983):

$$ZKL(J) = \frac{P + I - E - R}{\theta XR\left[1 + \frac{\rho Kd(J)}{\theta}\right]} \qquad (1)$$

where

P = annual average total precipitation (m d^{-1})
E = annual average evapotranspiration (m d^{-1})
I = annual average irrigation (m d^{-1})
R = annual average surface runoff (m d^{-1})
XR = depth of labile (active root zone) soil layer (m)
θ = annual average volumetric water content in the soil layer XR (m^3 m^{-3})
ρ = soil bulk density (g cm^{-3})
$Kd(J)$=element-specific soil-water distribution coefficient for decay chain member (*J*) (ml g^{-1})

Ideally, the user should calculate site-specific ZKLs using the *Kd* values given in Table A-2 and local annual average water surplus (P+I-E-R), θ, *XR*, and ρ values. The *Kd* values in Table A-2 are taken from Sheppard and Thibault (1990) for specific soil types and Baes et al. (1984) for generic agricultural soil. Both data sets are considered to be "best estimate" values. However, it is recommended that the soil-specific Shepherd and Thibault values be used as the primary source if

they are listed for a particular element. When selecting a value, it should be remembered that a *higher Kd* value will result in lower leaching from the root zone soil and is therefore more conservative (will result in greater root uptake).

Generic (nonsite specific) values for ZKL are given in Table A-3. These values were calculated using the *Kd* values from Table A-2 and generic temperate climate "default" parameters of 20 cm y^{-1} water surplus (P+I-E-R), θ=0.3, ρ=1.4 g cm^{-3}, and *XR*=0.2 m, as recommended by the International Atomic Energy Agency (IAEA) (1994). However, it should be emphasized that the 0.3 θ value is probably only appropriate for typical loam or clay/loam agricultural soils. Sandy soils will generally give lower θ values while high clay-content soils may give higher values. If site-specific values for annual water surplus, θ, ρ, or *XR* values are known and differ significantly from those assumed above, then the values in Table A-2 should be scaled or recalculated using equation (1). When selecting a ZKL value, it should be remembered that the *lowest* value will result in more root uptake and is therefore more conservative.

A.2.3 ZKAD- Adsorption Rate Constant, ZKDE- Desorption Rate Constant

COMIDA uses these rate constants to simulate long-term soil fixation of cesium isotopes in a fixed soil compartment from which root uptake does not occur. Any soil fixation of other radionuclides is assumed to be relatively rapid and accounted for by low observed soil-to-plant concentration ratios (Section A.2.3). Squire and Middleton (1966) found that ^{137}Cs uptake was reduced from 84 to 98% over 5 years in soils ranging in clay content of 3.2 to 19.5%. On peat bog soils, the reduction in root uptake is negligible (IAEA, 1994). Based on these data, the following values are recommended:

	ZKAD (d^{-1})	ZKDE (d^{-1})
Cs, general agricultural soils:	1.9E-03	2.1E-04 (90% fixed over 5 years)
Cs, peat bog soils and all other radionuclides:	1.0E-09	1.0E-09 (no fixation)

A.2.4 CR(C/P/H)- Concentration Ratios for Crops, Pasture Grass, and Hay

In COMIDA, concentration ratio (CR) is one of the parameters used to calculate the *rate* of root uptake in vegetation using a formulation developed for the PATHWAY model (Whicker and Kirchner 1987). Concentration ratio is defined as:

$$CR = \frac{\text{Bq g}^{-1} \quad \text{dry plant}}{\text{Bq g}^{-1} \quad \text{dry soil}} \qquad (2)$$

Table A-2. Soil-water partition coefficients (Kd values) for specific soil types as given by Sheppard and Thibault (1990) and for a generic "agricultural" soil as given by Baes et al. (1984).

	Partition Coefficient *Kd* (liters/kg) in soil type:				
	SAND	LOAM	CLAY	ORGANIC	BAES
	450	1500	2400	5400	1500
Ag	9	120	180	15000	45
Al					1500
Am	2000	990	8100	110000	700
As					200
At					10
Au					25
B					3
Ba					60
Be	240	810	1300	3000	650
Bi	120	400	670	1500	200
Br	15	49	74	180	7.5
C	5	20	1	70	
Ca	5	30	50	90	4
Cd	80	40	560	800	6.5
Ce	500	8100	20000	3300	850
Cl					0.25
Cm	4000	18000	6000	6000	2000
Co	60	1300	550	1000	45
Cr	70	30	1500	270	850
Cs	280	4600	1900	270	1000
Cu					35
Dy					650
Er					650
Eu					650
F					150
Fe	220	800	165	600	25
Fr					250
Ga					1500
Gd					650
Ge					25
Hf	450	1500	2400	5400	1500
Hg					10
Ho	250	800	1300	3000	650
I	1	5	1	25	60
In					1500
Ir					150
K	15	55	75	200	5.5
La					650
Li					300
Lu					650
Mg					4.5
Mn	50	750	180	150	65
Mo	10	125	90	25	20
N					0.5
Na					100

Table A-2. Soil-water partition coefficients (Kd values) for specific soil types as given by Sheppard and Thibault (1990) and for a generic "agricultural" soil as given by Baes et al. (1984).

	Partition Coefficient *Kd* (liters/kg) in soil type:				
	SAND	LOAM	CLAY	ORGANIC	BAES
Nb	160	550	900	2000	350
Nd					650
Ni	400	300	650	1100	150
Np	5	25	55	1200	30
Os					450
P	5	25	35	90	3.5
Pa	550	1800	2700	6600	2500
Pb	270	16000	550	22000	900
Pd	55	180	270	670	60
Pm					650
Po	150	400	3000	7300	300
Pr					650
Pt					90
Pu	550	1200	5100	1900	4500
Ra	500	36000	9100	2400	450
Rb	55	180	270	670	60
Re	10	40	60	150	7.5
Rh					60
Ru	55	1000	800	66000	350
S					7.5
Sb	45	150	250	550	45
Sc					1000
Se	150	500	740	1800	300
Si	35	110	180	400	30
Sm	245	800	1300	3000	650
Sn	130	450	670	1600	2500
Sr	15	20	110	150	35
Ta	220	900	1200	3300	650
Tb					650
Tc	0.1	0.1	1	1	1.5
Te	125	500	720	1900	300
Th	3.20e+03	3300	5800	89000	1.50e+05
Ti					1000
Tl					1500
Tm					650
U	35	15	1600	410	450
V					1000
W					150
Y	170	720	1000	2600	500
Yb					650
Zn	200	1300	2400	1600	40
Zr	600	2200	3300	7300	3000

Table A-3. Example leach rate constants (ZKL) in different soil types.

	Leach Rate Constant ZKL (d^{-1}) in soil type:				
	Sand	Loam	Clay	Organic	Baes et al.
Ac	4.35e-06	1.30e-06	8.15e-07	3.62e-07	1.30e-06
Ag	2.12e-04	1.63e-05	1.09e-05	1.30e-07	4.33e-05
Al					1.30e-06
Am	9.78e-07	1.98e-06	2.42e-07	1.78e-08	2.79e-06
As					9.77e-06
At					1.92e-04
Au					7.76e-05
B					6.09e-04
Ba					3.25e-05
Be	8.15e-06	2.42e-06	1.51e-06	6.52e-07	3.01e-06
Bi	1.63e-05	4.89e-06	2.92e-06	1.30e-06	9.77e-06
Br	1.29e-04	3.98e-05	2.64e-05	1.09e-05	2.54e-04
C	3.75e-04	9.68e-05	1.61e-03	2.79e-05	
Ca	3.75e-04	6.48e-05	3.90e-05	2.17e-05	4.64e-04
Cd	2.44e-05	4.87e-05	3.49e-06	2.45e-06	2.91e-04
Ce	3.91e-06	2.42e-07	9.78e-08	5.93e-07	2.30e-06
Cl	9.13e-03	9.13e-03	9.13e-03	9.13e-03	4.22e-03
Cm	4.89e-07	1.09e-07	3.26e-07	3.26e-07	9.78e-07
Co	3.25e-05	1.51e-06	3.56e-06	1.96e-06	4.33e-05
Cr	2.79e-05	6.48e-05	1.30e-06	7.24e-06	2.30e-06
Cs	6.98e-06	4.25e-07	1.03e-06	7.24e-06	1.96e-06
Cu					5.56e-05
Dy					3.01e-06
Er					3.01e-06
Eu					3.01e-06
F					1.30e-05
Fe	8.89e-06	2.45e-06	1.18e-05	3.26e-06	7.76e-05
Fr					7.82e-06
Ga					1.30e-06
Gd					3.01e-06
Ge					7.76e-05
Hf	4.35e-06	1.30e-06	8.15e-07	3.62e-07	1.30e-06
Hg					1.92e-04
Ho	7.82e-06	2.45e-06	1.51e-06	6.52e-07	3.01e-06
I	1.61e-03	3.75e-04	1.61e-03	7.76e-05	3.25e-05
In					1.30e-06
Ir					1.30e-05
K	1.29e-04	3.54e-05	2.60e-05	9.77e-06	3.42e-04
La					3.01e-06
Li					6.52e-06
Lu					3.01e-06
Mg					4.15e-04
Mn	3.90e-05	2.61e-06	1.09e-05	1.30e-05	3.00e-05
Mo	1.92e-04	1.56e-05	2.17e-05	7.76e-05	9.68e-05
N					2.74e-03

Table A-3. Example leach rate constants (ZKL) in different soil types.

	Leach Rate Constant ZKL (d^{-1}) in soil type:				
	Sand	Loam	Clay	Organic	Baes et al.
Na					1.95e-05
Nb	1.22e-05	3.56e-06	2.17e-06	9.78e-07	5.59e-06
Nd					3.01e-06
Ni	4.89e-06	6.52e-06	3.01e-06	1.78e-06	1.30e-05
Np	3.75e-04	7.76e-05	3.54e-05	1.63e-06	6.48e-05
Os					4.35e-06
P	3.75e-04	7.76e-05	5.56e-05	2.17e-05	5.27e-04
Pa	3.56e-06	1.09e-06	7.25e-07	2.97e-07	7.83e-07
Pb	7.24e-06	1.22e-07	3.56e-06	8.90e-08	2.17e-06
Pd	3.54e-05	1.09e-05	7.24e-06	2.92e-06	3.25e-05
Pm					3.01e-06
Po	1.30e-05	4.89e-06	6.52e-07	2.68e-07	6.52e-06
Pr					3.01e-06
Pt					2.17e-05
Pu	3.56e-06	1.63e-06	3.84e-07	1.03e-06	4.35e-07
Ra	3.91e-06	5.44e-08	2.15e-07	8.15e-07	4.35e-06
Rb	3.54e-05	1.09e-05	7.24e-06	2.92e-06	3.25e-05
Re	1.92e-04	4.87e-05	3.25e-05	1.30e-05	2.54e-04
Rh					3.25e-05
Ru	3.54e-05	1.96e-06	2.45e-06	2.97e-08	5.59e-06
S					2.54e-04
Sb	4.33e-05	1.30e-05	7.82e-06	3.56e-06	4.33e-05
Sc					1.96e-06
Se	1.30e-05	3.91e-06	2.64e-06	1.09e-06	6.52e-06
Si	5.56e-05	1.78e-05	1.09e-05	4.89e-06	6.48e-05
Sm	7.98e-06	2.45e-06	1.51e-06	6.52e-07	3.01e-06
Sn	1.50e-05	4.35e-06	2.92e-06	1.22e-06	7.83e-07
Sr	1.29e-04	9.68e-05	1.78e-05	1.30e-05	5.56e-05
Ta	8.89e-06	2.17e-06	1.63e-06	5.93e-07	3.01e-06
Tb					3.01e-06
Tc	6.23e-03	6.23e-03	1.61e-03	1.61e-03	1.14e-03
Te	1.56e-05	3.91e-06	2.72e-06	1.03e-06	6.52e-06
Th	6.12e-07	5.93e-07	3.37e-07	2.20e-08	1.30e-08
Ti					1.96e-06
Tl					1.30e-06
Tm					3.01e-06
U	5.56e-05	1.29e-04	1.22e-06	4.77e-06	4.35e-06
V					1.96e-06
W					1.30e-05
Y	1.15e-05	2.72e-06	1.96e-06	7.53e-07	3.91e-06
Yb					3.01e-06
Zn	9.77e-06	1.51e-06	8.15e-07	1.22e-06	4.87e-05
Zr	3.26e-06	8.89e-07	5.93e-07	2.68e-07	6.52e-07

COMIDA requires element-specific CRs for each crop type (grains, leafy vegetables, root crops, fruits, and legumes) and each decay chain member (CRC[I,J]), pasture grass (CRP[J]), and hay (CRH[J]). A great deal of published experimental data exist on this parameter, and there is a considerable range of variability, depending on soil characteristics, vegetation types, and agricultural management practices (e.g., fertilization). Also, the user should make sure that values used in COMIDA are based on dry plant weight, since some data [e.g., NRC Regulatory Guide 1.109 (NRC, 1977)] are published on a wet-weight basis.

