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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET

Complete Only Applicable Items

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Page: 1 of: 42

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD

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CONTENTS

TABLES

Page

ACRONYMS AND ABBREVIATIONS

ALI	Annual Limit on Intake
AMR	Analysis Model Report
BDCF	Biosphere Dose Conversion Factor
CPU	Central Processing Unit
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
DC	Dose Coefficient
DCF	Dose Conversion Factor
EPA	Environmental Protection Agency
FGR	Federal Guidance Report
FGR 11	Federal Guidance Report No. 11
FGR 12	Federal Guidance Report No. 12
ICRP	International Commission on Radiological Protection
ICRP-30	International Commission on Radiological Protection Publication 30
SDL	Stochastic Dose Limit
SUNS	Sensitivity and UNcertainty analysis Shell
TBV	To Be Verified
TSPA	Total System Performance Assessment

1. PURPOSE

Biosphere is one of the component process models supporting the Total System Performance Assessment (TSPA) used to predict the long-term behavior of the potential repository at Yucca Mountain. The biosphere model considers the movement of radionuclides in the environment, exposure of humans to these radionuclides, and the resulting doses. The dosimetric segment of the biosphere model allows assessment of doses following internal and external exposure to radionuclides present in environmental media, such as water, soil, air, and food. Internal exposure pathways under consideration include ingestion and inhalation of radionuclides; external exposure pathways include external irradiation from contaminated soil and air submersion.

A substantial part of the biosphere modeling for the TSPA is carried out by the computer code GENII-S (Leigh et al. 1993). GENII-S has been selected for its capabilities to support modeling of environmental transport and to perform multi-pathway dose calculations. GENII-S uses a comprehensive set of environmental pathway models and associated computer programs to estimate potential radiation doses to humans from radionuclides in the environment.

This analysis and model report (AMR) supports the biosphere component of TSPA by ensuring that doses calculated by dose assessment component of GENII-S are consistent with doses calculated using similar methods currently accepted by the scientific and engineering community in the field of radiation protection. For internal exposure, doses calculated by GENII-S were compared with doses calculated using published values of dose conversion factors (DCFs) and DCFs derived from published values of Annual Limits on Intake (ALI). For external exposure, GENII-S dose coefficients (DCs) were replaced with more recently published DC values. This report presents justification and documents decisions concerning dosimetric inputs.

This analysis was conducted within the applicable limits of the GENII-S code for the TSPA modeling, as described in the software qualification report (CRWMS M&O 1998). The conclusions in this report only apply to radionuclides listed in Section 6.1, rather than the full suite of radionuclides considered in GENII-S.

Activities described in this report were conducted in accordance with the *Development Plan for Dose Conversion Factor Analysis* (CRWMS M&O 1999a).

2. QUALITY ASSURANCE

This analysis has been determined to be Quality Affecting in accordance with CRWMS M&O procedure QAP-2-0, *Conduct of Activities,* because the information will be used to support Performance Assessment and other quality-affecting activities. Therefore, this analysis is subject to the requirements of the *Quality Assurance Requirements and Description* (DOE 1998a) document. This analysis is covered by the Activity Evaluation for *Scientific Investigation of Radiological Doses in the Biosphere* (CRWMS M&O 1999b).

Personnel performing work on this analysis were trained and qualified according to OCRWM procedures AP-2.1Q, *Indoctrination and Training of Personnel* and AP-2.2Q, *Establishment and Verification of Required Education and Experience of Personnel.* Preparation of this analysis did not require the classification of items in accordance with CRWMS M&O procedure QAP-2-3, *Classification of Permanent Items.* This analysis was not a field activity. Therefore, a determination of importance in accordance with CRWMS M&O procedure NLP-2-0, *Determination of Importance Evaluations,* was not required.

This report was written in accordance with OCRWM procedure AP-3.10Q, *Analyses and Models.*

3. COMPUTER SOFTWARE AND MODEL USAGE

As the part of the analysis, the computer code GENII-S V1.4.8.5 was used. GENII-S is a computer program used to calculate statistical and deterministic values of radiation doses to humans from exposure to radionuclides in the environment. GENII-S is qualified software (CRWMS M&O 1998) consisting of executable program and auxiliary files, all of which are maintained under Configuration Management (CSCI: 30034 V1.4.8.5). GENII-S was appropriate for this application and was used within the range of validation as described in the software qualification report (CRWMS M&O 1998) in accordance with AP-SI.1Q, *Software Management*.

Other software required to perform this work scope was industry standard software such as Microsoft Excel (spreadsheet) and WORD (word processing). No models or software routines and macros were developed for this analysis. Spreadsheet software only was used as an aid in calculations. Use of this software in this manner is exempt from the requirements in AP-SI.1Q. The analysis was performed using a Gateway 2000 Personal Computer, CPU# 111161.

4. INPUTS

Inputs to this analysis primarily consist of published sets of factors converting radionuclide intake to doses (for intake by inhalation and ingestion pathways), and published factors converting environmental concentrations of radionuclides to dose (for the external exposure pathway).

4.1 DATA AND PARAMETERS

In order to evaluate GENII-S conversion of radionuclide intakes to doses, output from the GENII-S code (numerically equivalent to DCFs) was compared to three published sources. The International Commission on Radiological Protection (ICRP) Publication 30 (ICRP 1979, 1980, and 1981), referred to as ICRP-30 in this report, and *Standards for Protection Against Radiation* (10 CFR 20) contain values for annual limits on intake (ALI) for radionuclides by inhalation and ingestion. The Federal Guidance Report No. 11 (EPA 1988), referred to in this report as FGR 11, includes DCFs for inhalation and ingestion (internal exposure). ALIs can be converted to DCFs, although with only one significant digit because ALIs were reported with only one significant digit.

For the external exposure pathway, dose coefficients used to convert environmental concentrations of radionuclides to dose also were used as input values for this analysis. The Federal Guidance Report No. 12 (EPA 1993), referred to in this report as FGR 12, includes dose coefficients for air submersion and exposure to contaminated soil, and these values were used to replace older GENII-S dose coefficients.

ICRP-30, 10 CFR 20, and FGR 11 and 12 represent international recommendations, federal regulations, and federal guidance, respectively, and are considered by the scientific community to be accepted standards for radiation protection.

The descriptions of inputs are presented in Table 1. Three of the inputs listed in Table 1 are unqualified, yet they do not require a TBV tracking number because of their use as corroborative evidence. These inputs do not satisfy the definition of TBV per AP-3.15Q, *Managing Technical Product Inputs*, because they are not preliminary, they do not need to be reevaluated, do not need confirmation, and do not affect critical characteristics of the product.

4.2 CRITERIA

None.

4.3 CODES AND STANDARDS

None.

Table 1. Description of Technical Input.

	Title	Source Identification	Q Status	Parameter Name/ Input Description
1	10 CFR 20. Energy: Standards for Protection Against Radiation.	Readily available	UQ[a]	Corroborative data: Annual Limits on Intake for inhalation and ingestion.
2	CRWMS M&O 1999c. Design Input Transmittal for Status of Radionuclide Screening for the TSPA-SR. Input Tracking Number: R&E-PA-99217.Ta.	ACC: MOL.19990719.0182	TBV-3059	List of primary radionuclides to be considered in analysis
3	EPA (Environmental Protection Agency) 1988. *Limiting Values Of Radionuclide Intake And Air Concentration and Dose Conversion Factors For Inhalation, Submersion, And Ingestion*. Federal Guidance Report No.11. EPA 520/1-88-020. Washington, District of Columbia.	ACC: MOL.19980520.0494 TIC: 203350	UQ[a]	Corroborative data: (1) Exposure-to-dose conversion factors for ingestion (2) Exposure-to-dose conversion factors for inhalation
4	EPA 1993. *External Exposure To Radionuclides In Air, Water, And Soil.* Federal Guidance Report No.12. EPA 402-R-93-081. Washington, District of Columbia.	ACC: MOL.19980520.0495 TIC: 225472	TBV	(1) Dose coefficients for exposure to soil contaminated to a depth of 15 cm for radionuclides of interest (2) Dose coefficients for air submersion for radionuclides of interest
5	ICRP (International Commission on Radiological Protection) 1979, 1980, and 1981. *Limits for Intakes of Radionuclides by Workers*. Part 1, 2, and 3. ICRP Publication 30. New York, New York: Pergamon Press.	TIC: 4939 (Part 1) TIC: 4941 (Part 2) TIC: 4943 (Part 3)	UQ[a]	Corroborative data: Annual limits on intake for inhalation and ingestion.
6	GENII-S 1.485. Environmental Radiation Dosimetry Software System.	CSCI: 30034 V1.4.8.5	TBV	Software package consisting of executable file and auxiliary files.

[a] UQ - unqualified

5. ASSUMPTIONS

5.1 THICKNESS OF TOP SOIL LAYER

For external exposure to contaminated soil, the thickness of the top layer of soil was assumed to be 15 cm. Data sets in FGR 12 are available for the following thicknesses of contaminated soil: ground surface (thickness equal to zero), 1 cm, 5 cm, 15 cm, and infinite depth. The thickness of 15 cm corresponds the best with the expected thickness of cultivated soil (CRWMS M&O 1999d, p. C-25).

5.2 EXPOSURE SCENARIOS

To obtain GENII-S doses per unit activity intake and doses from exposure per unit time to unit activity concentration in air and soil, simple exposure scenarios were developed. For internal exposure, doses resulting from unit activity intake are numerically equal to DCFs (DCF is defined as dose per unit activity intake). For external exposure, doses from exposure to unit activity in environmental media for unit time are equal to DCs (DC is defined as dose per unit time following exposure to unit activity concentration in environmental medium, such as air or soil).

