

# OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT SCIENTIFIC ANALYSIS COVER SHEET

1. QA: QA

Page: 1 Of: 44

2. Scientific Analysis Title  
Radionuclide Screening

3. DI (Including Revision Number)  
ANL-WIS-MD-000006 REV 01

4. Total Attachments  
6

5. Attachment Numbers - Number of pages in each  
I - 8, II - 6, III - 15, IV - 1, V - 1, VI - compact disk

	Print Name	Signature	Date
6. Originator	Guy Ragan	SIGNATURE ON FILE	8-7-02
7. Checker	Kathleen Economy	SIGNATURE ON FILE	8/8/02
8. QER	Daniel Tunney	SIGNATURE ON FILE	8/8/02
9. Responsible Manager/Lead	Christine Stockman	SIGNATURE ON FILE	8/8/02
10. Responsible Manager	Howard Adkins	SIGNATURE ON FILE	08/09/02

11. Remarks  
This revision fulfils the commitments regarding radionuclide screening that were made in response to Technical Error Report TER-02-0064 (see AP-15.3Q, Control of Technical Product Errors).

Technical Contact/Department: Christine Stockman / Waste Form Department

### Revision History

12. Revision/ICN No.	13. Description of Revision/Change
REV 00	Initial issue.
REV 00 ICN 01	Changed accounting for naval fuel.
REV 00 ICN 02	Replace citations of input transmittals with citations of calculations. Cite revised calculation CAI-WIS-MD-000004 REV 00 ICN 01. Make other minor changes.
REV 00 ICN 03	Add Attachment II to consider neutron-activation products outside the commercial spent nuclear fuel matrix. Correct a typographical error in the activity of Np-237 in Table I-7. Make other minor changes.
REV 01	Completely revise: (1) drop the inventory projections (the old Attachments I and II) to simplify the organization of the analysis and because an updated CSNF waste stream is expected after approval of this analysis;
REV 01 (continued)	(2) revise the screening method to include (a) an intermediate solubility class, (b) external exposure, & (c) effects of the biosphere. Change bars are not used due to extensive revision. See remarks in Box 11.

Rev. 12/21/2001

# CONTENTS

	Page
ACRONYMS AND ABBREVIATIONS .....	5
1. PURPOSE .....	6
2. QUALITY ASSURANCE .....	7
3. USE OF SOFTWARE.....	7
3.1 SOFTWARE APPROVED FOR QUALITY ASSURANCE (QA) WORK.....	7
3.2 COMMERCIAL OFF-THE-SHELF SOFTWARE USED .....	7
4. INPUTS .....	8
4.1 DATA AND PARAMETERS .....	8
4.2 CRITERIA .....	10
4.3 CODES AND STANDARDS.....	10
5. ASSUMPTIONS .....	11
6. SCIENTIFIC ANALYSIS DISCUSSION .....	21
6.1 PREVIOUS RADIONUCLIDE SCREENING ACTIVITIES .....	21
6.2 CONCEPTUAL BASIS.....	21
6.2.1 Summary of the Screening Process .....	21
6.2.2 Accounting for Variations in Waste Packages .....	23
6.2.3 Accounting for Time of Exposure.....	24
6.2.4 Accounting for Sorption.....	24
6.2.5 Accounting for Solubility.....	25
6.2.6 Determining the Screening Sets .....	25
6.2.7 Operational Description of the Screening Software.....	26
6.3 RESULTS .....	27
6.3.1 10,000-Year Regulatory Period.....	27
6.3.2 Incremental Effect of Including the 20,000-Year Screening Time .....	28
6.3.3 Times Beyond the Regulatory Period Up To 1 Million Years .....	28
6.4 OTHER SCREENING FACTORS CONSIDERED AND REJECTED .....	28
6.5 UNCERTAINTIES .....	30
6.6 ADDITIONAL RADIONUCLIDES RECOMMENDED .....	31
6.6.1 Separate Groundwater Protection Standard.....	31
6.6.2 Precursors of Other Recommended Radionuclides.....	32
6.7 RESPONSES TO COMMENTS FROM EXTERNAL REVIEWS .....	34
6.7.1 Nuclear Regulatory Commission .....	34
6.7.2 International Peer Review Panel .....	35
7. CONCLUSIONS .....	38
8. INPUTS AND REFERENCES .....	40
8.1 DOCUMENTS CITED.....	40

**CONTENTS (continued)**

	<b>Page</b>
8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES.....	44
8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER .....	44
ATTACHMENT I. SCREENING FACTORS FOR GROUNDWATER SCENARIOS.....	I-1
ATTACHMENT II. SCREENING FACTORS FOR THE ERUPTIVE SCENARIO .....	II-1
ATTACHMENT III. EVALUATION OF DOSE COEFFICIENTS FROM NCRP (1996) ....	III-1
ATTACHMENT IV. CORRECTION OF Se-79 ACTIVITIES.....	IV-1
ATTACHMENT V. CONTENTS OF ATTACHMENT VI.....	V-1
ATTACHMENT VI. RadNuScreen INPUTS AND RESULTS (COMPACT DISK) .....	N/A

## FIGURES

	<b>Page</b>
Figure III-1. Graphical Comparison of Inhalation Dose Coefficients from Two Sources .....	III-10
Figure III-2. Graphical Comparison of Ingestion Dose Coefficients from Two Sources.....	III-15
Figure V-1. Contents of Attachment VI .....	V-1

## TABLES

	<b>Page</b>
Table 1. Project-Generated Usage Factors.....	8
Table 2. Half-lives Used To Discriminate Between Long-lived ( $\geq 10$ y) and Short-lived Radionuclides.....	9
Table 3. Relative Contribution of the Inhalation Pathway for the Eruptive Screening Factors.....	12
Table 4. Assumed Solubility and Sorption Classes for the Screening Analysis.....	15
Table 5. Solubility Class Assignments and Rationales.....	17
Table 6. Radionuclides Included in Other TSPAs.....	22
Table 7. How Flow Conditions May Discriminate According to Sorptivity in the Groundwater Scenarios.....	25
Table 8. Descriptions of the Screening Sets for the Groundwater Scenarios .....	26
Table 9. Lists of Elements in Each Screening Set .....	26
Table 10. Screening Results for the 10,000-Year Regulatory Period.....	29
Table 11. Screening Results for Times Beyond 10,000 Years and Up To 1 Million Years.....	30
Table 12. Additional Radionuclides Needed for Accurate Accounting of Those Screened In .....	32
Table 13. Results of the Screening Analysis .....	39
Table I-1. Adjustment Factors for Groundwater and Eruptive Scenarios .....	I-1
Table I-2. Calculation of Groundwater Screening Factors .....	I-4
Table II-1. Calculation of Igneous Eruptive Screening Factors .....	II-2
Table III-1. Comparison of Ground Irradiation Dose Coefficients from Two Sources.....	III-2
Table III-2. Comparison of Inhalation Dose Coefficients from Two Sources .....	III-7
Table III-3. Comparison of Ingestion Dose Coefficients from Two Sources.....	III-11

## ACRONYMS AND ABBREVIATIONS

BWR	boiling water reactor
CSNF	commercial spent nuclear fuel
DOE	U.S. Department of Energy
DSNF	DOE spent nuclear fuel
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
H	High solubility or sorption class
HLW	high-level radioactive waste
L	Low solubility or sorption class
M	Medium solubility or sorption class
NCRP	National Council on Radiation Protection and Measurements
NRC	U.S. Nuclear Regulatory Commission
QA	Quality Assurance
OCRWM	DOE Office of Civilian Radioactive Waste Management
PWR	pressurized water reactor
SNF	spent nuclear fuel
TSPA	total system performance assessment

## 1. PURPOSE

The waste forms under consideration for disposal in the proposed repository at Yucca Mountain contain scores of radionuclides (Attachments V and VI). It would be impractical and highly inefficient to model all of these radionuclides in a total system performance assessment (TSPA). Thus, the purpose of this radionuclide screening analysis is to remove from further consideration (screen out) radionuclides that are unlikely to significantly contribute to radiation dose to the public from the proposed nuclear waste repository at Yucca Mountain. The remaining nuclides (those screened in) are recommended for consideration in TSPA modeling for license application. This analysis also covers radionuclides that are not screened in based on dose, but need to be included in TSPA modeling for other reasons. For example, U.S. Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (NRC) regulations require consideration of the combined activity of Ra-226 and Ra-228 in groundwater (40 CFR 197.30, 10 CFR 63.331). Also, Cm-245, Pu-241, and U-235 decay indirectly to potentially important radionuclides, and are not identified by the screening analysis as important.

The radionuclide screening analysis separately considers two different postclosure time periods: the 10,000-y regulatory period for the proposed repository at Yucca Mountain and the period after 10,000 y up to 1 million y after emplacement. The incremental effect of extending the screening for the regulatory period to 20,000 y is also addressed. Four release scenarios are considered: (1) the nominal scenario, which entails long-term degradation of disposal containers and waste forms, (2) a human-intrusion scenario, (3) an intrusive igneous event, and (4) an eruptive igneous event. Because the first three scenarios require groundwater transport, they are called groundwater scenarios below. The screening analysis considers the following waste forms: spent boiling water reactor (BWR) fuel, spent pressurized water reactor (PWR) fuel, U.S. Department of Energy (DOE) spent nuclear fuel (DSNF), and high-level waste (HLW). Average and outlying (high burnup, high initial enrichment, low age, or otherwise exceptional) forms of each waste-form type are considered. This analysis has been prepared in accordance with a technical work plan (BSC 2002c).

In a review of Revision 00 of this radionuclide screening analysis, the NRC found that “processes that affect transport in the biosphere, such as uptake by plants and bioaccumulation are not accounted for” and that “the direct exposure pathway is not accounted for” (Beckman 2001, Section 5.3.2.1). The NRC also found that the solubility and sorption classes were too broadly defined, noting, for example, that Se is in the same solubility and sorptivity groups as Np and U, yet is “more soluble than Np and U by several orders of magnitude” (Beckman 2001, Section 5.3.2.1). This revision seeks to build upon the strengths of the earlier screening method while responding to the specific concerns raised by the NRC and other reviewers. In place of simple inhalation and ingestion dose conversion factors, the revised radionuclide screening uses screening factors that also take into account soil accumulation, uptake by plants, exposure to contaminated ground, and other features of the biosphere that were neglected in the previous screening. Whereas the previous screening analysis allowed only two solubility classes (soluble and insoluble), the revised screening introduces an intermediate solubility class to better segregate the radionuclides into transport groups.

## 2. QUALITY ASSURANCE

An activity evaluation (BSC 2002c, Attachment I, Activity Evaluation for Waste Form Modeling and Analysis for LA), which was prepared in accordance with AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities*, determined that the Quality Assurance (QA) program applies to the activity under which this analysis was developed. Control of the electronic management of information was accomplished in accordance with the controls specified by BSC (2002c, Attachment III). The analysis was prepared in accordance with AP-SIII.9Q, *Scientific Analyses* and AP-3.15Q, *Managing Technical Product Inputs*.

## 3. USE OF SOFTWARE

### 3.1 SOFTWARE APPROVED FOR QUALITY ASSURANCE (QA) WORK

RadNuScreen 1.0 (BSC 2002a), which was obtained from Software Configuration Management, was used for the screening analysis. RadNuScreen 1.0 is appropriate for the application because it was designed specifically for use in this radionuclide screening analysis. RadNuScreen 1.0 is qualified and was used within the range of validation in accordance with AP-SI.1Q, *Software Management*. The software was used on a Dell Optiplex GX240 personal computer (central processing unit number 150418) with Excel 97 SR-2 and the Windows 2000 operating system. Input and output workbook files are provided in Attachment VI, with a listing of contents in Attachment V. Except for the Screening Summary file, which is an output summary, the first two worksheets in each workbook file provide the inputs, while the remaining worksheets provide the outputs.

### 3.2 COMMERCIAL OFF-THE-SHELF SOFTWARE USED

Microsoft Excel 97 SR-2, a commercially available spreadsheet software package, was used to process RadNuScreen inputs and results and to display information in graphical form. Excel is appropriate for the application because the calculations require simple mathematical expressions and operations that are standard in Excel to derive the results and because Excel has built-in graphical capabilities. The specific built-in functions of Excel that were used for calculations are described at the point of use.

## 4. INPUTS

### 4.1 DATA AND PARAMETERS

4.1.1 Project-generated usage factors (Table 1) are taken from *Disruptive Event Biosphere Dose Conversion Factor Analysis*, ANL-MGR-MD-000003 REV 01 (CRWMS M&O 2001a, Section 6.5.3) and *Nominal Performance Biosphere Dose Conversion Factor Analysis*, ANL-MGR-MD-000009 REV 01 (CRWMS M&O 2001c, Section 6.5). The inputs are appropriate for use in the screening analysis because they pertain to the local biosphere (or are generic values that have been found appropriate to represent the local biosphere) and are the most recent available at the time of this analysis.

Table 1. Project-Generated Usage Factors

Description	Value	Reference
Swimming and boating exposure	0 h/y	CRWMS M&O 2001c, Table 8
Shoreline exposure	0 h/y	CRWMS M&O 2001c, Table 8
Soil exposure for the groundwater scenarios	3,387 h/y	CRWMS M&O 2001c, Table 8 DTN: MO0010SPAAAM01.014
Soil exposure for the eruptive igneous scenario	3,387 h/y	CRWMS M&O 2001a, Table 10 DTN: MO0010SPAAAM01.014
Drinking water consumption	752.85 L/y	CRWMS M&O 2001c, Table 8 DTN: MO0007SPADMM05.002
Consumption of locally raised fish	0.47 kg/y	CRWMS M&O 2001c, Table 8 DTN: MO0007SPADMM05.002
Combined consumption of locally grown leafy and root vegetables, fruit, and grain	39 kg/y	CRWMS M&O 2001c, Table 8 DTN: MO0007SPADMM05.002
Consumption of locally produced milk	4.14 kg/y	CRWMS M&O 2001c, Table 8 DTN: MO0007SPADMM05.002
Combined consumption of locally produced beef, poultry, and eggs	10.41 kg/y	CRWMS M&O 2001c, Table 8 DTN: MO0007SPADMM05.002
Inadvertent ingestion of soil	50 mg/d	CRWMS M&O 2001c, Table 8 DTN: MO0010SPAPET07.004
Inhalation exposure	6,073.5 h/y	CRWMS M&O 2001a, Table 10 DTN: MO0010SPAAAM01.014
Chronic breathing rate	23 m <sup>3</sup> /d	DTN: MO0010SPAAAM01.014
Chronic and acute plume exposure	0 h/y	CRWMS M&O 2001a, Table 10

4.1.2 Half-lives for radioactive decay are primarily taken from Parrington et al. (1996), which is appropriate for use in this analysis because it is recognized as established fact in the Accepted Data database. For Se-79, a different source is used (Assumption 5.3). Except for Se-79, the only reason the half-lives are needed is to distinguish radionuclides with half-lives greater than or equal to 10 y from those with half-lives less than 10 years. Therefore, the half-lives used are sometimes rounded to the nearest year (Table 2), which results in 0-y half-lives for a number of nuclides. Table 2 covers all of the nuclides for which activities were calculated in the activity calculations that feed the screening

analysis (see Assumptions 5.4, 5.11, and 5.12) and is a complete list of the radionuclides that were considered in the screening analysis. As indicated in Table 2, a few of the extremely long-lived nuclides are listed as stable by Parrington et al. (1996).