Recommendations for CR values for use in COMIDA are given in Table A-4. These values are primarily based on data published by the International Union of Radioecologists (IUR) (Frissel, 1989, 1992) for most of the important radionuclides, and Baes et al. (1984) for other elements. In general, it is recommended that the IUR data be used if it is listed for a particular element. When the IUR listed more than one value for a particular crop category, the highest value was chosen. Limited IUR fruit data were supplemented using a compilation of published data by Peterson (1983). The CR value for carbon was taken from EPRI (1990). The data from IUR, Baes et al., and EPRI are all "best estimate" values while the data from Peterson represent the 84th percentile bound on the mean ($P <$ value is 0.84). For the important radionuclides, ^{90}Sr and ^{137}Cs, the IUR gives CR values for three major soil types (clay, sand, and peat). The IUR data have also been standardized for a homogeneously contaminated layers of 20 cm for crops and 10 cm for pasture, and for soil pH levels of 6 for clay, 5 for sand, and 4 for peat. These are somewhat low values but are conservative since higher pH values generally result in lower CR values. The following crop category assumptions were made when selecting CR values for Table A-4:

COMIDA Crop Category	IUR Crop Category	Baes et al. Category
grain (I1)	cereals	B_r (reproductive portions of plants)
leafy vegetables (I2)	vegetables	B_v (vegetative portions of plants)
root crops (I3)	root crops/tubers[a]	B_r
fruits (I4)	none[b]	B_r
legumes (I5)	pods	B_r
pasture	grass	B_v
hay	fodder	B_v

a. Tuber values were used only when no root crop values were given.
b. No IUR crop category is listed, but data are given for "fruit" (Sr), tomatoes (Ag, Cs, Ra), and cucumbers (Np, Pu). Additional fruit data for Mn, Zr/Nb, Ru, and Ce were taken from Peterson (1983).

Table A-4. Soil-to-plant concentration ratios (CRs) - (mg kg^{-1} dry plant/mg kg^{-1} dry soil).

	<---------- IUR(a) -----				Baes Br	<---------- IUR(a)			Baes
	Grains CRC[I1]	Root crops CRC[I3]	Fruits CRC[I4]	Legumes CRC[I5]	CRC[I1] CRC[I3-5]	Leafy Veg CRC[I2]	Pasture CRP	Hay CRH	CRC[I2] CRP, CRH
Ac					3.5e-04				3.5e-03
Ag	1.5e-01c	1.3e-03	8.0e-04	1.50e-01c	1.0e-01	2.7e-04	1.5e-01c	1.50e-01c	4.0e-01
Al					6.5e-04				4.0e-03
Am	2.2e-05	2.2e-03		3.9e-04	2.5e-04	6.6e-04	1.2e-03	7.1e-04	5.5e-03
As					6.0e-03				4.0e-02
At					1.5e-01				1.0e+00
Au					1.0e-01				4.0e-01
B					2.0e+00				4.0e+00
Ba	3.0e-02c	3.0e-02c	3.0e-02c	3.0e-02c	1.5e-02	3.0e-02c	3.0e-02c	3.0e-02c	1.5e-01
Be					1.5e-03				1.0e-02
Bi					5.0e-03				3.5e-02
Br					1.5e+00				1.5e+00
C					1.0e+00				1.0e+00
Ca					3.5e-01				3.5e+00
Cd					1.5e-01				5.5e-01
Ce	3.0e-02c	3.0e-02c	3.0e-02c	3.0e-02c	4.0e-03	3.0e-02c	3.0e-02c	3.0e-02c	1.0e-02
Cl					7.0e+01				7.0e+01
Cm	2.1e-05	1.3e-03		7.5e-04	1.5e-05	7.7e-04	1.1e-03	2.1e-04	8.5e-04
Co	3.7e-03	1.3e-01	7.0e-02g	3.0e-02	7.0e-03	2.9e-01	5.4e-02	1.1e+00e	2.0e-02
Cr	1.0e-03c	1.0e-03c	1.0e-03c	1.0e-03c	4.5e-03	1.0e-03c	1.0e-03c	1.0e-03c	7.5e-03
Cs(cl)f	1.0e-02	4.0e-02	2.2e-01j	1.7e-02	3.0e-02	1.8e-01	1.1e-01	1.7e-02	8.0e-02
Cs (s)f	2.6e-02	1.1e-02	2.2e-01j	9.4e-02	3.0e-02	4.6e-01	2.4e-01	2.9e-01	8.0e-02
Cs (p)f	8.3e-02		2.2e-01j		3.0e-02	2.6e-01	5.3e-01	3.0e-01	8.0e-02
Cu	8.0e-01c	8.0e-01c	8.0e-01c	8.0e-01c	2.5e-01	8.0e-01c	8.0e-01c	8.0e-01c	4.0e-01
Dy					4.0e-03				1.0e-02
Er					4.0e-03				1.0e-02
Eu					4.0e-03				1.0e-02
F					6.0e-03				6.0e-02
Fe	4.0e-03c	4.0e-03c	4.0e-03c	4.0e-03c	1.0e-03	4.0e-03c	4.0e-03c	4.0e-03c	4.0e-03
Fr					8.0e-03				3.0e-02
Ga					4.0e-04				4.0e-03
Gd					4.0e-03				1.0e-02
Ge					8.0e-02				4.0e-01
Hf					8.5e-04				3.5e-03
Hg					2.0e-01				9.0e-01
Ho					4.0e-03				1.0e-02
I	2.0e-02c	2.0e-02c	2.0e-02c	2.0e-02c	5.0e-02	2.0e-02c	3.4e-03	2.0e-02c	1.5e-01
In					4.0e-04				4.0e-03

Table A-4. Soil-to-plant concentration ratios (CRs) - (mg kg^{-1} dry plant/mg kg^{-1} dry soil).

	<---------- IUR(a) -----				Baes Br	<---------- IUR(a)			Baes
	Grains CRC[I1]	Root crops CRC[I3]	Fruits CRC[I4]	Legumes CRC[I5]	CRC[I1] CRC[I3-5]	Leafy Veg CRC[I2]	Pasture CRP	Hay CRH	CRC[I2] CRP, CRH
Ir					1.5e-02				5.5e-02
K					5.5e-01				1.0e+00
La		1.6e-03		4.2e-04	4.0e-03	5.2e-03		3.0e-05	1.0e-02
Li					4.0e-03				2.5e-02
Lu					4.0e-03				1.0e-02
Mg					5.5e-01				1.0e+00
Mn	3.0e-01	1.9e+00	4.6e-02g	1.9e-01	5.0e-02	8.6e-01	6.8e-01	9.8e+00e	2.5e-01
Mo	8.0e-01c	8.0e-01c	8.0e-01c	8.0e-01c	6.0e-02	8.0e-01c	8.0e-01c	8.0e-01c	2.5e-01
N					3.0e+01				3.0e+01
Na	3.0e-01c	3.0e-01c	3.0e-01c	3.0e-01c	5.5e-02	3.0e-01c	3.0e-01c	3.0e-01c	7.5e-02
Nb	5.0e-02d	5.0e-02d	5.4e-04g	1.7e-02	5.0e-03	5.0e-02d	5.0e-02d	5.0e-02d	2.0e-02
Nd	2.0e-02c	2.0e-02c	2.0e-02c	2.0e-02c	4.0e-03	2.0e-02c	2.0e-02c	2.0e-02c	1.0e-02
Ni	3.0e-02	1.6e-01i	2.9e-02i	2.3e-01i	6.0e-02		1.8e-01	5.1e-01	6.0e-02
Np	2.7e-03	3.5e-02	2.5e-02	1.8e-02	1.0e-02	2.4e-02	6.9e-02	2.1e-02	1.0e-01
Os					3.5e-03				1.5e-02
P					3.5e+00				3.5e+00
Pa					2.5e-04				2.5e-03
Pb	4.7e-03	2.0e-02			9.0e-03	1.0e-02		1.1e-03	4.5e-02
Pd					4.0e-02				1.5e-01
Pm					4.0e-03				1.0e-02
Po	2.3e-03h	7.0e-03h			4.0e-04	1.2e-03h	9.0e-02h		2.5e-03
Pr	2.0e-02c	2.0e-02c	2.0e-02c	2.0e-02c	4.0e-03	2.0e-02c	2.0e-02c	2.0e-02c	1.0e-02
Pt					2.5e-02				9.5e-02
Pu	8.6e-06	4.4e-03	9.0e-05	6.1e-05	4.5e-05	4.1e-05	3.4e-04	8.0e-04	4.5e-04
Ra	1.2e-03	2.1e-02	6.1e-03	7.0e-03	1.5e-03	1.0e-01	8.0e-02		1.5e-02
Rb	9.0e-01c	9.0e-01c	9.0e-01c	9.0e-01c	7.0e-02	9.0e-01c	9.0e-01c	9.0e-01c	1.5e-01
Re					3.5e-01				1.5e+00
Rh	9.0e-01c	9.0e-01c	9.0e-01c	9.0e-01c	4.0e-02	9.0e-01c	9.0e-01c	9.0e-01c	1.5e-01
Ru	5.0e-03	4.0e-02c	4.0e-02c	4.0e-02c	2.0e-02	2.0e-01	4.0e-02c	4.0e-02c	7.5e-02
S					1.5e+00				1.5e+00
Sb		5.6e-04			3.0e-02				2.0e-01
Sc					1.0e-03				6.0e-03
Se					2.5e-02				2.5e-02
Si					7.0e-02				3.5e-01
Sm					4.0e-03				1.0e-02
Sn					6.0e-03				3.0e-02
Sr(cl)f	1.2e-01	1.4e+00	1.7e-01g,k	1.3e+00	2.5e-01	2.7e+00	1.1e+00	1.9e+00	2.5e+00
Sr(s)f	2.1e-01	1.1e+00	2.0e-01k	2.2e+00	2.5e-01	3.0e+00	1.7e+00	1.0e+00	2.5e+00
Sr(p)f	2.0e-02	1.4e+00			2.5e-01	2.6e-01	3.4e-01		2.5e+00

Table A-4. Soil-to-plant concentration ratios (CRs) - (mg kg^{-1} dry plant/mg kg^{-1} dry soil).

	<---------- IUR(a) -----				Baes Br	<---------- IUR(a)			Baes
	Grains CRC[I1]	Root crops CRC[I3]	Fruits CRC[I4]	Legumes CRC[I5]	CRC[I1] CRC[I3-5]	Leafy Veg CRC[I2]	Pasture CRP	Hay CRH	CRC[I2] CRP, CRH
Ta					2.5e-03				1.0e-02
Tb					4.0e-03				1.0e-02
Tc	7.3e-01	7.9e+01		4.3e+00	1.5e+00	2.6e+03	7.6e+01	8.1e+00	9.5e+00
Te	7.0e+00c	7.0e+00c	7.0e+00c	7.0e+00c	4.0e-03	7.0e+00c	7.0e+00c	7.0e+00c	2.5e-02
Th	3.4e-05	3.9e-02		1.2e-04	8.5e-05	1.8e-03	1.1e-02	7.5e-03	8.5e-04
Ti					3.0e-03				5.5e-03
Tl					4.0e-04				4.0e-03
Tm					4.0e-03				1.0e-02
U	1.3e-03	1.4e-02			4.0e-03	8.3e-03	2.3e-02		8.5e-03
V					3.0e-03				5.5e-03
W	1.0e-01c	1.0e-01c	1.0e-01c	1.0e-01c	1.0e-02	1.0e-01c	1.0e-01c	1.0e-01c	4.5e-02
Y	1.0e-02c	1.0e-02c	1.0e-02c	1.0e-02c	6.0e-03	1.0e-02c	1.0e-02c	1.0e-02c	1.5e-02
Yb					4.0e-03				1.0e-02
Zn	1.6e+00	3.5e+01	1.1e-01i	7.1e-01	9.0e-01	3.3e+00	9.9e-01	5.6e-01	1.5e+00
Zr	1.0e-03c	1.0e-03c	1.0e-03c	1.0e-03c	5.0e-04	1.0e-03c	1.0e-03c	1.0e-03c	2.0e-03

a. Source: International Union of Radioecologists (Frissel 1989, 1992).
b. Source: Baes et al. (1984)
c. Unspecified IUR crop category.
d. Values for rape.
e. Value for alfalfa, which is higher than values given for clover and maize.
f. (cl)=clay, loam, pH=6; (s)=sand, pH=5; (p)=peat, pH=4.
g. Source: Peterson (1983).
h. Po values were not corrected for aerial contamination of plant surfaces. Actual uptake values are likely to be a factor of 2-10 lower.
I. Source: Ng et al. (1982).
j. For Cs in Florida soils, use CRC(I4)=1.5 (Peterson 1983).
k. For Sr in Florida soils, use CRC(I4)=1.3 (Peterson 1983).

