USE OF MACCS DOSE COEFFICIENT FILES TO COMPUTE TOTAL EFFECTIVE DOSE EQUIVALENT

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1 INTRODUCTION

By Informal Assistance Request (IAR) NRR-2021-018, "Verification of MACCS Dose Conversion to Compute Total Effective Dose Equivalent," dated June 14, 2021 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML21180A015), the Office of Nuclear Reactor Regulation (NRR) requested that the Office of Nuclear Regulatory Research (RES) undertake research to identify currently available MELCOR Accident Consequence Code System (MACCS) dose coefficient (DCF) files[1] providing dose coefficients that may be used to compute total effective dose equivalent (TEDE) and to verify the values for the dose coefficients in these files against Federal Guidance Reports (FGR) 11 (*Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*) [1] and 12 (*External Exposure to Radionuclides*) [2]. In particular, Task 1 of NRR-2021-018-IAR requested RES to document their assessment findings by 1) identifying which DCF files are most consistent with FGRs 11 and 12, 2) identifying any discrepancies between these DCF files and the values provided in FGRs 11 and 12, and 3) providing recommendations for the use of those files, including:

- consideration of how these files may be used to estimate acute doses for quantifying early health effects,
- how these files may be used to estimate chronic doses for quantifying latent health effects, and
- a description of how short-lived decay progeny are accounted for in the dose coefficients.

In addition, RES was tasked to provide a brief description of how the dose coefficient values in the DCF files may be used to evaluate the potential for deterministic fatal health effects using MACCS.

2 BACKGROUND

Regulations issued by the Nuclear Regulatory Commission are found in Chapter I of Title 10 the *Code of Federal Regulations* (10 CFR). Chapter I is divided into Parts 1 through 199, which contain regulatory requirements that are legally binding for all individuals and entities that possess, use, or store nuclear materials or operate nuclear facilities under the NRC's jurisdiction. Of these, the regulations that are most relevant to radiation protection are contained in 10 CFR Part 20 (*Standards for Protection Against Radiation)* and 10 CFR Part 50 (*Domestic Licensing of Production and Utilization Facilities)*. Additional regulatory requirements, specific to particular uses or classes of facilities, are found in other portions of the regulations. Both 10 CFR Part 50 and 10 CFR Part 20 refer to various dose-based criteria and limits based on dosimetry methodologies defined by the International Commission on Radiological Protection (ICRP) in Publication 26 (*Recommendations of the ICRP*) [3] published

[1] This report uses the more modern terminology "dose coefficient" rather than the older term "dose conversion factor" (DCF). However, since the MACCS documentation typically uses the older term, this report will refer to specific numerical values as dose coefficients but will retain the terminology of "DCF file" when referring to the files containing compilations of dose coefficients.

in 1977, and Publication 30 (*Limits for Intakes of Radionuclides by Workers*) [4] published in 1979. The ICRP 26 tissue weighing factors are directly codified by §20.1003 (*Definitions*), within the table labeled *Organ Dose Weighting Factors*.

The TEDE is defined in 10 CFR 20.1003 as the sum of the effective dose equivalent (EDE) for external exposures and the committed effective dose equivalent (CEDE) for internal exposures. Acceptable practices for computing design-basis accident radiological consequences in terms of TEDE are to apply the exposure-to-committed effective dose equivalent factors for inhalation of radioactive material found in Table 2.1 of FGR-11. The factors in the column headed "effective" yield doses corresponding to the committed effective dose equivalent. These tables are derived from the data provided in ICRP Publication 30 and have been found acceptable to the NRC staff as they meet the regulatory requirements found in 10 CFR Part 50 and 10 CFR Part 20. Likewise, the exposure-to-effective dose equivalent factors for external exposure of radioactive material apply FGR-12. Therefore, by default, compliance with the dose-related regulations of 10 CFR Part 50 and 10 CFR Part 20 are demonstrated when applying the exposure-to-dose conversion factors of FGRs 11 and 12.

The MACCS code, developed to evaluate the consequences of severe accidents at nuclear power plants, relies on the use of a user-specified formatted American Standard Code for Information Interchange (ASCII) dose coefficient file to estimate dose from cloudshine, groundshine, inhalation, and ingestion. These files are known as DCF files, following the original MACCS terminology of "dose conversion factor file." Since 2008, MACCS has been bundled with a Windows-based interface and framework known as WinMACCS [5]. The format of a MACCS DCF file is described in Appendix A.2 of [6]. The MACCS computer code, as well as the WinMACCS framework, has been distributed with a variety of DCF files over the years. However, not all of these MACCS DCF files are based on FGRs 11 and 12. The original MACCS DCF file *dosdata.inp* was based on the analysis documented in NUREG/CR-4185 [7], which recommended the use of data from [8] for external exposures and ICRP Publication 30 [4] for internal exposures. More recently, commonly used MACCS DCF files have included DOSFAC2 DCF files, FGRDCF DCF files, and FGR13 DCF files. DOSFAC2 DCF files are generated by the DOSFAC2 program [9] and are based on dose coefficients from DOE/EH-0070 [10] (for external exposures) and DOSD87 (for internal exposures). FGRDCF DCF files are generated by the FGRDCF program [11], which 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)" [11]. The FGRDCF software package includes the DLC-167 data libraries [12] which include, in plaintext form, Tables 2.1 and 2.2 of FGR 11 and Tables III.1 through III.7 of FGR 12. As described in [6], "The FGRDCF preprocessor accesses inhalation and ingestion DCFs for over 600 radionuclides, and cloudshine and groundshine DCFs for 825 radionuclides (Radiation Shielding Information Center 1994)." The most recent DCF file distributed with (and recommended for use in) MACCS is an FGR13 DCF file (*FGR13GyEquiv_RevA.inp*, documented in [13]) and is based on the dosimetric calculations of FGR-13 [14]. Although both the DOSFAC2 and FGR13DCF DCF files contain information needed to calculate acute health effects, as does the original MACCS DCF file *dosdata.inp*, FGRDCF DCF file do not. As stated in [6], "The FGRDCF DCFs, however, because they only

include 50-year dose commitments from inhalation, cannot be used to calculate acute health effect risks such as early fatality and prodromal vomiting. The calculation of those health effects requires a preprocessor that can generate dose commitments for incremental time periods as short as the days and weeks following inhalation intake".

There are four issues that arise when evaluating DCF files for use in MACCS: 1) the nuclides to be included in the DCF file; 2) the treatment of short-lived progeny; 3) the assumptions that are made regarding the selection of a chemical and physical form to be used for internal dosimetry; and 4) the exposure pathways that are needed for the analysis. These issues are discussed below.

There are hundreds of nuclides produced in a operating light water reactor (LWR). However, it is common to consider only a subset of these nuclides. Early versions of MACCS DCF files included consideration of only the 60 radionuclides identified as important in [15]. That analysis provided "… an indication of the relative importance to offsite consequences of each element in a reactor core, and to identify the elements that, if released in sufficient quantity, are of principal concern" [15]. This analysis resulted in a list (Table 1 of [15]) of 60 radionuclides that were considered to be important for offsite consequences for LWR accidents and that remains the basis for determining which nuclides are included in LWR consequence calculations. These 60 nuclides are included in the DOSFAC2 and FGRDCF files. More recent DCF files, such as the FGR13 DCF files, contain a much larger (825 radionuclides) database of dose coefficients.

With respect to the treatment of dose contributions from short lived progeny, early compilations of MACCS dose coefficients include the concept of "implicit progeny" (i.e., inclusion of dose contributions from short lived progeny together with the dose contributions of a parent nuclide). To save computational expense, early consequence analysis codes included the external dose coefficients of short-lived progeny (weighted by their branching fraction) together with the external dose coefficients of the parent radionuclides. The dose coefficients in the original MACCS *dosdata.inp* DCF file, as well as both DOSFAC2 and FGRDCF files, include the concept of "implicit progeny". The original list of the 60 radionuclides identified in [15] included dose contributions from 11 additional short-lived nuclides, listed in Table 2 of [15], that were included in the external dose factors of the parent nuclides listed in Table 1 of [15][1]. In the FGRDCF code used to generate FGRDCF files, a radionuclide is considered to be an implicit progeny if the following three conditions are met:

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

[1] Two of the implicit progeny listed in Table 2 of [15] (Rh-105m and Ba-136m) are not present in either the decay data provided in *INDEXR.DAT* or in the dosimetric databases of DLC-167. Conversely, two other short lived progeny (Te-131 and Xe-135m) are not listed in Table 2 of [15] but are present in the decay data provided in *INDEXR.DAT* as well as the dosimetric databases of DLC-167. Therefore, the current list of implicit progeny includes Te-131 and Xe-135m but does not include Rh-105m and Ba-136m.