Table 2. Half-lives Used To Discriminate Between Long-lived ( $\geq 10$  y) and Short-lived Radionuclides

Nuclide	Half-life (y)						
Ac-225	0	Co-58	0	Pb-212	0	Sm-148	Stable
Ac-227	22	Co-60	5	Pb-214	0	Sm-149	Stable
Ac-228	0	Cs-134	2	Pd-107	6,500,000	Sm-151	90
Ag-108	0	Cs-135	2,300,000	Pm-145	18	Sn-113	0
Ag-108m	130	Cs-137	30	Pm-146	6	Sn-119m	1
Ag-109m	0	Eu-150	36	Pm-147	3	Sn-121	0
Ag-110	0	Eu-152	14	Po-210	0	Sn-121m	55
Ag-110m	1	Eu-154	9	Po-211	0	Sn-123	0
Am-241	433	Eu-155	5	Po-212	0	Sn-126	250,000
Am-242	0	Fe-55	3	Po-213	0	Sr-90	29
Am-242m	1,141	Fr-221	0	Po-214	0	Tb-160	0
Am-243	7,370	Fr-223	0	Po-215	0	Tc-98	4,200,000
Ar-39	269	Gd-152	1.1E+14	Po-216	0	Tc-99	213,000
At-217	0	Gd-153	1	Po-218	0	Te-123m	0
Ba-133	11	H-3	12	Pr-144	0	Te-125m	0
Ba-137m	0	Ho-166m	0	Pr-144m	0	Te-127	0
Bi-210	0	I-129	15,700,000	Pt-193	60	Te-127m	0
Bi-211	0	In-113m	0	Pu-236	3	Th-227	0
Bi-212	0	K-40	1.27E+09	Pu-238	90	Th-228	2
Bi-213	0	Kr-85	11	Pu-239	24,100	Th-229	7,300
Bi-214	0	La-138	1.05E+11	Pu-240	6,560	Th-230	75,400
Bk-249	1	Mn-54	1	Pu-241	14	Th-231	0
C-14	5,715	Mo-93	3,500	Pu-242	375,000	Th-232	1.4E+10
Ca-41	103,000	Nb-91	700	Pu-243	0	Th-234	0
Ca-45	0	Nb-93m	16	Ra-223	0	Tl-206	0
Cd-109	1	Nb-94	20,000	Ra-224	0	Tl-207	0
Cd-113	9E+15	Nb-95	0	Ra-225	0	Tl-208	0
Cd-113m	14	Nb-95m	0	Ra-226	1,599	Tl-209	0
Ce-139	0	Nd-144	Stable	Ra-228	6	Tm-171	2
Ce-142	Stable	Ni-59	76,000	Rb-87	4.88E+10	U-232	70
Ce-144	1	Ni-63	100	Rh-102	3	U-233	159,200
Cf-249	351	Np-235	1	Rh-106	0	U-234	246,000
Cf-250	13	Np-236a	155,000	Rn-219	0	U-235	7.04E+08
Cf-251	900	Np-237	2,140,000	Rn-220	0	U-236	23,420,000
Cf-252	3	Np-238	0	Rn-222	0	U-237	0
Cl-36	301,000	Np-239	0	Ru-106	1	U-238	4.47E+09
Cm-242	0	Pa-231	32,800	Sb-125	3	Y-90	0
Cm-243	29	Pa-233	0	Sb-126	0	Y-91	0
Cm-244	18	Pa-234	0	Sb-126m	0	Zn-65	1
Cm-245	8,500	Pa-234m	0	Se-79	1,100,000	Zr-93	1,500,000
Cm-246	4,760	Pb-209	0	Sm-145	1	Zr-95	0
Cm-247	15,600,000	Pb-210	23	Sm-146	1.03E+08	--	--
Cm-248	348,000	Pb-211	0	Sm-147	1.06E+11	--	--

NOTE: Some values are rounded to the nearest year. Primary source is Parrington et al. (1996). Source for Se-79 is Assumption 5.3.

## 4.2 CRITERIA

There are no criteria specifically for radionuclide screening in the requirements documents. The present document addresses the NRC criteria that are specified in the *Issue Resolution Status Report Key Technical Issue: Container Life and Source Term*, Rev. 3 (Beckman 2001, Section 5.3.2.1).

4.2.1 “Total System Performance Assessment adequately incorporates important design features, physical phenomena, and couplings and uses consistent and appropriate assumptions throughout the radionuclide release rates and solubility limits abstraction process.” (Beckman 2001, Section 5.3.2.1).

4.2.2 “The Total System Performance Assessment abstraction on radionuclide release rates and solubility limits provides sufficient, consistent design information on [waste packages] and engineered barrier systems. For example, inventory calculations and selected radionuclides are based on the detailed information provided on the distribution (both spatially and by compositional phase) of the radionuclide inventory within the various types of HLW.” (Beckman 2001, Section 5.3.2.1).

## 4.3 CODES AND STANDARDS

There are no codes or standards directly associated with this analysis. The following sections of 10 CFR 63 (Disposal Of High-Level Radioactive Wastes In A Geologic Repository At Yucca Mountain, Nevada) are relevant to the use of the results from analysis in total system performance assessment: 113 (Performance objectives for the geologic repository after permanent closure), 114 (Requirements for performance assessment), 331 (Separate standards for protection of groundwater), 332 (Human intrusion scenario), and 341 (Projections of peak dose). Also relevant to the use of the results from analysis in total system performance assessment is 40 CFR 197 (Protection of Environment: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada).

## 5. ASSUMPTIONS

- 5.1 The analysis is deterministic. In particular, fixed values (not uncertainty distributions) are assumed for the screening factors (see Assumptions 5.2 and 5.8). Because of this assumption, some radionuclides that could contribute a significant fraction of the dose in unlikely circumstances (that is, if extreme values were drawn from uncertainty distributions for certain screening factors) could be screened out. The rationale for this assumption is that using a single representative screening factor for each radionuclide serves the purpose of this analysis, which is to screen out radionuclides that are unlikely to significantly contribute to radiation dose. This assumption does not require further confirmation because its limitations have been stated and it is consistent with the purpose of the screening analysis. This assumption is used throughout Section 6.
- 5.2 Air screening factors from National Council on Radiation Protection (NCRP) Report No. 123, *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground* (NCRP 1996, Table B.1)—adjusted to reflect the local biosphere—are assumed sufficiently representative of human dose effects for the eruptive igneous scenario to be used in the screening analysis. The usage factors built in to the NCRP screening factors, that is, the assumed times spent in various activities such as gardening and bathing or the quantities of water or food products consumed, are not necessarily appropriate for local conditions. The NCRP screening factors are adjusted for use in the present analysis by replacing the NCRP’s generic usage factors (NCRP 1996, Table 7.1) with project-generated usage factors (Section 4.1.1). Attachment II describes the development of the screening factors resulting from this assumption. An anomalously high value for the Np-236a air screening factor was discovered during the scoping calculations for this analysis; a corrected value is developed for the screening analysis as described in Attachment II. The rationale for the corrected Np-236a screening factor, which is strong enough to justify a claim that further confirmation is not required, is provided in Attachment II. The rationale for using the adjusted air screening factors is as follows.

The eruptive volcanic event bypasses the groundwater and injects radioactive contamination directly into the atmosphere, which then settles to the earth. Pathways considered by the NCRP air screening factors include inhalation and exposure to contaminated soil; consumption of contaminated crops and soil; and consumption of milk and meat from animals that consume contaminated forage (NCRP 1996, Section 8.2.1). A neglect of these factors in the previous radionuclide screening drew comments from the NRC, which noted that “processes that affect transport in the biosphere, such as uptake by plants and bioaccumulation are not accounted for” and that “the direct exposure pathway is not accounted for” (Beckman 2001, Section 5.3.2.1).

Although the NCRP screening factors account for inhalation and the other exposure pathways of interest for the volcanic scenario, they were not developed for volcanic eruptions. Inhalation is expected to be the dominant pathway for all but four of the 17 radionuclides considered in the site-recommendation analysis for the eruptive igneous scenario (CRWMS M&O 2001a, Section 6.6). Therefore, it is important to ensure that the screening factors developed for the screening analysis give appropriately high relative

weight to the inhalation pathway. The four radionuclides for which the inhalation pathway is not expected to dominate are Sr-90, Cs-137, Pb-210, and Ra-226 (CRWMS M&O 2001a, Section 6.6). The screening factors developed in the present analysis also show relatively low contributions from the inhalation pathway for these radionuclides (Table 3). For the remaining radionuclides, the inhalation pathway dominates (Table 3), with inhalation contributions comparable to those developed for the site-recommendation biosphere dose conversion factors (CRWMS M&O 2001a, Tables 16 through 20). Thus, the screening factors developed in Attachment II give appropriate weight to the inhalation pathway.

Table 3. Relative Contribution of the Inhalation Pathway for the Eruptive Screening Factors

Nuclide	Contribution to the Screening Factor from Inhalation (percent) <sup>a</sup>
Sr-90	8.9
Cs-137	0.1
Pb-210	10.6
Ra-226	5.6
Ac-227	95.1
Th-229	97.3
Th-230	98.1
Pa-231	85.2
U-232	85.2
U-233	96.2
U-234	96.2
Pu-238	86.9
Pu-239	87.3
Pu-240	87.3
Pu-242	86.3
Am-241	86.7
Am-243	81.8

<sup>a</sup>The percent contributions are calculated from the table in Attachment II as the value from Column 1 times 0.73 (the adjustment factor for inhalation developed in Attachment I) divided by the value in the last column.

In light of the error in the NCRP report for the ground-irradiation dose coefficient of Np-236a, Attachment III provides an evaluation of the ground-irradiation, inhalation, and ingestion dose coefficients that the NCRP report uses to develop air screening factors. Attachment III shows that the dose coefficients used are similar in magnitude to other published dose coefficients.

The results of the screening analysis are not sensitive to uncertainties in this assumption because results that screened out radionuclides known to be important or a failure to screen out radionuclides not previously suspected of being at least marginally important would be viewed skeptically. Thus, the worst-case consequence of uncertainties in the

air screening factors is that marginally important radionuclides could be inappropriately screened out. The rationale for this assumption is strong enough to justify a claim that further confirmation is not required. This assumption is used in Sections 6.2, 6.3, 6.5, and 6.7; and Attachment II.

- 5.3 The half-life for radioactive decay of Se-79 is assumed to be  $1.1 \times 10^6$  y. The rationale for this assumption is that it is based on a direct measurement technique and is not subject to the error that affected some earlier estimates (Songsheng et al. 1997). The calculations that provide input activities to the screening analysis used 330,000 y as the half-life for Se-79 (calculated from activities in the years 1,002,030 CE and 2130 CE as  $[1,002,030 - 2,130 \text{ y}] / \ln [1.85 \times 10^3 \text{ Ci} / 2.26 \times 10^2 \text{ Ci}]$ , CRWMS M&O 2000c, p. I-2). Parrington et al. (1996) gives a half-life of 650,000 y, but some earlier sources give an even lower value. For example, Weast (1978, p. B-291) gives 65,000 y. The worst-case consequence of uncertainties in this assumption is that marginally important radionuclides could be inappropriately screened out. This assumption is used in Sections 4.1.2, 6.2.3, 6.3, 6.7; and Attachment IV to correct the activity for Se-79.
- 5.4 It is assumed that the as-built characteristics of PWR and BWR assemblies and the calculated “average” and “outlying” radionuclide activities as functions of time that were developed by CRWMS M&O (1999a, Assumption 3.1, Section 5.5.3, and Attachment XV; 1999b, Assumption 3.1, Section 5.5, and Attachment X) are adequate for the screening analysis. The characteristics of the average CSNF waste forms were determined by weighted averages from the projected CSNF waste stream of the enrichments, burnups, and ages, where the weights are the numbers of assemblies with a given value of each characteristic in the waste stream. The characteristics of the outlying CSNF waste forms are the maximum burnup, the maximum initial enrichment, and the minimum age in the waste stream for each fuel type. The activities are listed in Attachment VI in the corresponding Excel workbooks for the 10,000-y regulatory period and beyond (see Attachment V for a listing). The rationale for this assumption, which is strong enough to justify a claim that further confirmation is not required, is that this information is the most recent available at the time of this analysis and was developed in accordance with the OCRWM quality assurance program. The possible consequences of uncertainties in this assumption are addressed in Section 6.5. This assumption is used in Sections 4.1.2, 6.2, and 6.3.
- 5.5 It is assumed that screening radionuclides at 95 percent of the cumulative radionuclide-screening product under the identified release scenarios is adequate for TSPA. For a given radionuclide in the repository inventory, the radionuclide-screening product is defined as the product of the radionuclide’s screening factor (Assumptions 5.2 and 5.8) and the activity of the radionuclide in the inventory. The cumulative screening product for a given radionuclide is computed by ranking the screening products from largest to smallest and summing them starting with the largest and adding the next largest until the screening product of the given radionuclide has been included in the sum. Screening at 95 percent means that the ranked radionuclides that contributed up to 95 percent of the maximum cumulative radionuclide-screening product are considered potentially important (see Section 6.2.1 for further explanation). The rationale for this assumption is as follows.

Radionuclide screening implies that a subset of the full inventory of radionuclides will be modeled in TSPA and, therefore, that the dose contributions from some radionuclides will not be included in the dose projections. The radionuclide-screening product for each radionuclide is meant to be roughly proportional to the dose. Choosing a high but not excessively conservative cutoff serves the purpose of this analysis, which is to screen out radionuclides that are unlikely to significantly contribute to radiation dose. To assess the effect of variation of the screening cutoff, a fine-screen test was conducted with a 99 percent cutoff (Section 6.3). This assumption does not require further confirmation because its limitations have been stated and it is consistent with the purpose of the screening analysis. This assumption is used in Sections 6.2, 6.3, and 6.5.

- 5.6 The sorption classes given by the columns of Table 4 are assumed for the groundwater scenarios. The rationale for this assumption, which is strong enough to justify a claim that further confirmation is not required, is as follows. With the exception of some adjustments (to be detailed below), the classification corresponds to the NCRP assignment of freshwater sorption adjustment factors in a report that addresses screening techniques for releases of radioactive materials to the environment (NCRP 1996, Table 6.1).

The NCRP report assigns dimensionless adjustment factors of 0, 0.1, 1, and 10 to adjust the dose contributions from radionuclides in shoreline deposits (NCRP 1996, pp. 69 & 70). Initial classifications are made here by assigning a correspondence as follows: the “Low” sorption class (L) corresponds to the 0 and 0.1 adjustment factors from the NCRP report; “Medium” (M) corresponds to an adjustment factor of 1; “High” (H) corresponds to an adjustment factor of 10. The NCRP derived the sorption adjustment factors from summary data on sorption to sediments at freshwater and marine shorelines.

The NCRP freshwater adjustment factors are used as an initial basis for the sorption classifications because NCRP freshwater values provide a rough but consistent indicator of sorptivity under freshwater conditions. Corroboration of this assumption is provided by project-generated sorption-coefficient distributions recommended for unsaturated and saturated conditions (CRWMS M&O 2001e, Tables 2a and 2b). Note that the recommended sorption-coefficient distributions are consistent with the classifications derived from the NCRP report for Cl, I, and Tc (Low); C, Ni, Np, Pa, Se, Sr, and U (Medium); and Ac, Am, Pb, Pu, Sm, Th, and Zr (High). Note also that, although Cs, Nb, and Ra were assigned sorption adjustment factors of 1 in the NCRP report, it is more consistent with recommended site-specific sorption values to assign Cs, Nb, and Ra to the High sorption class. Although the NCRP report gives sorption adjustment factor of 0.1 for Cd, Cd was placed in the High sorption class due to evidence (EPA 1999, Vol. II: Table 5.4) that indicates that the range of Cd sorptivity more closely resembles the range of other elements assigned to the High sorption class (CRWMS M&O 2001e, Tables 2a and 2b). Tin, which was assigned a sorption adjustment factor of 1 in the NCRP report, could reasonably have been placed in either the High or Medium classes based on the distributions presented by CRWMS M&O (2001e, Tables 2a and 2b). Tin was placed in the High sorption class due to evidence that Sn is highly sorbing compared to Se and U under a range of geochemical conditions (Ticknor et al. 1996, Abstract, p. 24, Table 11; Crowe and Vaniman 1985, pp. 33 through 37).