A.2.5 ZKAB- Foliar Absorption Rate Constant

The foliar absorption rate constant controls the rate at which surface contamination is absorbed into the internal plant compartment where weathering does not occur. COMIDA requires input for the five crop types (ZKAB[I=1-5]), pasture grass (ZKABP), and hay (ZKABH), although current data support only element-specific values that are the same for all vegetation. One method to calculate this rate constant assumes that this process is based on contaminant solubility and the relative effects of adsorption versus weathering (Whicker and Kirchner, 1987):

$$ZKAB = \frac{faKw}{1 - fa} \qquad (3)$$

where

fa = fraction of surface contamination that is absorbed and
Kw = nuclide weathering rate constant (d^{-1})

Whicker and Kirchner (1987) estimated ZKAB values based on measured *fa* data for I, Cs, Te, and Mo (0.10) and Sr and Ba (0.02) and *Kw* values of 7.65e-02 d^{-1} for radioiodines and 4.95e-02 for all other radionuclides (Hoffman and Baes, 1979). The remaining elements investigated (Pu, Ru, Rh, Nd, Ce, and Np) are relatively insoluble, and their ZKAB values were assumed to be 0. For COMIDA, additional elements were investigated and grouped into the above categories as given in Table A-5.

Table A-5. Foliar Absorption Rate Constants (ZKAB).

ZKAB (d^{-1})	fa	Measured for:	Assumed[a] for:
8.5×10^{-3}	0.10	I	At, Br, Cl, Fl
5.5×10^{-3}	0.10	Cs, Te, Mo	As, Cr, Fr, K, Li, Mo, Na, Os, P, Rb, Re, S, Se, Si, Tc, W
1.0×10^{-3}	0.02	Sr, Ba	Ag, C, Ca, Cd, Cm, Cu, Ge, Hg, Mg, Nb, Ni, Pb, Po, Ra, Sb, Sn, Ta, Tb, Ti, U, V, Y, Zn
1.0×10^{-9}	0.0		All other elements

[a] Based on solubilities similar to those given in Linke (1958) and assumed weathering rate constants.

A.2.6 TC(B/M/P/O)- Animal Product Transfer Coefficients

In COMIDA, animal product concentrations are assumed to be in rapid equilibrium with time-dependent feed concentrations in order to simplify the required model input parameters. Transfer to these products is described using the commonly employed feed-to-animal product transfer coefficient, which is the amount of an animal's daily intake of a radionuclide that is transferred to 1 kg of the animal product at equilibrium. COMIDA will evaluate four animal products in a single run, using the following transfer coefficients: beef (TCB), milk (TCM), poultry (TCP), and "other" animal product (TCO). The user can choose what this "other" animal product is by using transfer coefficients and appropriate feed consumption rates (see Section A.3.2) for a particular animal product. Generally, pork or eggs should be chosen for this "other" animal product, depending on the relative human consumption rates in a particular area. Recommended transfer coefficients are listed in Table A-6 and are taken from reviews by IAEA (1994) and Baes et al. (1984). It is recommended that the IAEA data be used as the primary source and the Baes data be used when no IAEA value is given for a particular element.

A.3 COMIDA.PAR Input Parameters

The COMIDA.PAR file contains the site-specific vegetation, animal, soil, and time parameters that are not considered to be nuclide- or element-specific in COMIDA. A description of the input parameters is given in Table A-7 and an example COMIDA.VAR file is given in Section A.4.

A.3.1 Vegetation Parameters

TVC(I1-5)- Fraction of Total Plant Deposition on Edible Crop Surfaces at Harvest - COMIDA multiplies the vegetation surface concentration by this factor at harvest so that total plant deposition will be subject to foliar absorption and subsequent translocation to edible parts during the growing season. Recommended values are 0.25 for grains (I1), 1.0 for leafy vegetables (I2), and 0.05 for root crops, fruits, and legumes (I3-5) and are based on investigations for the PATHWAY model (Whicker and Kirchner, 1987).

ZKG(C/P/H)- Plant Growth Rate Constant - For crops (ZKGC[I1-5]), pasture grass (ZKGP), and hay (ZKGH), this parameter represents the maximum plant growth rate (kg m^{-2} d^{-1}) per current (or existing) plant biomass (kg m^{-2}). Values can be derived from crop growth rate studies (e.g., Holt et al., 1975). Current values are assumed to be 0.12 d^{-1} for all crops and pasture grass and 0.27 d^{-1} for hay based on studies done for PATHWAY (Whicker and Kirchner, 1987).

BI(C/P/H)- Initial Areal Biomass - This parameter is used primarily for mathematical initialization of the plant growth rate model. For pasture (BIP), the parameter is also used as a minimum winter biomass between the end of the growing season and the start of the following year's growing season. Current values for initial biomass are assumed to be 0.015 kg dry m^{-2} for crops (BIC), 0.07 kg dry m^{-2} for pasture (BIP), and 0.08 kg dry m^{-2} for hay (BIH) based on PATHWAY.

Table A-6. Transfer coefficients for beef (TCB), cow's milk (TCM), poultry (TCP), pork (TCO), and eggs (TCO).

	TCB (d/kg)		TCM (d/L)		TCP (d/kg)		TCO-pork (d/kg)		TCO-eggs (d/kg)	
	IAEA[a]	(Baes 84)[b]	IAEA	(Baes 84)	IAEA	(Na 80)[c]	IAEA	(Na 80)	IAEA	(NA80)
Ac		2.5e-05		2.0e-05		4.0e-03		1.0e-02		2.0e-03
Ag	3.0e-03	3.0e-03	5.0e-05	2.0e-02	2.0e+00		2.0e-02			
Al		1.5e-03		2.0e-04						
Am	4.0e-05d 1.0e-03e	3.5e-06	1.5e-06	4.0e-07	6.0e-03	4.0e-03	1.7e-04	1.0e-02	4.0e-03	2.0e-03
As		2.0e-03		6.0e-05		8.3e-01		2.4e-02		
At		1.0e-02		1.0e-02						
Au		8.0e-03		5.5e-06						
B		8.0e-04		1.5e-03						
Ba	2.0e-04	1.5e-04	4.8e-04	3.5e-04	9.0e-03	5.0e-04		1.0e-02	9.0e-01	4.0e-01
Be		1.0e-03		9.0e-07		4.0e-01		1.0e-02		2.0e-02
Bi		4.0e-04		5.0e-04						
Br		2.5e-02		2.0e-02		4.0e-03		9.0e-02		1.6e+00
C		0c		0c		0		0		0
Ca	2.0e-03	7.0e-04	3.0e-03	1.0e-02	4.0e-02	3.3e-03		3.3e-03	4.0e-01	1.0e+00
Cd	4.0e-04	5.5e-04		1.0e-03	8.0e-01	1.5e-02	1.5e-02	1.6e-02	1.0e-01	
Ce	2.0e-05	7.5e-04	3.0e-05	2.0e-05	2.0e-03	6.0e-04	1.0e-04	5.0e-03	9.0e-05	3.0e-03
Cl	2.0e-02	8.0e-02	1.6e-02	1.5e-02						
Cm		3.5e-06		2.0e-05		4.0e-03		1.0e-02		2.0e-03
Co	3.0e-04f 7.0e-05g	2.0e-02	1.0e-02f 1.0e-04g	2.0e-03	2.0e+00	1.0e-03	2.0e-03	5.0e-03	1.0e-01	1.0e-01
Cr	9.0e-03	5.5e-03	1.0e-05	1.5e-03						
Cs	5.0e-02d 2.0e-01e	2.0e-02	7.9e-03	7.0e-03	1.0e+01	4.5e+00	2.4e-01	2.6e-01	4.0e-01	5.0e-01
Cu	9.0e-03	1.0e-02		1.5e-03	5.0e-01	1.5e-02	2.2e-02	2.0e-03	5.0e-01	2.0e-01
Dy		5.5e-03		2.0e-05						
Er		4.0e-03		2.0e-05						
Eu		4.0e-03		2.0e-05		4.0e-03		5.0e-03		7.0e-03
F		1.5e-01		1.0e-03				9.0e-02		
Fe	2.0e-02	2.0e-02	3.0e-05	2.5e-04	1.0e+00	1.0e-03	2.6e-02	5.0e-03	1.0e+00	1.0e-01
Fr		2.5e-03		2.0e-02						
Ga		5.0e-04		5.0e-05						
Gd		3.5e-03		2.0e-05						
Ge		7.0e-01		7.0e-02						
Hf		1.0e-03		5.0e-06						
Hg		2.5e-01	4.7e-04	4.5e-04	3.0e-02	1.1e-02		3.1e+00		
Ho		4.5e-03		2.0e-05		4.0e-03		5.0e-03		7.0e-03
I	4.0e-02	7.0e-03	1.0e-02	1.0e-02	1.0e-02	4.0e-03	3.3e-03	9.0e-02	3.0e+00	1.6e+00
In		8.0e-03		1.0e-04						
Ir		1.5e-03		2.0e-06						
K	2.0e-02	2.0e-02	7.2e-03	7.0e-03					1.0e+00	
La		3.0e-04		2.0e-05	1.0e-01	4.0e-03		5.0e-03	9.0e-03	2.0e-03
Li		1.0e-02		2.0e-02						
Lu		4.5e-03		2.0e-05						
Mg	2.0e-02	5.0e-03	3.9e-03	4.0e-03					2.0e+00	
Mn	5.0e-04	4.0e-04	3.0e-05	3.5e-04	5.0e-02	1.1e-01	3.6e-03	2.0e-02	6.0e-02	1.0e-01
Mo	1.0e-03	6.0e-03	1.7e-03	1.5e-03	1.0e+00	2.0e-03		2.0e-02	9.0e-01	4.0e-01
N		7.5e-02		2.5e-02						
Na	8.0e-02	5.5e-02	1.6e-02	3.5e-02		1.0e-02		1.0e-01	6.0e+00	2.0e-01
Nb	3.0e-07	2.5e-01	4.1e-07	2.0e-02	3.0e-04	1.0e-04	2.0e-04	1.0e-03	1.0e-03	1.2e-03
Nd		3.0e-04		2.0e-05	9.0e-02	4.0e-03		5.0e-03	3.0e-04	2.0e-04
Ni	5.0e-03	6.0e-03	1.6e-02	1.0e-03		1.0e-03		5.0e-03		1.0e-01
Np	1.0e-03	5.5e-05	5.0e-06	5.0e-06		4.0e-03		1.0e-02		2.0e-03
Os		4.0e-01		5.0e-03						
P	5.0e-02	5.5e-02	1.6e-02	1.5e-02		1.9e-01		5.4e-01		1.0e+01

Table A-6. Transfer coefficients for beef (TCB), cow's milk (TCM), poultry (TCP), pork (TCO), and eggs (TCO).

	TCB (d/kg)		TCM (d/L)		TCP (d/kg)		TCO-pork (d/kg)		TCO-eggs (d/kg)	
	IAEA[a]	(Baes 84)[b]	IAEA	(Baes 84)	IAEA	(Na 80)[c]	IAEA	(Na 80)	IAEA	(NA80)
Pa		1.0e-05		5.0e-06		4.0e-03		1.0e-02		2.0e-03
Pb	4.0e-04	3.0e-04		2.5e-04						
Pd		4.0e-03		1.0e-02		3.0e-04		5.0e-03		4.0e-03
Pm		5.0e-03		2.0e-05	2.0e-03	1.0e-04		5.0e-03	2.0e-02	7.0e-03
Po	5.0e-03	9.5e-05	3.4e-04	3.5e-04						
Pr		3.0e-04		2.0e-05	3.0e-02	1.0e-03		5.0e-03	5.0e-03	4.0e-03
Pt		4.0e-03		5.0e-03						
Pu	1.0e-05d 1.0e-03e	5.0e-07	1.1e-06	1.0e-07	3.0e-03	4.0e-03	8.0e-05	1.0e-02	5.0e-04	2.0e-03
Ra	9.0e-04	2.5e-04	1.3e-03	4.5e-04						2.0e-05
Rb	1.0e-02	1.5e-02	1.2e-02	1.0e-02		2.0e+00		2.0e-01		3.0e+00
Re		8.0e-03		1.5e-03						
Rh		2.0e-03		1.0e-02		3.0e-04		5.0e-03		4.0e-03
Ru	5.0e-02d 4.0e-01e	2.0e-03	3.3e-06	6.0e-07	8.0e+00	3.0e-04	6.6e-01	5.0e-03	5.0e-03	4.0e-03
S		1.0e-01	1.6e-02	1.5e-02						
Sb	4.0e-05	1.0e-03	2.5e-05	1.0e-04		6.0e-03		7.0e-03		7.9e-02
Sc		1.5e-02		5.0e-06		4.0e-03		1.0e-02		
Se		1.5e-02		4.0e-03	9.0e+00	3.7e-01	3.2e-01	4.5e-01	9.0e+00	2.1e+00
Si		4.0e-05		2.0e-05						
Sm		5.0e-03		2.0e-05		4.0e-03		5.0e-03		7.0e-03
Sn		8.0e-02		1.0e-03						
Sr	8.0e-03d 1.0e-01e	3.0e-04		1.5e-03	8.0e-02	9.0e-04	4.0e-02	7.3e-03	2.0e-01	4.0e-01
Ta		6.0e-04		3.0e-06						
Tb		4.5e-03		2.0e-05		4.0e-03		5.0e-03		7.0e-03
Tc	1.0e-04	8.5e-03	1.4e-04	1.0e-02	3.0e-02		1.5e-04		3.0e+00	
Te	7.0e-03	1.5e-02	4.5e-04	2.0e-04	6.0e-01	1.0e-02		1.0e-02	5.0e+00	4.0e-01
Th		6.0e-06		5.0e-06		4.0e-03		1.0e-02		2.0e-03
Ti		3.0e-02		1.0e-02						
Tl		4.0e-02		2.0e-03						
Tm		4.5e-03		2.0e-05						
U	3.0e-04	2.0e-04	4.0e-04	6.0e-04	1.0e+00	1.2e-03	6.2e-02	6.0e-04	1.0e+00	3.4e-01
V		2.5e-03		2.0e-05						
W	4.0e-02	4.5e-02		3.0e-04						
Y	1.0e-03	3.0e-04		2.0e-05	1.0e-02	5.0e-04		5.0e-03	2.0e-03	5.0e-04
Yb		4.0e-03		2.0e-05						
Zn	1.0e-01	1.0e-01		1.0e-02	7.0e+00	2.0e-03	1.5e-01	1.4e-01	3.0e+00	4.0e-03
Zr	1.0e-06	5.5e-03	5.5e-07	3.0e-05	6.0e-05	1.0e-04		1.0e-03	2.0e-04	1.2e-03

a. International Atomic Energy Agency (IAEA 1994).
b. Source: Baes et al. (1984).
c. Source: Napier et al. (1980).
d. Value for beef.
e. Value for veal.
f. Organically bound form.
g. Inorganic form.