- For the ingestion scenario, a receptor was assumed to consume one liter of water with an activity concentration of 1 Bq per liter (for definitions of dosimetric terms see Glossary, Attachment II) resulting in a unit (1 Bq) activity intake.

- For the inhalation scenario, it was assumed that a receptor with a breathing rate of 1 m^3 per h, was exposed to 1 Bq per m^3 of radioactivity in air for one hour. Activity intake in this case is equal to 1 Bq.

- For external exposure to contaminated soil, the receptor was exposed for one year to contaminated soil with an activity concentration of 1 Bq per m^3 uniformly distributed in 15-cm soil layer.

- For external exposure by air submersion, the receptor was exposed for one year to contaminated air with an activity concentration of 1 Bq per m^3.

6. ANALYSIS

This section contains evaluations of GENII-S radionuclide-specific doses for both internal and external exposures. For internal exposure, GENII-S doses per unit activity intake were compared with published values of DCFs and DCFs derived from ALIs. For external exposure a new GENII-S input file was developed based on recently published values of DCs. Detailed reference pointers for numerical values used in this section are listed in Attachment III.

6.1 RADIONUCLIDES OF INTEREST

A generic radionuclide screening analysis (CRWMS M&O 1999c, p.16) identified the following 16 radionuclides as relevant to the TSPA safety case: ^{14}C, ^{137}Cs, ^{129}I, ^{93}Mo, ^{63}Ni, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{90}Sr, ^{99}Tc, ^{232}U, ^{233}U, ^{234}U, ^{236}U, ^{238}U.

In addition, eleven radionuclides were identified as relevant for a direct release scenario (disruptive events) (CRWMS M&O 1999c, Tables 6 and 7): ^{227}Ac, ^{241}Am, ^{243}Am, ^{137}Cs, ^{237}Np, ^{231}Pa, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{90}Sr, ^{229}Th.

The GENII-S model accounts for the decay products of long-lived radionuclides which may be present in the environment together with their predecessors, and automatically tracks radioactive decay of the products (Table 2). Most of these radionuclides are members of four decay chains. Therefore, the analysis was performed for 36 radionuclides, including 21 radionuclides listed in the screening analysis (CRWMS M&O 1999c; Tables 6, 7, 10, 11 and 12), and 15 decay products automatically tracked by GENII-S. All of these radionuclides (long-lived and decay products) are included in GENII-S auxiliary file, (RMDLIB.DAT) that is maintained by Configuration Management, as described in Section 3.

Table 2. Primary Radionuclides and their Decay Products Included in the Analysis.

Primary Radionuclide	Decay products considered in GENII-S	Primary Radionuclide	Decay products considered in GENII-S
^{227}Ac	^{227}Th, ^{223}Ra, ^{223}Fr	^{239}Pu	None
^{241}Am	^{237}Np, ^{233}Pa	^{240}Pu	^{236}U
^{243}Am	^{239}Np, ^{239}Pu	^{90}Sr	^{90}Y
^{14}C	None	^{99}Tc	None
^{137}Cs	None	^{229}Th	^{225}Ra, ^{225}Ac
^{129}I	None	^{232}U	^{228}Th, ^{224}Ra, ^{212}Pb, ^{212}Bi
^{93}Mo	^{93m}Nb	^{233}U	^{229}Th, ^{225}Ra, ^{225}Ac
^{63}Ni	None	^{234}U	None
^{237}Np	^{233}Pa	^{236}U	None
^{231}Pa	^{227}Ac, ^{227}Th, ^{223}Ra, ^{223}Fr	^{238}U	^{234}Th, ^{234}Pa
^{238}Pu	^{234}U		

In addition, some of the radionuclides listed in Table 2 are considered to be in equilibrium with their own decay chains of short-lived radionuclides, called "implicit daughters" (Napier 1988b, p. 2.24). These additional radionuclides were also included in the analysis. They were:

- ^{137}Cs, in equilibrium with ^{137m}Ba (94.6%).
- ^{224}Ra, in equilibrium with ^{220}Rn (100%) and ^{216}Po (100%).
- ^{212}Bi, in equilibrium with ^{212}Po (64.07%) and ^{208}Tl (35.93%).
- ^{234}Th, in equilibrium with ^{234m}Pa (100%).
- ^{225}Ac, in equilibrium with ^{221}Fr (100%), ^{217}At (100%), ^{213}Bi (100%), ^{213}Po (97.84%), ^{209}Tl (2.16%), and ^{209}Pb (100%).
- ^{223}Ra, in equilibrium with ^{219}Rn (100%), ^{215}Po (100%), ^{211}Pb (100%), ^{211}Bi (100%), and ^{207}Tl (100%).

6.2 DOSIMETRIC MODELS OF GENII

Pacific Northwest Laboratories (Napier et al. 1988) has developed and documented a comprehensive set of environmental pathway models and associated computer programs, called GENII, for estimating potential radiation doses to humans from radionuclides in the environment. The GENII code was adapted for use on a personal computer using the Sensitivity and UNcertainty analysis Shell (SUNS) software by Sandia National Laboratories, and named GENII-S (Leigh et al. 1993).

GENII-S is a code designed to estimate doses to humans from radionuclide released to the environment (Napier et al. 1988a). For internal exposure, radionuclide activity intake is calculated by combining the radioactivity concentration in environmental media (e.g. food, soil, air, and water) with the amount of environmental medium taken into the body. Then, using dosimetric models, intake is converted into dose. To assess exposure from external sources, GENII-S uses dose coefficients that convert radionuclide concentrations in environmental media to doses for the duration of exposure.

Dose calculations performed by GENII-S are based on methods developed in ICRP-30. The code calculates incremental organ doses for each year following an initial radionuclide intake. Dose commitment (50-year dose following an intake) is then assembled from incremental doses to each organ over the commitment period. Effective dose equivalent (see Glossary of Dosimetric Terms in Attachment II) is calculated by producing a weighted sum of organ doses with organ/tissue weighting factors.

6.3 GENII-S INPUT STRUCTURE

The structure of GENII-S dosimetric input is different for internal and external doses. Only information related to external exposure-to-dose conversion can be modified readily by the code user.

6.3.1 Internal Doses

Internal doses are calculated in GENII-S from internal incremental organ doses in a series of steps, as described in the previous section. Yearly increments of committed dose equivalents are stored in binary form in the file DOSINC.DAT (Leigh et al. 1993, p. 5-64; Napier et al. 1988b, p. 2.33). This dosimetric database can not be accessed directly by the code user and is one of the auxiliary files used by GENII-S to calculate internal doses. The file is in the binary format, and the ASCII-to-binary conversion utility is not provided as a part of the GENII-S package.

6.3.2 External Doses

Radiation doses from external exposures are calculated by GENII-S more directly than calculation of internal doses. After radionuclide concentrations in soil and air are estimated, the code uses dose coefficients combined with the duration of exposure to soil and air to calculate radiation doses. Dose coefficients are stored in the text file named GRDF.DAT (Leigh et al. 1993, p. 5-67; Napier et al. 1988b, p. 2.30) which can be readily replaced or modified with user-selected values. A new file containing FGR 12 dose coefficients was created to replace original DCs provided in the GENII-S package.

6.4 ANALYSIS OF DOSE CONVERSION FACTORS FOR INGESTION AND INHALATION

Exposure-to-dose conversion can be carried out either by using dosimetric models or by application of DCFs, if the dose model is linear with respect to exposure. As noted earlier, DCFs represent committed dose per unit of activity intake. DCFs are tabulated in FGR 11, but they can also be derived from other sources, such as ICRP-30 or 10 CFR 20, by converting values of ALIs into dose.

To evaluate if GENII-S output is consistent with the values from sources accepted by the radiation protection community, GENII-S doses per unit activity intake were compared with FGR 11 DCFs and DCFs derived from ALIs presented in 10 CFR 20 and ICRP-30. Worst case solubility values, provided as a part of the code, representing the most conservative conditions for radionuclides under consideration, were used for this analysis. Similarly, the worst case DCFs from FGR 11, and the lowest ALIs from ICRP 30 and 10 CFR 20 were selected to represent the most conservative conditions for a specific radionuclide. In some cases only one value is given for a radionuclide, in other cases there are multiple entries for various chemical forms of a radionuclide. Multiple entries correspond to different fractional uptakes from the small intestine to blood (f_1) and different lung clearance classes (ICRP 1979, pp. 24 and 30-31).

The exception was ^{90}Sr. The most conservative values for ingestion and inhalation of strontium are for $SrTiO_3$, which is not common in an agricultural setting. Therefore, the value for other chemical forms of strontium was used for both inhalation and ingestion.

Tables 3 and 4 summarize results of the comparison for ingestion and inhalation, respectively. Dose conversion factors presented in Tables 3 and 4 include FGR 11 DCFs (called exposure-to-dose conversion factors in FGR 11) and DCFs derived from published values of ALIs in 10 CFR 20 and ICRP-30. ALI-based DCFs were calculated by dividing a stochastic dose limit, *SDL*, of 50 mSv (5 rem) by the stochastic ALI value for a given radionuclide.

To derive DCFs from ICRP-30 ALIs, the following equation was used (EPA 1988, equation 5a, modified):

$$DCF\left[\frac{Sv}{Bq}\right] = \frac{SDL}{ALI[Bq]} \times \frac{1\,Sv}{10^3\,mSv}. \tag{Eq. 1}$$

Derivation of DCFs from 10 CFR 20 ALIs, was performed using the following equation (EPA 1988, equation 5a, modified):

$$DCF\left[\frac{Sv}{Bq}\right] = \frac{SDL}{ALI[\mu Ci]} \times \frac{1\,Sv}{10^3\,mSv} \times \frac{1\mu Ci}{3.7\times 10^4\,Bq\,\mu Ci^{-1}}. \tag{Eq. 2}$$

All four sets of doses per unit activity intake (DCFs) presented in the Tables 3 and 4 are based on the ICRP-30 dosimetric methodology.