However, as noted in FGR 12, "In applying the dose coefficients of Tables III.1 through III.7 it is important to note that the values for each radionuclide do not include any contribution to dose from radioactive decay products formed in the spontaneous nuclear transformation of the nuclide. Rather, the tabulations contain separate entries for all such progeny." [2, p. 183]). Comparison of the results in MACCS DCF files that include implicit progeny (e.g., DOSFAC2 and FGRDCF DCF files) to the values tabulated in FGR-12 therefore require adjustment to account for consideration of implicit progeny. However, FGR13DCF files do not include any contribution to dose from radioactive progeny.

MACCS DCF files have traditionally assigned an inhalation clearance class and ingestion uptake fraction based on the original dosimetric analysis in NUREG/CR-4185 [7]. For inhaled radionuclides, the clearance classes used in ICRP-30 are summarized in Table 2 of [7] and Table D.4 of [16]. It may be noted that Table 2 of [7] provides a recommended inhalation clearance class for all of the elements present in Table 2 of [15] with the exception of rhodium. Rhodium is assigned a clearance class of Y in the *dosdata20organs.inp* and *Dosd60.inp* DCF files, which yields the highest inhalation DCF value of all the potential clearance classes for Rh, and is also consistent with the recommendation for rhodium provided in Table D.4 of [16]. Reference [7] also recommends use of ingestion f1 values consistent with ICRP30. However, the recommended ingestion f1 values are not reproduced in reference [7]. In the analyses that follow, the authors have assumed that the assignment of f1 values used for ingestion are consistent with the f1 value listed in assignment of the clearance class provided in Table 2.1 of FGR-11.

The format of a MACCS DCF file is described in Appendix A.2 of [6]. A MACCS DCF file contains, for each radionuclide and organ specified in the DCF file, seven columns of dose coefficients. As described in [6], these dose coefficients include

- a cloudshine dose-rate coefficient [Sv/(Bq-s/m^3)],
- a groundshine dose coefficient for an 8-hour exposure,
- a groundshine dose coefficient for a 7-day exposure,
- a groundshine dose-rate coefficient [Sv/(Bq-s/m^2)],
- an "acute" short-term inhalation dose coefficient (Sv/Bq) used for calculation of deterministic health effects,
- a "lifetime" 50-year committed inhalation dose coefficient (Sv/Bq) used for calculation of individual and societal doses and stochastic health effects, and
- 50-year committed ingestion doses (Sv/Bq) used for calculation of individual and societal doses and stochastic health effects from food and water ingestion.

The 8-hour and 7-day groundshine dose coefficient columns are included for backwards compatibility with the original version of MACCS. These dose coefficients are no longer used, and their value is typically set to -1. Likewise, as described in [6], “If an organ is not considered in the deterministic health effects models, no internal dose for early exposure from inhalation is given, or needed; the values on the file are set to -1.” Finally, a DCF file typically contains, for each nuclide and exposure pathway, a dose coefficient for a selected list of individual organs as

well as a dose coefficient for one or more “pseudo-organs” representing, for example, an effective dose equivalent or an effective dose.

A companion issue to that of computing a TEDE using a MACCS DCF file is the question of which MACCS dose coefficients may be used evaluate the potential for fatal deterministic health effects. MACCS can evaluate the potential for early fatalities arising from hematopoetic syndrome, pulmonary syndrome, or gastrointestinal syndrome. MACCS estimates the risk of these health effects using dose coefficients that represent equivalent doses to specific organs rather than the tissue-weighted effective dose (or effective dose equivalent). Assessment of the risk of fatal deterministic health effects using an effective dose (or similarly, an effective dose equivalent) is problematic because the effective dose is a dosimetric quantity intended for use in evaluating protection against stochastic effects such as cancer [17]. As stated in [18], “By ICRP convention, doses resulting in tissue reactions (deterministic effects) should be quoted in Gy or relative biological effectiveness (RBE)-weighted dose RBE-D (Gy), rather than Sv which is reserved for clearly stochastic effects.” Also, effective doses may represent conditions of protracted internal exposures following intake rather than the acute exposures that are typically associated with fatal early health effects. This is described in [17] which states that “effective dose is calculated as the sum of external dose received in the year and committed dose from internal exposures during the year, where committed dose is integrated over a 50-year period for adults and up to 70 years of age for children”. In contrast, fatal deterministic effects are typically dependent on dose rate as well as total dose, such that protraction of the dose over extended periods can result in a significant decrease (or even elimination) of the risk of deterministic effects. The effect of dose protraction is sufficiently important for early effects that MACCS uses an “effective acute dose” to account for dose protraction, as described in Section 6.1 of [16] and Section 3.3.7.1 of [5]. Although the external dose coefficients for cloudshine and groundshine are given in terms of instantaneous dose rate and therefore do not require a dose-rate correction[1], the MACCS internal dose coefficients for lifetime inhalation and ingestion represent a committed dose accumulated over a period of up to 50 years following exposure. Therefore, the ”effective acute dose” coefficients for inhalation, which account for the shorter dose commitment period suitable for determination of deterministic health effects and are

[1] It should be noted that Reference [16] states that:

> When calculating early health effects, all external dose (D_{ext}) delivered during the emergency phase of the accident is treated as though it had been delivered during the first day of the emergency phase (by definition the emergency phase commences upon plume arrival and lasts at least one and no more than seven days); and all materials in the plume or resuspended from the ground, that are inhaled during the emergency phase, are treated as though they were inhaled at the time of plume arrival. Thus, when Equation (6.6) is used to calculate the early health effect risks that are caused by external exposures (cloudshine and short-term groundshine exposures), only one term is used and the D_{50} value used with that term is chosen to be appropriate for intense exposures delivered over a 24-hour period. [16]

More recent versions of MACCS allow an early phase of up to 40 days duration. The assumption that the external dose delivered over up to 40 days may be treated, for purposes of estimating early health effects, as an intense exposure delivered over a 24-hour period may be somewhat conservative if the external dose is delivered in a highly protracted fashion. However, as noted in [5], “The error introduced by attributing the entire direct exposure dose to the first day is usually small and is in the direction of overestimating the hazard function and resulting value of risk of an early fatality. In most cases, emergency plans should ensure that no individuals are permitted to remain in a contaminated area for much longer than one day when dose levels are high enough to pose a risk of early health effects.”

labeled as “INHALED ACUTE” in the DCF file, are used to estimate early health effects. In WinMACCS 3.11 and above, these dosimetric quantities may be used by selecting the dosimetric quantities prefixed with “A-“ in the WinMACCS interface. This will ensure that the “effective acute dose” is used for the inhalation pathway. In contrast, dosimetric quantities prefixed with “L-“ in the WinMACCS interface will use the lifetime inhalation dose coefficient representing a 50-year commitment period, and are therefore unsuitable for use is evaluating the potential for early fatal health effects.

Available information (see, for example, Table F-1 of [19]) suggests that mortality is not expected at total whole body absorbed doses from external radiation or internal absorption less than 100 rad, are minimal at less than 200 rad, and are low (with aggressive therapy) at doses of 200-600 rad. This is consistent with the value of 200 rem used in [20] as a reference level for significant early health effects, which states that “200 rem whole body is the dose at which significant early injuries start to occur”. Although information is available on fatal deterministic effects as a function of the total whole body absorbed dose, MACCS DCF files do not contain a dosimetric quantity representing the whole body absorbed dose because MACCS calculates early health effects using equivalent doses to specified organs. However, for this analysis, the authors consider that A-RED MARR is a reasonable surrogate for the whole body absorbed dose for scenarios in which the majority of the exposure is associated with external irradiation of the whole body[1]. The current recommendations for early fatality threshold values recommended for use in MACCS in [21] based on based on expert elicitation data from [22] , are summarized in Table 1. The 5th to 95th percentile range is provided in parentheses below the central (median value) estimate value.