Table A-7. Description of COMIDA input parameters for the COMIDA.PAR file. The MIN and MAX values refer to the allowable minimum and allowable maximum values for that variable that the code will accept.

Card	Record	Variable	Code Variable	Type	Description
1	1	---	TITLE	CHARACTER	80 character title of computer simulation.
2	1 to 5	TVC	TVC(I)	REAL	Transfer factor from the exposed to edible surfaces of crops for grains (I=1), leafy vegetables (I=2), root crops (I=3), fruits (I=4), and legumes (I=5). Array of 5 elements. (unitless). MIN:0.0 MAX:1.0
3	1 to 5	Kg	ZKGC(I)	REAL	Crop growth rate constants for grains (I=1), leafy vegetables (I=2), root crops (I=3), fruits (I=4), and legumes (I=5). Array of 5 elements. (d^{-1}). MIN:0.0 MAX:10
4	1 to 5	BI	BIC(I)	REAL	Initial crop biomass for grains (I=1), leafy vegetables (I=2), root crops (I=3), fruits (I=4), and legumes (I=5). Array of 5 elements. (kg m^{-2}, dry weight). MIN:1E-6 MAX:100
5	1 to 5	BMAX	BMAXC(I)	REAL	Maximum crop biomass for grains (I=1), leafy vegetables (I=2), root crops (I=3), fruits (I=4), and legumes (I=5). Array of 5 elements. (kg m^{-2} dry weight). MIN:1E-2 MAX:1000
6	1 to 5	BSTAND	BSTAND(I)	REAL	Maximum standing biomass for grains (I=1), leafy vegetables (I=2), root crops (I=3), fruits (I=4), and legumes (I=5). Array of 5 elements. (kg m^{-2} dry weight). MIN:1E-2 MAX:1000
7	1 to 5	FD	FD(I)	REAL	Ratio of dry to wet weight for grains (I=1), leafy vegetables (I=2), root crops (I=3), fruits (I=4), and legumes (I=5). Array of 5 elements. (unitless). MIN:1E-10 MAX:1.0
8	1	Kg	ZKGP	REAL	Growth rate constant for pasture (d^{-1}). MIN:0 MAX:10
8	2	Ksen	ZSEN	REAL	Senescence rate constant for pasture (d^{-1}). MIN:0 MAX:10
9	1	BI	BIP	REAL	Initial biomass for pasture (kg m^{-2}, dry weight). MIN:1E-6 MAX:100
9	2	BMAX	BMAXP	REAL	Maximum biomass for pasture (kg m^{-2}, dry weight). MIN:1E-2 MAX:1000
10	1	Kg	ZKGH	REAL	Growth rate constant for hay (d^{-1}). MIN:0 MAX:10
10	2	BI	BIH	REAL	Initial biomass for hay (kg m^{-2}, dry weight). MIN:1E-6 MAX:100
10	3	BMAX	BMAXH	REAL	Maximum biomass for hay (kg m^{-2}, dry weight) MIN:1E-2 MAX:1000
11	1	---	NCUT	INTEGER	Number of hay cuttings in a year. MIN:1 MAX:3
11	2	---	TCUT(K)	REAL	Time of K^{th} hay cutting. Array of 3 elements where NCUT number of values are read. (Julian day) MIN:1 MAX:365
12	1	RP	RPB	REAL	Daily consumption rate of pasture for beef cattle while on pasture (kg d^{-1}, dry weight). MIN:0 MAX:100
12	2	RH	RHB	REAL	Annual average consumption rate of hay for beef cattle (kg d^{-1}, dry weight). MIN:0 MAX:100
12	3	RG	RGB	REAL	Annual average consumption rate of grain for beef cattle (kg d^{-1}, dry weight). MIN:0 MAX:100
12	3	RS	RSB	REAL	Annual average consumption rate of soil for beef cattle (kg d^{-1}). MIN:0 MAX:100

Table A-7. (continued).

Card	Record	Variable	Code Variable	Type	Description
12	3	RL	RLB	REAL	Annual average consumption rate of legumes for beef cattle (kg d^{-1}, dry weight). MIN:0 MAX:100
13	1	RP	RPM	REAL	Daily consumption rate of pasture for dairy cows while on pasture (kg d^{-1}, dry weight). MIN:0 MAX:100
13	2	RH	RHM	REAL	Annual average consumption rate of hay for dairy cows (kg d^{-1}, dry weight). MIN:0 MAX:100
13	3	RG	RGM	REAL	Annual average consumption rate of grain for dairy cows (kg d^{-1}, dry weight). MIN:0 MAX:100
13	4	RS	RSM	REAL	Annual average consumption rate of soil for dairy cows (kg d^{-1}). MIN:0 MAX:100
13	5	RL	RLM	REAL	Annual average consumption rate of legumes for dairy cows (kg d^{-1}, dry weight). MIN:0 MAX:100
14	1	RG	RGPL	REAL	Annual average consumption rate of grain for poultry (kg d^{-1}, dry weight). MIN:0 MAX:100
14	2	RS	RSPL	REAL	Annual average consumption rate of soil for poultry (kg d^{-1}). MIN:0 MAX:100
14	3	RG	RLPL	REAL	Annual average consumption rate of legumes for poultry (kg d^{-1}, dry weight). MIN:0 MAX:100
15	1	RP	RPO	REAL	Daily consumption rate of pasture for optional other animal while on pasture (kg d^{-1}, dry weight). MIN:0 MAX:100
15	2	RH	RHO	REAL	Annual average consumption rate of hay for optional other animal (kg d^{-1}, dry weight). MIN:0 MAX:100
15	3	RG	RGO	REAL	Annual average consumption rate of grain for optional other animal (kg d^{-1}, dry weight). MIN:0 MAX:100
15	4	RS	RSO	REAL	Annual average consumption rate of soil for optional other animal (kg d^{-1}). MIN:0 MAX:100
15	5	RL	RLO	REAL	Annual average consumption rate of legumes for optional other animal (kg d^{-1}, dry weight). MIN:0 MAX:100
16	1	Kp	ZKP	REAL	Percolation rate constant (d^{-1}).
16	2	Kw	ZKW	REAL	Weathering rate constant (d^{-1}).
16	3	Kr	ZKR	REAL	Resuspension rate constant (d^{-1}).
16	4	Krs	ZKRS	REAL	Rainsplash rate constant (d^{-1}).
17	1	Pss	PSS	REAL	Surface soil bulk density (kg m^{-3}). MIN:1 MAX:1E4
17	2	Psr	PSR	REAL	Labile soil bulk density (kg m^{-3}). MIN:1 MAX:1E4
17	3	Xr	XR	REAL	Thickness of rooting (labile) soil zone (m). MIN:1E-6 MAX:100
17	4	Xs	XS	REAL	Thickness of surface soil (m). MIN:1E-6 MAX:100
18	1 to 7	α	ALPHA(I)	REAL	Foliar interception constant for grains (I=1), leafy vegetables (I=2), root crops (I=3), fruits (I=4), legumes (I=5), hay (I=6) and pasture (I=7). Array, 7 elements (m^2 kg^{-1}). MIN:0 MAX:100
19	1	---	TINTM	REAL	Short term integration time for milk while cows are on pasture (d). MIN:1 MAX:(TEL-TSL)
19	2	TT	TT	REAL	Time of crop tillage (Julian day). MIN:1 MAX:365

Table A-7. (continued).

Card	Record	Variable	Code Variable	Type	Description
19	3	TSC	TSC	REAL	Start of crop growing season (Julian day). MIN:1 MAX:200
19	4	---	TSP	REAL	Start of pasture growing season (Julian day). MIN:1 MAX:200
19	5	TSL	TSL	REAL	Start of livestock grazing season (Julian day). MIN:1 MAX:365
20	1	---	TSH	REAL	Start of hay growing season (Julian day). MIN:1 MAX:200
20	2	TEC	TEC	REAL	Crop harvest time (Julian day). MIN:1 MAX:365
20	3	TEL	TEL	REAL	End of livestock grazing season (Julian day). MIN:1 MAX:365
20	4	TI	TI	REAL	Day of release incident (Julian day) MIN:1 MAX:365
21	1	T_h	THBEEF	REAL	Hold-up time for beef from time of slaughter to time of human ingestion (days). MIN:0 MAX:365
21	2	T_h	THMILK	REAL	Hold-up time for milk from time of production to time of human ingestion (days). MIN:0 MAX:365
21	3	T_h	THPOL	REAL	Hold-up time for poultry from time of slaughter to time of human ingestion (days). MIN:0 MAX:365
21	4	T_h	THOTHER	REAL	Hold-up time for other animal from time of slaughter to time of human ingestion (days). MIN:0 MAX:365
21	5	T_h	THGL	REAL	Hold-up time for grain and legume animal feed from time of harvest to start of consumption (days). MIN:0 MAX:(365-TEC)
21	6	T_h	THHAY	REAL	Hold-up time for hay from time of harvest to start of consumption (days). MIN:0 MAX:(365-TCUT(NCUT))
22	1	---	NTIMES	INTEGER	Number of years results are to be printed for. MIN:1 MAX:100
22	1+NTIMES	---	KYEAR(I)	INTEGER	The year numbers, following the release incident, for which results are to be printed. First value of KYEAR must be 1. This corresponds to the year the incident occurred. The last value of KYEAR is the last year results are calculated for. MIN:1 MAX:1E6

FD(I1-5)- Dry-to-Wet Weight Conversion Factors for Human Crops - Weighted average values were derived from data on water content and relative importance (total U.S. yield) of specific vegetables as compiled in Baes et al. (1984):

Crop Category	FD(I)	Vegetables Included in Weighted Average
grains (I1)	0.888	(barley, corn, oats, rye, soybean, wheat)
leafy veg (I2)	0.066	(lettuce, cabbage, celery, spinach greens, broccoli, cauliflower, green onions, escarole, brussel sprouts)
root crops (I3)	0.204	(carrots, onions, potatoes, sugar beets, sweet potatoes)
fruits (I4)	0.126	("exposed produce" category, includes noncitrus fruits)
legumes (I5)	0.782	(dry beans, peas)

BMAX(C/P/H)- Maximum Areal Biomass - For pasture grass and hay, this parameter is used in COMIDA's plant growth model to calculate the vegetation biomass at the time of deposition and

also to convert concentrations to a mass basis. For harvested crops, it is the maximum areal yield of the edible crop at harvest and is only used to convert harvested areal concentrations to a mass basis. Site-specific values for any state or county in the U.S. are compiled in Shor et al. (1982) based on 1974 Census of Agriculture information. These sources provide information for leafy vegetables, (I2), root crops (I3), fruits (I4), and legumes (I5) on a fresh weight basis and therefore must be converted to a dry weight basis by multiplying by the FD(I) values previously listed. Recommended BMAXC values for generic site assessments using average U.S. agricultural productivity values weighted by relative importance (total yield) were calculated to be:

BMAXC	kg dry m^{-2}	(U.S. average)
grains (I1)	0.27	(average of grains for food [0.23] and animal feed [0.31])
leafy veg (I2)	0.16	
root crops (I3)	0.19	("protected produce" category)
fruit (I4)	0.21	("exposed produce" category - includes most noncitrus fruits)
legumes (I5)	0.19	("protected produce" category)

Recommended values for BMAXP (kg dry m^{-2}) are:

BMAXP		
	0.5	(maximum estimate for eastern U.S. "cropland" or western U.S. "irrigated" pastures)
	0.1	(woodland pastures)
	0.04	(rangeland pastures)

The data given in Shor et al. (1982) for hay are "annual areal" yields (kg dry m^{-2} y^{-1}), which are based on the annual yield of hay summed over one or more harvests. Since COMIDA evaluates multiple (up to three) hay harvests per year, the Shor data must be divided by number of hay harvests per year (see NCUT parameter, below) to obtain the areal biomass for a single harvested crop. The maximum (U.S. average) hay areal yield given in Shor is 0.46 kg dry m^{-2} y^{-1}. Dividing by different numbers of hay harvests per year gives a maximum U.S. average value of

BMAXH		
	0.46	(single harvest [NCUT=1])
	0.23	(two harvests [NCUT=2])
	0.15	(three harvests [NCUT=3])

The value used for BMAXH should not be less than 0.15 kg dry m^{-2}, which is the productivity below which a farmer will not harvest hay (Shor et al., 1982). If the calculated value is less than this, then NCUT should be reduced until this minimum value for BMAXH is obtained.