Table 3. Comparison of GENII-S Doses per Unit Activity Intake by Ingestion to FGR 11 DCFs and 10 CFR 20 ALI-based, and ICRP 30 ALI-based DCFs for the Primary Radionuclides.

Radionuclide	GENII-S	FGR 11		10 CFR 20		ICRP-30		
	Dose per unit intake, Sv/Bq	f_1[a]	DCF, Sv/Bq	Stochastic ALI, µCi	ALI-based DCF, Sv/Bq	f_1[a]	Stochastic ALI, Bq	ALI-based DCF, Sv/Bq
Ac-227	3.8E-06	1.E-03	3.80E-06	4.E-01	3.E-06	1.E-03	1.E+04	5.E-06
Am-241	9.8E-07	1.E-03	9.84E-07	1.E+00	1.E-06	5.E-04	9.E+04	6.E-07
Am-243	9.8E-07	1.E-03	9.79E-07	1.E+00	1.E-06	5.E-04	9.E+04	6.E-07
C-14	5.6E-10	1.E+00	5.64E-10	2.E+03	7.E-10	---	9.E+07	6.E-10
Cs-137	1.3E-08	1.E+00	1.35E-08	1.E+02	1.E-08	1.E+00	4.E+06	1.E-08
I-129	6.8E-08	1.E+00	7.46E-08	2.E+01	7.E-08	1.E+00	7.E+05	7.E-08
Mo-93	3.7E-10	8.E-01	3.64E-10	4.E+03	3.E-10	8.E-01	1.E+08	5.E-10
Ni-63	1.5E-10	5.E-02	1.56E-10	9.E+03	2.E-10	5.E-02	3.E+08	2.E-10
Np-237	1.4E-06	1.E-03	1.20E-06	1.E+00	1.E-06	1.E-02	5.E+03	1.E-05
Pa-231	2.9E-06	1.E-03	2.86E-06	5.E-01	3.E-06	1.E-03	2.E+04	3.E-06
Pu-238	8.7E-07	1.E-03	8.65E-07	2.E+00	7.E-07	1.E-04	5.E+05	1.E-07
Pu-239	9.6E-07	1.E-03	9.56E-07	1.E+00	1.E-06	1.E-04	4.E+05	1.E-07
Pu-240	9.6E-07	1.E-03	9.56E-07	1.E+00	1.E-06	1.E-04	4.E+05	1.E-07
Sr-90	3.3E-08	3.E-01	3.85E-08	4.E+01	3.E-08	3.E-01	1.E+06	5.E-08
Tc-99	6.0E-10	8.E-01	3.95E-10	4.E+03	3.E-10	8.E-01	1.E+08	5.E-10
Th-229	9.5E-07	2.E-04	9.54E-07	1.E+00	1.E-06	2.E-04	5.E+04	1.E-06
U-232	3.5E-7	5.E-02	3.54E-07	4.E+00	3.E-07	5.E-02	1.0E+05	5.E-07
U-233	7.8E-08	5.E-02	7.81E-08	2.E+01	7.E-08	5.E-02	7.E+05	7.E-08
U-234	7.7E-08	5.E-02	7.66E-08	2.E+01	7.E-08	5.E-02	7.E+05	7.E-08
U-236	7.3E-08	5.E-02	7.26E-08	2.E+01	7.E-08	5.E-02	7.E+05	7.E-08
U-238	7.0E-08	5.E-02	6.88E-08	2.E+01	7.E-08	5.E-02	8.E+05	6.E-08

[a] The fractional uptake from the small intestine to blood for common chemical forms of the radionuclide. There may be more than one DCF for a radionuclide to reflect differences in metabolism of various chemical forms of the radionuclide. In this analysis, the highest DCF value for a radionuclide was selected, except for strontium.

Table 4. Comparison of GENII-S Doses per Unit Activity Intake by Inhalation to FGR 11 DCFs and 10 CFR 20 ALI-based, and ICRP 30 ALI-based DCFs for the Primary Radionuclides.

Radionuclide	GENII-S	FGR 11			10 CFR 20			ICRP-30			
	Dose per unit intake, Sv/Bq	Class[a]	f_1[b]	DCF, Sv/Bq	Class[a]	Stoch. ALI, µCi	ALI-based DCF, Sv/Bq	Class[a]	f_1[b]	Stoch. ALI, Bq	ALI-based DCF, Sv/Bq
Ac-227	1.8E-03	D	1.E-03	1.81E-03	D	8.E-04	2.E-03	D	1.E-03	3.E+01	2.E-03
Am-241	1.2E-04	W	1.E-03	1.20E-04	W	1.E-02	1.E-04	W	5.E-04	4.E+02	1.E-04
Am-243	1.2E-04	W	1.E-03	1.19E-04	W	1.E-02	1.E-04	W	5.E-04	4.E+02	1.E-04
C-14	5.6E-10	---	1.E+00	5.64E-10	---	2.E+03	7.E-10	---	---	9.E+07	6.E-10
Cs-137	8.1E-09	D	1.E+00	8.63E-09	D	2.E+02	7.E-09	D	1.E+00	6.E+06	8.E-09
I-129	4.1E-08	D	1.E+00	4.69E-08	D	3.E+01	5.E-08	D	1.E+00	1.E+06	5.E-08
Mo-93	7.7E-09	Y	5.E-02	7.68E-09	Y	2.E+02	7.E-09	Y	5.E-02	7.E+06	7.E-09
Ni-63	8.2E-10	D	5.E-02	8.39E-10	D	2.E+03	7.E-10	D	5.E-02	6.E+07	8.E-10
Np-237	1.7E-04	W	1.E-03	1.46E-04	W	1.E-02	1.E-04	W	1.E-02	4.E+02	1.E-04
Pa-231	3.5E-04	W	1.E-03	3.47E-04	W	4.E-03	3.E-04	W	1.E-03	1.E+02	5.E-04
Pu-238	1.1E-04	W	1.E-03	1.06E-04	W	1.E-02	1.E-04	W	1.E-04	4.E+02	1.E-04
Pu-239	1.2E-04	W	1.E-03	1.16E-04	W	1.E-02	1.E-04	W	1.E-04	4.E+02	1.E-04
Pu-240	1.2E-04	W	1.E-03	1.16E-04	W	1.E-02	1.E-04	W	1.E-04	4.E+02	1.E-04
Sr-90	5.5E-08	D	3.E-01	6.47E-08	D	2.E+01	7.E-08	D	3.E-01	8.E+05	6.E-08
Tc-99	2.4E-09	W	8.E-01	2.25E-09	W	7.E+02	2.E-09	W	8.E-01	2.E+07	3.E-09
Th-229	5.8E-04	W	2.E-04	5.80E-04	W	2.E-03	7.E-04	W	2.E-04	9.E+01	6.E-04
U-232	1.8E-04	Y	2.E-03	1.78E-04	Y	8.E-03	2.E-04	Y	2.E-03	3.E+02	2.E-04
U-233	3.7E-05	Y	2.E-03	3.66E-05	Y	4.E-02	3.E-05	Y	2.E-03	1.E+03	5.E-05
U-234	3.6E-05	Y	2.E-03	3.58E-05	Y	4.E-02	3.E-05	Y	2.E-03	1.E+03	5.E-05
U-236	3.4E-05	Y	2.E-03	3.39E-05	Y	4.E-02	3.E-05	Y	2.E-03	1.E+03	5.E-05
U-238	3.2E-05	Y	2.E-03	3.20E-05	Y	4.E-02	3.E-05	Y	2.E-03	2.E+03	3.E-05

[a] The lung clearance class (D, W, or Y) reflecting time (days, weeks, years) it takes for the given chemical form of radionuclide to be cleared from the lungs. There may be more than one DCF for a radionuclide to account for different lung clearance classes of its chemical forms.

[b] The fractional uptake from the small intestine to blood for common chemical forms of the radionuclide. There may be more than one DCF for a radionuclide to reflect differences in metabolism of various chemical forms of the radionuclide. In this analysis, the highest DCF value for a radionuclide was selected, except for strontium.

Relative differences between GENII-S doses per unit activity intake and DCFs shown in Tables 3 and 4 are listed in Tables 5 and 6. Relative differences were calculated (using FGR 11 DCFs as the example) using the equation:

$$Percent\ relative\ difference = \frac{\left(DCF_{GENII-S} - DCF_{FGR11}\right)}{DCF_{FGR11}} \times 100. \qquad \text{(Eq. 3)}$$

In order to assess relative differences, the numbers were rounded so all values in Equation 3 had the same number of significant digits. For example, when GENII-S doses per unit activity intake were compared to FGR 11 DCFs, the latter were rounded to two significant digits because GENII-S results have two significant digits. For comparison with ICRP-30-based values and 10 CFR 20-based values of DCFs, GENII-S doses per unit activity intake were rounded to one significant digit because ALIs are given with one significant digit. Rounding may result in an apparent increase in the relative difference between compared values of up to 100%. For example, values of 1.6 and 1.4 (a difference of 14%), rounded to 2 and 1, results in a difference of 100%.

Analysis of values presented in Tables 5 and 6 shows that GENII-S doses per unit activity intake are similar to other DCFs because all of these values are derived from the same general principles of ICRP-30-based dosimetric methods. The differences between DCFs reflect changes in dosimetric methods since the publication of ICRP-30, and are a result of better understanding of radionuclide behavior in the human body. In addition, fractional uptakes from small intestine to blood (f_1) for the worst case are not always the same among the sets of DCFs/ALIs, which may lead to different conversion factors.