It is recognized that sorptivity may vary depending on water chemistry, temperature, nature of the surrounding rock, and other variables. Class assignments are insensitive to uncertainties in sorptivity because only a rough division into three sorption classes has been done. The results of the screening analysis are insensitive to uncertainties in class assignments because the most important radionuclides have high enough radionuclide-screening products that they will not be screened out regardless of their assigned class. At worst, this assumption could lead marginally important radionuclides to be improperly screened out. This assumption is used in Sections 6.2.1, 6.2.4, 6.2.6, 6.3, and 6.6.

Table 4. Assumed Solubility and Sorption Classes for the Screening Analysis

Solubility Class	Sorption Class		
	Low (L)	Medium (M)	High (H)
High (H)	Ar, Cl, H, I, K, Kr, Rb, Tc	C, Se, Sr	Cs
Medium (M)	Mo	Ag, Ba, Ca, Eu, Gd, La, Ni, Np, U	Ac, Am, Cf, Cm, Pd, Pm, Pu, Ra, Sm, Th, Tm
Low (L)	--	Pa, Pt	Cd, Nb, Pb, Sn, Zr

5.7 The solubility classes given by the rows of Table 4 are assumed for the groundwater scenarios. The solubility classifications roughly reflect the ability of solubility limits to restrict mobilization and transport to the accessible environment. It is recognized that solubility may vary over several orders of magnitude depending on water chemistry, temperature, composition of the surrounding rock, and other variables. Rough definitions of the solubility classes are: High (H): greater than 0.1 mol/L (or mol/kg); Medium (M): less than 0.1 but greater than  $10^{-6}$  mol/L (or mol/kg), Low (L): less than  $10^{-6}$  mol/L (or mol/kg). The rationale for the class assignments is provided in Table 5. The rationale for this assumption is strong enough to justify a claim that further confirmation is not required.

For the most important elements, other project documents provide corroborating information for the class assignments (Table 5). For some of the less important elements, due to their apparent lack of importance to repository performance, little project work has been done to estimate solubility under site-specific conditions. In these cases, approximate solubilities for plausible controlling solids were used in the spirit in which the project's solubility investigations have been conducted (BSC 2001b, Sections 6.1.2, 6.1.8). Class assignments are not sensitive to uncertainties in solubility limits because the solubility classes span several orders of magnitude. The results of the screening analysis are insensitive to uncertainties in class assignments because the most important

radionuclides have high enough radionuclide-screening products that they will not be screened out regardless of their assigned class. At worst, this assumption could lead marginally important radionuclides to be improperly screened out. This assumption is used Sections 6.2.1, 6.2.5, 6.2.6, 6.3, and 6.6.

- 5.8 Freshwater screening factors provided by NCRP Report No. 123, *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground* (NCRP 1996, Table C.1)—adjusted to reflect the local biosphere—are assumed sufficiently representative of biosphere transport and human dose effects for the nominal, human-intrusion, and intrusive igneous scenarios (the groundwater scenarios) to be used in the screening analysis. In the present analysis, the screening factors are adjusted by replacing the generic usage factors (NCRP 1996, Table 7.1) with project-generated usage factors (Section 4.1.1). An anomalously high value for the Np-236a freshwater screening factor was discovered during the scoping calculations for this analysis; a corrected value is developed for the screening analysis as described in Attachment I. The rationale for this assumption, which is strong enough to justify a claim that further confirmation is not required, is as follows.

The nominal, human-intrusion, and intrusive igneous scenarios entail the transport of radionuclides to the accessible environment through groundwater (in contrast, the eruptive volcanic event bypasses the groundwater and injects radionuclides directly into the atmosphere). The freshwater screening factors include dose from: exposure to irrigated soil; consumption of drinking water, irrigated crops, and soil; consumption of milk and meat from animals that consume irrigated forage; and consumption of freshwater fish (NCRP 1996, Section 8.2.2). A neglect of these factors in the previous radionuclide screening drew comments from the NRC, which noted that “processes that affect transport in the biosphere, such as uptake by plants and bioaccumulation are not accounted for” and that “the direct exposure pathway is not accounted for” (Beckman 2001, Section 5.3.2.1). The generic usage factors built in to the NCRP screening factors, that is, the assumed times spent in various activities such as gardening and bathing or the quantities of water or food products consumed, apply to a generic biosphere. NCRP’s development of the freshwater screening factors acknowledges the use of agricultural irrigation, so the resulting screening factors were intended to apply to climates where irrigation is practiced. Irrigated soil has high water content during irrigation, when sorption is important, so it is appropriate to apply the freshwater sorption adjustment factors that were discussed in Assumption 5.6 there. The sorption adjustment factors do not play any role in the pathways for ingestion of water, soil, or locally produced terrestrial food. Attachment I describes the development of screening factors based on the replacement of the NCRP usage factors by project-generated values.

The inhalation pathway is not considered in the groundwater scenarios. This is consistent with the findings of project documentation of biosphere dose conversion factors. For the nominal scenario, the inhalation pathway contributes at most a few tenths of a percent to the dose for any of the radionuclides considered (CRWMS M&O 2001c, Table 15).

Table 5. Solubility Class Assignments and Rationales

Element	Rationale for Solubility Class Assignment
<b>High (&gt; ~0.1 mol/L)</b>	
Ar, Kr	Transport of noble gasses is not restricted by solubility limits because they can travel in the gaseous phase.
Cl	Forms naturally occurring, highly soluble ionic compounds with alkali metals, for example, KCl (sylvite) and NaCl (halite) (Weast 1978, B-150, B-165; Pauling 1970, Figure 13-3, Section 13-4).
H, K, Rb	Form compounds with halogens, for example, KCl (sylvite), RbCl, and HCl, which are highly soluble (Weast 1978, B-123, B-150, B-157; Pauling 1970, Figure 13-3, Section 13-4).
C, Cs, I, Sr, Tc	Highly soluble (BSC 2001b, pp. 54 & 55).
Se	Highly soluble, most likely solubility of 0.1 mol/L (CRWMS M&O 1998, Table 6-32, p. 6-84).
<b>Medium (&gt; ~10<sup>-6</sup> mol/L; &lt; ~0.1 mol/L)</b>	
Mo	With naturally occurring molybdenite (MoO <sub>3</sub> ) as the controlling solid, in cold water, solubility = (0.1 g/100 cc) / (143.94 g/mol) × 1000 cc/L = 7×10 <sup>-3</sup> mol/L (Weast 1978, p. B-139, CRWMS M&O 2001d, Section 6.3.4).
Ag	With naturally occurring horn silver (AgCl) as the controlling solid, in cold water, solubility = (8.9×10 <sup>-5</sup> g/100 cc)/(143.32 g/mol) × 1000 cc/L = 6.2×10 <sup>-6</sup> mol/L (Weast 1978, pp. B-52, B-53, B-162).
Ba	Taking naturally occurring barite (BaSO <sub>4</sub> ) as controlling, the solubility of Ba in cold water is about (2×10 <sup>-4</sup> g/100 cc) / (233.4 g/mol) × 1000 cc/L = 9×10 <sup>-2</sup> mol/L (Weast 1978, pp. B-11, B-99), which is on the upper end of the M class. According to another source, BaSO <sub>4</sub> has a solubility of less than about 10 <sup>-2</sup> mol/L (Pauling 1970, Section 13-4), which places Ba solidly in the M class.
Ca	Taking CaCO <sub>3</sub> as the controlling solid, note that J-13 water is saturated or nearly so in CaCO <sub>3</sub> and has 13 mg/L Ca, that is, 13 mg/L / [(1000 mg/g) × (40 g/mol)] = 3.3 × 10 <sup>-4</sup> mol/L (MO0006J13WTRCM.000). Also, the solubility of CaCO <sub>3</sub> in cold water is about (0.0014 g/100 cc) / (100.09 g/mol) × 1000 cc/L = 1.4×10 <sup>-4</sup> mol/L (Weast 1978, p. B-105). One could argue that near saturation would inhibit the dissolution of Ca in the waste form. However, Ca is assigned to M because the M class spans several orders of magnitude and because percolating unsaturated storm water could transport Ca.
La, Pm, Eu, Tm	Lanthanides have similar chemical properties (Cotton 1999, Section 19.1) and Gd is assigned to M.
Gd	Taking GdOHCO <sub>3</sub> as the controlling solid gives a solubility of about 10 <sup>-6</sup> mol/L at neutral pH and normal atmospheric partial pressure of CO <sub>2</sub> (CRWMS M&O 1997, Table C-1).
Ni	Loguniform distribution from 1.4×10 <sup>-6</sup> to 3.1 mol/L (mean = √(1.4×10 <sup>-6</sup> ×3.1) = 2.1×10 <sup>-3</sup> mol/L) (CRWMS M&O 2000d, Table 19, p. 41).
Np	Solubility 4.28×10 <sup>-5</sup> mol/L at pH 7 and CO <sub>2</sub> fugacity 10 <sup>-3</sup> bar (BSC 2001b, Table 14).
U	Solubility 2.04 mg/L at pH 7 and 30° C (BSC 2001b, Table 10). For approximate atomic weight 238, this is (2.04 mg/L) / (238 g/mol) × (10 <sup>-3</sup> g/mg) = 8.6 × 10 <sup>-6</sup> mol/L.
Ac, Cf	Actinides have similar chemical properties (Cotton 1999, Section 20.1) and Th, U, Np, Pu, and Am are assigned to M.
Am	A solubility of 1.8×10 <sup>-6</sup> mol/L at pH 7 and CO <sub>2</sub> fugacity of 10 <sup>-3</sup> bar is suggested for Am (BSC 2001b, Table 17).
Cm, Sm	Assigned to M as Am analogs (CRWMS M&O 2000d, p. 40).
Pd	Loguniform distribution from 9.4×10 <sup>-6</sup> to 9.4×10 <sup>-2</sup> mol/L (CRWMS M&O 1998, Table 6-32).
Pu	Solubility 2.22×10 <sup>-4</sup> mol/kg at pH 7 and CO <sub>2</sub> fugacity 10 <sup>-3</sup> bar (BSC 2001b, Table 16).
Ra	Solubility 2.3×10 <sup>-6</sup> mol/L is recommended (BSC 2001b, p. 54, Table 19).
Th	Solubility 1.0×10 <sup>-5</sup> mol/L is recommended (BSC 2001b, p. 54, Table 19).
<b>Low (&lt; ~10<sup>-6</sup> mol/L)</b>	
Pa	A loguniform distribution from 10 <sup>-10</sup> to 10 <sup>-5</sup> mol/L (mean = 3.2×10 <sup>-8</sup> mol/L) is given (BSC 2001b, p. 55, Table 19).
Pt	Pt is chemically unreactive and is found in nature in native alloys (Pauling 1970, Section 20-7). Because elemental Pt is insoluble even in hydrochloric and nitric acids (Weast 1978, p. B-42.), Pt is placed in L.
Sn	Solubility 5.0 × 10 <sup>-8</sup> mol/L is suggested (CRWMS M&O 2000d, p. 42, Table 19).
Cd	Cd concentrations in natural waters saturated with respect to otavite (CdCO <sub>3</sub> ) may be as high as 0.25 ppm (or mg/kg) (Carroll et al. 1998, p. 960 & Figure 3E), that is 0.25 mg/kg / [(1000 mg/g) × (112 g/mol)] = 2.2 × 10 <sup>-6</sup> mol/kg, though Cd concentrations this high in natural waters are rare (Langmuir 1997, Table 8.13). Taking otavite as the controlling solid, the solubility cited (2.2 × 10 <sup>-6</sup> mol/kg) would place Cd roughly at the bottom of M. However, because a solid solution of otavite and calcite (CaCO <sub>3</sub> ) may greatly reduce Cd solubility (Langmuir 1997, pp. 14 & 15), Cd is placed in L.
Nb	Solubility 1.0 × 10 <sup>-7</sup> mol/L is suggested (CRWMS M&O 2000d, p. 41, Table 19).
Pb	Loguniform distribution from 10 <sup>-10</sup> to 10 <sup>-5</sup> mol/L (mean = √(10 <sup>-10</sup> ×10 <sup>-5</sup> ) = 3.2×10 <sup>-8</sup> mol/L) (BSC 2001b, p. 55, Table 19).
Zr	Solubility 6.8×10 <sup>-10</sup> mol/L is suggested (CRWMS M&O 2000d, p. 41, Table 19).

In light of the error in the NCRP report for the ground-irradiation dose coefficient of Np-236a, Attachment III provides an evaluation of the dose coefficients that the NCRP report uses to develop freshwater screening factors. Attachment III shows that the dose coefficients used are similar in magnitude to other published dose coefficients.

The results of the screening analysis are not sensitive to uncertainties in this assumption because results that screened out radionuclides known to be important or a failure to screen out radionuclides not previously suspected of being at least marginally important would be viewed skeptically. Thus, the worst-case consequence of uncertainties in the groundwater screening factors is that marginally important radionuclides could be inappropriately screened out. This assumption is used in Sections 6.2, 6.3, 6.5, and 6.7; and Attachment I.

- 5.9 It is assumed that radionuclides with half lives less than 10 y that are not decay products of other radionuclides in the waste inventory will not contribute significantly to the dose in the groundwater scenarios. This assumption is implemented by a logical feature of the RadNuScreen software, which ignores direct contributions from radionuclides with half-lives less than a user-specified cutoff. The rationale for this assumption, which is strong enough to justify a claim that further confirmation is not required, is as follows.

The first time considered for the screening analysis is 100 y after emplacement. This is at least 10 half-lives for radionuclides with half-lives of 10 y or less, by which time only a miniscule fraction of the original activity ( $0.5^{10} \cong 10^{-3}$ ) is left. In-growth of decay products, regardless of half-life, is accounted for by the screening factors (NCRP 1996, Section 8.2.2). For the NCRP screening factors, the period assumed for accumulation in soil is 30 y (NCRP 1996, Section 8.2.2). The number of atoms  $N_d$  of a radionuclide produced by the decay of its parent when the daughter is initially absent is given by

$$N_d(t) = \frac{\lambda_p}{\lambda_d - \lambda_p} N_p^0 [\exp(-\lambda_p t) - \exp(-\lambda_d t)],$$

where  $N_p^0$  is the initial number of atoms of the parent,  $\lambda_p$  and  $\lambda_d$  are the decay constants of the parent and daughter, and  $t$  is time (adapted from Faure 1986, Equation 4.21). Note that the number of parent atoms as a function of time is given by  $N_p(t) = N_p^0 \exp(-\lambda_p t)$ , so that

$$N_d(t) = \frac{\lambda_p}{\lambda_d - \lambda_p} N_p(t) \{1 - [\exp(\lambda_p - \lambda_d)t]\}.$$

For in-growth of a daughter product with a short half-life compared to the parent, the number of parent atoms can be considered nearly constant during the short times under consideration and the decay constant for the parent is much less than that of the daughter such that  $\lambda_p - \lambda_d \cong -\lambda_d$ . Under these circumstances, the number of daughter atoms is approximately proportional to  $1 - \exp(-\lambda_d t)$ . For three or more half-lives of in-growth time (30 y with a half-life of 10 y),  $t \geq 3(\ln 2)/\lambda_d$ , the fraction of the equilibrium quantity generated equals or exceeds  $1 - \exp[-3(\ln 2)] = 87.5\%$ . If two or more radioactive

daughters are produced, the situation is more complex, but this calculation indicates that 30-y or greater in-growth times should capture sufficient contributions from the in-growth of radionuclides with half-lives less than 10 y whose direct contributions are neglected. The results of the screening analysis are insensitive to uncertainties in this assumption because there are few radionuclides in the waste inventory with half-lives near 10 y (Table 2). This assumption is used in Sections 6.2, 6.2.3, 6.3, and 6.6; and Attachment III.

- 5.10 The groundwater and eruptive screening factors for Ce-142, Nb-91, Nd-144, Po-212, Sm-148, and Sm-149, are assumed equal to zero. The NCRP report does not provide screening factors or dose coefficients for these nuclides or it lists the values as zero (NCRP 1996, Tables A.1, B.1, and C.1). Federal Guidance Report No. 11 and 12 do not cover them or give zero values for dose coefficients (Eckerman et al. 1988; Eckerman & Ryman 1993). The rationale for this assumption, which is strong enough to justify a claim that further confirmation is not required, is as follows.