TABLE 1: Early fatality health effect dose-response parameters

Health Effect	MACCS Target Organ (ORGNAM)	$D_{Threshold}$, Gy-Eq (EFFTHR)	D_{50}, Gy-Eq (EFFACA)	Shape Factor (EFFACB)
Hematopoietic Syndrome	A-RED MARR	2.3 (1.1–5.3)	5.6 (3.3–10)	6.1 (2.8–14)
Pulmonary Syndrome	A-LUNGS	14 (8.6–24)	24 (17–45)	9.6 (4.4–19)
Gastrointestinal Syndrome	A-STOMACH	6.5 (3.8–9.5)	12 (7.9–19)	9.3 (3.4–18)

Source: [21], based on expert elicitation data from [22]

If the majority of the exposure is associated with external irradiation of the whole body, Table 1 suggests that the limiting fatal health effect would be related to exposure to the red bone marrow. This is consistent with [23], which states that “The MACCS code does not have an organ defined as "whole body" so red marrow was used as a substitute. In CRAC2 calculations

[1] It should be noted that in cases where the exposure is predominantly associated with internal exposures rather than external irradiation of the whole body, the A-LUNG dosimetric quantity may be more limiting. As stated in [24, p. II.15], “For some nuclear accident scenarios, internal dose to critical organs other than the bone marrow can also lead to loss of life from early effects. The internal irradiation is due to inhaled and ingested radionuclides. A large internal radiation dose to the lung can cause lethal radiation pneumonitis”

it was found that the red marrow dose was about 30% higher than the whole body dose. Also, early health effects are sensitive to the red marrow dose. Thus, the red marrow dose is a good substitute." The use of the A-RED MARR dosimetric quantity as a surrogate for the onset of early fatality from whole body exposure is also consistent with the statement in [24] that "the median lethal dose for total-body irradiation is in the dose range that causes death by depression of blood cell formation." Based on the discussion above, the authors consider that the use of the MACCS A-RED MARR dosimetric quantity provides a reasonable indicator of the risk of early fatality for cases where external irradiation of the whole body is the dominant exposure pathway.

3 ASSUMPTIONS

The analysis in this report relies on the following assumptions:

- The data files provided with the FGRDCF software (listed in Table 4 below) are assumed to be an accurate reflection of the published dose coefficients in FGRs 11 and 12.

- The f1 values used to estimate the ingestion dose coefficients from Table 2.2 of FGR-11 are assumed to be consistent with the f1 value that corresponds to the recommended clearance class, as provided in Table 2.1 of FGR-11.

4 METHODOLOGY

The methodology is as follows:

1) Identify sources for dose coefficients that are consistent with definitions provided in 10 CFR Part 20;

2) Identify DCF files that are commonly supplied with MACCS or its preprocessor codes; and

3) Verify the consistency of the effective dose coefficients of the files identified in step 2 with the sources identified in Step 1 by computing the ratio between the dose coefficient values identified in Step 1 and the dose coefficient values identified in Step 2.

Each of these steps will be discussed in sequence.

4.1 Identify sources for dose coefficients

In order to compute a TEDE value, the dose coefficients from the MACCS DCF files listed in Table 1 should be consistent with those dose coefficients reported in FGRs 11 and 12. A detailed mapping of the DCF file value and the recommended source is shown in Table 2.

TABLE 2: Sources for TEDE Dose Coefficients consistent with FGR-11 and FGR-12

MACCS Dose Coefficient	Source
CLOUDSHINE	FGR 12 Table III.1, column headed "Effective"
GROUND SHINE 8HR	not needed when using MACCS2 and above
GROUND SHINE 7DAY	not needed when using MACCS2 and above
GROUND SHINE RATE	FGR 12 Table III.3, column headed "Effective"
INHALED ACUTE	not needed for computation of TEDE
INHALED CHRONIC	FGR 11 Table 2.1, column headed "Effective"
INGESTION	FGR 11 Table 2.2, column headed "Effective"

The DLC-167 data files included in [12], as supplied with FGRDCF, provide dose coefficients that are consistent with FGRs 11 and 12.

4.2 Identify DCF files to be reviewed

As shown in Table 3, there are seven available DCF files supplied with MACCS2, WinMACCS 3.11, WinMACCS 4.0, and their supporting preprocessor codes.

TABLE 3: Currently available MACCS DCF files

Filename	Type	Effective dose equivalent pseudo-organ	Supplied with:
DOSDATA.INP dated 25-JUN-92	-	EDEWBODY	MACCS2 1.13.1
DOSDATA.INP dated 11/19/2013	DOSFAC2	EDEWBODY	DOSFAC2
dosdata20organs.inp dated 03/27/97.	DOSFAC2	EDEWBODY	WinMACCS 3.11, WinMACCS 4.0
Dosd60.inp dated 11/19/2013[1]	FGRDCF	EFFECTIVE	FGRDCF, MACCS2 1.13.1
Dosd825.inp dated 01/12/2004	FGRDCF	EFFECTIVE	FGRDCF, MACCS2 1.13.1, WinMACCS 3.11
FGR13DCF.INP dated 7/13/2007	FGR13DCF	not available. The effective dose pseudo-organ is provided by "ICRP60ED"	WinMACCS 3.11, WinMACCS 4.0
FGR13GyEquiv_RevA.inp dated 5/23/2018	FGR13DCF	not available. The effective dose pseudo-organ is provided by "ICRP60ED"	WinMACCS 4.0

The final five DCF files were examined in this analysis. The authors consider the *DOSDATA.INP* DCF files provided with MACCS2 and DOSFAC2 to be superseded by the *dosdata20organs.inp* file because they have not been included with recent WinMACCS

[1] The *Dosd60.inp* file supplied with FGRDCF is dated 11/19/2013, whereas the *DOSD60.INP* file supplied with MACCS2 is dated 01/12/2004. Comparison of the text of the two files shows that the only difference is in the run date; all other text, including the dose coefficients, are identical.

distributions, whereas the *dosdata20organs.inp* is still distributed with WinMACCS. The *DOSDATA.INP* files were therefore not analyzed. The FGRDCF files, although not currently distributed with WinMACCS, were included because they were been produced for the express purpose of creating a MACCS file consistent with FGRs 11 and 12, at least one such file (*Dosd825.inp*) was distributed with WinMACCS code versions as recently as version 3.11, and both files are currently available as part of the legacy MACCS2 1.13.1 software package.

4.3 Verification of dose coefficients

The verification was performed by computing the ratio of the dose coefficient in the applicable DCF file to the dose coefficient, corrected as necessary by including the contribution from implicit progeny, from the appropriate FGR database. The DLC-167 data files included in [12], as supplied with the FGRDCF preprocessor, were read to determine the appropriate dose coefficients from FGR 11 and 12. Where there was a choice of the inhalation clearance class or ingestion f1 value in the DLC-167 data files, the inhalation clearance class or ingestion f1 value identified in the DCF file was selected from the DLC-167 data files. Half-lifes, decay chains, and branching fractions were obtained from the file *INDEXR.DAT* supplied with FGRDCF.

TABLE 4: Files used for verification of MACCS DCF files

Filename	Source	MACCS DCF
FGR11T21.INH	FGR-11 Table 2.1: Exposure-to-Dose Conversion Factors for Inhalation	INHALED CHRONIC
FGR11T22.ING	FGR-11 Table 2.2: Exposure-to-Dose Conversion Factors for Ingestion	INGESTION
FGR12T31.SUB	FGR-12 Table III.1 Dose Coefficients for Air Submersion	CLOUDSHINE
FGR12T32.IMM	FGR-12 TABLE III.2 Dose Coefficients for Water Immersion	n/a
FGR12T33.SUR	FGR-12 TABLE III.3 Dose Coefficients for Exposure to Contaminated Ground Surface	GROUND SHINE RATE
FGR12T34.1CM	FGR-12 TABLE III.4 Dose Coefficients for Exposure to Soil Contaminated to a Depth of 1 cm	n/a
FGR12T35.5CM	FGR-12 TABLE III.5 Dose Coefficients for Exposure to Soil Contaminated to a Depth of 5 cm	n/a
FGR12T36.15C	FGR-12 TABLE III.6 Dose Coefficients for Exposure to Soil Contaminated to a Depth of 15 cm	n/a
FGR12T37.INF	TABLE III.7 Dose Coefficients for Exposure to Soil Contaminated to an Infinite Depth	n/a

The underlying structure of all the DCF files are consistent for all the DCF files under consideration. The first portion of the file defines the organs considered in the DCF file, followed by a section defining the isotopes considered in the file, and finally the DCF values for

each organ grouped by isotope. The clearance class, and fractional uptake if included, were defined with the list of isotopes included in the file, along with a note that indicates whether daughter isotope's DCF value was included with the parent. However, there are slight differences in the formatting of the DCF files presented in Table 3 regarding the naming of the organs and the labeling of the clearance classes and fractional uptake (f1) for inhalation and ingestion dose conversion factors. The pseudo-organ associated with the effective dose equivalent is labeled as *EFFECTIVE* in the DCF files *Dosd825.inp* and *Dosd60.inp* and is labeled *EDEWBODY* in *dosdata20organs.inp*. The files *FGR13DCF.inp* and *FGR13GyEquiv_RevA.inp* do not contain DCF values that reflect an effective dose equivalent pseudo-organ consistent with FGRs 11 and 12 but instead contain effective dose DCF values labeled as *ICRP60ED* that are consistent with FGR 13. Additionally, the files *Dosd825.inp*, *Dosd60.inp*, and *Dosdata20organs.inp* label the clearance classes consistently with the nomenclature of FGR11, using *D*, *W*, and *Y* identifiers, but the fractional uptake is not defined explicitly in the files. The FGR13DCF files *FGR13DCF.inp* and *FGR13GyEquiv_RevA.inp* label the clearance classes as *S*, *M*, and *F* and includes a fractional uptake value.