BSTAND(I)- Maximum Standing Biomass - This parameter is required for crops (I1-5) and is an estimate of the maximum aboveground vegetation biomass (both edible and nonedible parts). It is used instead of BMAX in the COMIDA plant growth model to calculate the amount of vegetation biomass at the time of deposition. Currently, however, little data are available on this parameter for human crop categories, and it is recommended that BSTAND be set equal to BMAX. For leafy vegetables, this is a reasonable assumption. For root crops and "protected" grains (e.g. corn), fruits (e.g., citrus), and legumes, setting BSTAND equal to BMAX will allow foliar absorption and

translocation to the edible crop to occur during the growing season. Surface concentrations on edible parts (from direct deposition) are then reduced at harvest using the TVC parameter.

ZSEN- Senescence Rate Constant - This parameter only applies to pasture grass and determines the rate at which internally fixed radioactivity is returned to the soil at the end of the pasture growing season (assumed to be the end of the livestock grazing season in COMIDA). A value may be calculated based on the assumption that 99.9% of the radioactivity in the plant is returned to the soil between the end of the livestock grazing season (TEL) and day 365 (December 31) (10 half-times):

$$ZSEN = \frac{\ln 2}{T_s} \tag{4}$$

where

T_s = senescence half-time (d) = $0.1 \times (365 - \text{TEL})$.

NCUT- Number of Hay Cuttings per Year, TCUT(k) Time of Hay Cuttings - The number of hay harvests per year in a particular area can usually be determined by contacting the local county agricultural extension service. A site-specific value (rounded to the nearest whole number) may be estimated by dividing the number of frost-free days in a particular county (Shor et al., 1982) by an assumed average growth time to harvest of 60 days. NCUT has a minimum value of 1 and a maximum value of 3 in COMIDA. If BMAXH (previously described) is calculated by the quotient of "annual areal yield" (kg m^{-2} y^{-1}) from Shor et al. (1982) and NCUT, the results should not be less than 0.15 kg dry m^{-2} (minimum productivity at which a farmer will harvest hay). If it is, then NCUT should be reduced until this minimum productivity is obtained or NCUT has been reduced to one -- whichever comes first.

The time of each hay cutting, TCUT(k), can be calculated by adding successive 60-day harvest cycle periods to the start of the hay growing season (see TSH, below) and each successive harvest (up to a maximum of NCUT harvests).

ZKW- Weathering Rate Constant - This process moves radioactivity from vegetation surfaces to the soil surface as a result of wind and water removal, growth dilution, and herbivorous grazing. A value of 4.95×10^{-2} d^{-1} is generally used for all radionuclides except radioiodine, which is removed at a faster rate of 8.67×10^{-2} d^{-1} (Miller and Hoffman, 1983). COMIDA uses a single value for all radionuclides in the source term. Therefore, it is recommended that the conservative slower rate of 4.95×10^{-2} d^{-1} be used.

ALPHA-Foliar Interception Constant for Crops (I1-5), Hay (I6), and Pasture (I7) - The foliar interception constant is an empirical parameter used to calculate the fraction of total fallout that is intercepted and initially retained on vegetation surfaces. Values vary as a function of vegetative surface area as well as the fallout particle size, type of deposition (wet vs. dry), and the physicochemical form of the contamination (Hoffman et al., 1984, 1992; Pinder, 1988). For general safety assessments of fallout smaller than a few micrometers, a value of 3 m^2 kg^{-1} is suggested for all vegetation except fruit based on grass canopy (Miller, 1980) and corn plant

measurements (Pinder et al., 1988). Observed interception fractions for orange trees (Pinder et al., 1987) suggest a lower α value of 0.3 m^2 kg^{-1} for the fruit category.

A.3.2 Animal Parameters

Dairy Cow Feed Rates: RPM- Pasture, RHM- Hay, RGM- Grain, RLM- Legumes, RSM- Soil;
Beef Cattle Feed Rates: RPB- Pasture, RHB- Hay, RGB- Grain, RLB- Legumes, RSB- Soil - COMIDA calculates average annual milk and beef concentrations based on simplified cattle feeding schedules that assume (1) pasture consumption averaged over a user-defined grazing season (kg dry d^{-1}) and (2) annual average consumption of harvested feed crops [hay, grain, legumes (soybean concentrates)] and soil (kg dry d^{-1}). Estimates of these parameters may be obtained from local county agricultural extension agents, although the diversity of cattle categories and time-variable feeding regimes that usually exist in a particular area may make it difficult to quantify single annual average values for all beef or milk cows. Also, for collective (population) dose assessments, feeds that are imported from outside of the assessment impact area should be accounted for. If data are available, this can be accomplished by multiplying actual animal ingestion rates by the fraction of the total feed (by feed category) that is locally produced. For "maximum individual" dose assessments, it is reasonable to assume that all animal feeds are grown in the assessment area.

Total dry matter (TDM) intake for milk cows ranges from 10 to 25 kg d^{-1}, with an expected value of 16.1 kg d^{-1} (IAEA, 1994). Site-specific or generic consumption rates for use in COMIDA can be developed by defining the fractions of TDM for grain (f_g), soybean (legume) protein supplements (f_l), hay when cows are not on pasture (f_h), hay supplement when cows are on pasture (f_{hp}), and pasture (f_p):

f_g = 0.39 (39% of TDM daily feeding requirement from Shor et al., 1982)
f_l = 0.05 (2 lbs d^{-1} supplement [~5% TDM] from Hamilton, 1995)
f_h = 0.56 (remaining fraction when cows are not on pasture)
f_{hp} = 0.10 (3.5 lbs d^{-1} supplement [~10% TDM] when cows are on pasture from Hamilton) (personal communication*)
f_p = 0.46 (remaining fraction when cows are on pasture)

Using these fractions, input parameter values are:

RGM = (16.1 kg d^{-1})(0.39) = 6.3 kg d^{-1} (annual average)
RLM = (16.1 kg d^{-1})(0.05) = 0.81 kg d^{-1} (annual average)
RPM = (16.1 kg d^{-1})(0.46) = 7.4 kg d^{-1} (while cows are on pasture)
RHM = weighted annual average calculated by:

$$RHM(\text{kg d}^{-1}) = \frac{(16.1\ \text{kg d}^{-1})(f_{hp})(T_p) + (16.1\ \text{kg d}^{-1})(f_h)(365\ \text{d} - T_p)}{365\ \text{d}} \quad (5)$$

* G. Hamilton, Bonneville County, Idaho, agricultural extension agent.

where T_p = number of days in pasture grazing season (COMIDA parameters, TEL -TSL)

Solving this equation for a pasture grazing season (T_p) of 180 days gives

$\underline{RHM}$ = 5.4 kg d^{-1} (annual average)

Most dairies in the U.S. no longer utilize pasture for milk cows, although there are isolated areas where the practice is being revived. The recommended milk cow diet for those areas that do not put milk cows on pasture is:

$\underline{RGM}$ = (16.1 kg d^{-1})(0.39) = 6.3 kg d^{-1}
$\underline{RLM}$ = (16.1 kg d^{-1})(0.05) = 0.81 kg d^{-1}
$\underline{RPM}$ = 0.0 kg d^{-1}
$\underline{RHM}$ = (16.1 kg d^{-1})(0.56) = 9.0 kg d^{-1} (remaining fraction)

Beef cattle TDM intake ranges from 5 to 10 kg d^{-1}, with an expected value of 7.2 kg d^{-1} (IAEA, 1994). Input parameters are calculated in a similar manner after defining site-specific or generic beef cattle feed fractions:

f_g = 0.05 [5% for "all other (beef) cattle" from Shor et al. 1982]
f_l = 0.0 (assumed)
f_h = 0.95 (remaining fraction when cows are not on pasture)
f_{hp} = 0.10 (3.5 lbs d^{-1} supplement when cows are on pasture; from Hamilton, personal communication)
f_p = 0.85 (remaining fraction when cows are on pasture)

$\underline{RGB}$ = 0.36 kg d^{-1} (7.2 kg d^{-1})(0.05)
$\underline{RLB}$ = 0.0 kg d^{-1}
$\underline{RPB}$ = 6.8 kg d^{-1} (7.2 kg d^{-1})(0.95)
$\underline{RHB}$ = 3.8 kg d^{-1} [equation (5) using 7.2 kg d^{-1} TDM and T_p = 180 d]

Soil ingestion rates (kg d^{-1}) are strongly influenced by many site-specific factors, including season, soil characteristics, stocking rates, pasture management, and the soil ingestion propensity of individual animals (IAEA, 1994; Healy, 1968). COMIDA evaluates soil ingestion based on yearly integrated concentrations in pasture surface soil. This includes times when livestock are not on pasture because it is assumed that animals are normally outside eating feed that is either growing on or placed on ground surfaces that have contaminant concentrations similar to pasture surface soil. It is also assumed that soil particles that *adhere to* feed vegetation are accounted for by the vegetation/soil transfer processes (e.g. weathering, resuspension, rainsplash) in COMIDA. Therefore, the input soil ingestion rates should be for the additional component of soil that animals inadvertently ingest as they consume feed on the ground. Based on data that indicate strong seasonal influences (Healy, 1968; Darwin, 1990), recommended annual average soil ingestion rates for outside beef cattle are:

$$RSB(\text{kg d}^{-1}) = \frac{(0.5 \text{ kg d}^{-1})(T_p) + (2.0 \text{ kg d}^{-1})(365 \text{ d} - T_p)}{365 \text{ d}} \quad (6)$$

for T_p = 180 d, RSB = 1.3 kg d^{-1}.

Contaminated soil ingestion rates for milk cows (RSM) in the U.S. are likely to be significantly lower because most dairies are operated indoors where feeding areas are protected from fallout. If, however, an area has milk cows that use pasture and are fed outdoors, the soil ingestion rate may be calculated as above using the length of the pasture season for milk cows. For all other areas, the recommended contaminated soil ingestion rate for milk cows is:

RSM = 0.0 kg d^{-1}

Poultry Feed Rates: RGPL- Grain, RLPL- Legumes, RSPL- Soil
"Other Animal" Rates: RPO- Pasture, RHO- Hay, RGO- Grain, RLO- Legumes, RSO- Soil
TDM intake for poultry ranges from 0.05 to 0.15 kg dry d^{-1} with expected values of 0.07 kg d^{-1} for chickens and 0.1 kg d^{-1} for laying hens (IAEA, 1994). In most areas, this TDM will be composed primarily of grain. Soil ingestion can be assumed to be 0.01 kd d^{-1} (Whicker and Kirchner, 1987). From these assumptions, recommended feed rates for poultry (chickens) and "other animal-layer hens" (eggs) are:

Poultry - chickens (kg d^{-1})	"Other animal" -layer hens (eggs) option (kg d^{-1})	
RGPL - 0.07 kg d^{-1}	RPO - 0.0	RLO - 0.0
RLPL - 0.0 kg d^{-1}	RHO - 0.0	RSO - 0.01
RSPL - 0.01 kg d^{-1}	RGO - 0.10	

Additional options for the "other animal" for which feed rates can be developed using the above procedures include:

	TDM (kg dry d^{-1}) Expected (Range)	Primary Feeds
Dairy goats	1.3 (1.0-3.5)	pasture in season; hay
Dairy sheep	1.3 (1.0-2.5)	pasture in season; hay
Lambs (50 kg)	1.1 (0.5-2.0)	pasture in season; hay
Pigs (110 kg)	2.4 (2.0-3.0)	grain

A.3.3 Soil Parameters

ZKP- Percolation Rate Constant - This parameter controls the rate at which contaminants are transferred from the surface to the labile (root) soil compartment, thereby decreasing the surface soil inventory and, as a result, the rate of resuspension to plant surfaces. PATHWAY used a value of 1.98×10^{-2} d^{-1} which is based on a 35-d half-time observed for declines in resuspension for western U.S. semiarid areas (Langham, 1972; Anspaugh et al., 1975). More recent data from Chernobyl (IAEA, 1992) measured much slower declines in ^{137}Cs resuspension: 1.0×10^{-3} to 4.0×10^{-3} d^{-1} (half-times of 2 to 4.7 years). Based on these data, recommended values for ZKP are:

ZKP = 2×10^{-2} d^{-1} for sites in the western U.S.
= 2×10^{-3} d^{-1} for all other locations.