Considering all data sets (Tables 5 and 6), GENII-S doses per unit activity were most similar to FGR 11 DCFs. The greatest number of differences occur between GENII-S and ICRP-30 set. With a few exceptions, relative differences between GENII-S and other DCFs are relatively small, on the order of several percent. In several cases, such as for ingestion of americium, neptunium, and plutonium isotopes (Table 5), the relative difference between GENII-S doses per unit activity intake and ALI-based sets of DCFs is much greater, up to several tens to several hundred percent. This is because the worst-case DCFs are given for radionuclides with different fractional uptakes from the small intestine f_1 (see Tables 3 and 4).

In many cases the differences may be attributable to rounding errors. Such differences are the largest for values with only one significant digit. For example, if DCFs for ingestion of ^{232}U are considered (see Table 6), the difference of one in the value of the significant digit resulted in relative difference of 33% for the 10 CFR 20 set and –20% for the ICFR-30 set.

For ingestion of ^{99}Tc (Table 5), GENII-S doses are more conservative than doses calculated using any of the remaining sets.

Table 5. Relative Difference Between GENII-S Doses per Unit Activity Intake by Ingestion and DCFs from Other Data Sets for the Primary Radionuclides.

Radionuclide	GENII-S vs. FGR 11			GENII-S vs. 10 CFR 20			GENII-S vs. ICRP-30		
	GENII-S DCF Sv/Bq	FGR 11[a] DCF Sv/Bq	Percent relative difference	GENII-S[b] DCF Sv/Bq	10CFR 20 DCF Sv/Bq	Percent relative difference	GENII-S[b] DCF Sv/Bq	ICRP-30 DCF Sv/Bq	Percent relative difference
Ac-227	3.8E-06	3.8E-06	0.0	4.E-06	3.E-06	30	4.E-06	5.E-06	-20
Am-241	9.8E-07	9.8E-07	0.0	1.E-06	1.E-06	0	1.E-06	6.E-07	70
Am-243	9.8E-07	9.8E-07	0.0	1.E-06	1.E-06	0	1.E-06	6.E-07	70
C-14	5.6E-10	5.6E-10	0.0	6.E-10	7.E-10	-10	6.E-10	6.E-10	0
Cs-137	1.3E-08	1.4E-08	-7.1	1.E-08	1.E-08	0	1.E-08	1.E-08	0
I-129	6.8E-08	7.0E-08	-2.9	7.E-08	7.E-08	0	7.E-08	7.E-08	0
Mo-93	3.7E-10	3.6E-10	2.8	4.E-10	3.E-10	30	4.E-10	5.E-10	-20
Ni-63	1.5E-10	1.6E-10	-6.3	2.E-10	2.E-10	0	2.E-10	2.E-10	0
Np-237	1.4E-06	1.2E-06	17	1.E-06	1.E-06	0	1.E-06	1.E-05	-90
Pa-231	2.9E-06	2.9E-06	0.0	3.E-06	3.E-06	0	3.E-06	3.E-06	0
Pu-238	8.7E-07	8.7E-07	0.0	9.E-07	7.E-07	30	9.E-07	1.E-07	800
Pu-239	9.6E-07	9.6E-07	0.0	1.E-06	1.E-06	0	1.E-06	1.E-07	900
Pu-240	9.6E-07	9.6E-07	0.0	1.E-06	1.E-06	0	1.E-06	1.E-07	900
Sr-90	3.3E-08	3.9E-08	-15	3.E-08	3.E-08	0	3.E-08	5.E-08	-40
Tc-99	6.0E-10	4.0E-10	50.0	6.E-10	3.E-10	100	6.E-10	5.E-10	20
Th-229	9.5E-07	9.5E-07	0.0	1.E-06	1.E-06	0	1.E-06	1.E-06	0
U-232	3.5E-07	3.5E-07	0.0	4.E-07	3.E-07	30	4.E-07	5.E-07	-20
U-233	7.8E-08	7.8E-08	0.0	8.E-08	7.E-08	10	8.E-08	7.E-08	10
U-234	7.7E-08	7.7E-08	0.0	8.E-08	7.E-08	10	8.E-08	7.E-08	10
U-236	7.3E-08	7.3E-08	0.0	7.E-08	7.E-08	0	7.E-08	7.E-08	0
U-238	7.0E-08	6.9E-08	1.4	7.E-08	7.E-08	0	7.E-08	6.E-08	20

[a] Values rounded to two significant digits
[b] Values rounded to one significant digit

Table 6. Relative Difference Between GENII-S Doses per Unit Activity Intake by Inhalation and DCFs from Other Data Sets for the Primary Radionuclides.

Radionuclide	GENII-S vs. FGR 11			GENII-S vs. 10 CFR 20			GENII-S vs. ICRP-30		
	GENII-S DCF Sv/Bq	FGR 11[a] DCF Sv/Bq	Percent relative difference	GENII-S[b] DCF Sv/Bq	10CFR 20 DCF Sv/Bq	Percent relative difference	GENII-S[b] DCF Sv/Bq	ICRP 30 DCF Sv/Bq	Percent relative difference
Ac-227	1.8E-03	1.80E-03	0.0	2.E-03	2.E-03	0	2.E-03	2.E-03	0
Am-241	1.2E-04	1.2E-04	0.0	1.E-04	1.E-04	0	1.E-04	1E-04	0
Am-243	1.2E-04	1.2E-04	0.0	1.E-04	1.E-04	0	1.E-04	1.E-04	0
C-14	5.6E-10	5.6E-10	0.0	6.E-10	7.E-10	-10	6.E-10	6.E-10	0
Cs-137	8.1E-09	8.6E-09	-5.8	8.E-09	7.E-09	10	8.E-09	8.E-09	0
I-129	4.1E-08	4.7E-08	-13	4.E-08	5.E-08	-20	4.E-08	5.E-08	-20
Mo-93	7.7E-09	7.7E-09	0.0	8.E-09	7.E-09	10	8.E-09	7.E-09	10
Ni-63	8.2E-10	8.4E-10	-2.4	8.E-10	7.E-10	10	8.E-10	8.E-10	0
Np-237	1.7E-04	1.5E-04	13	2.E-04	1.E-04	100	2.E-04	1.E-04	100
Pa-231	3.5E-04	3.5E-04	0.0	4.E-04	3.E-04	30	4.E-04	5.E-04	-20
Pu-238	1.1E-04	1.1E-04	0.0	1.E-04	1.E-04	0	1.E-04	1.E-04	0
Pu-239	1.2E-04	1.2E-04	0.0	1.E-04	1.E-04	0	1.E-04	1.E-04	0
Pu-240	1.2E-04	1.2E-04	0.0	1.E-04	1.E-04	0	1.E-04	1.E-04	0
Sr-90	5.5E-08	6.5E-08	-15	6.E-08	7.E-08	-10	6.E-08	6.E-08	0
Tc-99	2.4E-09	2.3E-09	4.3	2.E-09	2.E-09	0	2.E-09	3.E-09	-30
Th-229	5.8E-04	5.8E-04	0.0	6.E-04	7.E-04	-10	6.E-04	6.E-04	0
U-232	1.8E-04	1.8E-04	0.0	2.E-04	2.E-04	0	2.E-04	2E-04	0
U-233	3.7E-05	3.7E-05	0.0	4.E-05	3.E-05	30	4.E-05	5.E-05	-20
U-234	3.6E-05	3.6E-05	0.0	4.E-05	3.E-05	30	4.E-05	5.E-05	-20
U-236	3.4E-05	3.4E-05	0.0	3.E-05	3.E-05	0	3.E-05	5.E-05	-40
U-238	3.2E-05	3.2E-05	0.0	3.E-05	3.E-05	0	3.E-05	3.E-05	0

[a] Values rounded to two significant digits
[b] Values rounded to one significant digit

For the decay products automatically included by GENII-S with the primary radionuclides, the comparison of GENII-S doses per unit activity intake with DCFs from other sources is presented in Tables 7 and 8, for ingestion and inhalation, respectively. Some of these radionuclides are assumed to be in equilibrium with their short-lived decay products (see Section 4.1). Therefore DCFs in Tables 7 and 8 include contributions from these decay products. Table 9 contains calculations of these composite entries for Tables 7 and 8. Dashed lines in some Table 9 cells indicate that data for the specific radionuclide were not available from the source under consideration.

Similar to Tables 5 and 6, Tables 10 and 11 show relative percentage differences between GENII-S doses per unit activity intake and the three sets of DCFs. Again, the values are similar, especially between GENII-S doses and FGR 11 DCFs. The largest difference is for ingestion of radium isotopes. GENII-S seems to underestimate doses from radium by up to about 60%.

Table 7. Comparison of GENII-S Doses per Unit Activity Intake by Ingestion to FGR 11 DCFs and 10 CFR 20 ALI-based, and ICRP 30 ALI-based DCFs for the Decay Products Included with the Primary Radionuclides.