Because the scope of the references cited is extensive, radionuclides that are omitted from these references are not likely to be important sources of radiation exposure. Further corroboration is provided as follows. Ce-142 is stable according to Parrington et al. (1996). Nb-91 decays to a stable daughter almost exclusively by electron capture (Parrington et al. 1996) with little emission of radiation (about 10 keV, Firestone and Shirley 1996, Vol. 1, energy diagram on p. 580). Nd-144 has a half-life so long ( $2.38 \times 10^{15}$  y) that it may be considered stable (Parrington et al. 1996). Po-212 has effective dose coefficients of zero (NCRP 1996, Table A.1). Sm-148 has a half-life so long ( $7 \times 10^{15}$  y) that it may be considered stable (Parrington et al. 1996). Sm-149 is stable according to Parrington et al. (1996). The worst-case consequence of uncertainties in this assumption is that marginally important radionuclides could be inappropriately screened out. This assumption is used in Section 6.2.1 and Attachments I and II.

- 5.11 It is assumed that the calculated “average” and “outlying” radionuclide activities for DSNF as functions of time that were developed by CRWMS M&O (2000b, Tables 2 through 7) are adequate for the screening analysis. For average DSNF, the activities used in the screening are the total inventories of each radionuclide for all DSNF. For outlying DSNF, the activities are the total inventories for each radionuclide in spent uranium/thorium carbide fuel. Uranium/thorium carbide fuel was chosen as the outlying DSNF waste form for the screening calculations because it contains substantial activities of U-233 and Th-230, whose potential importance to dose should be evaluated. The activities are listed in Attachment VI in the corresponding Excel workbooks for the 10,000-y regulatory period and beyond (see Attachment V for a listing). The rationale for this assumption, which is strong enough to justify a claim that further confirmation is not required, is that this information is the most recent available at the time of this analysis and was developed in accordance with the OCRWM quality assurance program. The possible consequences of uncertainties in this assumption are addressed in Section 6.5. This assumption is used in Sections 4.1.2, 6.2, and 6.3.

- 5.12 It is assumed that the calculated “average” and “outlying” radionuclide activities for HLW as functions of time that were developed by CRWMS M&O (2000c, Attachments I

and II) are adequate for the screening analysis. For average HLW, the activities used in the screening are the total inventories of each radionuclide for all HLW. For outlying HLW, the activities are the totals for HLW glass from the Savannah River Site. HLW from Savannah River was chosen as the outlying HLW waste form due to its high total activity per canister as compared to glass from the other sites where HLW will be produced (CRWMS M&O 2000c, Table 6-1). The activities are listed in Attachment VI in the corresponding Excel workbooks for the 10,000-y regulatory period and beyond (see Attachment V for a listing). The rationale for this assumption, which is strong enough to justify a claim that further confirmation is not required, is that this information is the most recent available at the time of this analysis and was developed in accordance with the OCRWM quality assurance program. The possible consequences of uncertainties in this assumption are addressed in Section 6.5. This assumption is used in Sections 4.1.2, 6.2, and 6.3.

## 6. SCIENTIFIC ANALYSIS DISCUSSION

### 6.1 PREVIOUS RADIONUCLIDE SCREENING ACTIVITIES

Oversby (1987) conducted early work on radionuclide screening related to the proposed Yucca Mountain repository. Radionuclide screening was required for a series of total system performance analyses including the 1993 TSPA (Wilson et al. 1994), the 1995 TSPA (CRWMS M&O 1995), the TSPA for viability assessment (DOE 1998), and the TSPA for site recommendation (CRWMS M&O 2000e). Other organizations, including the NRC and the Electric Power Research Institute (EPRI), have conducted performance assessments, which required radionuclide screening (for example, Wescott et al. 1995 and EPRI 2002). The results of the cited radionuclide screening activities are provided in Table 6.

The formal screening method that was introduced in REV 00 of the present analysis (CRWMS M&O 2000a, Section 4) drew favorable comments from the NRC (Beckman 2001, Section 5.3.2.1):

This clear description of the screening process used to identify important radionuclides is an improvement in the transparency of the TSPA. Also, consideration of important radionuclides for the human intrusion and igneous event scenarios in the inventory abstraction AMR is an improvement in the comprehensiveness of the analysis. ... The approach appears to account for all waste types that will be emplaced in the repository and seems complete in this regard.

However, the NRC also provided constructive criticism (Beckman 2001, Section 5.3.2.1). This revision seeks to build upon the strengths of the earlier screening method while responding to comments by the NRC. Specific comments and how they are addressed in the present analysis were mentioned in Section 1, are brought to light in the following discussion and the supporting assumptions from Section 5, and are treated fully in Section 6.7.1.

### 6.2 CONCEPTUAL BASIS

#### 6.2.1 Summary of the Screening Process

The screening analysis considers four release scenarios (nominal, human intrusion, intrusive igneous, and eruptive igneous) and two time periods (the 10,000-y regulatory period and the period after 10,000 y up to 1 million years). The nominal scenario envisions the gradual deterioration of the disposal containers, the subsequent exposure of the waste to the potentially corrosive effects of the environment, and the natural transport of radioactive contaminants through unsaturated and saturated groundwater to the accessible environment, where the groundwater is withdrawn by the human population. The human-intrusion scenario considers the possibility that future inhabitants of the Yucca Mountain area might drill down into the repository, through a waste package, and down to the water table. Under the human-intrusion scenario (as compared to the nominal scenario), the waste would be exposed to the environment sooner and radioactive contaminants would have a quicker path to the saturated groundwater through the postulated borehole. The intrusive igneous scenario envisions the intrusion of magma into the repository where it damages waste packages, making radioactive contaminants available for transport in the unsaturated groundwater zone. As noted above, the nominal,

human-intrusion, and intrusive igneous scenarios may be called the groundwater scenarios. Under the eruptive scenario, a volcanic eruption releases waste directly into the atmosphere.

Table 6. Radionuclides Included in Other TSPAs

Nuclide	TSPA 1993 <sup>a</sup>	TSPA 1995 <sup>b</sup>	TSPA for viability assessment <sup>c</sup>	TSPA for site recommendation <sup>d</sup>	NRC <sup>e</sup>	EPRI <sup>f</sup>
Ac-227	Ac-227	Ac-227		Ac-227		
Ag-108m	Ag-108m					
Am-241	Am-241	Am-241		Am-241	Am-241	Am-241
Am-242m	Am-242m	Am-242m				
Am-243	Am-243	Am-243		Am-243	Am-243	
C-14	C-14	C-14	C-14	C-14	C-14	
Cl-36	Cl-36	Cl-36				Cl-36
Cm-243	Cm-243					
Cm-244	Cm-244	Cm-244				
Cm-245	Cm-245	Cm-245			Cm-245	
Cm-246	Cm-246	Cm-246			Cm-246	
Cs-135	Cs-135	Cs-135			Cs-135	Cs-135
Cs-137	Cs-137			Cs-137	Cs-137	
I-129	I-129	I-129	I-129	I-129	I-129	I-129
Mo-93	Mo-93					
Nb-93m		Nb-93m				
Nb-94	Nb-94	Nb-94			Nb-94	Nb-94
Ni-59	Ni-59	Ni-59			Ni-59	
Ni-63	Ni-63	Ni-63				
Np-237	Np-237	Np-237	Np-237	Np-237	Np-237	Np-237
Pa-231	Pa-231	Pa-231	Pa-231	Pa-231		Pa-231
Pb-210	Pb-210	Pb-210		Pb-210	Pb-210	
Pd-107	Pd-107	Pd-107				
Pu-238	Pu-238	Pu-238		Pu-238		
Pu-239	Pu-239	Pu-239	Pu-239	Pu-239	Pu-239	Pu-239
Pu-240	Pu-240	Pu-240		Pu-240	Pu-240	Pu-240
Pu-241	Pu-241	Pu-241				
Pu-242	Pu-242	Pu-242	Pu-242	Pu-242		Pu-242
Ra-226	Ra-226	Ra-226		Ra-226	Ra-226	Ra-226
Ra-228		Ra-228		Ra-228		
Se-79	Se-79	Se-79	Se-79		Se-79	Se-79
Sm-151	Sm-151	Sm-151				
Sn-121m	Sn-121m					
Sn-126	Sn-126	Sn-126				Sn-126
Sr-90	Sr-90			Sr-90		
Tc-99	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99	Tc-99
Th-229	Th-229	Th-229		Th-229		Th-229
Th-230	Th-230	Th-230		Th-230	Th-230	Th-230
Th-232		Th-232		Th-232		Th-232
U-232	U-232			U-232		
U-233	U-233	U-233		U-233		U-233
U-234	U-234	U-234	U-234	U-234	U-234	U-234
U-235	U-235	U-235		U-235		U-235
U-236	U-236	U-236		U-236		U-236
U-238	U-238	U-238		U-238	U-238	U-238
Zr-93	Zr-93	Zr-93				Zr-93

SOURCES: <sup>a</sup>Wilson et al. 1994, Table 5-11; <sup>b</sup>CRWMS M&O 1995, Tables 3.7-1 & 3.7-2; <sup>c</sup>DOE 1998, Table 3.14; <sup>d</sup>CRWMS M&O 2000a, Table 34; <sup>e</sup>Wescott et al. 1995, Table 5.1; <sup>f</sup>EPRI 2002, Section 6.5.

For the groundwater scenarios, the screening process first requires a subdivision of the complete set of radionuclides for a given waste form into screening sets according to transport characteristics of each radionuclide (Sections 6.2.4 through 6.2.6, Assumptions 5.6 and 5.7). It then ranks radionuclides within a screening set according to the product of the activity in the waste form and a screening factor corresponding to each radionuclide without regard to solubility or sorption (Assumptions 5.2 and 5.8). Because radionuclide mobilization and transport under the eruptive scenario do not require groundwater transport, which may sort elements according to sorption and solubility, no subdivision according to groundwater transport characteristics is needed for the eruptive scenario.

The radionuclide screening is based on the premise that the products of the activity inventories and the screening factors indicate the relative importance of each radionuclide with respect to the radiation dose that a person near the repository might receive. The units of the product of activity and screening factor need not correspond to a dose to an individual, so long as the units are consistent across radionuclides within a waste form and the product provides a measure of relative importance. For example, a valid pair of units is activity in Ci and screening factor in  $(\text{Sv/y}) / (\text{Bq/m}^3)$ , which corresponds to the groundwater scenarios (Assumption 5.8). The resulting units  $\text{Ci} \times (\text{Sv/y}) / (\text{Bq/m}^3)$  do not correspond to the dose to an individual, but the product still provides a measure of relative importance because it is proportional to dose under the assumptions of the screening for a particular screening time and waste form. Air and freshwater screening factors from NCRP Report 123, adjusted to reflect project-generated usage factors, are used as screening factors in the screening analysis (Assumptions 5.2 and 5.8). In a few cases, screening factors are approximated as zero (Assumption 5.10).

A radionuclide is screened out for a particular screening set and waste form at a particular time if the sum of its screening product and those of the radionuclides below it in rank fails to contribute 5 percent (Assumption 5.5) of the total of the screening products within the screening set. The complement of this fraction (95 percent) may be called the screening-product cutoff fraction. As described in Section 6.2.3, the screening is performed at a number of screening times for each waste form. A radionuclide that is screened out for all screening times and for all screening sets in which it is included is considered screened out for the waste form. A radionuclide that is screened out for all waste forms is screened out generally.

The following sections describe how the screening analysis accounts for exposure time and variation in waste package contents, how the screening sets are determined for the groundwater scenarios, and how the RadNuScreen software performs the screening.

## **6.2.2 Accounting for Variations in Waste Packages**

Some waste packages will contain spent BWR fuel only while others will contain spent PWR fuel only. Some will contain canisters of vitrified HLW only and others will contain a mixture of canisters, each of which contains either DSNF or HLW. In addition, the design of the disposal container and the non-fuel internals varies according to intended contents. Under such conditions, the random failure of only a few waste packages or systematic differences in breach time or radionuclide transport characteristics that depend on waste form or waste package type could mean that any of the several waste forms could independently determine the most important radionuclides. Therefore, the screening calculation is performed separately for BWR,

PWR, HLW, and DSNF. Furthermore, the screening is performed for “average” and “outlying” waste forms of each type (see Assumptions 5.4, 5.11, and 5.12).

### **6.2.3 Accounting for Time of Exposure**

Due to radioactive decay and in-growth, the makeup of the waste changes over time. Therefore, the screening analysis is performed independently at a number of times, which span the regulatory and post-regulatory periods and are approximately evenly spaced on a logarithmic scale (at multiples of roughly two to three). For the 10,000-y regulatory period, the screening times are 100 y, 200 y, 300 y, 500 y, 1,000 y, 2,000 y, 5,000 y, and 10,000 y after emplacement. An independent screening for times after the regulatory period is conducted with screening times at 20,000 y, 30,000 y, 100,000 y, 300,000 y, and 1 million y after emplacement. These sets of screening times capture the main features of the changing relative activities of dominant radionuclides (Benedict et al. 1981, Figure 11.29). To be screened out for the 10,000-y regulatory period, a radionuclide must be screened out at all times less than or equal to 10,000 y. Likewise, for the screening analysis for times after 10,000 y, to be screened out generally, a radionuclide must be screened out at all times greater than 10,000 y. A separate screening at 20,000 y only is conducted to address the effect of extending the regulatory-period screening out to 20,000 y.

Except for Se-79, projecting the makeup of the waste as a function of time up to 1 million years after emplacement is not part of this analysis, but is provided as input (Assumptions 5.4, 5.11, and 5.12). An activity correction factor for Se-79 is used to correct the erroneous half-life that was used in the activity calculations (Assumption 5.3). The correction factor reduces the Se-79 activity throughout the regulatory period by a factor of about 0.3. At 1 million years, the correction factor is about 1.3 (Attachment IV).

As a simplification that avoids the need to classify short-lived elements into sorption and solubility classes, radionuclides with half-lives less than 10 y are not considered as direct contributors to dose in the groundwater scenarios (Assumption 5.9).

### **6.2.4 Accounting for Sorption**

For groundwater scenarios, elements are grouped into three sorption classes: high (H), medium (M), and low (L) (Assumption 5.6). Different modes of transport to the accessible environment may sort chemical elements according to sorption class (Table 7). The screening analysis allows for the possibility that any of the identified modes of transport may predominate at any time. Under some conditions, fracture flow may allow highly sorbing elements to be transported by colloids while low-sorbing and medium-sorbing elements travel in solution (Table 7, first row after header). Under more restrictive fracture-flow conditions, highly sorbing elements may attach to fracture walls and colloids may be filtered out, so that highly sorbing elements are discriminated against while medium-sorbing and low-sorbing elements travel in solution (Table 7, second row). Matrix flow discriminates in favor of low-sorbing elements due to the prolonged intimate contact of the groundwater with the rock matrix during which medium-sorbing and highly sorbing elements are likely to sorb to the fracture walls or to colloids, which are likely to be filtered out (Table 7, last row). The sorption class combinations identified in Table 7 are used to form screening sets as described in Table 8.

Table 7. How Flow Conditions May Discriminate According to Sorptivity in the Groundwater Scenarios

<b>Groundwater Flow Conditions</b>	<b>Favored Sorption Classes</b>
Fracture flow, rich in colloids	High, Medium, and Low
Fracture flow, low in colloids	Medium and Low
Matrix flow (no colloids)	Low

### 6.2.5 Accounting for Solubility

In the groundwater scenarios, solubility affects the ability of an element in the waste form to mobilize within the degraded waste package and transport through groundwater to the accessible environment. The greater the solubility of an element, the greater the likelihood that its isotopes will be mobilized sufficiently to affect repository performance. For this analysis, elements are grouped into three solubility classes: high (H), medium (M), and low (L) (Assumption 5.7). The solubility and sorption classes are used to form screening sets as described in Table 8. The three solubility classes serve to divide the elements into sets based on alternative low-solubility cutoffs. Thus, with no consideration of solubility, all three classes are included H, M, and L (see the first row of Table 8). A relatively high solubility cutoff discounts only the least soluble elements, leaving H and M solubility elements to be considered together (Table 8, second row). The most restrictive sets consider only the most soluble elements as possible contributors to dose (Table 8, last row). Within each screening set, no further account is taken of differences in solubility. In effect, within each screening set, solubility limits do not apply. Instead, the screening analysis represents each radionuclide in proportion to its fraction of the inventory, not in accordance with solubility limits that might apply to the element in question.