The analysis for the DCF files *Dosd825.inp*, *Dosd60.inp*, and *dosdata20organs.inp* were all performed in a similar way. The respective DCF files were opened, and the isotopes considered in the file were extracted, along with the clearance class and note indicating which implicit progeny DCF values were included with the parent's dose coefficient value. The remaining portion of the DCF file was parsed to extract the *Cloudshine*, *Groundshine Rate*, *Inhaled Chronic*, and *Ingestion* dose coefficient values for each isotope included in the file. The parsing resulted in a structured dataset defining the isotopes, clearance class, note, and desired dose coefficient values for the *EFFECTIVE* organ, or *EDEWBODY* for *dosdata20organs.inp*.

The effective dose equivalent coefficient values were then extracted from the files *FGR11T21.INH*, *FGR11T22.ING*, *FGR12T31.SUB*, and *FGR12T33.SUR*, listed in Table 3. The cloudshine (*FGR12T31.SUB*) and groundshine rate (*FGR12T33.SUR*) data files were parsed to create a structured dataset of the EFFECTIVE (*H sub E* column) dose coefficient values for all the isotopes included on the respective file, but the dataset was reduced to only consider the isotopes included in the DCF file under consideration (*Dosd825.inp*, *Dosd60.inp*, or *dosdata20organs.inp*). The files *FGR11T21.INH* and *FGR11T22.ING* were formatted differently. In these files, a single isotope could have multiple dose coefficient values depending on the clearance class and fractional uptake. If an isotope had multiple clearance classes, only the first row contained the isotope name and a blank was present in the isotope field for subsequent clearance classes. Therefore, as the *FGR11T21.INH* and *FGR11T22.ING* files were processed, if a blank was present in the column defining the isotope, the previously defined isotope was repeated. The EFFECTIVE dose coefficient value was taken from the *H sub E* column. As in the case for the *FGR12T31.SUB* and *FGR12T33.SUR* files, only isotopes considered in the dose coefficient file under consideration (*Dosd825.inp*, *Dosd60.inp*, and *dosdata20organs.inp*) were included. Screening was performing by joining the isotope with the clearance class identified in the DCF file. Therefore, dose coefficient values with clearance classes not included in the DCF file under consideration were excluded. The *FGR11T22.ING* file was slightly different in that isotopes with multiple fractional uptakes were repeated, but the

clearance class was not included in the file. The extracted *FGR11T22.ING* data was merged with the extracted *FGR11T21.INH* data by joining the isotope with the fractional uptake and merging the results into a single structured dataset. This yields a structured dataset of both the chronic inhalation and ingestion dose coefficient values for the isotopes and clearance classes defined in the MACCS DCF file. Finally, the structured dataset for the Inhalation and Ingestion dose coefficient values were merged with the structured dataset for the Cloudshine and Groundshine Rate to yield a single dataset defining all the EFFECTIVE dose coefficient values taken from FGR 11 and 12 for the isotopes for the DCF file under consideration.

Once structured datasets reflecting the EFFECTIVE dose coefficient values were created for both the files defining dose coefficient values used in MACCS and the dose coefficient values defined in FGR 11 and 12, a comparison could be made by taking the ratio of the values between the dose coefficients from the DCF file and the dose coefficients from the FGRs 11 and 12 datasets. Deviations from unity would indicate a difference between the dose coefficient files defined for use in MACCS and those defined in FGR 11 and 12. A ratio of less than 1 indicated that the value in the MACCS DCF file dose coefficient was less than the corresponding dose coefficient from FGR 11 or 12, whereas a value greater than 1 indicated that the dose coefficient in the MACCS DCF file was larger than the corresponding dose coefficient from FGR 11 or 12. A deviation from 1 could also indicate that the dose coefficient value defined in MACCS included dose coefficient values from a progeny, as indicated by the note included in the MACCS DCF file (as listed in Table 2). Therefore, if a note indicated the MACCS dose coefficient value included the dose coefficient value of a progeny radionuclide, the progeny dose coefficient values from the FGR 11 and 12 datasets are weighted by the branching ratio defined in the *INDEXR.DAT* file and added to the parent's dose coefficient value. The verification check could then be performed between DCF file defined for MACCS and those defined in FGR 11 and 12.

The analyses for the *FGR13DCF.inp* and *FGR13GyEquiv_RevA.inp* are similar to those described in the discussion above except that these files use clearance classes designated as *S*, *M*, and *F* rather than *D*, *W*, and *Y*, and a fractional uptake is provided. To ensure consistency with the analysis discussed above, the clearance class from *Dosd825.inp* was used to mask the *S*, *M*, and *F*. The fractional uptake was ignored. A check of the mapping was performed, and the mapping appeared correct for most of the isotopes. For those cases where there was not a match between the mapping, the clearance class did not appear to be present in the *Dosd825.inp file*. It should be noted that there was no discrepancy in the mapping of *F*, *M*, and *S* to *D*, *W*, and *Y* for the 71 isotopes identified in reference [15] and tabulated in the appendix. However, if a user wishes to include additional isotopes beyond those identified in reference [15] by using an FGR13DCF file, the user should note that there are instances where the fractional uptake (f1) do not appear to be consistent between the FGR13 MACCS files and those in FGR 11 and 12.

5 RESULTS

The results of the comparison are shown in Appendix A for each of the DCF files examined. The results for each type of file are discussed below.

The dose coefficient values from the DOSFAC2 DCF file *dosdata20organs.inp* were generally close, but not identical to the FGRs 11 and 12 dose coefficient values. For the *dosdata20organs.inp* file, the external dose factors were typically somewhat (<30%) less than the FGR-11 and FGR12 values, with 8 isotopes differing by more than 30% for cloudshine and 15 isotopes differing by more than 30% for groundshine from the FGR-12 values. The internal dose factors were generally similar (within a few percent) of the FGR-11 values. The dose coefficient values for isotopes of iodine and cesium were generally within 10% of the FGRs 11 and 12 values.

As expected, the FGRDCF files *Dosd60.INP* and *Dosd825.INP* largely demonstrated ratios of 1.00. However, the user should be aware of some issues associated with Kr-88, Zr-97, Sb-127, Sb-129, and Te-129m. The FGRDCF Kr-88 dose coefficient values do not include contributions from the short-lived Rb-88 decay progeny. As a result, the Kr-88 external dose coefficient values are approximately 75% of the FGR-12 values, if it assumed that Rb-88 should be included as an implicit progeny of Kr-88 in the DCF file. This could result in undercounting external doses from Kr-88 if Rb-88 is not explicitly included in the list of isotopes given by NUCNAM. Also, the cloudshine and groundshine dose coefficient values for Zr-97 are slightly (<5% difference) different between the *Dosd60.inp* and *Dosd825*.inp files despite having the same implicit progeny listed in the DCF file. The external dose coefficient values provided by *Dosd60.inp* appear to be consistent with FGR-12. Thirdly, the inhalation clearance class for Sb-127 and Sb-129 in the *Dosd825.inp* file is assigned as D whereas it is assigned in W in the *dosdata20organs.inp* and *Dosd60.inp* files. This is likely due to the fact that the chemical forms in *Dosd60.INP* and *Dosd825.INP* are not assumed to be identical; as described in [11], “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 effect of this is that the inhalation and ingestion dose coefficient values for Sb isotopes in the *Dosd825.inp* file is lower than those in the *Dosd60.inp* file (a ratio of about 0.4 for Sb-127 inhalation and a factor of about 0.94 for Sb-127 ingestion and for Sb-129 inhalation and ingestion). Finally, the FGRDCF dose coefficient values for Te-129m include contributions from Te-129. However, because Te-129 is already typically included explicitly for most LWR applications, this could result in overcounting (by a factor of about 2) the external dose contributions from Te-129m.