Radionuclide	GENII-S	FGR 11		10 CFR 20		ICRP-30		
	Dose per unit intake, Sv/Bq	f_1[a]	DCF, Sv/Bq	Stochastic ALI, μCi	ALI-based DCF, Sv/Bq	f_1[a]	Stochastic ALI, Bq	ALI-based DCF, Sv/Bq
Thorium series								
Th-228	1.1E-07	2.E-04	1.07E-07	1.E+01	1.E-07	2.E-04	5.E+05	1.E-07
Ra-224	3.5E-08	2.E-01	9.89E-08	2.E+01	8.E-08	2.E-01	6.E+05	8.E-08
Pb-212	1.3E-08	2.E-01	1.51E-08	1.E+02	1.E-08	2.E-01	5.E+06	1.E-08
Bi-212	3.0E-10	5.E-02	2.87E-10	5.E+03	3.E-10	5.E-02	2.E+08	3.E-10
Uranium series								
Th-234	3.6E-09	2.E-04	3.69E-09	4.E+02	3.E-09	2.E-04	1.E+07	5.E-09
Pa-234	6.0E-10	1.E-03	5.84E-10	2.E+03	7.E-10	1.E-03	9.E+07	6.E-10
Neptunium series								
Pa-233	9.6E-10	1.E-03	9.81E-10	2.E+03	7.E-10	1.E-03	6.E+07	8.E-10
Ra-225	6.0E-08	2.E-01	1.04E-07	2.E+01	7.E-08	2.E-01	6.E+05	8.E-08
Ac-225	3.0E-08	1.E-03	3.03E-08	5.E+01	3.E-08	1.E-03	2.E+06	3.E-08
Actinium series								
Np-239	8.9E-10	1.E-03	8.82E-10	2.E+03	7.E-10	1.E-02	6.E+07	8.E-10
Th-227	1.0E-08	2.E-04	1.03E-08	1.E+02	1.E-08	2.E-04	5.E+06	1.E-08
Ra-223	7.2E-08	2.E-01	1.91E-07	9.E+00	2.E-07	2.E-01	3.E+05	2.E-07
Fr-223	3.0E-09	1.E+00	2.33E-09	6.E+02	2.E-09	1.E+01	2.E+07	3.E-09
Other radionuclides								
Nb-93m	1.4E-10	1.E-02	1.41E-10	1.E+04	1.E-10	1.E-02	4.E+08	1.E-10
Y-90	2.9E-09	1.E-04	2.91E-09	5.E+02	3.E-09	1.E-04	2.E+07	3.E-09

[a] The fractional uptake from the small intestine to blood for common chemical forms of the radionuclide. There may be more than one DCF for a radionuclide to reflect differences in metabolism of various chemical forms of the radionuclide. In this analysis, the highest DCF value for a radionuclide was selected, except for strontium.

Table 8. Comparison of GENII-S Doses per Unit Activity Intake by Inhalation to FGR 11 DCFs and 10 CFR 20 ALI-based, and ICRP 30 ALI-based DCFs for the Decay Products Included with the Primary Radionuclides.

Radionuclide	GENII-S	FGR 11			10 CFR 20			ICRP-30			
	Dose per unit intake, Sv/Bq	Class[a]	f_1[b]	DCF, Sv/Bq	Class	Stoch. ALI, μCi	ALI-based DCF, Sv/Bq	Class[a]	f_1[b]	Stoch. ALI, Bq	ALI-based DCF, Sv/Bq
Thorium series											
Th-228	9.3E-05	Y	2.E-04	9.23E-05	W, Y	2.E-02	7.E-05	Y	2.E-04	6.E+02	8.E-05
Ra-224	8.1E-07	W	2.E-01	8.53E-07	W	2.E+00	8.E-07	W	2.E-01	6.E+04	8.E-07
Pb-212	4.8E-08	D	2.E-01	4.56E-08	D	3.E+01	5.E-08	D	2.E-01	1.E+06	5.E-08
Bi-212	6.1E-09	D	5.E-02	5.83E-09	D	2.E+02	7.E-09	D	5.E-02	9.E+06	6.E-09
Uranium series											
Th-234	9.5E-09	Y	2.E-04	9.47E-09	W,Y	2.E+02	7.E-09	Y	2.E-04	6.E+06	8.E-09
Pa-234	2.3E-10	Y	1.E-03	2.20E-10	Y	7.E+03	2.E-10	Y	1.E-03	2.E+08	3.E-10
Neptunium series											
Pa-233	2.6E-09	Y	1.E-03	2.58E-09	Y	6.E+02	2.E-09	Y	1.E-03	2.E+07	3.E-09
Ra-225	2.6E-06	W	2.E-01	2.10E-06	W	7.E-01	2.E-06	W	2.E-01	2.E+04	3.E-06
Ac-225	3.0E-06	D	1.E-03	2.92E-06	D	5.E-01	3.E-06	D,W,Y	1.E-03	2.E+04	3.E-06
Actinium series											
Np-239	7.0E-10	W	1.E-03	6.78E-10	W	2.E+03	7.E-10	W	1.E-02	9.E+07	6.E-10
Th-227	4.4E-06	Y	2.E-04	4.37E-06	W, Y	3.E-01	5.E-06	W, Y	2.E-04	1.E+04	5.E-06
Ra-223	2.1E-06	W	2.E-01	2.12E-06	W	7.E-01	2.E-06	W	2.E-01	3.E+04	2.E-06
Fr-223	2.1E-09	D	1.E+00	1.68E-09	D	8.E+02	2.E-09	D	1.E+00	3.E+07	2.E-09
Other radionuclides											
Nb-93m	8.1E-09	Y	1.E-02	7.90E-09	Y	2.E+02	7.E-09	Y	1.E-02	6.E+06	8.E-09
Y-90	2.4E-09	Y	1.E-04	2.28E-09	Y	6.E+02	2.E-09	Y	1.E-04	2.E+07	3.E-09

[a] The lung clearance class (D, W, or Y) reflecting time (days, weeks, years) it takes for the given chemical form of radionuclide to be cleared from the lungs. There may be more than one DCF for a radionuclide to account for different lung clearance classes of its chemical forms.

[b] The fractional uptake from the small intestine to blood for common chemical forms of the radionuclide. There may be more than one DCF for a radionuclide to reflect differences in metabolism of various chemical forms of the radionuclide. In this analysis, the highest DCF value for a radionuclide was selected, except for strontium.

Table 9. Contribution to DCFs from Secondary Decay Products.

Radionuclide		Ingestion					Inhalation				
		FGR 11	10 CFR 20		ICRP-30		FGR 11	10 CFR 20		ICRP-30	
		DCF, Sv/Bq	ALI, µCi	DCF, Sv/Bq	ALI, Bq	DCF, Sv/Bq	DCF, Sv/Bq	ALI, µCi	DCF, Sv/Bq	ALI, Bq	DCF, Sv/Bq
Ac-225	Ac-225	3.00E-08	5.E+01	3.E-08	2.E+06	3.E-08	2.92E-06	5.E-01	3.E-06	2.E+04	3.E-06
	Fr-221	---	---	---	---	---	---	---	---	---	---
	At-217	---	---	---	---	---	---	---	---	---	---
	Bi-213	1.95E-10	7.E+03	2.E-10	3.E+08	2.E-10	4.63E-09	3.E+02	5.E-09	1.E+07	5.E-09
	Po-213	---	---	---	---	---	---	---	---	---	---
	Tl-209	---	---	---	---	---	---	---	---	---	---
	Pb-209	5.75E-11	2.E+04	7.E-11	9.E+08	6.E-11	2.56E-11	6.E+04	2.E-11	2.E+09	3.E-11
	Total	**3.03E-08**		**3.E-08**		**3.E-08**	**2.92E-06**		**3.E-06**		**3.E-06**
Th-234	Th-234	3.69E-09	4.E+02	3.E-09	1.E+07	5.E-09	9.47E-09	2.E+02	7.E-09	6.E+06	8.E-09
	Pa-234m	---	---	---	---	---	---	---	---	---	---
	Total	**3.69E-09**	---	**3.E-09**	---	**5.E-09**	**9.47E-09**	---	**7.E-09**	---	**8.E-09**
Ra-224	Ra-224	9.89E-08	2.E+01	7.E-08	6.E+05	8.E-08	8.53E-07	2.E+00	7.E-07	6.E+04	8.E-07
	Rn-220	---	---	---	---	---	---	2.E+01	7.E-08	---	---
	Po-216	---	---	---	---	---	---	---	---	---	---
	Total	**9.89E-08**	---	**7.E-08**	---	**8.E-08**	**8.53E-07**	---	**8.E-07**	---	**8.E-07**
Bi-212	Bi-212	2.87E-10	5.E+03	3.E-10	2.E+08	3.E-10	5.83E-09	2.E+02	7.E-09	9.E+06	6.E-09
	Po-212	---	---	---	---	---	---	---	---	---	---
	Tl-208	---	---	---	---	---	---	---	---	---	---
	Total	**2.87E-10**	---	**3.E-10**	---	**3.E-10**	**5.83E-09**	---	**7.E-09**	---	**6.E-09**
Ra-223	Ra-223	1.78E-07	9.E+00	2.E-07	3.E+05	2.E-07	2.12E-06	7.E-01	2.E-06	3.E+04	2.E-06
	Rn-219	---	---	---	---	---	---	---	---	---	---
	Po-215	---	---	---	---	---	---	---	---	---	---
	Pb-211	1.23E-08	1.E+04	1.E-10	4.E+08	1.E-10	2.35E-09	6.E+02	2.E-09	2.E+07	3.E-09
	Bi-211	2.87E-10	---	---	---	---	---	---	---	---	---
	Tl-207	---	---	---	---	---	---	---	---	---	---
	Total	**1.91E-07**	---	**2.E-07**	---	**2.E-07**	**2.12E-06**	---	**2.E-06**	---	**2.E-06**

Table 10. Relative Difference Between GENII-S Doses per Unit Activity Intake by Ingestion and DCFs from Other Data Sets for Decay Products Included with the Primary Radionuclides.