The previous screening analysis allowed only two groups: soluble and insoluble. Introducing an intermediate solubility group in this revision addresses the NRC's claim that transport groupings were too broad. NRC observed, for example, that Se is in the same solubility and sorptivity groups as Np and U, yet is "more soluble than Np and U by several orders of magnitude" (Beckman 2001, Section 5.3.2.1).

### 6.2.6 Determining the Screening Sets

The considerations given in Sections 6.2.4 and 6.2.5, along with the solubility and sorption classes developed in Assumptions 5.6 and 5.7, result in a rule for combining solubility and sorption classes into screening sets for the groundwater scenarios. That is: consider the combinations of the solubility groupings H, M, and L; H and M; and H with the sorption groupings H, M, and L; M and L; and L. Table 8 provides descriptions of the nine resulting screening sets. The elements included in each screening set are given in Table 9.

Table 8. Descriptions of the Screening Sets for the Groundwater Scenarios

Solubility Class Combinations	Sorption Class Combinations		
	H, M, & L	M & L	L
<b>H, M, &amp; L</b>	Colloidal transport is important; solubility limits do not inhibit mobilization or transport.	Colloidal transport is not important, highly sorbing elements are immobilized, but medium sorbing elements are allowed to pass; solubility limits do not inhibit mobilization or transport.	Colloidal transport is not important, highly and moderately sorbing elements are immobilized, but low sorbing elements are allowed to pass; solubility limits do not inhibit mobilization or transport.
<b>H &amp; M</b>	Colloidal transport is important but solubility limits inhibit mobilization of the least soluble elements.	Colloidal transport is not important, highly sorbing elements are immobilized, but medium sorbing elements are allowed to pass; however, solubility limits inhibit mobilization of the least soluble elements.	Colloidal transport is not important, highly and moderately sorbing elements are immobilized, but low sorbing elements are allowed to pass; however, solubility limits inhibit mobilization of the least soluble elements.
<b>H</b>	Colloidal transport is important but solubility limits inhibit mobilization of all but the most soluble elements.	Colloidal transport is not important, highly sorbing elements are immobilized, but medium sorbing elements are allowed to pass; however, solubility limits inhibit mobilization of all but the most soluble elements.	Colloidal transport is not important, highly and moderately sorbing elements are immobilized, but low sorbing elements are allowed to pass; however, solubility limits inhibit mobilization of all but the most soluble elements.

Table 9. Lists of Elements in Each Screening Set

Solubility Class Combinations	Sorption Class Combinations		
	H, M & L	M & L	L
<b>H, M &amp; L</b>	Ac, Ag, Am, Ar, Ba, C, Ca, Cd, Cf, Cl, Cm, Cs, Eu, Gd, H, I, K, Kr, La, Mo, Nb, Ni, Np, Pa, Pb, Pd, Pm, Pt, Pu, Ra, Rb, Se, Sm, Sn, Sr, Tc, Th, Tm, U, Zr	Ag, Ar, Ba, C, Ca, Cl, Eu, Gd, H, I, K, Kr, La, Mo, Ni, Np, Pa, Pt, Rb, Se, Sr, Tc, U	Ar, Cl, H, I, K, Kr, Mo, Rb, Tc
<b>H &amp; M</b>	Ac, Ag, Am, Ar, Ba, C, Ca, Cf, Cl, Cm, Cs, Eu, Gd, H, I, K, Kr, La, Mo, Ni, Np, Pd, Pm, Pu, Ra, Rb, Se, Sm, Sr, Tc, Th, Tm, U	Ag, Ar, Ba, C, Ca, Cl, Eu, Gd, H, I, K, Kr, La, Mo, Ni, Np, Rb, Se, Sr, Tc, U	Ar, Cl, H, I, K, Kr, Mo, Rb, Tc
<b>H</b>	Ar, C, Cl, Cs, H, I, K, Kr, Rb, Se, Sr, Tc	Ar, C, Cl, H, I, K, Kr, Rb, Se, Sr, Tc	Ar, Cl, H, I, K, Kr, Rb, Tc

SOURCE: Assumptions 5.6 and 5.7.

### 6.2.7 Operational Description of the Screening Software

The purpose of RadNuScreen is to perform the calculations, rankings, and screenings that are required for the screening analysis described in Section 6.2.1. The fundamental calculation performed by the software is to multiply the activity of a radionuclide by a screening factor. The resulting product may be called a screening product. As the basic screening operation, RadNuScreen ranks radionuclides based on the magnitudes of the screening products, sums the screening products in rank order to form the cumulative screening product for each radionuclide, and applies a screening cutoff limit. The software performs the basic screening operation for two

exposure scenarios (groundwater and eruptive) for each screening time (Section 6.2.3). For the groundwater scenarios, multiple repetitions of the basic screening operation are required to cover all of the screening sets (see Table 9). The user must execute separate RadNuScreen runs for each waste form under consideration (Section 6.2.2).

RadNuScreen requires the user to provide the inputs listed below. For further information on RadNuScreen, see the Software Management Report (BSC 2002b).

- The activity of each radionuclide in each waste form at each screening time.
- Groundwater and eruptive screening factors for each radionuclide under consideration.
- Solubility and sorption classes for each radionuclide. Three solubility classes (High, Medium, and Low) and three sorption classes (High, Medium, and Low) are allowed.
- Compositions of the groundwater screening sets as combinations of solubility and sorption classes (see, for example, the column and row headers of Table 9).
- Coarse-screen and fine-screen cutoff levels (95 and 99 percent were used in the present screening analysis).
- Decay half-lives for each radionuclide and the half-life cutoff that RadNuScreen will use to discriminate between long- and short-lived radionuclides. Except for the optional Se-79 correction, RadNuScreen uses half-lives only to exclude short-lived radionuclides from the groundwater screening. The specified half-lives and half-life cutoffs have no effect on the eruptive screening.

## **6.3 RESULTS**

### **6.3.1 10,000-Year Regulatory Period**

The screening results for the 10,000-y regulatory period, which were produced using RadNuScreen 1.0, are provided in Table 10. Table 2 provides a complete list of the radionuclides that were considered in the screening analysis. Attachment VI (a compact disk) provides Excel workbook files that list the inputs for RadNuScreen 1.0 and provide detailed results for every waste form and screening time; Attachment V lists the contents of the compact disk. A file that summarizes the results for each waste form is also included. The formal screening was conducted using a screening-product cutoff of 0.95. The results listed for a 0.99 cutoff allow the reader to identify the marginally important radionuclides. The marginally important radionuclides might not have been screened out, had inputs or assumptions been significantly different. The rightmost two columns give the unions of the groundwater and eruptive sets. Note that the totals for the groundwater set and the totals of the unions of sets are the same for the 95 percent cutoff; therefore, the eruptive set does not contain any radionuclides that are not members of the groundwater set. For the eruptive scenario at 99 percent cutoff, three new marginally important radionuclides are introduced as compared to the groundwater set (Ac-225, Ra-225, and Th-228). The intended use of the screening results is discussed in Section 7. Refer to Section 5 for a list of underlying assumptions.

### **6.3.2 Incremental Effect of Including the 20,000-Year Screening Time**

With a 0.95 screening-product cutoff, no additional radionuclides are screened in if times up to 20,000 y are considered along with screening times within the 10,000-y regulatory period. With a 0.99 cutoff, no additional marginally important radionuclides are identified for the groundwater scenarios, but three additional marginally important radionuclides are identified for the igneous eruptive scenario: Cm-245, Ra-226, and Th-230. Attachment VI (a compact disk) provides Excel workbook files that list the inputs for RadNuScreen 1.0 and provide detailed results for every waste form at the 20,000-y screening time; Attachment V lists the contents of the compact disk. A file that summarizes the results for each waste form is also included.

### **6.3.3 Times Beyond the Regulatory Period Up To 1 Million Years**

The screening results from RadNuScreen 1.0 for times beyond the 10,000-y regulatory period, up to 1 million years after emplacement, are provided in Table 11. Table 2 provides a complete list of the radionuclides that were considered in the screening analysis. Attachment VI (a compact disk) provides Excel workbook files that list the inputs for RadNuScreen 1.0 and provide detailed results for every waste form and screening time; Attachment V lists the contents of the compact disk. A file that summarizes the results for each waste form is also included. The formal screening was conducted using a screening-product cutoff of 0.95. The results listed for a 0.99 cutoff allow the reader to identify the marginally important radionuclides. The rightmost two columns give the unions of the groundwater and eruptive sets. Note that the totals for the groundwater set and the totals of the unions of sets are the same for the 95 percent cutoff; therefore, the eruptive set does not contain any radionuclides that are not members of the groundwater set. For the eruptive scenario at 99 percent cutoff, four new marginally important radionuclides are introduced as compared to the groundwater set: Ac-225, Cm-245, Ra-225, and Th-228. The intended use of the screening results is discussed in Section 7. Refer to Section 5 for a list of underlying assumptions.

## **6.4 OTHER SCREENING FACTORS CONSIDERED AND REJECTED**

In the course of developing the screening analysis, two alternative sets of screening factors were considered and rejected. First, unadjusted screening factors directly from NCRP (1996) were considered. It was found that the NCRP screening factors, which were not intended to apply specifically to a sparsely populated arid environment, overemphasized some pathways (in particular, consumption of fish, milk, and soil), as can be easily seen in retrospect from the adjustment factors calculated in Attachments I and II (Table I-1).

Second, a hybrid set of screening factors, based on biosphere dose conversion factors from Yucca Mountain viability-assessment and site-recommendation studies, where available, and NCRP screening factors wherever project-generated dose conversion factors were unavailable, was considered. The presumed advantage of the hybrid approach was that the forty or so most important radionuclides would be represented by project-generated screening factors and the NCRP factors would apply only to the less important radionuclides. However, it was found that differences in methods used in the various sources, such as treatments of radionuclide buildup in soil and the relative importance of exposure pathways, precluded the development of an internally consistent set of screening factors.

Table 10. Screening Results for the 10,000-Year Regulatory Period

Radionuclide	Screening Results by Transport Scenario and Screening Product Cutoff Fraction					
	Groundwater Scenarios		Eruptive Igneous Scenario		Union of Sets for Groundwater and Eruptive Scenarios	
	0.95	0.99	0.95	0.99	0.95	0.99
Ac-225				Ac-225		Ac-225
Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227
Am-241	Am-241	Am-241	Am-241	Am-241	Am-241	Am-241
Am-243	Am-243	Am-243	Am-243	Am-243	Am-243	Am-243
C-14	C-14	C-14			C-14	C-14
Cl-36		Cl-36				Cl-36
Cm-244		Cm-244		Cm-244		Cm-244
Cs-135	Cs-135 <sup>a</sup>	Cs-135			Cs-135	Cs-135
Cs-137	Cs-137 <sup>a</sup>	Cs-137	Cs-137	Cs-137	Cs-137	Cs-137
I-129	I-129	I-129			I-129	I-129
Ni-63		Ni-63				Ni-63
Np-237	Np-237	Np-237		Np-237	Np-237	Np-237
Pa-231	Pa-231	Pa-231	<sup>b</sup>	Pa-231	Pa-231	Pa-231
Pb-210	<sup>b</sup>	Pb-210	<sup>b</sup>			Pb-210
Pu-238	Pu-238	Pu-238	Pu-238	Pu-238	Pu-238	Pu-238
Pu-239	Pu-239	Pu-239	Pu-239	Pu-239	Pu-239	Pu-239
Pu-240	Pu-240	Pu-240	Pu-240	Pu-240	Pu-240	Pu-240
Pu-241		Pu-241				Pu-241
Pu-242		Pu-242		Pu-242		Pu-242
Ra-225				Ra-225		Ra-225
Ra-226	Ra-226 <sup>a</sup>	Ra-226			Ra-226	Ra-226
Sn-126		Sn-126		Sn-126		Sn-126
Sr-90	Sr-90 <sup>a</sup>	Sr-90	Sr-90	Sr-90	Sr-90	Sr-90
Tc-99	Tc-99	Tc-99		Tc-99	Tc-99	Tc-99
Th-228				Th-228		Th-228
Th-229	Th-229	Th-229	Th-229	Th-229	Th-229	Th-229
Th-232		Th-232				Th-232
U-232	U-232	U-232	U-232	U-232	U-232	U-232
U-233	U-233	U-233	U-233	U-233	U-233	U-233
U-234	U-234	U-234	U-234	U-234	U-234	U-234
U-235		U-235				U-235
U-236	<sup>b</sup>	U-236				U-236
U-238	U-238	U-238			U-238	U-238
<b>Counts</b>	<b>20</b>	<b>30</b>	<b>12</b>	<b>21</b>	<b>20</b>	<b>33</b>

NOTES: <sup>a</sup>Was screened out under REV 00 (BSC 2001a, Table 37) for the nominal scenario.

<sup>b</sup>Was not screened out under REV 00 (BSC 2001a, Table 37) for the corresponding scenario.

Table 11. Screening Results for Times Beyond 10,000 Years and Up To 1 Million Years

Radionuclide	Screening Results by Transport Scenario and Screening Product Cutoff Fraction					
	Groundwater Scenarios		Eruptive Igneous Scenario		Union of Sets for Groundwater and Eruptive Scenarios	
	0.95	0.99	0.95	0.99	0.95	0.99
Ac-225				Ac-225		Ac-225
Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227	Ac-227
Am-243	Am-243	Am-243	Am-243	Am-243	Am-243	Am-243
C-14	C-14 <sup>a</sup>	C-14			C-14	C-14
Cl-36	Cl-36 <sup>a</sup>	Cl-36			Cl-36	Cl-36
Cm-245				Cm-245		Cm-245
Cs-135	Cs-135 <sup>a</sup>	Cs-135			Cs-135	Cs-135
I-129	I-129	I-129			I-129	I-129
Nb-94		Nb-94				Nb-94
Np-237	Np-237	Np-237	Np-237	Np-237	Np-237	Np-237
Pa-231	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231	Pa-231
Pb-210	Pb-210	Pb-210	Pb-210	Pb-210	Pb-210	Pb-210
Pu-239	Pu-239	Pu-239	Pu-239	Pu-239	Pu-239	Pu-239
Pu-240	Pu-240	Pu-240	Pu-240	Pu-240	Pu-240	Pu-240
Pu-242	Pu-242	Pu-242	Pu-242	Pu-242	Pu-242	Pu-242
Ra-225				Ra-225		Ra-225
Ra-226	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226	Ra-226
Se-79	Se-79 <sup>a</sup>	Se-79			Se-79	Se-79
Sn-126	Sn-126 <sup>a</sup>	Sn-126	Sn-126 <sup>a</sup>	Sn-126	Sn-126	Sn-126
Tc-99	Tc-99	Tc-99	Tc-99 <sup>a</sup>	Tc-99	Tc-99	Tc-99
Th-228				Th-228		Th-228
Th-229	Th-229	Th-229	Th-229	Th-229	Th-229	Th-229
Th-230	Th-230	Th-230	Th-230	Th-230	Th-230	Th-230
Th-232	Th-232 <sup>a</sup>	Th-232	Th-232	Th-232	Th-232	Th-232
U-233	U-233	U-233	U-233	U-233	U-233	U-233
U-234	U-234	U-234	U-234	U-234	U-234	U-234
U-235		U-235		U-235		U-235
U-236	U-236	U-236	U-236	U-236	U-236	U-236
U-238	U-238	U-238	U-238	U-238	U-238	U-238
<b>Counts</b>	<b>23</b>	<b>25</b>	<b>18</b>	<b>23</b>	<b>23</b>	<b>29</b>

NOTES <sup>a</sup>Was screened out under REV 00 (BSC 2001a, Table 37) for the corresponding scenario.