The dose coefficient values from the FGR13DCF files were not identical to the FGRs 11 and 12 dose coefficient values. It should be noted that for the 71 nuclides considered in this analysis, the effective dose coefficient values in the *FGR13DCF.inp* and *FGR13GyEquiv_RevA.inp* are identical and may be discussed together. Although many of the FGR13DCF dose coefficient values files are within 15% of the values in FGRs 11 and 12, a substantial number of the dose coefficient values are not. The dose coefficient values for iodine isotopes in the FGR13DCF

DCF files were within a few percent of the values in FGR-12, but the ingestion dose coefficient values were generally approximately 50% larger than the FGR-11 values. The inhalation dose coefficient values ranged from being within a few percent of the FGR-11 values (I-132, I-133, and I-135) to within approximately 25% (I-131 and I-135) of the FGR-11 values. Cesium isotopes (considering Ba-137m as the dominant external contributor associated with Cs-137) were within 10% of the dose coefficient values in FGR-12 and the ingestion dose coefficient values in FGR-11, but were between only 50%-60% of the inhalation dose coefficient values in FGR-11. It should also be noted that it is not clear whether the clearance classes and uptake fractions used to develop the FGR13DCF files are consistent with ICRP-30; for example, the clearance class assumed for Sb in the FGR13DCF files is F, whereas the clearance class recommended in Table 2 of [7] for Sb is W, which would correspond to M.

6 CONCLUSIONS

Of the DCF files listed in Table 2, the only set of dose coefficient files specifically designed to be fully consistent with FGRs 11 and 12 are the FGRDCF files. The currently recommended DCF file to use if dose coefficients fully consistent with FGR 11 and 12 are needed would be *Dosd60.inp* because it a) contains the dose coefficients for the 60 radionuclides identified by NUREG/CR-4467; b) contains an effective dose equivalent dose coefficient consistent with FGR-11 and FGR-12; and c) has chemical forms for inhalation that that are consistent with the recommendations of [7] and [16]. However, the user should be aware of certain caveats if the *Dosd60.inp* file is used. These include:

- The *Dosd60.inp* (and *Dosd825.inp*) DCF files include contributions from implicit progeny. The list of isotopes included in NUCNAM, as well as the pseudostable nuclide list, needs to be adjusted accordingly so that doses from short-lived implicit progeny are not double counted. This is particularly true of the *Dosd825.inp* DCF file, because although implicit progeny are included in the DCF file, their dose coefficients are also reflected in other nuclides that are also included in the DCF file. If used in a MACCS analysis, they should be listed as pseudostable to ensure that the decay chains are properly terminated.

- The *Dosd60.inp* dose coefficient values for Kr-88 do not include contributions from the short-lived Rb-88 decay progeny. As a result, the Kr-88 external dose coefficient values are approximately 75% of the FGR-12 values, if it assumed that Rb-88 should be included as an implicit progeny of Kr-88 in the *Dosd60.inp* DCF file.

- The *Dosd60.inp* dose coefficient values for Te-129m include contributions from Te-129. However, because Te-129 is typically included explicitly for most LWR applications, this can result in overcounting (by a factor of about 2) the external dose contributions from Te-129m

- As noted in [11] and previously discussed, FGRDCF DCF files do not contain dose coefficient values for the acute inhalation pathway necessary for estimation of acute health effects.

- Also as noted in [11], “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.” Alternately, the user could independently develop cancer fatality and cancer incidence risk values for organ-specific values that are consistent with the list of organs included in the FGRDCF files (GONADS, BREAST, LUNGS, RED MARR, BONE SUR, THYROID, and REMAINDER).

- A COMIDA file is not available for use with the *Dosd60.inp* DCF file. A *Dosd60.inp* based COMIDA file would need to be developed if the ingestion pathway were to be included. A COMIDA file consistent with Dosd825.inp is available in the WinMACCS 3.11 distribution.

It may also be possible to use the *Dosd825.inp* file supplied with WinMACCS 3.11 with the additional caveat that the inhalation and ingestion DCF values for Sb-127 and Sb-129 in the *Dosd825.inp* file use a faster clearance class (D vs W) with a correspondingly lower inhalation and ingestion dose coefficient.

Because of these limitations, it may be necessary to perform multiple MACCS runs if a computation of both TEDE and early or latent health effects are required and an FGRDCF DCF file is used. However, it should be noted that it may be possible to develop a modified FGR13DCF file that includes a pseudo-organ that represents an ICRP-30-based TEDE. Versions of WinMACCS starting with Version 3.11 and above allow the organ list to be read from the DCF file, which would make both an ICRP60ED and an ICRP30EDE pseudo-organ available for use in MACCS within the same execution. It should be noted that should such an effort be undertaken, it would also be recommended to verify that the chemical forms (i.e., clearance classes and uptake fractions) used in the updated file are consistent with ICRP-30.

The net impact of using a DCF file with dose coefficient values different than those described in FGRs 11 and 12 is difficult to generalize because the impact would be dependent on both the magnitude of the ratio for each radionuclide and the relative importance of each radionuclide to the dose. For that reason, no general recommendation is provided regarding how the computed effective dose equivalent may vary depending on which DCF file is used.

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APPENDIX

The tables below provide the ratio of the dose coefficient from the DCF file to the dose coefficient derived from FGRs 11 and 12. Only the 60 nuclides identified as important to dose in [15], together with their 11 short lived progeny, are included in the tables in this appendix. For the files *dosdata20organs.inp*, *Dosd60.inp*, and *Dosd825.inp*, the dose coefficients derived from FGRs 11 and 12 are supplemented with the dose coefficients from the implicit progeny noted in the notes column, weighted by the appropriate branching fraction from *INDEXR.DAT*. For the files *FGR13DCF.inp* and *FGR13GyEquivRevA.inp*, the dose coefficients derived from FGRs 11 and 12 are not supplemented by implicit progeny.

Several items should be noted:

- If the inhalation clearance class used in the DCF file is identified, it is listed in the “Notes” column.

- If the uptake (f1) fraction used in the DCF file is identified, it is listed in the “Notes” column.

- If implicit progeny are included in a dose coefficient value, the implicit progeny are noted in the “Notes” column.

- Several isotopes are present in FGR-12 but not in FGR-11. These include all Kr and Xe isotopes as well as Nb-97m, Rh-106, Ba-137m, and Pr-144m. As explained in [11], “FGR 11 does not include DCFs for noble gases. It also omits aerosols and non-noble gases with short half-lives.”

- Ru-106 has entries of 0 for external dose coefficients in FGR-12. The external dose coefficients for Ru-106 are therefore due only to the short-lived progeny Rh-106.

- In the file *dosdata20organs.inp*, Rb-88 is included as an implicit progeny of Kr-88; however, it is not included as implicit progeny in the FGRDCF DCF files.

- In the file *dosdata20organs.inp*, Te-129 is not included as an implicit progeny of Te-129m but is included as implicit progeny in the FGRDCF DCF files. The FGRDCF DCF files will therefore overcount the contributions from Te-129 if Te-129 is also included in the NUCNAM list.

- The cloudshine and groundshine dose coefficient values for Zr-97 are slightly different between the *Dosd60.inp* and *Dosd825.*inp files despite having identified the same implicit progeny as being included in the DCF file. The reason for this discrepancy is unclear. The dose coefficient values in *Dosd60.inp* are consistent with FGR-12.

- The inhalation clearance class for Sb-127 and Sb-129 in the *Dosd825.inp* file is assigned as D whereas it is assigned in W in the *dosdata20organs.inp* and *Dosd60.inp* files. The

dosdata20organs.inp and *Dosd60.inp* files also use an ingestion f1 value of 0.01. The effect of this is that the inhalation and ingestion dose coefficient values for Sb in the *Dosd825.inp* file are lower than those in the *Dosd60.inp* file (a factor of 0.4 for inhalation of Sb-127 and a factor of about 0.94 for ingestion of Sb-127 and for inhalation and ingestion of Sb-129)

- For isotopes beyond the 71 considered in this analysis, there are additional instances in the *Dosd825.inp* DCF file where it could be possible to either double count or neglect the contribution of some radionuclides. For example, the note for Ac-223 indicates that it includes Fr-219 and comparisons against the FGR 11 and 12 dose coefficient composite values indicates this is correct. But the note for Fr-219 indicates it includes the progeny dose coefficient value for At-215, where checks against the FGR11 and 12 composite dose coefficient value indicates this is correct. Therefore, if one were to include both Ac-223 and Fr-219, the impact of Fr-219 would be considered twice. If Fr-219 was neglected as an isotope in the analysis, there would be a small (approximately 5% discrepancy) by not incorporating the presence of Fr-219.

- There appear to be inconsistencies between the fractional uptake values between those defined in *FGR13DCF.inp* and *FGR13GyEquiv_RevA.inp* files and those in FGR 11 and FGR 12. However, with the exception of Sb isotopes noted above, these inconsistencies do not affect any of the 71 isotopes identified as important in reference [15].