ZKR- Resuspension Rate Constant - This rate constant controls the rate at which radioactivity is resuspended from the surface soil to vegetation surfaces. Values for *Kr* range from 10^{-7} to 10^{-1} d^{-1} for various locations, particle types, and wind speeds (Healy, 1980; Sutter, 1982). A value may be calculated from the product of a resuspension factor (RF, m^{-1}) and the deposition velocity (m d^{-1}). RF values range from 1×10^{-10} to 1×10^{-2} m^{-1}, depending on the location, source material, and type of resuspension stress (Sutter, 1982). Generally accepted initial RF values are 1×10^{-4} m^{-1} for fresh deposits in desert areas (Anspaugh et al., 1975), 1×10^{-5} m^{-1} for areas where there is regular disturbance by pedestrian or vehicular traffic (Linsley, 1978) or vegetated arid areas (Whicker and Kirchner, 1987), and 1×10^{-6} m^{-1} for other well-vegetated soils (Linsley, 1978). Recent measurements from Chernobyl ^{137}Cs fallout indicate significantly lower initial RF values, ranging from 3.6×10^{-9} to 4.9×10^{-8} m^{-1}, with a representative deposition velocity of 864 m d^{-1} (IAEA, 1992). Since higher values are more conservative, it is recommended that general safety analyses use RF values ranging from 1×10^{-4} to 1×10^{-6} m^{-1}, depending on the area being investigated, and a 173 m d^{-1} deposition velocity [generally accepted value for particulate <4 μm (IAEA, 1982)] to calculate ZKR. Recommended values for ZKR are therefore:

ZKR = 1.7×10^{-2} d^{-1} (fresh deposits in desert areas)
= 1.7×10^{-3} d^{-1} (areas with traffic or vegetated arid areas)
= 1.7×10^{-4} d^{-1} (other well vegetated soils)

ZKRS- Rainsplash Rate Constant - This parameter works in the same way as ZKR but simulates additional transport from surface soil to plant surfaces due to rainsplash, which can be significant for low-lying (<40 cm) crops and pasture grass in areas that have intense rainstorms or large (>2 mm) median rain drop sizes (Dreicer et al., 1984). To simulate this process for rangeland and agricultural areas in southwestern Utah, PATHWAY derived a value of 8.6×10^{-4} d^{-1} from experimental data (Dreicer et al., 1984). This value is recommended for general use in COMIDA for typical semiarid U.S. locations or other areas with the above characteristics. For temperate locations with normally light showers, a ZKRS value of 1×10^{-9} d^{-1} is recommended, which will result in negligible rainsplash. Recommended values are therefore:

ZKRS = 8.6×10^{-4} d^{-1} (semiarid locations)

$= 1 \times 10^{-9}$ d^{-1} (temperate climates not characterized by intense rainstorms)

PSS- Surface Soil Bulk Density, PSR- Root Soil Bulk Density, XR- Thickness of Root Zone Soil, XS- Thickness of Surface Soil - These parameters apply to cultivated cropland and are only used to calculate the redistribution of surface fallout that occurs as a result of tillage. In lieu of site-specific data, suggested values are:

PSS, PSR = 1300 kg m^{-3} (IAEA, 1982)
XS = 0.001 m (Whicker and Kirchner, 1987)
XR = 0.20 m (IAEA, 1994)

A.3.4 Time Parameters

TINTM- Short-Term Integration Time for Milk When Cows Are on Pasture - This parameter is the number of days from the time of fallout that the user would like short-term integrated milk concentrations evaluated for. This subroutine only evaluates pasture grass and soil while cows are on pasture. The minimum value is 1 day and the maximum value is the length of the growing season (TEL-TSL). If TINTM is specified as the length of the growing season, then the results for short-term integrated milk concentrations will be identical to the first year's integrated milk concentrations.

TT- Time of Crop Tillage - This is the Julian day on which tillage for human crops (I1-5) is assumed to take place. A site-specific estimate may obtained from local county extension agents or a value may be assumed that is 1-2 weeks prior to the start of the crop growing season (TSC).

TSC- Start of Crop Growing Season, TEC- Harvest Date for Crops, TSH- Start of Hay Growing Season - For harvested crops, the start of the growing season should be assumed to occur on the approximate Julian date that vegetation begins aboveground growth. This information is highly site-specific, depending on climate and crop type, and is readily available from local county extension agents for a particular area. Since COMIDA only allows input of a single value for each parameter, it is recommended that TSC/TEC values be chosen to coincide with the first and last frost dates (median probability) for an area (also available from county extension agents). The start of the hay growing season, TSH, will generally be several weeks prior to TSC. Example values for Bonneville County, Idaho are:

TSC = 142 (May 22)
TEC = 263 (September 20)
TSH = 105 (April 15)

TSP- Start of Pasture Growing Season, TSL- Start of Livestock Grazing Season, TEL- End of Livestock Grazing Season - For perennial pasture vegetation, TSP is the approximate Julian date that vegetation transitions from a state of dormancy to active growth. For COMIDA input, the value for TSL may be assumed to occur within 1 week after TSP, unless other site data are available. These dates are highly site-specific and may be estimated from information obtained

from local county (livestock) extension agents. Example values for Bonneville County, Idaho are estimated to be:

TSP = 105 (April 15)
TSL = 112 (April 22)
TEL = 288 (October 15)

Delay Times for Animal Products from Time of Production (Slaughter, Milking) to Human Consumption: THBEEF- Beef, THMILK- Milk, THPOL- Poultry, THOTHER- "Other" Animal - COMIDA explicitly accounts for decay and ingrowth over consecutive 1-year integration times during which human consumption is assumed to occur. The parameters listed here allow for additional decay during the average time required for slaughter of a meat animal to consumption and the average transport time from milk cow feeding to milk consumption. In lieu of site-specific information, the following values are recommended (NRC, 1977):

THBEEF, THPOL, THOTHER = 20 d
THMILK = 4 d

Delay Times for Stored Animal Feeds from Harvest to Start of Consumption: THGL- Grain and Legumes, THHAY- Hay - Individual hay cuttings are explicitly decayed and ingrown to the date of the final hay harvest. Decay and ingrowth over the assumed 1 year storage and feeding periods are explicitly accounted for in the animal product integrations. The delay times specified by THGL and THHAY allow for additional decay during the time between final harvests of the current calendar year's feed crops and the start of animal consumption of these crops. In effect, they are the time periods between the current year's harvests and exhaustion of the prior year's stored feed inventory. Based on this, the 90 d average feed storage time specified in NRC (1977) is probably not appropriate for use. The following conservative values are recommended unless site-specific information is available:

THGL = 7 d
THHAY = 7 d

NTIMES, KYEAR(I)- Output Options - These values are based on 365-d periods ("accident years") following the deposition. As an example, concentrations for the first and fiftieth year following the deposition date would be specified as:

NTIMES = 2 (two years of printout)
KYEAR(I) = 1 50 (printout for accident years 1 and 50)

A.4 Sample Input Files

A.4.1 COMIDA.VAR File

A sample COMIDA.VAR file is provided for $^{90}Sr/^{90}Y$, $^{95}Zr/^{95}Nb$, ^{131}I, ^{137}Cs, $^{241}Pu/^{241}Am$ on the following page ["J"= number of progeny, "I"=crop category (grains, leafy veg, root veg, fruit, legumes)]. Parameters were selected for a clay-loam soil in a temperate climate. Eggs (layer hens) were chosen as the optional "other" animal.

```
5                                                    NNUC
'SR-90' 1 'Y-90'                                     NUC(1) NPROG NUC(J..NPROG)
1.062E+4  2.671                                      THALF(J)                SR/Y
9.68E-5   2.72E-6                                    ZKL(J) (for LOAM SOIL)  SR/Y
1.0E-9  1.0E-9  10                                   ZKAD ZKDE ncutoff        SR
0.12  2.7  1.4  0.17  1.3                            CRC(I,J) (CLAY LOAM SOIL) SR
1.0E-3  1.0E-3  1.0E-3  1.0E-3  1.0E-3               ZKABC(I,J)               SR
1.1  1.9                                            CRP(J) CRH(J)            SR
1.0E-3  1.0E-3                                       ZKABP(J) ZKABH(J)        SR
8.0E-3  1.5E-3  8.0E-2 0.2              TCB(J) TCM(J) TCP(J)TCO(J)(EGGS) SR
0.01  0.01  0.01  0.01  0.01                        CRC(I,J) (CLAY LOAM SOIL)  Y
1.0E-3  1.0E-3  1.0E-3  1.0E-3  1.0E-3               ZKABC(I,J)                Y
0.01  0.01                                          CRP(J) CRH(J)             Y
1.0E-3  1.0E-3                                       ZKABP(J) ZKABH(J)         Y
1.0E-3  2.0E-5  1.0E-2  5.0E-4                       TCB(J) TCM(J) TCP(J)TCO(J) Y
'ZR-95' 1  'NB-95'                                   NUC(1) NPROG NUC(J..NPROG)
64.02      34.97                                     THALF(J)
8.89E-7  3.56E-6                                     ZKL(J) (LOAM SOIL) ZR/NB
1.0E-9  1.0E-9  10                                   ZKAD ZKDE ncutoff  ZR
1.0E-3  1.0E-3  1.0E-3  1.0E-3  1.0E-3               CRC(I,J)           ZR
1.0E-9  1.0E-9  1.0E-9  1.0E-9  1.0E-9               ZKABC(I,J)         ZR
1.0E-3  1.0E-3                                       CRP(J) CRH(J)      ZR
1.0E-9  1.0E-4                                       ZKABP(J) ZKABH(J)  ZR
1.0E-6  5.5E-7  6.0E-5  2.0E-4                       TCB(J) TCM(J) TCP(J) TCO(J) ZR
5.0E-2  5.0E-2  5.0E-2  5.0E-2  5.0E-2               CRC(I,J)           NB
1.0E-9  1.0E-9  1.0E-9  1.0E-9  1.0E-2               ZKABC(I,J)         NB
5.0E-2  5.0E-2                                       CRP(J) CRH(J)      NB
1.0E-9  1.0E-9                                       ZKABP(J) ZKABH(J)  NB
3.0E-7  4.1E-7  3.0E-4  1.0E-3                       TCB(J) TCM(J) TCP(J) TCE(J) NB
'I-131' 0                                            NUC(1) NPROG NUC(J..NPROG)
8.04                                                 THALF(J)
3.75E-4                                              ZKL(J) (LOAM SOIL)
1.0E-9  1.0E-9  10                                   ZKAD ZKDE ncutoff
2.0E-2  2.0E-2  2.0E-2  2.0E-2  2.0E-2               CRC(I,J)
8.5E-3  8.5E-3  8.5E-3  8.5E-3  8.5E-3               ZKABC(I,J)
2.0E-2  2.0E-2                                       CRP(J) CRH(J)
8.5E-3  8.5E-3                                       ZKABP(J) ZKABH(J)
4.0E-2  1.0E-2  1.0E-2  3.0E+0                       TCB(J) TCM(J) TCP(J) TCO(J)
'CS-137' 0                                           NUC(1) NPROG NUC(J..NPROG)
1.099E+4                                             THALF(J)
4.25E-7                                              ZKL(J) (LOAM SOIL)
1.9E-3  2.1E-4  10                                   ZKAD ZKDE ncutoff
1.0E-2  1.8E-1  4.0E-2  2.2E-1  1.7E-2               CRC(I,J) (LOAM SOIL)
5.5E-3  5.5E-3  5.5E-3  5.5E-3  5.5E-3               ZKABC(I,J)
1.1E-1  1.7E-2                                       CRP(J) CRH(J) (LOAM SOIL)
5.5E-3  5.5E-3                                       ZKABP(J) ZKABH(J)
5.0E-2  7.9E-3  4.5E+0  4.0E-1                       TCB(J) TCM(J) TCP(J) TCO(J)
'PU-241' 1  'AM-241'                                 NUC(1) NPROG NUC(J..NPROG)
5.238E+3   1.579E+5                                  THALF(J)
1.63E-6  1.98E-6                                     ZKL(J) (LOAM SOIL) PU/AM
1.0E-9  1.0E-9  10                                   ZKAD ZKDE ncutoff  PU
8.6E-6  4.1E-5  4.4E-3  9.0E-5  6.1E-5               CRC(I,J)           PU
1.0E-9  1.0E-9  1.0E-9  1.0E-9  1.0E-9               ZKABC(I,J)         PU
3.4E-4  8.0E-4                                       CRP(J) CRH(J)      PU
1.0E-9  1.0E-4                                       ZKABP(J) ZKABH(J)  PU
4.0E-5  1.5E-6  6.0E-3  4.0E-3                       TCB(J) TCM(J) TCP(J) TCO(J) PU
2.2E-5  6.6E-4  2.2E-3  2.5E-4  3.9E-4               CRC(I,J)           AM
1.0E-9  1.0E-9  1.0E-9  1.0E-9  1.0E-2               ZKABC(I,J)         AM
1.2E-3  7.1E-4                                       CRP(J) CRH(J)      AM
1.0E-9  1.0E-9                                       ZKABP(J) ZKABH(J)  AM
4.0E-5  1.5E-6  6.0E-3  4.0E-3                       TCB(J) TCM(J) TCP(J) TCE(J) AM
```

A.4.2 COMIDA.PAR File

The sample COMIDA.PAR file given below was developed for a "generic" U.S. site location with the following characteristics:

1. nonarid vegetated area with regular pedestrian and vehicular traffic,
2. average U.S. productivity values for crops, woodland pasture, and hay,
3. layer hen (eggs) selected as the optional "other animal,"
4. milk obtained from typical dairy where milk cows are not put on pasture,
5. 100% local production and consumption of animal feeds
6. southeastern Idaho seasonal dates (tillage, growing and grazing season, and harvest).