## 6.5 UNCERTAINTIES

The radionuclide screening analysis has been performed against a backdrop of several previous Yucca Mountain TSPAs and reviews by the NRC and an international peer review panel (Riotte 2001). The results of the radionuclide screening analysis are not sensitive to uncertainties in input values or assumptions because the results of the screening analysis are partly known ahead

of time (based on other TSPAs and on Revision 0 of this screening analysis). Screening out a radionuclide known to be important or a failure to screen out a radionuclide not previously suspected of being at least marginally important would be viewed skeptically. Before finalization of the screening analysis, an inquiry into the unexpected result would lead either to an explanation and confirmation of the unexpected result or to a discovery that some fault with the inputs or the screening method required correction. An example of this sequence of events happened during the scoping calculations when Np-236a was unexpectedly screened in: errors in the screening factors for Np-236a were discovered and corrected (Assumptions 5.2 and 5.8 and Attachments I and II).

The worst-case consequence of uncertainties in the inputs or assumptions is that marginally important radionuclides could be inappropriately screened out. To highlight radionuclides that are of marginal importance, and might have made the 95 percent cut under a different set of assumptions (such as solubility- and sorption-class assignments; screening factors; and characteristics of the average and outlying waste forms), a finer screening was conducted at a screening-product cutoff fraction of 99 percent (Assumption 5.5).

## **6.6 ADDITIONAL RADIONUCLIDES RECOMMENDED**

### **6.6.1 Separate Groundwater Protection Standard**

U.S. Environmental Protection Agency (EPA) regulations (40 CFR 197.30) and the separate groundwater protection standard in 10 CFR 63.331 set limits on:

1. The combined activity of Ra-226 and Ra-228 in groundwater
2. Gross alpha activity (including Ra-226 but excluding radon and uranium)
3. Dose from combined beta and photon emitting radionuclides in groundwater.

The first item requires the addition of Ra-228 to the list of radionuclides that must be included in the radionuclide inventory and tracked for TSPA.

The second item is concerned only with alpha decay. The screening analysis used dose considerations to identify the important radionuclides, including alpha emitters. Because dose is the best measure of the relative importance of alpha emitters from the human perspective, the same screening is appropriate to identify the radionuclides to be included in a gross-alpha calculation. However, some of the screened-in radionuclides will be in secular equilibrium with short-lived daughter products that were screened out as primary contributors. To show compliance with the gross-alpha regulation, it will be necessary to include appropriate equilibrium activity contributions for the short-lived decay products. The short-lived products will not need to be transported in the TSPA and their equilibrium activities can be computed from the activities of the parents, so it is not necessary to list them here or to include them in the radionuclide inventory. Long-lived decay products of important radionuclides have either been screened in or out. If they have been screened in, their alpha activities and those of their short-lived daughters will be counted in the gross-alpha calculation. If they have been screened out, they need not be considered in the gross-alpha calculation because the screening analysis showed them and their short-lived daughters to be unimportant.

The third item is concerned with dose from drinking contaminated groundwater. This pathway was included in the screening analysis, so no further screening to identify potentially important contributors is necessary.

### 6.6.2 Precursors of Other Recommended Radionuclides

Some radionuclides that are precursors of important radionuclides are not necessarily identified by the screening analysis as potentially important. Table 12 provides a systematic examination of the radionuclides screened in according to the 95 percent cutoff (Table 10 and Table 11) and of Ra-228, which is needed for the groundwater protection standard. The additional radionuclides in the last column should be accounted for in the inventory, either by direct inclusion, or by appropriate augmentation of the daughter product.

Table 12. Additional Radionuclides Needed for Accurate Accounting of Those Screened In

Nuclide Examined	Discussion	Additional Nuclides
Ac-227	Daughter of Pa-231, which is screened in (See Table Note).	--
Am-241	Cm-245→Pu-241→Am-241. Cm-245 has a half-life much greater than that of Am-241 and can provide a source of Am-241. Toward the end of the regulatory period, Am-241 is in secular equilibrium with Cm-245 (See Table Note). Also, Bk-245→Am-241, but Bk-245 does not appear in the waste forms used for the screening analysis.	Pu-241 Cm-245
Am-243	Bk-247→Am-243, but Bk-247 does not appear in the waste forms used for the screening analysis (See Table Note). Also, Cm-247→Pu-243→ Am-243. Pu-243 has a half-life less than one year and need not be included in the inventory because it is merely serving as a conduit for the decay of Cm-247 to Am-243. Cm-247 has a half-life of more than 15 million years and therefore would provide a nearly constant source of Am-243 throughout the period of this analysis. However, Cm-247 does not appear in the waste forms used for the screening analysis except in DSNF, where its activity is a very small fraction of the Am-243 activity throughout the period of analysis; therefore, Cm-247 need not be included in the inventory.	--
C-14	Activation product; not produced by the decay of anything in the waste forms used for the screening analysis.	--
Cl-36	Activation product; not produced by the decay of anything in the waste forms used for the screening analysis.	--
Cs-135	Fission product; not produced by the decay of anything in the waste forms used for the screening analysis	--
Cs-137	Fission product; not produced by the decay of anything in the waste forms used for the screening analysis	--
I-129	Fission product; not produced by the decay of anything in the waste forms used for the screening analysis	--
Np-237	Decay product of Am-241, which is screened in. Also produced by decay of U-237, which is produced by a minor branch of the decay of Pu-241. U-237 has a half-life less than 1 year and need not be included in the initial inventory because it is merely serving as a conduit for the decay of Pu-241 to Np-237. Pu-241 is listed above as needed for the inventory.	--
Pa-231	U-235→Th-231→Pa-231. Th-231 has a half-life less than 1 y and need not be included in the initial inventory because it is merely serving as a conduit for the decay of U-235 to Pa-231. U-235 is present in the waste forms used for the screening analysis for all waste forms and its inventory is needed to accurately project the inventory of Pa-231, especially for times beyond the regulatory period.	U-235
Pb-210	Ra-226→Pb-210 through a series of short-lived radionuclides that need not be included in the inventory. Ra-226 is screened in wherever Pb-210 is screened in.	--

Table 12. Additional Radionuclides Needed for Accurate Accounting of Those Screened In (continued)

Nuclide Examined	Discussion	Additional Nuclides
Pu-238	Am-242m→Am-242→Cm-242→Pu-238. Cm-242 and Am-242 have half-lives less than 1 y and need not be included in the inventory because they are merely serving as a conduit for the decay of Am-242m to Pu-238. Also Am-242m→Np-238→Pu-238. Np-238 has a half-life of less than 1 y and need not be included in the inventory. Am-242m has a longer half-life than Pu-238, so could conceivably provide a source of Pu-238 worth tracking in TSPA. However, although Am-242m shows up in BWR, DSNF, HLW, and PWR waste forms, in each case, the Am-242m activity is negligible compared to that of Pu-238.	--
Pu-239	Am-243→Np-239→Pu-239. Np-239 has a half-life less than 1 y and need not be included in the inventory. Am-243 is screened in. Also, Cm-243→Pu-239. Cm-243 appears in BWR, DSNF, HLW, and PWR waste forms, but in each case, the Cm-243 activity is negligible compared to that of Pu-239.	--
Pu-240	Cm-244→Pu-240. Cm-244 has a half-life much shorter than that of Pu-240. For that reason, its initial activity would have to be much greater than that of Pu-240 to significantly affect the activity of Pu-240. This claim can be verified as follows. A necessary condition for the inventory of the parent radionuclide to significantly affect that of the daughter is that the number of atoms in initial inventory for the parent $N_p$ be at least comparable to that of the daughter, $N_d$ . That is, $N_p \cong N_d$ or $N_p > N_d$ . In this case, because the half-life of the parent is much less than that of the daughter, the relationship between the decay constants is $\lambda_p \gg \lambda_d$ . Given the required relationship of the numbers of atoms $N_p$ and $N_d$ , the necessary condition stated in terms of activities ( $A=N\lambda$ ) is $N_p\lambda_p \gg N_d\lambda_d$ . As it happens, the necessary condition is not met because the initial Cm-244 activity in the waste forms that were used for the screening analysis is less than the initial Pu-240 activity. Therefore, Cm-244 need not be included in the inventory.	--
Pu-242	Cm-246→Pu-242. Cm-246 has a half-life much shorter than that of Pu-242. For that reason, its activity would have to be much higher than that of Pu-242 to significantly affect the activity of Pu-242. (See the discussion for Pu-240 for a justification of this claim.) As it happens, the initial Cm-246 activity in the waste forms that were used for the screening analysis is less than the initial Pu-242 activity. Therefore, Cm-246 need not be included in the inventory.	--
Ra-226	Decay product of Th-230, which is screened in.	--
Ra-228	Decay product of Th-232, which is screened in.	--
Se-79	Fission product; not produced by the decay of anything in the waste forms used for the screening analysis	--
Sn-126	Fission product; not produced by the decay of anything in the waste forms used for the screening analysis	--
Sr-90	Fission product; not produced by the decay of anything in the waste forms used for the screening analysis	--
Tc-99	Fission product; not produced by the decay of anything in the waste forms used for the screening analysis	--
Th-229	Decay product of U-233, which is screened in.	--
Th-230	Decay product of U-234, which is screened in.	--
Th-232	Decay product of U-236, which is screened in.	--
U-232	Decay product of Pu-236, which has a half-life of about 3 y. With such a short half-life, by the time the waste is received at the repository, most of the Pu-236 will have decayed to U-232. In any case, Pu-236 has a half-life much shorter than that of U-232. For that reason, its activity would have to be much higher than that of U-232 to significantly affect the activity of U-232. (See the discussion for Pu-240 for a justification of this claim.) As it happens, the initial Pu-236 activity in the waste forms that were used for the screening analysis is less than the initial U-232 activity. Therefore, Pu-236 need not be included in the inventory.	--

Table 12. Additional Radionuclides Needed for Accurate Accounting of Those Screened In (continued)

Nuclide Examined	Discussion	Additional Nuclides
U-233	Np-237→Pa-233→U-233. Np-237 is screened in. Pa-233 has a half-life less than 1 y and need not be included in the inventory.	--
U-234	U-238→Th-234→Pa-234→U-234. U-238 is screened in. Pa-234 and Th-234 have half-lives less than 1 y and need not be included in the inventory.	--
U-236	Decay product of Pu-240, which is screened in.	--
U-238	Decay product of Pu-242, which is screened in.	--

NOTE: See Parrington et al. (1996) for decay relationships. See Table 2 for half-lives. See Attachment VI for activities in the waste forms used in the screening analysis.

## 6.7 RESPONSES TO COMMENTS FROM EXTERNAL REVIEWS

### 6.7.1 Nuclear Regulatory Commission

As has been mentioned above (Section 6.1), the NRC provided a constructive critique of the previous revision of the radionuclide screening analysis (Beckman 2001, Section 5.3.2.1). Partial responses to the NRC’s comments are scattered throughout the present analysis. The NRC comments are stated more fully here, and responses are provided.

**Comment:** “First, the product of the inventory and the inhalation and ingestion DCFs for the radionuclide are not directly related to the risk that the radionuclide poses to the critical group, even when the solubility and transport properties in the geosphere of the radionuclide are accounted for. Processes that affect transport in the biosphere, such as uptake by plants and bioaccumulation, are not accounted for using this methodology. Also, the direct exposure pathway is not accounted for by this approach. Thus, radionuclides for which ground shine constitutes a significant exposure pathway, such as Nb-94 and Sn-126, could be inappropriately screened using this methodology.”

**Response:** The use of the adjusted NCRP screening factors (Assumptions 5.2 and 5.8) answers this concern by accounting for the effects of the biosphere (including uptake by plants, bioaccumulation, and direct exposure). Furthermore, the relative contribution of each biosphere pathway is appropriately weighted by project-generated usage factors (Section 4.1.1, Assumptions 5.2 and 5.8).

Note that, consistent with NRC’s observation above, Sn-126 is screened in after the regulatory period for the groundwater and igneous eruptive scenarios (Table 11). Despite inclusion of the direct exposure pathway in this screening analysis, Nb-94 is screened out for all scenarios and time periods; however, Nb-94 is of marginal significance for the groundwater scenario after the regulatory period (Table 10 and Table 11). An examination of Table 9 will confirm that Nb and Sn appear in only one groundwater screening set owing to their high sorptivity and low solubility. Thus, the only way for Sn-126 and Nb-94 to be screened in is to prevail in competition with all other radionuclides.

**Comment:** “Second, the grouping of radionuclides based on solubility and transport properties appears to be too broad. Dividing the radionuclides into only two groups of solubility classes

and three groups of transport classes can lead to the grouping of radionuclides that do not really behave similarly under repository conditions and the masking of potentially important radionuclides. For example, Se-79, which has been screened from the analysis, is grouped in the soluble and moderately sorbing transport group. This group also contains elements such as Np and U, which have significantly larger DCFs [dose conversion factors] than Se. However, Se is more soluble than Np and U by several orders of magnitude and also is transported much more quickly than Np and U. Thus, Se could pose a much greater risk to the critical group than Np or U, especially at early times, but be screened from the analysis.”

**Response:** The revised analysis reevaluates and revises the solubility and sorption classifications, using project studies for corroboration wherever possible, and introduces an intermediate solubility class (Assumptions 5.6 and 5.7, Sections 6.2.4 and 6.2.5). One effect of the revised groundwater transport classifications is that Se is in the high solubility class, while U and Np are in the intermediate solubility class (Table 4). Although Se is now classed separately from U and Np, Se-79 is screened out during the regulatory period (Table 10). Selenium-79 becomes potentially important after the regulatory period for the groundwater scenarios (Table 11).

**Comment:** “Also, there does not seem to be any proposed methodology to investigate the effect of certain radionuclides such as Se-79 that have been identified in previous DOE and NRC TSPAs as important but have not been identified as important using the proposed methodology.”

**Response:** An investigation of the potential effects of screened-out radionuclides is beyond the scope of the radionuclide screening analysis. However, it is hoped that the improved methods introduced in this revision will allay concerns that radionuclides of more than marginal importance could have been improperly screened out. For further discussion on this topic, see the response to the first comment in Section 6.7.2. As an aside with respect to Se-79 (the radionuclide used as an example in the comment), some of the earlier studies used an erroneously low half-life, which then led to overstatement of the Se-79 activity during the regulatory period (Assumption 5.3, Attachment IV). The present screening analysis corrects for the erroneous Se-79 half-life that was used in the activity calculations (Section 6.2.3).

**Comment:** “Finally, the inventory abstraction AMR does not indicate how radionuclides not considered important to performance in themselves, but that generate daughter products important to performance, will be accounted for.”

**Response:** Significant sources of the potentially important radionuclides that were identified by the screening analysis are listed in Table 12. For further discussion on a related topic, see the response to the second comment in Section 6.7.2.

## 6.7.2 International Peer Review Panel

In the summer of 2001, an international panel reviewed site recommendation documents at the request of the DOE. The panel was jointly organized by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development, and the International Atomic Energy Agency of the United Nations. The final report (OECD 2002, Section 3.3) provides comments on the radionuclide screening that was performed for site recommendation.

**Comment:** “The [international review team] notes that some radionuclides (such as Cl-36 and Cs-135) that feature as important in other international studies [OECD 1997] were screened out after the TSPA-1995. ... For instance, Cl-36 has been screened out because it is not a fission product. However, it is produced by neutron activation of contaminating Cl in the fuel. It has been shown to be an important contributor to dose in, for instance, the Canadian program (Johnson et al. 1995).”