Table A-1: Ratio of dose coefficients from *dosdata20organs.inp* dated 03/27/97 to those from Federal Guidance Reports 11 and 12

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CO-58	Y	0.91	0.89	1.05	1.01
CO-60	Y	0.88	0.82	1.01	1.02
KR-85		0.81	0.00	†	†
KR-85M		0.93	0.00	†	†
KR-87		0.93	0.00	†	†
KR-88	Includes Rb-88	0.94	0.00	†	†
RB-86	D	0.88	0.82	1.01	1.01
*RB-88	Isotope not present in DCF file	‡	‡	‡	‡
SR-89	D	0.08	0.05	1.02	1.00
SR-90	D	0.00	0.00	0.91	0.91
SR-91	D, Including Y-91m	0.89	0.86	1.02	1.00
*Y-91m	Isotope not present in DCF file	‡	‡	‡	‡
SR-92	D	0.87	0.82	1.02	1.00
Y-90	Y	0.00	0.00	1.00	1.00
Y-91	Y	0.61	0.49	0.99	1.00
Y-92	Y	0.86	0.82	1.01	1.00
Y-93	Y	0.86	0.80	1.00	1.00
ZR-95	W	0.90	0.88	1.01	1.01
ZR-97	W, Includes Nb-97m† and Nb-97	0.87	0.85	1.01	1.00
*NB-97m	Isotope not present in DCF file	‡	‡	‡	‡
*NB-97	Isotope not present in DCF file	‡	‡	‡	‡
NB-95	Y	0.91	0.89	1.05	1.01
MO-99	Y	0.94	0.93	1.00	1.00
TC-99M	W	0.96	1.03	1.03	1.00
RU-103	Y, Includes Rh-103m	0.92	0.92	1.03	1.00
*RH-103m	Isotope not present in DCF file	‡	‡	‡	‡
RU-105	Y	0.90	0.89	1.00	1.00
RU-106	Y, Includes Rh-106†	0.86	0.85	1.00	1.00
*RH-106	Isotope not present in DCF file	‡	‡	‡	‡
RH-105	Y	0.90	0.94	1.00	1.00
SB-127	W	0.87	0.86	1.00	1.00
SB-129	W	0.90	0.87	1.00	1.00
TE-127	W	0.86	0.84	1.00	1.00
TE-127M	W	0.90	0.50	1.00	1.00
TE-129	W	0.85	0.81	1.00	1.00
TE-129M	W	0.95	0.83	1.00	1.00
TE-131M	W, Includes Te-131	0.85	0.83	0.93	0.94
*TE-131	Isotope not present in DCF file	‡	‡	‡	‡
TE-132	W	0.91	0.92	0.87	0.84
I-131	D	0.90	0.92	1.00	1.00
I-132	D	0.90	0.88	1.00	1.00
I-133	D	0.89	0.88	1.00	1.00
I-134	D	0.90	0.87	1.00	1.00
I-135	D, Includes Xe-135m	0.89	0.84	1.00	0.99
*XE-135m	Isotope not present in DCF file	‡	‡	‡	‡
XE-133		0.96	0.00	†	†
XE-135		0.90	0.00	†	†
CS-134	D	0.90	0.88	1.00	1.00
CS-136	D	0.90	0.88	1.01	1.01

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CS-137	D, Includes Ba-137m	0.91	0.89	1.00	1.00
*BA-137m	Isotope not present in DCF file	‡	‡	‡	‡
BA-139	D	0.71	0.72	1.01	1.00
BA-140	D	0.94	0.94	1.01	0.99
LA-140	W	0.89	0.84	1.00	1.00
LA-141	W	0.79	0.71	1.01	1.00
LA-142	W	0.93	0.85	1.02	1.00
CE-141	Y	0.96	1.01	1.01	1.00
CE-143	Y	0.87	0.87	1.00	1.00
CE-144	Y, Includes Pr-144m† and Pr-144	0.28	0.32	1.00	1.00
*PR-144m	Isotope not present in DCF file	‡	‡	‡	‡
*PR-144	Isotope not present in DCF file	‡	‡	‡	‡
PR-143	Y	0.00	0.00	1.00	1.00
ND-147	Y	0.92	0.91	1.00	1.00
NP-239	W	0.93	1.00	1.00	1.00
PU-238	Y	0.77	0.88	1.00	1.00
PU-239	Y	0.82	0.88	1.00	1.00
PU-240	Y	0.78	0.87	1.00	1.00
PU-241	Y	0.00	0.00	1.00	1.00
AM-241	W	0.98	0.92	1.00	1.00
CM-242	W	0.74	0.84	1.00	1.00
CM-244	W	0.73	0.81	1.00	1.00

** Implicit progeny not explicitly included in DCF file*

† Dose coefficient values not available in FGR 11 databases

‡ Not present in MACCS DCF file

Table A-2: Ratio of dose coefficients from *Dosd60.inp* dated 11/19/2013 to those from Federal Guidance Reports 11 and 12

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CO-58	Y	1.00	1.00	1.00	1.00
CO-60	Y	1.00	1.00	1.00	1.00
KR-85		1.00	1.00	†	†
KR-85M		1.00	1.00	†	†
KR-87		1.00	1.00	†	†
KR-88	Does not include Rb-88	1.00‡	1.00‡	†	†
RB-86	D	1.00	1.00	1.00	1.00
*RB-88	Isotope not present in DCF file	§	§	§	§
SR-89	D	1.00	1.00	1.00	1.00
SR-90	D	1.00	1.00	1.00	1.00
SR-91	D, Includes Y-91m	1.00	1.00	1.00	1.00
*Y-91m	Isotope not present in DCF file	§	§	§	§
SR-92	D	1.00	1.00	1.00	1.00
Y-90	Y	1.00	1.00	1.00	1.00
Y-91	Y	1.00	1.00	1.00	1.00
Y-92	Y	1.00	1.00	1.00	1.00
Y-93	Y	1.00	1.00	1.00	1.00
ZR-95	W	1.00	1.00	1.00	1.00
ZR-97	W, Includes Nb-97m† and Nb-97	1.00	1.00	1.00	1.00
*NB-97m	Isotope not present in DCF file	§	§	§	§
*NB-97	Isotope not present in DCF file	§	§	§	§
NB-95	Y	1.00	1.00	1.00	1.00
MO-99	Y	1.00	1.00	1.00	1.00
TC-99M	W	1.00	1.00	1.00	1.00
RU-103	Y, Includes Rh-103m	1.00	1.00	1.00	1.00
*RH-103m	Isotope not present in DCF file	§	§	§	§
RU-105	Y	1.00	1.00	1.00	1.00
RU-106	Y, Includes Rh-106†	1.00	1.00	1.00	1.00
*RH-106	Isotope not present in DCF file	§	§	§	§
RH-105	Y	1.00	1.00	1.00	1.00
SB-127	W	1.00	1.00	1.00	1.00
SB-129	W	1.00	1.00	1.00	1.00
TE-127	W	1.00	1.00	1.00	1.00
TE-127M	W	1.00	1.00	1.00	1.00
TE-129¶	W	1.00	1.00	1.00	1.00
TE-129M	W, Includes Te-129	1.00|	1.00|	1.00	1.00
TE-131M	W, Includes Te-131	1.00	1.00	1.00	1.00
*TE-131	Isotope not present in DCF file	§	§	§	§
TE-132	W	1.00	1.00	1.00	1.00
I-131	D	1.00	1.00	1.00	1.00
I-132	D	1.00	1.00	1.00	1.00
I-133	D	1.00	1.00	1.00	1.00
I-134	DD, Including Xe-135m†	1.00	1.00	1.00	1.00
I-135	D, Includes Xe-135m	1.00	1.00	1.00	1.00
*XE-135m	Isotope not present in DCF file	§	§	§	§
XE-133		1.00	1.00	†	†
XE-135		1.00	1.00	†	†
CS-134	D	1.00	1.00	1.00	1.00
CS-136	D	1.00	1.00	1.00	1.00

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CS-137	D, Includes Ba-137m	1.00	1.00	1.00	1.00
*BA-137m	Isotope not present in DCF file	§	§	§	§
BA-139	D	1.00	1.00	1.00	1.00
BA-140	D	1.00	1.00	1.00	1.00
LA-140	W	1.00	1.00	1.00	1.00
LA-141	W	1.00	1.00	1.00	1.00
LA-142	W	1.00	1.00	1.00	1.00
CE-141	Y	1.00	1.00	1.00	1.00
CE-143	Y	1.00	1.00	1.00	1.00
CE-144	Y, Includes Pr-144m and Pr-144	1.00	1.00	1.00	1.00
*PR-144m	Isotope not present in DCF file	§	§	§	§
*PR-144	Isotope not present in DCF file	§	§	§	§
PR-143	Y	1.00	1.00	1.00	1.00
ND-147	Y	1.00	1.00	1.00	1.00
NP-239	W	1.00	1.00	1.00	1.00
PU-238	Y	1.00	1.00	1.00	1.00
PU-239	Y	1.00	1.00	1.00	1.00
PU-240	Y	1.00	1.00	1.00	1.00
PU-241	Y	1.00	1.00	1.00	1.00
AM-241	W	1.00	1.00	1.00	1.00
CM-242	W	1.00	1.00	1.00	1.00
CM-244	W	1.00	1.00	1.00	1.00

** Implicit progeny not explicitly included in DCF file*

† Dose coefficient values not available in FGR 11 databases

‡ Ratio is based on FGR-12 value without accounting for contributions from Rb-88. If Rb-88 contributions were included the ratio would be 0.75 for cloudshine and groundshine.