The parameter values that were selected for this problem should not be considered "default" values for all location in the U.S. Site-specific values, especially for milk cow pasture consumption (RPM) and seasonal dates (TT, TSC, TSP, TSL, TSH, TEC, TEL), should be investigated and used.

```
'SAMPLE PROBLEM 1--GENERIC U.S. VALUES'   TITLE
0.25  1.00  0.05  0.05  0.05              TVC(I),I=1,5
0.12  0.12  0.12  0.12  0.12              ZKGC(I),I=1,5
0.015 0.015 0.015 0.015 0.015             BIC(I),I=1,5
0.27  0.16  0.19  0.21  0.19              BMAXC(I),I=1,5
0.27  0.16  0.19  0.21  0.19              BSTAND(I),I=1,5
0.888 0.066 0.204 0.126 0.782             FD(I),I=1,5
0.12  0.09                                ZKGP ZSEN
0.07  0.10                                BIP BMAXP (WOODLAND)
0.27  0.08  0.15                          ZKGH BIH BMAXH
3   165.  225.  285.                      NCUT (TCUT(I),I=1,NCUT)
6.8   3.8   0.36  1.3   0.0             RPB RHB RGB RSB RLB
0.0   9.0   6.3   0.0   0.81            RPM RHM RGM RSM RLM (NO PASTURE)
0.07  0.0   0.01                        RGPL RLPL RSPL
0.0   0.0   0.10  0.01  0.0             RPO RHHO RGO RSO RLO(EGGS)
2.0E-3  4.95-2  1.7E-3  8.6E-4           ZKP ZKW ZKR ZKRS
1300.  1300.  0.20  0.001               PSS PSR XR XS
3.0  3.0  3.0  0.3  3.0  3.0  3.0       ALPHA(I),I=1,7
30.  128.  142.  105.  112.             TINTM TT TSC TSP TSL(S.E. IDAHO)
105.  263.  288.  249.                  TSH TEC TEL TI (S.E. IDAHO)
20. 4. 20. 20.  7. 7.                       THBEEF THMILK THPOL THOTHER THGL
THHAY
3  1  2  50                              NTIMES KYEAR
```

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APPENDIX B

ADDITIONAL INFORMATION PERTINENT TO IDCF2

B.1 Nuclide List from DECAYLIB.DAT

A special output file was created during modifications to IDCF. The output file, shown here, includes an integer representing the order in which the nuclide was found in the DECAYLIB file, the nuclide name surrounded by colons to highlight names that include leading blanks, and the branch fraction, as read from the file. A branch fraction of less than 1.0000 indicates a secondary branch. This file is presented in Table B-1.

Table B-1

Nuclide List from File DECAYLIB.DAT

1: H-3	: 1.0000	30: K-43	: 1.0000	59:Fe-55	: 1.0000
2:Be-7	: 1.0000	31:Ca-41	: 1.0000	60:Fe-59	: 1.0000
3:Be-10	: 1.0000	32:Ca-45	: 1.0000	61:Fe-60	: 1.0000
4: C-14	: 1.0000	33:Ca-47	: 1.0000	62:Co-57	: 1.0000
5: N-13	: 1.0000	34:Sc-44	: 1.0000	63:Co-58	: 1.0000
6: N-16	: 1.0000	35:Sc-44m	: 0.0139	64:Co-58m	: 1.0000
7: F-18	: 1.0000	36:Sc-44m	: 0.9861	65:Co-60	: 1.0000
8:Na-22	: 1.0000	37:Sc-46	: 1.0000	66:Co-60m	: 1.0000
9:Na-24	: 1.0000	38:Sc-47	: 1.0000	67:Co-61	: 1.0000
10:Mg-27	: 1.0000	39:Sc-48	: 1.0000	68:Co-62m	: 1.0000
11:Mg-28	: 1.0000	40:Sc-49	: 1.0000	69:Ni-57	: 1.0000
12:Al-26	: 1.0000	41:Sc-50	: 1.0000	70:Ni-59	: 1.0000
13:Al-28	: 1.0000	42:Ti-44	: 1.0000	71:Ni-63	: 1.0000
14:Al-29	: 1.0000	43:Ti-45	: 1.0000	72:Ni-65	: 1.0000
15:Si-31	: 1.0000	44:Ti-51	: 1.0000	73:Cu-62	: 1.0000
16:Si-32	: 1.0000	45: V-48	: 1.0000	74:Cu-64	: 1.0000
17: P-32	: 1.0000	46: V-49	: 1.0000	75:Cu-66	: 1.0000
18: P-33	: 1.0000	47: V-52	: 1.0000	76:Zn-63	: 1.0000
19: S-35	: 1.0000	48: V-53	: 1.0000	77:Zn-65	: 1.0000
20: S-37	: 1.0000	49:Cr-49	: 1.0000	78:Zn-69	: 1.0000
21:Cl-36	: 1.0000	50:Cr-51	: 1.0000	79:Zn-69m	: 1.0000
22:Cl-38	: 1.0000	51:Cr-55	: 1.0000	80:Zn-71m	: 1.0000
23:Cl-39	: 1.0000	52:Mn-52	: 1.0000	81:Ga-68	: 1.0000
24:Cl-40	: 1.0000	53:Mn-52m	: 1.0000	82:Ga-70	: 0.9960
25:Ar-39	: 1.0000	54:Mn-53	: 1.0000	83:Ga-70	: 0.0040
26:Ar-41	: 1.0000	55:Mn-54	: 1.0000	84:Ga-72	: 1.0000
27:Ar-42	: 1.0000	56:Mn-56	: 1.0000	85:Ge-69	: 1.0000
28: K-	: 1.0000	57:Mn-57	: 1.0000	86:Ge-75	: 1.0000
29: K-42	: 1.0000	58:Fe-53	: 1.0000	87:Ge-77	: 1.0000

88:As-74 : 1.0000
89:As-76 : 1.0000
90:As-77 : 1.0000
91:As-78 : 1.0000
92:Se-75 : 1.0000
93:Se-79 : 1.0000
94:Br-80 : 0.9170
95:Br-80 : 0.0830
96:Br-80m : 0.9170
97:Br-80m : 0.0830
98:Br-82 : 1.0000
99:Kr-81 : 1.0000
100:Kr-85 : 1.0000
101:Kr-85m : 0.7900
102:Kr-85m : 0.2100
103:Kr-87 : 1.0000
104:Kr-88 : 1.0000
105:Rb-84 : 0.9600
106:Rb-84 : 0.0400
107:Rb-86 : 1.0000
108:Rb-86m : 1.0000
109:Rb-87 : 1.0000
110:Rb-88 : 1.0000
111:Sr-85 : 1.0000
112:Sr-89 : 1.0000
113:Sr-90 : 1.0000
114:Sr-91 : 0.5700
115:Sr-91 : 0.4300
116: Y-88 : 1.0000
117: Y-90 : 1.0000
118: Y-90m : 1.0000
119: Y-91 : 1.0000
120: Y-91m : 1.0000
121: Y-92 : 1.0000
122: Y-93 : 1.0000
123: Y-94 : 1.0000
124:Zr-89 : 1.0000
125:Zr-93 : 1.0000
126:Zr-95 : 1.0000
127:Zr-97 : 1.0000
128:Nb-90 : 1.0000
129:Nb-91 : 1.0000
130:Nb-91m : 1.0000
131:Nb-92 : 1.0000
132:Nb-92m : 1.0000
133:Nb-93m : 1.0000
134:Nb-94 : 1.0000
135:Nb-94m : 1.0000
136:Nb-95 : 1.0000
137:Nb-95m : 1.0000
138:Nb-96 : 1.0000
139:Nb-97 : 1.0000
140:Nb-97m : 1.0000
141:Nb-98m : 1.0000
142:Mo-91 : 1.0000
143:Mo-93 : 1.0000
144:Mo-93m : 1.0000
145:Mo-99 : 0.8700
146:Mo-99 : 0.1300
147:Mo-101 : 1.0000
148:Tc-95 : 1.0000
149:Tc-96 : 1.0000
150:Tc-97 : 1.0000
151:Tc-98 : 1.0000
152:Tc-99 : 1.0000
153:Tc-99m : 1.0000
154:Tc-101 : 1.0000
155:Ru-97 : 1.0000
156:Ru-103 : 1.0000
157:Ru-105 : 1.0000
158:Ru-106 : 1.0000
159:Rh-101 : 1.0000
160:Rh-101m : 0.0800
161:Rh-101m : 0.9200
162:Rh-102 : 1.0000
163:Rh-102m : 0.7500
164:Rh-102m : 0.2000
165:Rh-102m : 0.0500
166:Rh-103m : 1.0000
167:Rh-104 : 0.9960
168:Rh-104 : 0.0040
169:Rh-104m : 0.9950
170:Rh-104m : 0.0040
171:Rh-104m : 0.0010
172:Rh-105 : 1.0000
173:Pd-107 : 1.0000
174:Pd-109 : 1.0000
175:Pd-111 : 1.0000
176:Pd-111m : 1.0000
177:Ag-106 : 1.0000
178:Ag-106m : 1.0000
179:Ag-108 : 1.0000
180:Ag-108m : 0.0870
181:Ag-108m : 0.9130
182:Ag-110 : 1.0000
183:Ag-110m : 1.0000
184:Ag-111 : 1.0000
185:Cd-109 : 1.0000
186:Cd-113m : 1.0000
187:Cd-115 : 1.0000
188:In-114 : 1.0000
189:In-114m : 1.0000
190:In-115 : 1.0000
191:In-115m : 1.0000
192:In-116 : 1.0000
193:In-116m : 1.0000
194:Sn-113 : 1.0000
195:Sn-113m : 1.0000
196:Sn-119m : 1.0000
197:Sn-121 : 1.0000
198:Sn-121m : 0.2240
199:Sn-121m : 0.7760
200:Sn-123 : 1.0000
201:Sn-126 : 0.8600
202:Sn-126 : 0.1400
203:Sb-120m : 1.0000
204:Sb-122 : 1.0000
205:Sb-124 : 1.0000
206:Sb-125 : 0.2300
207:Sb-125 : 0.7700
208:Sb-126 : 1.0000
209:Sb-126m : 0.8600
210:Sb-126m : 0.1400
211:Sb-129 : 1.0000
212:Te-121 : 1.0000
213:Te-121m : 0.8860
214:Te-121m : 0.1140
215:Te-123 : 1.0000
216:Te-123m : 1.0000
217:Te-125m : 1.0000
218:Te-129 : 1.0000
219:Te-129m : 0.6340
220:Te-129m : 0.3660
221:Te-131 : 1.0000
222:Te-131m : 0.2200