**Response:** A study that was cited by the international review team (OECD 1997, Section 2.11) identifies the radionuclides that contributed most to dose rate in the “reference” cases of ten repository performance assessment studies. The ten studies vary with respect to waste form, geologic media, repository concept, and purpose of the assessment, so there is no reason to expect precisely the same radionuclides to be important for every study. Nevertheless, there are many similarities in influential variables such as initial waste inventories, geological processes, and characteristics of the biosphere, which make it useful to compare the results of the ten studies with the results of the present screening. For comparisons of results, take the screening for the groundwater scenarios as the “reference” case for the present screening. Of the 20 radionuclides collectively identified by the ten studies, 13 were screened in for groundwater scenarios during the 10,000-y regulatory period: Ac-227, Am-243, C-14, Cs-135, I-129, Np-237, Pa-231, Pu-239, Pu-240, Ra-226, Tc-99, Th-229, U-233. Four more were screened in for times up to 1 million years: Cl-36, Pu-242, Se-79, and U-236. The two radionuclides that were specifically mentioned in the comment (Cs-135 and Cl-36) are discussed below. The three radionuclides that were identified as important by one or more of the ten studies but screened out by the present analysis (Nb-94, Pd-107, and Ra-223) are also discussed below.

In the revised screening, Cs-135 is screened in for the groundwater scenarios and screened out for the eruptive scenario (Table 10 and Table 11). The fine-screen test (based on the 99 percent screening-product cutoff) does not identify Cs-135 as even marginally important in the eruptive scenario.

For the Canadian repository concept, Johnson et al. (1995, Abstract) found that “the estimated radiological risks from Cl-36 are forty times lower than from I-129 at [10,000 y].” Consistent with that observation, Cl-36 is screened out by the present screening, except for the groundwater scenarios in the period beyond 10,000 y. However, the fine-screen test indicates that Cl-36 is potentially of marginal importance in the groundwater scenarios during the 10,000-y regulatory period (Table 10). In the activity calculations that feed the present and previous revisions of the screening analysis, Cl-36 appears in commercial fuel as an activation product due to a 5.3-ppm Cl impurity in the fuel (CRWMS M&O 1999a, Table 14; CRWMS M&O 1999b, Table 4).

Only one of the ten studies found Nb-94 to be a major contributor to dose. This apparent lack of importance is consistent with its insignificance as a fission product (Parrington et al. 1996), its consequently limited inventory as a neutron-activation product of the niobium present in zirconium based cladding, and niobium’s tendency to exhibit low solubility and high sorptivity (Table 4). In the present screening analysis, Nb-94 is screened out for all scenarios and times (Table 10 and Table 11). However, Nb-94 is found to be potentially of marginal importance for the groundwater scenarios after the regulatory period.

One of the ten studies found Pd-107 and Ra-223 to be important contributors to dose. Palladium-107 is a low-yield fission product (Parrington et al. 1996) with a relatively low groundwater screening factor (Table I-2). In the present screening analysis, Pd-107 is screened out for all scenarios and times, and is not identified as marginally important by the fine-screen test. Radium-223 has a half-life less than 10 y (Table 2), so it is accounted for in the groundwater scenarios only as a decay daughter (Assumption 5.9) from parents such as Ac-227 (Parrington et al. 1996). Thus, the logic of the screening process for the groundwater scenarios makes it impossible to screen in Ra-223. The selection of radionuclides in the eruptive scenario is not restricted by half-life; nevertheless, Ra-223 was screened out at all times for the eruptive scenario and was not identified as marginally important by the fine-screen test.

Although Cm-245, Cm-246, and Ni-59 were not mentioned in the NRC or international reviews, the NRC included them in its iterative performance assessment (Table 6). None of the ten studies under discussion (OECD 1997, Table 2), which include the NRC's iterative performance assessment, found Cm-245, Cm-246, or Ni-59 to be important contributors to dose, as can be seen from the listing earlier in this response.

**Comment:** "Furthermore, it is noted that the biosphere dose conversion factors used in screening out radionuclides did not properly account for short-lived daughters of long-lived parents when determining whether to screen out the parent."

**Response:** For the groundwater screening, direct contributions from radionuclides with half-lives less than 10 y are not included (Assumption 5.9). However, the adjusted NCRP screening factors allow for radioactive in-growth during a 30-y period of radionuclide accumulation in the soil. For the eruptive screening, direct contributions from all radionuclides are accounted for regardless of longevity, and indirect contributions due to in-growth are accounted for by a 30-y soil accumulation period. Thus, the revised screening avoids the possibility that a radionuclide could be screened out because its short-lived decay products had not been accounted for, as was possible under the previous revision.

For a response to a related comment, see the response to the final NRC comment above.

## 7. CONCLUSIONS

The radionuclide screening analysis separately considers two different postclosure time periods: the 10,000-y regulatory period for the proposed repository at Yucca Mountain and the period up to 1 million y after emplacement. The incremental effect of extending the screening for the regulatory period to 20,000 y is also addressed. Four release scenarios are considered: (1) the nominal scenario, (2) the human-intrusion scenario, (3) an intrusive igneous event, and (4) an eruptive igneous event. The screening analysis considers spent boiling water reactor fuel, spent pressurized water reactor fuel, U.S. Department of Energy spent nuclear fuel, and high-level radioactive waste. Average and outlying (that is, high burnup, high initial enrichment, low age, or otherwise exceptional) forms of each waste-form type are considered. The screening factors used for the analysis account for the influence of the biosphere and are consistent with the characteristics of the receptor based on the local population.

The screening analysis has shown that the radionuclides listed in Table 13 may substantially affect repository performance for the exposure scenarios and times listed. These radionuclides should be considered in total system performance assessment modeling for license application. Extending the screening for the regulatory period to include the 20,000-y screening time does not add any radionuclides to the lists for regulatory period as presented in Table 10. While the purpose of the analysis is to identify all of the radionuclides of major importance to dose and virtually all of the marginally important radionuclides, it is recognized that some radionuclides that could contribute a marginally significant fraction of the dose in unlikely circumstances might have been screened out. For this reason, a fine-screen test was conducted (Table 10, Table 11). See Section 6.5 for a discussion of the effect of uncertainties on the results of the screening analysis.

In addition to the radionuclides identified by the screening analysis, four other radionuclides (Pu-241, Cm-245, Ra-228, and U-235) should be included in the radionuclide inventory, either by direct inclusion, or by appropriate augmentation of the daughter product, as discussed in Section 6.6.

Table 13. Results of the Screening Analysis

Radionuclide	Nominal, Human-Intrusion, and Intrusive Igneous Scenarios		Eruptive Igneous Scenario	
	10 <sup>2</sup> to 2 × 10 <sup>4</sup> years	2 × 10 <sup>4</sup> to 10 <sup>6</sup> years	10 <sup>2</sup> to 2 × 10 <sup>4</sup> years	2 × 10 <sup>4</sup> to 10 <sup>6</sup> years
Ac-227	Ac-227	Ac-227	Ac-227	Ac-227
Am-241	Am-241		Am-241	
Am-243	Am-243	Am-243	Am-243	Am-243
C-14	C-14	C-14		
Cl-36		Cl-36		
Cs-135	Cs-135	Cs-135		
Cs-137	Cs-137		Cs-137	
I-129	I-129	I-129		
Np-237	Np-237	Np-237		Np-237
Pa-231	Pa-231	Pa-231		Pa-231
Pb-210		Pb-210		Pb-210
Pu-238	Pu-238		Pu-238	
Pu-239	Pu-239	Pu-239	Pu-239	Pu-239
Pu-240	Pu-240	Pu-240	Pu-240	Pu-240
Pu-242		Pu-242		Pu-242
Ra-226	Ra-226	Ra-226		Ra-226
Se-79		Se-79		
Sn-126		Sn-126		Sn-126
Sr-90	Sr-90		Sr-90	
Tc-99	Tc-99	Tc-99		Tc-99
Th-229	Th-229	Th-229	Th-229	Th-229
Th-230		Th-230		Th-230
Th-232		Th-232		Th-232
U-232	U-232		U-232	
U-233	U-233	U-233	U-233	U-233
U-234	U-234	U-234	U-234	U-234
U-236		U-236		U-236
U-238	U-238	U-238		U-238
<b>Counts</b>	<b>20</b>	<b>23</b>	<b>12</b>	<b>18</b>

NOTES: Extending the screening for the regulatory period to include the 20,000-y screening time does not add any radionuclides to the screening lists for regulatory period (see Section 6.3.2).

See Section 6.6 for a discussion of additional radionuclides that should be included in the radionuclide inventory: Pu-241, Cm-245, Ra-228, and U-235.

## 8. INPUTS AND REFERENCES

### 8.1 DOCUMENTS CITED

Beckman, D.A. 2001. "NRC Issue Resolution Status Report on Container Life and Source Term, Revision 3." Memorandum from D.A. Beckman (BSC) to Distribution, February 21, 2001, LV.LAP.AH.02/2001-236, with enclosure. ACC: MOL.20010418.0048.

Benedict, M.; Pigford, T.H.; and Levi, H.W. 1981. *Nuclear Chemical Engineering*. 2nd Edition. New York, New York: McGraw-Hill. TIC: 245089.

BSC (Bechtel SAIC Company) 2001a. *Inventory Abstraction*. ANL-WIS-MD-000006 REV 00 ICN 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020123.0278.

BSC (Bechtel SAIC Company) 2001b. *Summary of Dissolved Concentration Limits*. ANL-WIS-MD-000010 REV 01, ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010702.0085.

BSC 2002a. *Software Code: RadNuScreen*. V1.0. 10732-1.0-00.

BSC (Bechtel SAIC Company) 2002b. *Software Management Report (SMR) for RadNuScreen 1.0*. SND: 10732-SMR-1.0-00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020401.0141.

BSC (Bechtel SAIC Company) 2002c. *Technical Work Plan for Waste Form Degradation Modeling, Testing, and Analyses in Support of SR and LA*. TWP-WIS-MD-000008 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020524.0133.

Carroll, S.A.; O'Day, P.A.; and Piechowski, M. 1998. "Rock-Water Interactions Controlling Zinc, Cadmium, and Lead Concentrations in Surface Waters and Sediments, U.S. Tri-State Mining District. 2. Geochemical Interpretation." *Environmental Science & Technology*, 32, (7), 956-965. Washington, D.C.: American Chemical Society. TIC: 247008.

Cotton, F.A.; Wilkinson, G.; Murillo, C. A.; Bochmann, M. 1999. *Advanced Inorganic Chemistry*. 6th Edition. New York, NY: John Wiley & Sons. TIC: 245931.

Crowe, B.M. and Vaniman, D.T. 1985. *Research and Development Related to the Nevada Nuclear Waste Storage Investigations, January 1-March 31, 1984*. LA-10154-PR. Los Alamos, New Mexico: Los Alamos National Laboratory. ACC: HQS.19880517.1142.

CRWMS M&O 1995. *Total System Performance Assessment - 1995: An Evaluation of the Potential Yucca Mountain Repository*. B00000000-01717-2200-00136 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19960724.0188.

CRWMS M&O 1997. *Degraded Mode Criticality Analysis of Immobilized Plutonium Waste Forms in a Geologic Repository*. Predecisional Document. A00000000-01717-5705-00014 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980422.0911.

CRWMS M&O 1998. "Waste Form Degradation, Radionuclide Mobilization, and Transport Through the Engineered Barrier System." Chapter 6 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00006 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0006.

CRWMS M&O 1999a. *BWR Source Term Generation and Evaluation*. BBAC00000-01717-0210-00006 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000113.0334.

CRWMS M&O 1999b. *PWR Source Term Generation and Evaluation*. BBAC00000-01717-0210-00010 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000113.0333.

CRWMS M&O 2000a. *Inventory Abstraction*. ANL-WIS-MD-000006 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001130.0002.

CRWMS M&O 2000b. *Radionuclide Inventories for DOE SNF Waste Stream and Uranium/Thorium Carbide Fuels*. CAL-MGR-NU-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000412.0764.

CRWMS M&O 2000c. *Source Terms for HLW Glass Canisters*. CAL-MGR-NU-000002 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000823.0004.

CRWMS M&O 2000d. *Summary of Dissolved Concentration Limits*. ANL-WIS-MD-000010 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000525.0372.

CRWMS M&O 2000e. *Total System Performance Assessment for the Site Recommendation*. TDR-WIS-PA-000001 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001220.0045.

CRWMS M&O 2001a. *Disruptive Event Biosphere Dose Conversion Factor Analysis*. ANL-MGR-MD-000003 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010125.0233.

CRWMS M&O 2001b. *Environmental Transport Parameter Analysis*. ANL-MGR-MD-000007 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010208.0001.

CRWMS M&O 2001c. *Nominal Performance Biosphere Dose Conversion Factor Analysis*. ANL-MGR-MD-000009 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010123.0123.

CRWMS M&O 2001d. *Pure Phase Solubility Limits - LANL*. ANL-EBS-MD-000017 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010126.0005.

CRWMS M&O 2001e. *Unsaturated Zone and Saturated Zone Transport Properties (U0100)*. ANL-NBS-HS-000019 REV 00 ICN 1. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20010201.0026.

DOE (U.S. Department of Energy) 1998. *Total System Performance Assessment*. Volume 3 of *Viability Assessment of a Repository at Yucca Mountain*. DOE/RW-0508. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0030.

Eckerman, K.F. and Ryman, J.C. 1993. *External Exposure to Radionuclides in Air, Water, and Soil, Exposure-to-Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance*. EPA 402-R-93-081. Federal Guidance Report No. 12. Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. TIC: 225472.

Eckerman, K.F.; Wolbarst, A.B.; and Richardson, A.C.B. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*. EPA 520/1-88-020. Federal Guidance Report No. 11. Washington, D.C.: U.S. Environmental Protection Agency. ACC: MOL.20010726.0072.

EPA (U.S. Environmental Protection Agency) 1999. *Understanding Variation in Partition Coefficient,  $K_d$ , Values*. EPA 402-R-99-004A&B Two volumes. Washington, D.C.: U.S. Environmental Protection Agency. TIC: 249201.

EPRI (Electric Power Research Institute) 2002. *Evaluation of the Proposed High-Level Radioactive Waste Repository at Yucca Mountain Using Total System Performance Assessment, Phase 6*. Technical Report 1003031. Palo Alto, California: Electric Power Research Institute. TIC: 252239.

Faure, G. 1986. *Principles of Isotope Geology*. 2nd Edition. New York, New York: John Wiley & Sons. TIC: 237212.

Firestone, R.B. and Shirley, V.S. 1996. *Table of Isotopes*. 8th Edition, Volumes 1 and 2. New York, New York: John Wiley & Sons. TIC: 245571.

Johnson, L.H.; Goodwin, B.W.; Sheppard, S.C.; Tait, J.C.; Wuschke, D.M.; and Davison, C.C. 1995. *Radiological Assessment of  $^{36}\text{Cl}$  in the Disposal of Used CANDU Fuel*. AECL-11213. Pinawa, Manitoba, Canada: AECL Whiteshell Laboratories. TIC: 220859.

Kocher, D.C. 1983. "Dose-Rate Conversion Factors for External Exposure to Photons and Electrons." *Health Physics*, 45, (3), 665-686. New York, NY: Pergamon Press. TIC: 251385.

Langmuir, D. 1997. *Aqueous Environmental Geochemistry*. Upper Saddle River, New Jersey: Prentice Hall. TIC: 237107.

NCRP (National Council on Radiation Protection and Measurements) 1996. *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground*. NCRP Report No. 123 I. Bethesda, Maryland: National Council on Radiation Protection and Measurements. TIC: 225158.

OECD (Organisation for Economic Co-operation and Development) 1997. *Lessons Learnt From Ten Performance Assessment Studies*. Paris, France: Organisation for Economic Co-operation and Development. TIC: 243964.

OECD Nuclear Energy Agency and the International Atomic Energy Agency 2002. *An International Peer Review of the Yucca Mountain Project TSPA-SR*. Paris, France: OECD Publications. TIC: 252385.

Oversby, V.M. 1987. "Important Radionuclides in High Level Nuclear Waste Disposal: Determination Using a Comparison of the U.S. EPA and NRC Regulations." *Nuclear and Chemical Waste Management*, 7, 149-161. New York, New York: Pergamon Journals. TIC: 220003.