§ Not present in MACCS DCF file

| Ratio computed using FGR-12 values including contributions from Te-129. If the FGR-12 values were not were adjusted to account for contributions from Te-129 the ratio would be 2.15 for cloudshine and 2.03 for groundshine, respectively.

¶ Te-129 is included in the DCF file and is also included as an implicit progeny of Te-129m. This can result in double-counting of contributions from Te-129.

Table A-3: Ratio of Dose Coefficients from *Dosd825.INP* dated 01/12/2004 to those from Federal Guidance Reports 11 and 12

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CO-58	Y	1.00	1.00	1.00	1.00
CO-60	Y	1.00	1.00	1.00	1.00
KR-85		1.00	1.00	†	†
KR-85M		1.00	1.00	†	†
KR-87		1.00	1.00	†	†
KR-88	Does not include Rb-88	1.00‡	1.00‡	†	†
RB-86	D	1.00	1.00	1.00	1.00
*RB-88	D	1.00	1.00	1.00	1.00
SR-89	D	1.00	1.00	1.00	1.00
SR-90	D	1.00	1.00	1.00	1.00
SR-91	D, Includes Y-91m	1.00	1.00	1.00	1.00
*Y-91m	Y	1.00	1.00	1.00	1.00
SR-92	D	1.00	1.00	1.00	1.00
Y-90	Y	1.00	1.00	1.00	1.00
Y-91	Y	1.00	1.00	1.00	1.00
Y-92	Y	1.00	1.00	1.00	1.00
Y-93	Y	1.00	1.00	1.00	1.00
ZR-95	W	1.00	1.00	1.00	1.00
ZR-97	W, Includes Nb-97m† and Nb-97	0.96	0.96	1.00	1.00
*NB-97m		1.00	1.00	†	†
*NB-97	Y	1.00	1.00	1.00	1.00
NB-95	Y	1.00	1.00	1.00	1.00
MO-99	Y	1.00	1.00	1.00	1.00
TC-99M	W	1.00	1.00	1.00	1.00
RU-103	Y, Includes Rh-103m	1.00	1.00	1.00	1.00
*RH-103m	Y	1.00	1.00	1.00	1.00
RU-105	Y	1.00	1.00	1.00	1.00
RU-106	Y, Includes Rh-106	1.00	1.00	1.00	1.00
*RH-106		1.00	1.00	†	†
RH-105	Y	1.00	1.00	1.00	1.00
SB-127	D	1.00	1.00	1.00§	1.00§
SB-129	D	1.00	1.00	1.00§	1.00§
TE-127	W	1.00	1.00	1.00	1.00
TE-127M	W	1.00	1.00	1.00	1.00
*TE-129¶	W	1.00	1.00	1.00	1.00
TE-129M	W, Includes Te-129	1.00‖	1.00‖	1.00	1.00
TE-131M	W, Includes Te-131	1.00	1.00	1.00	1.00
*TE-131	W	1.00	1.00	1.00	1.00
TE-132	W	1.00	1.00	1.00	1.00
I-131	D	1.00	1.00	1.00	1.00
I-132	D	1.00	1.00	1.00	1.00
I-133	D	1.00	1.00	1.00	1.00
I-134	D	1.00	1.00	1.00	1.00
I-135	D, Includes Xe-135m	1.00	1.00	1.00	1.00
*XE-135m		1.00	1.00	†	†
XE-133		1.00	1.00	†	†
XE-135		1.00	1.00	†	†
CS-134	D	1.00	1.00	1.00	1.00
CS-136	D	1.00	1.00	1.00	1.00

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CS-137	D, Includes Ba-137m†	1.00	1.00	1.00	1.00
*BA-137m		1.00	1.00	†	†
BA-139	D	1.00	1.00	1.00	1.00
BA-140	D	1.00	1.00	1.00	1.00
LA-140	W	1.00	1.00	1.00	1.00
LA-141	W	1.00	1.00	1.00	1.00
LA-142	W	1.00	1.00	1.00	1.00
CE-141	Y	1.00	1.00	1.00	1.00
CE-143	Y	1.00	1.00	1.00	1.00
CE-144	Y, Includes Pr-144m† and Pr-144	1.00	1.00	1.00	1.00
*PR-144m		1.00	1.00	†	†
*PR-144	Y	1.00	1.00	1.00	1.00
PR-143	Y	1.00	1.00	1.00	1.00
ND-147	Y	1.00	1.00	1.00	1.00
NP-239	W	1.00	1.00	1.00	1.00
PU-238	Y	1.00	1.00	1.00	1.00
PU-239	Y	1.00	1.00	1.00	1.00
PU-240	Y	1.00	1.00	1.00	1.00
PU-241	Y	1.00	1.00	1.00	1.00
AM-241	W	1.00	1.00	1.00	1.00
CM-242	W	1.00	1.00	1.00	1.00
CM-244	W	1.00	1.00	1.00	1.00

** Decay progeny that is both explicitly included in DCF file and also included as an implicit progeny of another isotope present in the DCF file. The user should take care not to include these progeny in the nuclide list given by NUCNAM or else the dose contributions from this isotope may be double-counted.*

† Dose coefficient values not available in FGR 11 databases

‡ Ratio is based on FGR-12 value without accounting for contributions from Rb-88. If Rb-88 contributions were included the ratio would be 0.75 for cloudshine and groundshine..

§ Ratio computed based on using the FGR-11 clearance class = D and f1 = 0.1 values. If computed using the FGR-11 clearance class = W and f1 = 0.01 values, the ratios would be 0.40 for inhalation of Sb-127 and approximately 0.94 for ingestion of Sb-127 and inhalation and ingestion of Sb-129.

| Ratio computed using FGR-12 values including contributions from Te-129. If the FGR-12 values were not were adjusted to account for contributions from Te-129 the ratio would be 2.15 for cloudshine and 2.03 for groundshine, respectively.

¶ Te-129 is included in the DCF file and is also included as an implicit progeny of Te-129m. This can result in double-counting of contributions from Te-129.

Table A-4: Ratio of Dose Coefficients from *FGR13DCF.INP* dated 7/13/2007 to those from Federal Guidance Reports 11 and 12

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CO-58	Y, 0.01	0.93	0.97	0.72	0.93
CO-60	Y, 0.01	0.94	0.98	0.52	1.24
KR-85	1	2.02	3.98	†	†
KR-85M	1	0.92	1.03	†	†
KR-87	1	0.97	1.15	†	†
KR-88	1	0.95	0.99	†	†
RB-86	D, 1	1.03	1.79	0.52	1.12
*RB-88	D, 1	0.99	1.24	0.72	1.92
SR-89	D, 0.3	5.65	30.2	0.57	1.03
SR-90	D, 0.3	13.05	5.77	0.37	0.72
SR-91	D, 0.3	0.95	1.07	0.62	0.97
*Y-91m	Y, 0.0001	0.93	0.97	1.16	1.03
SR-92	D, 0.3	0.94	0.98	0.58	0.96
Y-90	Y, 0.0001	4.17	20.7	0.66	0.92
Y-91	Y, 0.0001	2.40	13.0	0.68	0.92
Y-92	Y, 0.0001	1.02	1.51	0.84	0.96
Y-93	Y, 0.0001	1.10	2.30	0.73	0.94
ZR-95	W, 0.002	0.94	0.97	1.12	0.94
ZR-97	W, 0.002	0.99	1.44	0.87	0.90
*NB-97m	1	0.93	0.97	†	†
*NB-97	Y, 0.01	0.94	1.04	2.02	1.09
NB-95	Y, 0.01	0.93	0.97	1.12	0.85
MO-99	Y, 0.01	0.96	1.21	0.93	0.45
TC-99M	W, 0.1	0.89	0.94	2.67	1.33
RU-103	Y, 0.01	0.93	0.97	1.22	0.89
*RH-103m	Y, 0.05	0.69	0.71	2.15	1.21
RU-105	Y, 0.01	0.94	1.02	1.46	0.93
RU-106	Y, 0.01	1.00‡	1.00‡	0.51	0.95
*RH-106	1	1.02	1.63	†	†
RH-105	Y, 0.05	0.94	0.97	1.37	0.92
SB-127	D, 0.1	0.94	1.00	0.66§	0.92§
SB-129	D, 0.1	0.94	0.99	0.64§	0.92§
TE-127	W, 0.1	1.38	1.99	1.47	0.90
TE-127M	W, 0.1	0.77	0.76	1.28	1.05
TE-129M	W, 0.1	1.01	1.51	1.01	1.03
*TE-129	W, 0.1	1.04	1.90	1.77	1.16
TE-131M	W, 0.1	0.94	0.98	0.62	0.80
*TE-131	W, 0.1	0.95	1.16	0.23	0.36
TE-132	W, 0.1	0.91	0.93	0.81	1.50
I-131	D, 1	0.93	0.97	0.83	1.52
I-132	D, 1	0.94	1.00	0.91	1.58
I-133	D, 1	0.94	1.03	0.93	1.53
I-134	D, 1	0.94	1.00	1.27	1.61
I-135	D, 1	0.94	1.00	0.97	1.54
*XE-135m	1	0.93	0.99	†	†
XE-133	1	0.86	0.86	†	†
XE-135	1	0.93	1.03	†	†
CS-134	D, 1	0.93	0.97	0.54	0.98
CS-136	D, 1	0.94	0.97	0.62	1.01