Radionuclide	GENII-S vs. FGR 11			GENII-S vs. 10 CFR 20			GENII-S vs. ICRP-30		
	GENII-S DCF Sv/Bq	FGR 11 DCF Sv/Bq	Percent relative difference	GENII-S DCF Sv/Bq	10CFR 20 DCF Sv/Bq	Percent relative difference	GENII-S DCF Sv/Bq	ICRP 30 DCF Sv/Bq	Percent relative difference
Thorium series									
Th-228	1.1E-07	1.1E-07	0.0	1.E-07	1.E-07	0	1.E-07	1.E-07	0
Ra-224	3.5E-08	9.9E-08	-65	4.E-08	7.E-08	-40	4.E-08	8.E-08	-50
Pb-212	1.3E-08	1.5E-08	-13	1.E-08	1.E-08	0	1.E-08	1.E-08	0
Bi-212	3.0E-10	2.9E-10	3.4	3.E-10	3.E-10	0	3.E-10	3.E-10	0
Uranium series									
Th-234	3.6E-09	3.7E-09	-2.7	4.E-09	3.E-09	30	4.E-09	5.E-09	-20
Pa-234	6.0E-10	5.8E-10	3.4	6.E-10	7.E-10	-10	6.E-10	6.E-10	0
Neptunium series									
Pa-233	9.6E-10	9.8E-10	-2.0	1.E-09	7.E-10	40	1.E-09	8.E-10	25
Ra-225	6.0E-08	1.0E-07	-40	6.E-08	7.E-08	-10	6.E-08	8.E-08	-25
Ac-225	3.0E-08	3.0E-08	0.0	3.E-08	3.E-08	0	3.E-08	3.E-08	0
Actinium series									
Np-239	8.9E-10	8.8E-10	1.1	9.E-10	7.E-10	30	9.E-10	8.E-10	13
Th-227	1.0E-08	1.0E-08	0.0	1.E-08	1.E-08	0	1.E-08	1.E-08	0
Ra-223	7.2E-08	1.9E-07	-62	7.E-08	2.E-07	-70	7.E-08	2.E-07	-70
Fr-223	3.0E-09	2.3E-09	30	3.E-09	2.E-09	50	3.E-09	3.E-09	0
Other radionuclides									
Nb-93m	1.4E-10	1.4E-10	0.0	1.E-10	1.E-10	0	1.E-10	1.E-10	0
Y-90	2.9E-09	2.9E-09	0.0	3.E-09	3.E-09	0	3.E-09	3.E-09	0

Table 11. Relative Difference Between GENII-S Doses per Unit Activity Intake by Inhalation and DCFs from Other Data Sets for Decay Products Included with the Primary Radionuclides.

Radionuclide	GENII-S vs. FGR 11			GENII-S vs. 10 CFR 20			GENII-S vs. ICRP-30		
	GENII-S DCF Sv/Bq	FGR 11 DCF Sv/Bq	Percent relative difference	GENII-S DCF Sv/Bq	10CFR 20 DCF Sv/Bq	Percent relative difference	GENII-S DCF Sv/Bq	ICRP 30 DCF Sv/Bq	Percent relative difference
Thorium series									
Th-228	9.3E-05	9.2E-05	1.1	9.E-05	7.E-05	30	9.E-05	8.E-05	10
Ra-224	8.1E-07	8.5E-07	-4.7	8.E-07	8.E-07	0	8.E-07	8.E-07	0
Pb-212	4.8E-08	4.6E-08	4.3	5.E-08	5.E-08	0	5.E-08	5.E-08	0
Bi-212	6.1E-09	5.8E-09	5.2	6.E-09	7.E-09	-10	6.E-09	6.E-09	0
Uranium series									
Th-234	9.5E-09	9.5E-09	0.0	1.E-08	7.E-09	40	1.E-08	8.E-09	30
Pa-234	2.3E-10	2.2E-10	4.5	2.E-10	2.E-10	0	2.E-10	3.E-10	-30
Neptunium series									
Pa-233	2.6E-09	2.6E-09	0.0	3.E-09	2.E-09	50	3.E-09	3.E-09	0
Ra-225	2.6E-06	2.1E-06	24	3.E-06	2.E-06	50	3.E-06	3.E-06	0
Ac-225	3.0E-06	2.9E-06	3.4	3.E-06	3.E-06	0	3.E-06	3.E-06	0
Actinium series									
Np-239	7.0E-10	6.8E-10	2.9	7.E-10	7.E-10	0	7.E-10	6.E-10	17
Th-227	4.4E-06	4.4E-06	0.0	4.E-06	5.E-06	-20	4.E-06	5.E-06	-20
Ra-223	2.1E-06	2.1E-06	0.0	2.E-06	2.E-06	0	2.E-06	2.E-06	0
Fr-223	2.1E-09	1.7E-09	24	2.E-09	2.E-09	0	2.E-09	2.E-09	0
Other radionuclides									
Nb-93m	8.1E-09	7.9E-09	2.5	8.E-09	7.E-09	10	8.E-09	8.E-09	0
Y-90	2.4E-09	2.3E-09	4.3	2.E-09	2.E-09	0	2.E-09	3.E-09	-30

6.5 ANALYSIS OF DOSE COEFFICIENTS FOR EXTERNAL EXPOSURE

As previously noted, GENII-S offers an option of substituting user-defined values of dose coefficients for external exposure for the original values. The FGR 12 contains the most recent EPA compilation of dose coefficients for exposure to contaminated soil and for air submersion. Therefore, FGR 12 values were used to replace older GENII-S values. The new values were incorporated into the new GENII-S input file, replacing GRDF.DAT, following unit conversion from Sv/s per Bq/m^3 to Sv/y per Bq/m^3 (DC in Sv/s per Bq/m^3 was multiplied by 3.15×10^7 sec/y to get DC in Sv/y per Bq/m^3). Doses from external exposure were then calculated using GENII-S for the simple exposure scenarios (see Section 5.2) to verify that the dose coefficients were incorporated correctly into the input file. The scenario considered for exposure to contaminated soil included a receptor exposed for one year to a unit activity concentration of a radionuclide in the top 15-cm layer of soil. For the air submersion scenario, a receptor was exposed for a year to a unit activity concentration in air.

FGR 12 dose coefficients and the results of GENII-S calculations of doses from external exposure for the primary radionuclides under consideration are listed in Table 12. Table 13 contains results for the decay products of some of these radionuclides that are tracked by GENII-S. Table 14 shows calculation of composite entries for Table 13 that result from the contribution of the decay products in equilibrium with the parent radionuclide (see Section 6.1). The only differences between GENII-S dose values and FGR 12 DCs are due to rounding, indicating that the input file (GRDF.DAT) had been developed correctly. The printout of the new GRDF.DAT file is included in Attachment 4.

Table 12. Verification of DCs for Exposure to Soil Contaminated to a Depth of 15 cm and DCs for Air Submersion for the Primary Radionuclides.

Radionuclide	Exposure to Contaminated Soil			Air Submersion		
	FGR 12 Dose Coefficient		GENII-S Annual Dose Sv per Bq/m3	FGR 12 Dose Coefficient		GENII-S Annual Dose Sv per Bq/m3
	Sv/s per Bq/m3	Sv/y per Bq/m3		Sv/s per Bq/m3	Sv/y per Bq/m3	
Ac-227	2.62E-21	8.26E-14	8.3E-14	5.82E-18	1.84E-10	1.8E-10
Am-241	2.34E-19	7.38E-12	7.4E-12	8.18E-16	2.58E-08	2.6E-08
Am-243	7.60E-19	2.40E-11	2.4E-11	2.18E-15	6.87E-08	6.9E-08
C-14	7.20E-23	2.27E-15	2.3E-15	2.24E-19	7.06E-12	7.1E-12
Cs-137 (Ba-137m)	1.71E-17	5.39E-10	5.4E-10	2.88E-14	9.08E-07	9.1E-07
I-129	6.93E-20	2.19E-12	2.2E-12	3.80E-16	1.20E-08	1.2E-08
Mo-93	3.16E-21	9.97E-14	1.0E-13	2.52E-17	7.95E-10	8.0E-10
Ni-63	0.00E+00	0.00E+00	0.0E+00	0.00E+00	0.00E+00	0.0E+00
Np-237	4.16E-19	1.31E-11	1.3E-11	1.03E-15	3.25E-08	3.3E-08
Pa-231	9.62E-19	3.03E-11	3.0E-11	1.72E-15	5.42E-08	5.4E-08
Pu-238	8.07E-22	2.54E-14	2.5E-14	4.88E-18	1.54E-10	1.5E-10
Pu-239	1.52E-21	4.79E-14	4.8E-14	4.24E-18	1.34E-10	1.3E-10
Pu-240	7.84E-22	2.47E-14	2.5E-14	4.75E-18	1.50E-10	1.5E-10
Sr-90	3.72E-21	1.17E-13	1.2E-13	7.53E-18	2.37E-10	2.4E-10
Tc-99	6.70E-22	2.11E-14	2.1E-14	1.62E-18	5.11E-11	5.1E-11
Th-229	1.70E-18	5.36E-11	5.4E-11	3.83E-15	1.21E-07	1.2E-07
U-232	4.77E-21	1.50E-13	1.5E-13	1.42E-17	4.48E-10	4.5E-10
U-233	7.24E-21	2.28E-13	2.3E-13	1.63E-17	5.14E-10	5.1E-10
U-234	2.14E-21	6.75E-14	6.8E-14	7.63E-18	2.41E-10	2.4E-10
U-236	1.14E-21	3.60E-14	3.6E-14	5.01E-18	1.58E-10	1.6E-10
U-238	5.52E-22	1.74E-14	1.7E-14	3.41E-18	1.08E-10	1.1E-10

Table 13. Verification of DCs for Exposure to Soil Contaminated to a Depth of 15 cm and DCs for Air Submersion for the Decay Products Included with the Primary Radionuclides.