223:Te-131m : 0.7800
224:Te-132 : 1.0000
225: I-126 : 0.5630
226: I-126 : 0.4370
227: I-128 : 0.9310
228: I-128 : 0.0690
229: I-129 : 1.0000
230:I-130 : 1.0000
231: I-131 : 1.0000
232: I-132 : 1.0000
233: I-133 : 1.0000
234: I-134 : 1.0000
235: I-135 : 1.0000
236:Xe-133 : 1.0000
237:Xe-133m : 1.0000
238:Xe-135 : 1.0000
239:Cs-132 : 0.9800
240:Cs-132 : 0.0200
241:Cs-134 : 1.0000
242:Cs-135 : 1.0000
243:Cs-136 : 1.0000
244:Cs-137 : 1.0000
245:Ba-133 : 1.0000
246:Ba-133m : 1.0000
247:Ba-139 : 1.0000
248:Ba-140 : 1.0000
249:La-137 : 1.0000
250:La-138 : 1.0000
251:La-140 : 1.0000
252:Ce-139 : 1.0000
253:Ce-141 : 1.0000
254:Ce-144 : 1.0000
255:Pr-142 : 1.0000
256:Nd-141 : 1.0000
257:Nd-144 : 1.0000
258:Nd-147 : 1.0000
259:Nd-149 : 1.0000
260:Pm-143 : 1.0000
261:Pm-145 : 1.0000
262:Pm-146 : 0.6610
263:Pm-146 : 0.3390
264:Pm-147 : 1.0000
265:Pm-149 : 1.0000
266:Sm-146 : 1.0000
267:Sm-147 : 1.0000
268:Sm-148 : 1.0000
269:Sm-151 : 1.0000
270:Sm-153 : 1.0000
271:Eu-150 : 1.0000
272:Eu-152 : 1.0000
273:Eu-152m : 0.7200
274:Eu-152m : 0.2800
275:Eu-152g : 0.7200
276:Eu-152g : 0.2800
277:Eu-154 : 1.0000
278:Gd-148 : 1.0000
279:Gd-150 : 1.0000
280:Gd-152 : 1.0000
281:Gd-159 : 1.0000
282:Gd-161 : 1.0000
283:Tb-157 : 1.0000
284:Tb-158 : 1.0000
285:Tb-160 : 1.0000
286:Tb-161 : 1.0000
287:Dy-154 : 1.0000
288:Dy-159 : 1.0000
289:Ho-164 : 0.5800
290:Ho-164 : 0.4200
291:Ho-164m : 0.5800
292:Ho-164m : 0.4200
293:Ho-166 : 1.0000
294:Er-169 : 1.0000
295:Er-171 : 1.0000
296:Tm-168 : 1.0000
297:Tm-170 : 0.9990
298:Tm-170 : 0.0010
299:Tm-171 : 1.0000
300:Lu-174 : 1.0000
301:Lu-174m : 1.0000
302:Lu-176 : 1.0000
303:Lu-176m : 1.0000
304:Lu-177 : 1.0000
305:Lu-177m : 0.7800
306:Lu-177m : 0.2200
307:Lu-178 : 1.0000
308:Lu-178m : 1.0000
309:Hf-175 : 1.0000
310:Hf-177m : 1.0000
311:Hf-177g : 1.0000
312:Hf-178m : 1.0000
313:Hf-179m : 1.0000
314:Hf-179g : 1.0000
315:Hf-181 : 1.0000
316:Hf-182 : 1.0000
317:Hf-183 : 1.0000
318:Ta-179 : 1.0000
319:Ta-180m : 1.0000
320:Ta-182 : 1.0000
321:Ta-182m : 1.0000
322:Ta-183 : 1.0000
323:Ta-184 : 1.0000
324:Ta-185 : 1.0000
325:Ta-186 : 1.0000
326: W-179 : 1.0000
327: W-179m : 0.9969
328: W-179m : 0.0031
329: W-181 : 1.0000
330: W-185 : 1.0000
331: W-187 : 1.0000
332: W-188 : 1.0000
333:Re-184 : 1.0000
334:Re-184m : 0.7470
335:Re-184m : 0.2530
336:Re-186 : 1.0000
337:Re-186m : 1.0000
338:Re-187 : 1.0000
339:Re-188 : 1.0000
340:Re-188m : 1.0000
341:Re-189 : 0.8950
342:Re-189 : 0.1050
343:Os-189m : 1.0000
344:Os-191 : 1.0000
345:Os-194 : 1.0000
346:Ir-190 : 1.0000
347:Ir-190m : 1.0000
348:Ir-192 : 1.0000
349:Ir-192m : 1.0000
350:Ir-194 : 1.0000
351:Ir-194m : 1.0000
352:Pt-190 : 1.0000
353:Pt-193 : 1.0000
354:Pt-193m : 1.0000
355:Pt-197 : 1.0000
356:Pt-197m : 0.9670
357:Pt-197m : 0.0330

358:Au-194 : 1.0000
359:Au-196 : 0.9250
360:Au-196 : 0.0750
361:Au-197m : 1.0000
362:Au-198 : 1.0000
363:Au-198m : 1.0000
364:Hg-194 : 1.0000
365:Hg-197 : 1.0000
366:Hg-197m : 0.9300
367:Hg-197m : 0.0700
368:Hg-199m : 1.0000
369:Hg-203 : 1.0000
370:Hg-205 : 1.0000
371:Tl-202 : 1.0000
372:Tl-204 : 1.0000
373:Tl-206 : 1.0000
374:Tl-206m : 1.0000
375:Pb-202 : 1.0000
376:Pb-203 : 1.0000
377:Pb-205 : 1.0000
378:Pb-209 : 1.0000
379:Pb-210 : 1.0000
380:Bi-207 : 1.0000
381:Bi-208 : 1.0000
382:Bi-210 : 1.0000
383:Bi-210m : 1.0000
384:Po-209 : 1.0000
385:Po-210 : 1.0000
386:Rn-222 : 1.0000
387:Ra-223 : 1.0000
388:Ra-224 : 1.0000
389:Ra-225 : 1.0000
390:Ra-226 : 1.0000
391:Ra-228 : 1.0000
392:Ac-225 : 1.0000
393:Ac-227 : 1.0000
394:Ac-228 : 1.0000
395:Th-227 : 1.0000
396:Th-228 : 1.0000
397:Th-229 : 1.0000
398:Th-230 : 1.0000
399:Th-231 : 1.0000
400:Th-232 : 1.0000
401:Th-233 : 1.0000
402:Th-234 : 1.0000
403:Pa-231 : 1.0000
404:Pa-232 : 1.0000
405:Pa-233 : 1.0000
406:U-232 : 1.0000
407:U-233 : 1.0000
408:U-234 : 1.0000
409:U-235 : 1.0000
410:U-235m : 1.0000
411:U-236 : 1.0000
412:U-238 : 1.0000
413:U-239 : 1.0000
414:U-240 : 1.0000
415:Np-236 : 0.0890
416:Np-236 : 0.9110
417:Np-237 : 1.0000
418:Np-239 : 1.0000
419:Pu-236 : 1.0000
420:Pu-238 : 1.0000
421:Pu-239 : 1.0000
422:Pu-240 : 1.0000
423:Pu-241 : 1.0000
424:Pu-242 : 1.0000
425:Pu-244 : 1.0000
426:Am-241 : 1.0000
427:Am-242 : 0.1730
428:Am-242 : 0.8270
429:Am-242m : 0.1730
430:Am-242m : 0.8270
431:Am-243 : 1.0000
432:Cm-242 : 1.0000
433:Cm-243 : 1.0000
434:Cm-244 : 1.0000
435:Cm-245 : 1.0000
436:Cm-246 : 1.0000
437:Cm-248 : 1.0000

APPENDIX C

IDCF CODE MODIFICATIONS INCORPORATED INTO IDCF2

C.1 Implementation of Portable Random Number Generator

The purpose of using random numbers in IDCF is to make some slight random change to the value of a decay constant when a "redundant" value is found in the same array. This is discussed in articles by Skrable et al. (1974) and Birchall (1986). If any such pairs are allowed to remain equal, their difference is zero and a divide by zero error occurs in the calculations. The original IDCF code made a change of as much as one-half of 1 percent to decay constant values to avoid this error.

In addition, it was noted that the Lahey FORTRAN function that was used, RRAND(), relies on the system clock and produces different values for each run of the program. This creates non-reproducible results for some nuclides that exhibit these redundancies. This was demonstrated by producing three output files from the PC version of IDCF and making a full comparison. Indeed, some relative differences of one-half percent were seen in the resulting values for dose conversion factors, although no large discrepancies were produced.

To minimize the numerical error discussed above, the change in value applied to a redundant decay constant in IDCF2 was constrained to be in the range from one-tenth to two-tenths of 1 percent, and could be plus or minus. Therefore, a change of zero is strictly avoided. However, in making such a change to one member of an array, it is possible to make that member equal to some other member of the array. That likelihood is judged to be small given that there are at most six elements in the arrays when this change is effected. Further, the entire nuclide set has been run at Sandia National Laboratories without creating any such "secondary" redundancies; therefore, they could occur only if the radiological or biological decay constant data is changed.

In order to achieve reproducibility of results, any run of IDCF2 must utilize the same set of random numbers based on a random number seed. The machine-independent random number generator for MACCS was used to produce this result. Further, for IDCF2, given that separate runs may be performed for different sets of nuclides, it was necessary to determine a nuclide-dependent random number seed. This change was implemented by setting the random number seed equal to the atomic number of the nuclide. Several runs of IDCF2 with different selected nuclide sets were done to verify this reproducibility of results.

Random number generators provided in a library of FORTRAN functions generally are machine-dependent routines. Even when using the same function name, different systems often use different coding and may generate different random number sequences. The random number function used in the PC version of IDCF was RRAND(), which referenced the system clock at each occurrence of the statement. The MACCS/MACCS2 machine-independent random number routine was used in IDCF2 so that random number sequences would be the same, even on different systems or run at different times of day, making all results directly comparable.

C.2 Correction of "Negative Dose" Problem

During the modification of IDCF to IDCFMAX, it was found that the nuclide ^{241}Pu displayed some calculational sensitivity when run on the VAX/VMS system; that is, a negative dose conversion factor was calculated for the liver for a commitment period of 2 days. Further investigation led to an examination of FUNCTION EXPINT. This function uses two different statements to evaluate the integral of an exponential function. These statements represent two different formulae for the calculation of the required exponential function. The choice made depends on the value of the exponent. A value of 0.0001 was used as the criterion for choosing between the formulae in IDCF. However, Birchall (1986) recommends 0.01 for the same purpose. Setting the criterion to 0.01 in IDCF2 caused the VAX/VMS system to calculate the same value as the original IDCF code rather than the obviously erroneous negative result. Further experimentation showed that simply using double precision arithmetic, without using the new criterion of 0.01, produced a comparable result. In order to maximize the portability of the code, IDCF2 performs this calculation in double precision as well as using the 0.01 criterion recommended by Birchall.

C.3 Change From Cumulative to Incremental Dose

The IDCF code calculates each DCF independently of all others as the time-integrated dose commitment from zero to an end-point time. This calculation is carried out for each component of the model in subroutine CHAIN. The components are summed and converted in subroutine U_CALC and the main routine. The IDCF2 DCFs are therefore cumulative.

MACCS, however, requires dose conversion factors on an incremental basis, that is, for time periods which begin and end at user-defined times in the model's simulation. Because the calculations have shown some sensitivity to numerical error for the short commitment periods, dose commitments are set to zero if the results are negative.

C.4 Elimination of FORTRAN BACKSPACE Statement

DECAYLIB.DAT is the file generated by Steve Fetter of Idaho National Engineering and Environmental Laboratory for 396 radionuclides. One modification was made to it for IDCF2 to achieve faster run times under VAX/VMS. A blank line preceding the first nuclide, H-3, was removed. This allowed the deletion of a BACKSPACE statement in IDCF2 so that the file would always be read forward.

IDCF2 therefore rapidly reads through the data for the nuclides that are not selected, even those near the end of the file. (For sequential access, variable record length files VAX/VMS simulates a BACKSPACE by resetting the pointer to the top of the file and skipping through all previous records minus one.)

C.5 Implementation of MACCS2 Date/Time/Abort Routines

Machine-dependent routines for date, time, CPU clock, and abort were developed for MACCS for VAX/VMS systems, MS-DOS systems, and three UNIX systems, Sun Sparc, IBM S/6000, and Cray UNICOS. These routines, which are unchanged in MACCS2, are also utilized in IDCF2.

C.6 Built-In Dose Commitment Periods Matching DOSFAC2

In the predecessor code IDCFMAX, the user had the capability of modifying the dose commitment periods used for the calculations. This flexibility is not preserved in IDCF2. The dose commitment periods used for the IDCF2 calculations match the eighteen commitment periods used in DOSFAC2, as follows:

> 0-1 days, 1-2 days, 2-7 days, 7-10 days, 10-14 days, 14-18 days, 18-21 days, 21-28 days, 28-30 days, 30-50 days, 50-60 days, 60-200 days, 200-365 days, 1-10 years, 10-20 years, 20-30 years, 30-40 years, and 40-50 years.

C.7 Selection of IDCF2 Nuclide Set

The IDCF code, when run, produces output for all 396 nuclides in the data library for 9 specific commitment periods. The major change to this code in creating IDCF2 allows the user to specify a subset of nuclides for which dose commitment calculations are desired, along with the commitment periods for those calculations. These selections are provided to IDCF2 in the form of the User Input files used by MACCS and MACCS2. This file is denoted as the .INP file.

C.8 Incorporation of DOE/EH-0070 Dose-Rate Factors

In addition to implementing the metabolic models necessary to calculate inhalation and ingestion dose commitments, the original software package developed by Fetter (1988;1991) also included a series of routines to perform the shielding calculations necessary to obtain external dose-rate factors. The FORTRAN code used by Fetter to calculate external dose-rate factors, however, was never utilized as part of the MACCS2 development effort. IDCF2, and its limited-distribution predecessor IDCMAX, utilize the external dose-rate factors of DOE/EH-0070.

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