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CS-137	D, 1	12.0	10.5	0.54	1.01
*BA-137m	1	0.93	0.99	†	†
BA-139	D, 0.2	1.18	3.18	0.73	1.12
BA-140	D, 0.2	0.94	1.06	1.02	1.02
LA-140	W, 0.0005	0.95	1.00	0.82	0.89
LA-141	W, 0.0005	1.21	3.35	0.96	0.96
LA-142	W, 0.0005	0.95	1.01	1.63	1.02
CE-141	Y, 0.0005	0.91	0.94	1.55	0.91
CE-143	Y, 0.0005	0.94	1.08	0.91	0.91
CE-144	Y, 0.0005	0.90	0.91	0.52	0.92
*PR-144m	1	0.79	0.81	†	†
*PR-144	Y, 0.0005	1.36	4.31	1.56	1.61
PR-143	Y, 0.0005	9.24	29.4	1.12	0.92
ND-147	Y, 0.0005	0.93	1.01	1.30	0.91
NP-239	W, 0.0005	0.91	0.94	1.38	0.91
PU-238	Y, 0.00001	0.72	0.75	0.21	17.02
PU-239	Y, 0.00001	0.82	0.77	0.19	17.91
PU-240	Y, 0.00001	0.72	0.75	0.19	17.91
PU-241	Y, 0.00001	0.88	0.89	0.13	22.94
AM-241	W, 0.0005	0.83	0.85	0.35	0.21
CM-242	W, 0.0005	0.71	0.74	1.12	0.38
CM-244	W, 0.0005	0.69	0.73	0.40	0.23

** Decay progeny of another isotope present in the DCF file that are not implicitly included in DCF file. The user should take care to include these progeny in the nuclide list given by NUCNAM or else the dose contributions from this isotope may be under-counted.*

† Dose coefficient values not available in FGR 11 databases

‡ Value of 0 is present in FGR-12 databases

§ Ratio computed based on using the FGR-11 clearance class = D and f1 = 0.1 values rather than Dosd60.inp clearance class = W and f1 = 0.01 values.

Table A-5: Ratio of Dose Coefficients from *FGR13GyEquiv_RevA.inp* dated 5/23/2018 to those from Federal Guidance Reports 11 and 12

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CO-58	Y, 0.01	0.93	0.97	0.72	0.93
CO-60	Y, 0.01	0.94	0.98	0.52	1.24
KR-85	1	2.02	3.98	†	†
KR-85M	1	0.92	1.03	†	†
KR-87	1	0.97	1.15	†	†
KR-88	1	0.95	0.99	†	†
RB-86	D, 1	1.03	1.79	0.52	1.12
*RB-88	D, 1	0.99	1.24	0.72	1.92
SR-89	D, 0.3	5.65	30.2	0.57	1.03
SR-90	D, 0.3	13.1	5.77	0.37	0.72
SR-91	D, 0.3	0.95	1.07	0.62	0.97
*Y-91m	Y, 0.0001	0.93	0.97	1.16	1.03
SR-92	D, 0.3	0.94	0.98	0.58	0.96
Y-90	Y, 0.0001	4.17	20.7	0.66	0.92
Y-91	Y, 0.0001	2.40	13.0	0.68	0.92
Y-92	Y, 0.0001	1.02	1.51	0.84	0.96
Y-93	Y, 0.0001	1.10	2.30	0.73	0.94
ZR-95	W, 0.002	0.94	0.97	1.12	0.94
ZR-97	W, 0.002	0.99	1.44	0.87	0.90
*NB-97m	1	0.93	0.97	†	†
*NB-97	Y, 0.01	0.94	1.04	2.02	1.09
NB-95	Y, 0.01	0.93	0.97	1.12	0.85
MO-99	Y, 0.01	0.96	1.21	0.93	0.45
TC-99M	W, 0.1	0.89	0.94	2.67	1.33
RU-103	Y, 0.01	0.93	0.97	1.22	0.89
*RH-103m	Y, 0.05	0.69	0.71	2.15	1.21
RU-105	Y, 0.01	0.94	1.02	1.46	0.93
RU-106	Y, 0.01	1.00‡	1.00‡	0.51	0.95
*RH-106	1	1.02	1.63	†	†
RH-105	Y, 0.05	0.94	0.97	1.37	0.92
SB-127	D, 0.1	0.94	1.00	0.66§	0.92§
SB-129	D, 0.1	0.94	0.99	0.64§	0.92§
TE-127	W, 0.1	1.38	1.99	1.47	0.90
TE-127M	W, 0.1	0.77	0.76	1.28	1.05
TE-129M	W, 0.1	1.01	1.51	1.01	1.03
*TE-129	W, 0.1	1.04	1.90	1.77	1.16
TE-131M	W, 0.1	0.94	0.98	0.62	0.80
*TE-131	W, 0.1	0.95	1.16	0.23	0.36
TE-132	W, 0.1	0.91	0.93	0.81	1.50
I-131	D, 1	0.93	0.97	0.83	1.52
I-132	D, 1	0.94	1.00	0.91	1.58
I-133	D, 1	0.94	1.03	0.93	1.53
I-134	D, 1	0.94	1.00	1.27	1.61
I-135	D, 1	0.94	1.00	0.97	1.54
*XE-135m	1	0.93	0.99	†	†
XE-133	1	0.86	0.86	†	†
XE-135	1	0.93	1.03	†	†
CS-134	D, 1	0.93	0.97	0.54	0.98
CS-136	D, 1	0.94	0.97	0.62	1.01

Isotope	Note	Cloud	Ground	Inhalation	Ingestion
CS-137	D, 1	12.0	10.5	0.54	1.01
*BA-137m	1	0.93	0.99	†	†
BA-139	D, 0.2	1.18	3.18	0.73	1.12
BA-140	D, 0.2	0.94	1.06	1.02	1.02
LA-140	W, 0.0005	0.95	1.00	0.82	0.89
LA-141	W, 0.0005	1.21	3.35	0.96	0.96
LA-142	W, 0.0005	0.95	1.01	1.63	1.02
CE-141	Y, 0.0005	0.91	0.94	1.55	0.91
CE-143	Y, 0.0005	0.94	1.08	0.91	0.91
CE-144	Y, 0.0005	0.90	0.91	0.52	0.92
*PR-144m	1	0.79	0.81	†	†
*PR-144	Y, 0.0005	1.36	4.31	1.56	1.61
PR-143	Y, 0.0005	9.24	29.4	1.12	0.92
ND-147	Y, 0.0005	0.93	1.01	1.30	0.91
NP-239	W, 0.0005	0.91	0.94	1.38	0.91
PU-238	Y, 0.00001	0.72	0.75	0.21	17.02
PU-239	Y, 0.00001	0.82	0.77	0.19	17.91
PU-240	Y, 0.00001	0.72	0.75	0.19	17.91
PU-241	Y, 0.00001	0.88	0.89	0.13	22.94
AM-241	W, 0.0005	0.83	0.85	0.35	0.21
CM-242	W, 0.0005	0.71	0.74	1.12	0.38
CM-244	W, 0.0005	0.69	0.73	0.40	0.23

** Decay progeny of another isotope present in the DCF file that are not implicitly included in DCF file. The user should take care to include these progeny in the nuclide list given by NUCNAM or else the dose contributions from this isotope may be under-counted.*

† Dose coefficient values not available in FGR-11 databases

‡ Value of 0 is present in FGR-12 databases

§ Ratio computed based on using the FGR-11 clearance class = D and f1 = 0.1 values rather than Dosd60.inp clearance class = W and f1 = 0.01 values.