Radionuclide	Exposure to Contaminated Soil			Air Submersion		
	FGR 12 Dose Coefficient		GENII-S Annual Dose, Sv per Bq/m3	FGR 12 Dose Coefficient		GENII-S Annual Dose, Sv per Bq/m3
	Sv/s per Bq/m3	Sv/y per Bq/m3		Sv/s per Bq/m3	Sv/y per Bq/m3	
Thorium series						
Th-228	4.17E-20	1.32E-12	1.3E-12	9.20E-17	2.90E-09	2.9E-09
Ra-224	2.73E-19	8.62E-12	8.6E-12	4.90E-16	1.55E-08	1.5E-08
Pb-212	3.62E-18	1.14E-10	1.1E-10	6.87E-15	2.17E-07	2.2E-07
Bi-212	4.01E-17	1.27E-09	1.3E-09	7.28E-14	2.30E-06	2.3E-06
Uranium series						
Th-234	5.48E-19	1.73E-11	1.7E-11	1.06E-15	3.33E-08	3.3E-08
Pa-234	5.38E-17	1.70E-09	1.7E-09	9.34E-14	2.95E-06	2.9E-06
Neptunium series						
Pa-233	5.16E-18	1.63E-10	1.6E-10	9.35E-15	2.95E-07	3.0E-07
Ra-225	5.90E-20	1.86E-12	1.9E-12	2.79E-16	8.80E-09	8.8E-09
Ac-225	6.14E-18	1.94E-10	1.9E-10	1.08E-14	3.40E-07	3.4E-07
Actinium series						
Np-239	3.90E-18	1.23E-10	1.2E-10	7.69E-15	2.43E-07	2.4E-07
Th-227	2.65E-18	8.36E-11	8.4E-11	4.88E-15	1.54E-07	1.5E-07
Ra-223	7.48E-18	2.36E-10	2.4E-10	1.37E-14	4.30E-07	4.3E-07
Fr-223	1.01E-18	3.19E-11	3.2E-11	2.29E-15	7.22E-08	7.2E-08
Other radionuclides						
Nb-93m	5.57E-22	1.76E-14	1.8E-14	4.44E-18	1.40E-10	1.4E-10
Y-90	1.20E-19	3.78E-12	3.8E-12	1.90E-16	5.99E-09	6.0E-09

Table 14. Contribution to DCs from Secondary Decay Products.

Radionuclide		FGR 12 Dose Coefficients			
		Ingestion		Inhalation	
		Sv/s per Bq/m3	Sv/y per Bq/m3	Sv/s per Bq/m3	Sv/y per Bq/m3
Ac-225	Ac-225	3.34E-19		7.21E-16	
	Fr-221	7.90E-19		1.46E-15	
	At-217	8.61E-21		1.48E-17	
	Bi-213	3.75E-18		6.39E-15	
	Po-213	0		0	
	Tl-209	1.25E-18		2.20E-15	
	Pb-209	4.08E-21		8.12E-18	
	Total	**6.14E-18**	**1.94E-10**	**1.08E-14**	**3.40E-07**
Th-234	Th-234	1.29E-19		3.38E-16	
	Pa-234m	4.19E-19		7.18E-16	
	Total	**5.48E-19**	**1.73E-11**	**1.06E-15**	**3.33E-08**
Ra-224	Ra-224	2.62E-19		4.71E-16	
	Rn-220	1.10E-20		1.85E-17	
	Po-216	4.87E-22		8.29E-19	
	Total	**2.73E-19**	**8.62E-12**	**4.90E-16**	**1.55E-08**
Bi-212	Bi-212	5.36E-18		9.24E-15	
	Po-212	0		0	
	Tl-208	3.48E-17		6.36E-14	
	Total	**4.01E-17**	**1.27E-09**	**7.28E-14**	**2.30E-06**
Ra-223	Ra-223	3.10E-18		6.09E-15	
	Rn-219	1.54E-18		2.68E-15	
	Po-215	4.98E-21		8.43E-18	
	Pb-211	1.46E-18		2.49E-15	
	Bi-211	1.28E-18		2.22E-15	
	Tl-207	9.48E-20		1.62E-16	
	Total	**7.48E-18**	**2.36E-10**	**1.37E-14**	**4.30E-07**

7. CONCLUSIONS

The objective of this analysis was to ensure that doses calculated by dose assessment component of GENII-S are consistent with doses calculated using similar methods currently accepted by the scientific and engineering community in the field of radiation protection. The analysis of internal doses confirmed that doses from radionuclide intake generated by GENII-S are, in most cases, consistent with doses that would be obtained if other ICRP-30-based DCFs were used. Among the DCF sets under consideration, the comparison between GENII-S and FGR 11 doses was the most meaningful because both models were developed in the late 1980s and therefore reflect similar states of knowledge in the area of radiation dosimetry. When these two dosimetric approaches are considered, relative differences between doses were less than 10% for about 86% of the primary radionuclides under consideration. In case of ^{99}Tc, GENII-S overestimates doses over FGR 11 doses by about 50%. In case of radium isotopes, GENII-S underestimates doses by about 60% relative to FGR 11 doses. These differences are acceptable considering the level of inherent uncertainties involved in the dose assessment process. Furthermore, it is not likely that underestimation of total doses (from all radionuclides) will result. Therefore, based on the results of this analysis, it is recommended that GENII-S internal dose assessment be conducted with no modifications to the auxiliary files.

For external exposure, a new input file containing dose coefficients for exposure to contaminated soil and for air submersion for radionuclides under consideration was developed using dose coefficients given in FGR 12. The new file was validated by comparing the resulting GENII-S doses with the expected values based on FGR 12.

The results of this analysis apply to radionuclides specified in preliminary screening analysis (CRWMS M&O 1999c), which is subject to potential modifications (TBV-3059). Upon receipt of the final results of radionuclide screening, this report may need to be revised. No impacts of other TBVs indicated in this analysis are anticipated.

Consideration of uncertainties associated with dosimetric modes, which are subject of this analysis, will be discussed in the related Biosphere Process Model Report.

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9. ATTACHMENTS

Attachment I - Document Input Reference Sheets (3 pages)
Attachment II – Glossary of Dosimetric Terms (1 page)
Attachment III – Detailed Reference Pointers for Numerical Input and Corroborative Data (2 pages)

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DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.:	Change:	Title:

Input Document							8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
2a			NA,		Ingestion and inhalation ALI; TBV not required because data are used as corroborative evidence. These inputs do not satisfy the definition of TBV per AP-3.15Q, *Managing Technical Product Inputs*, because they are not preliminary, they do not need to be reevaluated, do not need confirmation and do not affect critical characteristics of the product.				
1									
2									Pending release of AMR
3	Initial use.		Accepted data			1			
4			NA, Refer-ence	6.3	TBV not required because data are used as corroborative evidence. These inputs do not satisfy the definition of TBV per AP-3.15Q, *Managing Technical Product Inputs*, because they are not preliminary, they do not need to be reevaluated, do not need confirmation and do not affect critical characteristics of the product.				

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DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.:	Change:	Title:

	Input Document		4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
5			NA,	6.3	TBV not required because data are used as corroborative evidence. These inputs do not satisfy the definition of TBV per AP-3.15Q, *Managing Technical Product Inputs*, because they are not preliminary, they do not need to be reevaluated, do not need confirmation and do not affect critical characteristics of the product.				
6			NA,	Entire					
7			NA,		used in support of one of the assumptions.				
8			NA,		Description of incorporation of radioactive decay products into GENII-S code.				

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.:	Change:	Title:

	Input Document		4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
9	ACC: MOL.19980715.0029.		NA,		Reference used to indicate that software qualification has been completed.				
10			NA,		Description of dosimetric input files' format.				
11			Q			NA			

ATTACHMENT II
GLOSSARY OF DOSIMETRIC TERMS

Becquerel (Bq)
A unit of activity equal to one radioactive disintegration per second.

Curie (Ci)
A unit of activity equal to 3.7×10^{10} disintegrations per second.

Dose or radiation dose
A generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, total effective dose equivalent, equivalent dose, effective dose, committed equivalent dose, or committed effective dose.

Exposure
Being exposed to ionizing radiation or to radioactive material.

External dose
That portion of the dose equivalent or equivalent dose received from radiation sources outside the body.

Internal dose
That portion of the dose equivalent or equivalent dose received from radioactive material taken into the body.

Rem
A special unit of dose equivalent, and effective dose equivalent. 1 rem = 0.01 Sv.

Sievert (Sv)
The name for the unit of equivalent dose, effective dose, dose equivalent, and effective dose equivalent. $1 \text{ Sv} = 1 \text{ J kg}^{-1}$.

Weighting factor
For organs or tissue is the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly.

ATTACHMENT III

Table 15. Detailed Reference Pointers for Numerical Input and Corroborative Data.

Radionuclide	FGR 11 DCF for Internal Exposure		FGR 12 DC for External Exposure		10 CFR 20 ALI Ingestion and Inhalation	ICRP-30 ALI for Ingestion and Inhalation
	Ingestion	Inhalation	From Soil	From Air		
Primary Radionuclides of Interest						
Ac-227	Table 2.2, p. 176	Table 2.1, p. 149	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 3, p. 107
Am-241	Table 2.2, p. 178	Table 2.1, p. 152	Table III.6, p. 162	Table III.1, p. 72	Appendix B, Table 1	Part 1, p. 110
Am-243	Table 2.2, p. 178	Table 2.1, p. 152	Table III.6, p. 162	Table III.1, p. 72	Appendix B, Table 1	Part 1, p. 110
C-14	Table 2.2, p. 156	Table 2.1, p. 122	Table III.6, p. 148	Table III.1, p. 58	Appendix B, Table 1	Part 3, p. 9
Cs-137	Table 2.2, p. 166	Table 2.1, p. 137	Table III.6, p. 155	Table III.1, p. 65	Appendix B, Table 1	Part 1, p. 93
I-129	Table 2.2, p. 166	Table 2.1, p. 136	Table III.6, p. 154	Table III.1, p. 64	Appendix B, Table 1	Part 1, p. 90
Mo-93	Table 2.2, p. 161	Table 2.1, p. 129	Table III.6, p. 151	Table III.1, p. 61	Appendix B, Table 1	Part 1, p. 84
Ni-63	Table 2.2, p. 158	Table 2.1, p. 125	Table III.6, p. 149	Table III.1, p. 59	Appendix B, Table 1	Part 3, p. 27
Np-237	Table 2.2, p. 177	Table 2.1, p. 151	Table III.6, p. 162	Table III.1, p. 72	Appendix B, Table 1	Part 2, p. 71
Pa-231	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 3, p. 110
Pu-238	Table 2.2, p. 177	Table 2.1, p. 151	Table III.6, p. 162	Table III.1, p. 72	Appendix B, Table 1	Part 1, p. 107
Pu-239	Table 2.2, p. 177	Table 2.1, p. 151	Table III.6, p. 162	Table III.1, p. 72	Appendix B, Table 1	Part 1, p. 107
Pu-240	Table 2.2, p. 177	Table 2.1, p. 151	Table III.6, p. 162	Table III.1, p. 72	Appendix B, Table 1	Part 1, p. 107
Sr-90	Table 2.2, p. 160	Table 2.1, p. 128	Table III.6, p. 151	Table III.1, p. 61	Appendix B, Table 1	Part 1, p. 78
Tc-99	Table 2.2, p. 162	Table 2.1, p. 130	Table III.6, p. 152	Table III.1, p. 62	Appendix B, Table 1	Part 2, p. 34
Th-229	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 101
U-232	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 104
U-233	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 104
U-234	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 104
U-236	Table 2.2, p. 176	Table 2.1, p. 151	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 104
U-238	Table 2.2, p. 176	Table 2.1, p. 151	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 104
Decay Products of Primary Radionuclides Tracked in GENII-S						
Th-228	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 101
Ra-224	Table 2.2, p. 175	Table 2.1, p. 149	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 99
Pb-212	Table 2.2, p. 175	Table 2.1, p. 148	Table III.6, p. 160	Table III.1, p. 70	Appendix B, Table 1	Part 2, p. 66
Bi-212	Table 2.2, p. 175	Table 2.1, p. 148	Table III.6, p. 160	Table III.1, p. 70	Appendix B, Table 1	Part 2, p. 68
Th-234	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 101
Pa-234	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 3, p. 110

Table 15. continued.

Radionuclide	FGR 11 DCF for Internal Exposure		FGR 12 DC for External Exposure		10 CFR 20 ALI Ingestion and Inhalation	ICRP-30 ALI for Ingestion and Inhalation
	Ingestion	Inhalation	From Soil	From Air		
Decay Products of Primary Radionuclides Tracked in GENII-S						
Pa-233	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 3, p. 110
Ra-225	Table 2.2, p. 175	Table 2.1, p. 149	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 99
Ac-225	Table 2.2, p. 175	Table 2.1, p. 149	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 3, p. 107
Np-239	Table 2.2, p. 177	Table 2.1, p. 151	Table III.6, p. 162	Table III.1, p. 72	Appendix B, Table 1	Part 2, p. 71
Th-227	Table 2.2, p. 176	Table 2.1, p. 150	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 101
Ra-223	Table 2.2, p. 175	Table 2.1, p. 149	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 1, p. 99
Fr-223	Table 2.2, p. 175	Table 2.1, p. 149	Table III.6, p. 161	Table III.1, p. 71	Appendix B, Table 1	Part 3, p. 105
Nb-93m	Table 2.2, p. 161	Table 2.1, p. 129	Table III.6, p. 151	Table III.1, p. 61	Appendix B, Table 1	Part 1, p. 82
Y-90	Table 2.2, p. 161	Table 2.1, p. 128	Table III.6, p. 151	Table III.1, p. 61	Appendix B, Table 1	Part 2, p. 31
Decay Products in Equilibrium with their Parents						
Fr-221	---	---	Table III.6, p. 161	Table III.1, p. 71	---	---
At-217	---	---	Table III.6, p. 161	Table III.1, p. 71	---	---
Bi-213	Table 2.2, p. 175	Table 2.1, p. 149	Table III.6, p. 160	Table III.1, p. 70	Appendix B, Table 1	Part 2, p. 68
Po-213	---	---	Table III.6, p. 160	Table III.1, p. 70	---	---
Tl-209	---	---	Table III.6, p. 160	Table III.1, p. 70	---	---
Pb-209	Table 2.2, p. 175	Table 2.1, p. 148	Table III.6, p. 160	Table III.1, p. 70	Appendix B, Table 1	Part 2, p. 66
Pa-234m	---	---	Table III.6, p. 161	Table III.1, p. 71	---	---
Rn-220	---	---	Table III.6, p. 161	Table III.1, p. 71	---	
Po-216	---	---	Table III.6, p. 160	Table III.1, p. 70	---	---
Po-212	---	---	Table III.6, p. 160	Table III.1, p. 70	---	---
Tl-208	---	---	Table III.6, p. 160	Table III.1, p. 70	---	---
Rn-219	---	---	Table III.6, p. 161	Table III.1, p. 71	---	---
Po-215	---	---	Table III.6, p. 160	Table III.1, p. 70	---	---
Pb-211	Table 2.2, p. 175	Table 2.1, p. 148	Table III.6, p. 160	Table III.1, p. 70	Appendix B, Table 1	Part 2, p. 66
Bi-211	---	---	Table III.6, p. 160	Table III.1, p. 70	---	---
Tl-207	---	---	Table III.6, p. 160	Table III.1, p. 70	---	---

ATTACHMENT IV

Printout of GRDF.DAT file.

FGR12 air, water, soil(15 cm) DCs (Sv/yr per Bq/n) (25 Jul 99 MAW)

	Air	Water	Soil	Buried	Buried	Buried
	Submersion	Surface	15 cm	0.15 m	0.5 m	1.0m
n	m3	L	"m3"	m3	m3	m3
C 14	7.06E-12	0.00E+00	2.27E-15	0.00E+00	0.00E+00	0.00E+00
NI63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR90	2.37E-10	0.00E+00	1.17E-13	0.00E+00	0.00E+00	0.00E+00
Y 90	5.99E-09	0.00E+00	3.78E-12	0.00E+00	0.00E+00	0.00E+00
MO93	7.95E-10	0.00E+00	9.97E-14	0.00E+00	0.00E+00	0.00E+00
NB93M	1.40E-10	0.00E+00	1.76E-14	0.00E+00	0.00E+00	0.00E+00
TC99	5.11E-11	0.00E+00	2.11E-14	0.00E+00	0.00E+00	0.00E+00
I 129	1.20E-08	0.00E+00	2.19E-12	0.00E+00	0.00E+00	0.00E+00
CS137	9.08E-07	0.00E+00	5.39E-10	0.00E+00	0.00E+00	0.00E+00
U 232	4.48E-10	0.00E+00	1.50E-13	0.00E+00	0.00E+00	0.00E+00
TH228	2.90E-09	0.00E+00	1.32E-12	0.00E+00	0.00E+00	0.00E+00
RA224	1.55E-08	0.00E+00	8.62E-12	0.00E+00	0.00E+00	0.00E+00
PB212	2.17E-07	0.00E+00	1.14E-10	0.00E+00	0.00E+00	0.00E+00
BI212	2.30E-06	0.00E+00	1.27E-09	0.00E+00	0.00E+00	0.00E+00
U 234	2.41E-10	0.00E+00	6.75E-14	0.00E+00	0.00E+00	0.00E+00
U 236	1.58E-10	0.00E+00	3.60E-14	0.00E+00	0.00E+00	0.00E+00
PA231	5.42E-08	0.00E+00	3.03E-11	0.00E+00	0.00E+00	0.00E+00
AC227	1.84E-10	0.00E+00	8.26E-14	0.00E+00	0.00E+00	0.00E+00
TH227	1.54E-07	0.00E+00	8.36E-11	0.00E+00	0.00E+00	0.00E+00
FR223	7.22E-08	0.00E+00	3.19E-11	0.00E+00	0.00E+00	0.00E+00
RA223	4.30E-07	0.00E+00	2.36E-10	0.00E+00	0.00E+00	0.00E+00
NP237	3.25E-08	0.00E+00	1.31E-11	0.00E+00	0.00E+00	0.00E+00
PA233	2.95E-07	0.00E+00	1.63E-10	0.00E+00	0.00E+00	0.00E+00
U 233	5.14E-10	0.00E+00	2.28E-13	0.00E+00	0.00E+00	0.00E+00
TH229	1.21E-07	0.00E+00	5.36E-11	0.00E+00	0.00E+00	0.00E+00
RA225	8.80E-09	0.00E+00	1.86E-12	0.00E+00	0.00E+00	0.00E+00
AC225	3.40E-07	0.00E+00	1.94E-10	0.00E+00	0.00E+00	0.00E+00
U 238	1.08E-10	0.00E+00	1.74E-14	0.00E+00	0.00E+00	0.00E+00
TH234	3.33E-08	0.00E+00	1.73E-11	0.00E+00	0.00E+00	0.00E+00
PA234	2.95E-06	0.00E+00	1.70E-09	0.00E+00	0.00E+00	0.00E+00
PU238	1.54E-10	0.00E+00	2.54E-14	0.00E+00	0.00E+00	0.00E+00
PU240	1.50E-10	0.00E+00	2.47E-14	0.00E+00	0.00E+00	0.00E+00
AM241	2.58E-08	0.00E+00	7.38E-12	0.00E+00	0.00E+00	0.00E+00
AM243	6.87E-08	0.00E+00	2.40E-11	0.00E+00	0.00E+00	0.00E+00
NP239	2.43E-07	0.00E+00	1.23E-10	0.00E+00	0.00E+00	0.00E+00
PU239	1.34E-10	0.00E+00	4.79E-14	0.00E+00	0.00E+00	0.00E+00