Parrington, J.R.; Knox, H.D.; Breneman, S.L.; Baum, E.M.; and Feiner, F. 1996. *Nuclides and Isotopes, Chart of the Nuclides*. 15th Edition. San Jose, California: General Electric Company and KAPL, Inc. TIC: 233705.

Pauling, L. 1970. *General Chemistry*. 3rd Edition. San Francisco, California: W.H. Freeman and Company. TIC: 244746.

Riotte, H. 2001. OECD/NEA-IAEA Joint International Peer Review of the Yucca Mountain Site Characterization Project's Total System Performance Assessment Supporting the Site Recommendation Process. Correspondence from H. Riotte (OECD/NEA-IAEA) to L. Barrett (DOE/OCRWM), November 2, 2001, with enclosure. ACC: MOL.20011113.0240.

Songsheng, J.; Jingru, G.; Shan, J.; Chunsheng, L.; Anzhi, C.; Ming, H.; Shaoyong, W.; and Shilin, L. 1997. "Determination of the Half-Life of <sup>79</sup>Se with the Accelerator Mass Spectrometry Technique." *Nuclear Instruments and Methods in Physics Research B: Beam Interactions with Materials and Atoms*, 123, (1-4), 405-409. New York, New York: Elsevier. TIC: 251958.

Ticknor, K.V.; Vandergraaf, T.T.; McMurry, J.; Boisvenue, L.; and Wilkin, D.L. 1996. *Parametric Studies of Factors Affecting Se and Sn Sorption*. AECL-TR-723. Pinawa, Manitoba, Canada: Atomic Energy of Canada Limited. TIC: 223923.

Weast, R.C., ed. 1978. *CRC Handbook of Chemistry and Physics*. 59th Edition. West Palm Beach, Florida: CRC Press. TIC: 246814.

Wescott, R.G.; Lee, M.P.; Eisenberg, N.A.; McCartin, T.J.; and Baca, R.G., eds. 1995. *NRC Iterative Performance Assessment Phase 2, Development of Capabilities for Review of a Performance Assessment for a High-Level Waste Repository*. NUREG-1464. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.19960710.0075.

Wilson, M.L.; Gauthier, J.H.; Barnard, R.W.; Barr, G.E.; Dockery, H.A.; Dunn, E.; Eaton, R.R.; Guerin, D.C.; Lu, N.; Martinez, M.J.; Nilson, R.; Rautman, C.A.; Robey, T.H.; Ross, B.; Ryder, E.E.; Schenker, A.R.; Shannon, S.A.; Skinner, L.H.; Halsey, W.G.; Gansemer, J.D.; Lewis, L.C.; Lamont, A.D.; Triay, I.R.; Meijer, A.; and Morris, D.E. 1994. *Total-System Performance Assessment for Yucca Mountain – SNL Second Iteration (TSPA-1993)*. SAND93-2675. Executive Summary and two volumes. Albuquerque, New Mexico: Sandia National Laboratories. ACC: NNA.19940112.0123.

## **8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES**

10 CFR 63. 2002. Energy: Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada. Readily available.

40 CFR 197. 2001. Protection of Environment: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada. Readily available.

AP-2.21Q, Rev. 1, BSCN 1. *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities*. [Washington, D.C.]: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20010212.0018.

AP-3.15Q, Rev. 1, ICN 2. *Managing Technical Product Inputs*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020423.0155.

AP-15.3Q, Rev. 0. *Control of Technical Product Errors*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020212.0254.

AP-SI.1Q, Rev. 3, ICN 4. *Software Management*. Washington, D.C.: U.S. Department of Energy. ACC: MOL.20020520.0283.

AP-SIII.9Q, Rev. 0, ICN 1. *Scientific Analyses* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20020404.0083.

## **8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER**

MO0006J13WTRCM.000. Recommended Mean Values of Major Constituents in J-13 Well Water. Submittal date: 06/07/2000.

MO0007SPADMM05.002. Distributions, Mean, Minimum, and Maximum Consumption Levels of Locally Produced Food by Type and Tap Water for the Amargosa Valley Receptor of Interest. Submittal date: 07/31/2000.

MO0010SPAAM01.014. Input Parameter Values for External and Inhalation Radiation Exposure Analysis. Submittal date: 10/02/2000.

MO0010SPAPET07.004. Environmental Transport Parameters. Submittal date: 10/03/2000.

**ATTACHMENT I.**  
**SCREENING FACTORS FOR GROUNDWATER SCENARIOS**

(8 pages)

**DEVELOPMENT OF GROUNDWATER SCREENING FACTORS**

As stated in Assumption 5.8, freshwater screening factors for various pathways from NCRP Report 123 are used as the basis of screening factors in the screening analysis. The usage factors that are built in to the NCRP screening factors, that is, the assumed times spent in various activities such as gardening and bathing or the quantities of water or food products consumed, are not necessarily appropriate for local conditions. The NCRP screening factors are adjusted here by replacing the generic usage factors (NCRP 1996, Table 7.1) with usage factors developed in project documents (Section 4.1.1). The following sections describe the development of adjustment factors (Table I-1) for each additive component from the NCRP report (NCRP 1996, Table C.1). The adjusted total screening factor (Table I-2) is the sum of the products of the components and their adjustment factors. Table I-2 provides a complete list of the radionuclides considered in the screening calculation along with the corresponding groundwater screening factors.

Table I-1. Adjustment Factors for Groundwater and Eruptive Scenarios

<b>Pathway Description</b>	<b>Applicable Scenarios</b>	<b>Adjustment Factor</b>
Gardening and shoreline activities	Groundwater	0.23
Consumption of drinking water	Groundwater	0.94
Consumption of fish	Groundwater	0.024
Consumption of vegetables	Groundwater & Eruptive	0.2
Consumption of milk	Groundwater & Eruptive	0.014
Consumption of meat	Groundwater & Eruptive	0.1
Inadvertent ingestion of soil	Groundwater & Eruptive	0.05
Inhalation	Eruptive	0.73
Contaminated ground	Eruptive	0.42

**Swimming and boating**

The agricultural community in Amargosa Valley, which serves as the model for the receptor, does not have many opportunities to engage in swimming and boating. Swimming and boating are not considered in the development of biosphere dose conversion factors (CRWMS M&O 2001c, Section 6.3.1, Table 8), so they are not considered in this screening analysis. In effect, the adjustment factor for swimming and boating is zero.

## Gardening and shoreline activities

The screening factor for gardening and shoreline activities is calculated in the NCRP report in accordance with its Equations 8.11 and 8.12 (NCRP 1996). These two contributions are reported together in Table C.1 (NCRP 1996), so it is necessary to treat them together here. The nuclide-independent adjustment is performed as follows.

$$SF'_{G\&S} = F_{adj} (SF_{shore} + SF_{soil, irrad})$$

$$= \left( \frac{F_s U'_{sh} F_W + F_{ir} U'_{so}}{F_s U_{sh} F_W + F_{ir} U_{so}} \right) \left[ (F_s U_{sh} F_W + F_{ir} U_{so}) \sum_{i=1}^N BC(\lambda_i, t_b) DF_{Dir,i} F_{d,i} \right] \quad \text{Eq. I-1}$$

The adjustment factor is the initial multiplier in Eq. I-1. Multiplication by the adjustment factor replaces the usage factors in the NCRP report (NCRP 1996, Table 7.1) with the project's identified by the prime symbol. NCRP usage factors are as follows  $U_{sh} = 2000$  h/y is the time spent annually on the shoreline;  $U_{so} = 500$  h/y is the time spent annually in irrigated fields or gardens (NCRP 1996, Table 7.1). Best estimates of the corresponding quantities from project documents are as follows:  $U'_{sh} = 0$  h/y,  $U'_{so} = 3387$  h/y (Section 4.1.1). The other quantities needed to calculate the adjustment factor are the shoreline deposition velocity  $F_s = 0.07$  m/d (NCRP 1996, p. 69), the shoreline width factor,  $F_W = 0.02$  (NCRP 1996, p. 70), and the irrigation deposition velocity  $F_{ir} = 0.002$  m/d (NCRP 1996, Table 5.1). The definitions of the other symbols in Eq. I-1 are not needed for the development here, but may be found in the NCRP report (NCRP 1996, Section 8.2). Plugging in the NCRP and project values yields a value for the adjustment factor for garden and shoreline activities as follows.

$$F_{adj} = \frac{F_s U'_{sh} F_W + F_{ir} U'_{so}}{F_s U_{sh} F_W + F_{ir} U_{so}}$$

$$= \frac{(0.07 \text{ m/d})(0 \text{ h/y})(0.2) + (0.002 \text{ m/d})(3387 \text{ h/y})}{(0.07 \text{ m/d})(2000 \text{ h/y})(0.2) + (0.002 \text{ m/d})(500 \text{ h/y})} \quad \text{Eq. I-2}$$

$$= 0.23$$

## Consumption of drinking water

The screening factor for drinking water is a simple multiple of the usage factor for consumption of drinking water (NCRP 1996, Equation 8.13). Therefore, the adjustment factor is simply the ratio of project-generated to generic usage factors. The project-generated best estimate of the usage factor is 752.85 L/y (Section 4.1.1), while the generic value is 800 L/y (NCRP 1996, Table 7.1). Thus, almost no adjustment is indicated for drinking water. The adjustment factor for drinking water is  $752.85 / 800 = 0.94$ .

## Consumption of fish

The screening factor for fish consumption is a simple multiple of the usage factor for consumption of locally raised fish (NCRP 1996, Equation 8.14). Therefore, the adjustment factor is simply the ratio of project-generated to generic usage factors. The project-generated

best estimate of the usage factor is 0.47 kg/y (Section 4.1.1), while the generic value is 20 kg/y (NCRP 1996, Table 7.1). The adjustment factor for fish consumption is  $0.47 / 20 = 0.024$ .

### **Consumption of vegetables**

The screening factor for vegetable consumption is a simple multiple of the usage factor for consumption of locally grown vegetables (NCRP 1996, Equations 8.15 and 8.16). Therefore, the adjustment factor is simply the ratio of project-generated to generic usage factors. The project-generated best estimate of the usage factor (including leafy and root vegetables, fruit, and grain) is 39 kg/y (Section 4.1.1), while the generic value is 200 kg/y (NCRP 1996, Table 7.1). The adjustment factor for vegetable consumption is  $39 / 200 = 0.20$ .

### **Consumption of milk**

The screening factor for milk consumption is a simple multiple of the usage factor for consumption of locally produced milk (NCRP 1996, Equations 8.15 and 8.17). Therefore, the adjustment factor is simply the ratio of project-generated to generic usage factors. The project-generated best estimate of the usage factor is 4.14 kg/y (Section 4.1.1), while the generic value is 300 L/y or 300 kg/y (with the density of milk approximately equal to that of water, 1 kg/L) (NCRP 1996, Table 7.1). The adjustment factor for milk consumption is  $4.14 / 300 = 0.014$ .

### **Consumption of meat**

The screening factor for meat consumption is a simple multiple of the usage factor for consumption of locally produced meat (NCRP 1996, Equations 8.15 and 8.18). Therefore, the adjustment factor is simply the ratio of project-generated to generic usage factors. The project-generated best estimate of the usage factor (including beef, poultry, and eggs) is 10.41 kg/y (Section 4.1.1), while the generic value is 100 kg/y (NCRP 1996, Table 7.1). The adjustment factor for meat consumption is  $10.41 / 100 = 0.10$ .

### **Inadvertent ingestion of soil**

The screening factor for soil ingestion is a simple multiple of the usage factor for ingestion of soil (NCRP 1996, Equations 8.6a and 8.6c). Therefore, the adjustment factor is simply the ratio of two usage factors. The best estimate of the usage factor from project documentation is 50 mg/d (Section 4.1.1), while the NCRP's generic value is 0.365 kg/y (NCRP 1996, Table 7.1). Although the project's best estimate is actually a generic value based on a recommendation by the EPA, it has been found appropriate to characterize the soil ingestion rate for the project's biosphere dose conversion factor calculations (CRWMS M&O 2001b, Section 6.5). The adjustment factor for soil ingestion is  $(50 \text{ mg/d})(1 \text{ kg}/10^6 \text{ mg})(365 \text{ d/y}) / 0.365 \text{ kg/y} = 0.05$ .

## **CORRECTING THE GROUND-EXPOSURE COMPONENT FOR Np-236a**

As noted in Assumption 5.8, the value of the freshwater screening factor for Np-236a from the NCRP report is erroneously high. Scoping calculations using the value  $1.4 \times 10^{-2}$  (Sv/y) / (Bq/m<sup>3</sup>) failed to screen out Np-236a although only miniscule activities appeared in the waste form. Evidently, the error can be traced to an erroneously high effective dose factor for

ground irradiation:  $1.19 \times 10^{-6}$  (Sv/y) / (Bq/m<sup>3</sup>). The source cited by the NCRP report (Kocher 1983, Table 3) gives a value of  $4.35 \times 10^{-5}$  (Sv/y) / (Bq/m<sup>3</sup>) / (365.25 d/y) / (100<sup>2</sup> cm<sup>2</sup>/m<sup>2</sup>) =  $1.19 \times 10^{-11}$  (Sv/d)/(Bq/m<sup>2</sup>), which is a factor of 10<sup>5</sup> lower than the value given in the NCRP report (1996, Table A.1).

The dose coefficient from contaminated ground influences the freshwater screening factor by two avenues: the dose contributions from direct exposure to garden soil and to shoreline deposits (NCRP 1996, Equations 8.11 and 8.12). The two contributions are combined into a single value for garden soil and shoreline deposits (G&S) (NCRP 1996, p. 138). Because the dose coefficient is a simple multiplier for each radionuclide, the corrected value for the G&S component is a factor of 10<sup>5</sup> less than the value provided in the NCRP report (1996, Table C.1):  $1.4 \times 10^{-2} / 10^5$  =  $1.4 \times 10^{-7}$  (Sv/y) / (Bq/m<sup>3</sup>).

Table I-2. Calculation of Groundwater Screening Factors

Nuclide	Garden & Shoreline	Water	Fish	Vegetable	Milk	Meat	Soil	Adjusted Total
Ac-225	8.8E-10	3.0E-08	2.8E-09	1.5E-08	1.2E-11	2.2E-11	3.7E-11	3.1E-08
Ac-227	1.1E-06	1.8E-06	6.7E-07	2.3E-06	1.2E-08	6.0E-09	1.0E-06	2.5E-06
Ac-228	3.9E-10	3.4E-10	3.6E-12	4.1E-11	4.3E-12	5.9E-13	3.5E-12	4.2E-10
Ag-108	3.7E-15	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.5E-16
Ag-108m	1.3E-06	1.6E-09	4.1E-10	2.1E-09	4.5E-09	5.7E-10	1.2E-09	3.0E-07
Ag-109m	5.2E-16	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-16
Ag-110	1.1E-15	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.5E-16
Ag-110m	8.5E-08	2.3E-09	5.2E-10	2.6E-09	5.6E-09	6.9E-10	6.8E-11	2.2E-08
Am-241	2.4E-07	4.6E-07	3.5E-07	5.6E-07	4.3E-10	2.7E-09	3.6E-07	6.3E-07
Am-242	1.6E-11	3.0E-10	5.7E-12	7.3E-11	4.8E-14	1.2E-13	6.1E-12	3.0E-10
Am-242m	1.7E-07	4.4E-07	3.3E-07	5.4E-07	4.1E-10	2.6E-09	3.6E-07	5.9E-07
Am-243	7.1E-07	4.6E-07	3.4E-07	5.6E-07	4.3E-10	2.7E-09	3.6E-07	7.3E-07
Ar-39	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
At-217	9.2E-18	1.1E-15	1.8E-18	8.5E-21	1.6E-23	9.0E-35	8.2E-21	1.0E-15
Ba-133	1.6E-07	7.6E-10	7.5E-11	9.8E-10	1.7E-10	1.7E-11	2.8E-10	3.8E-08
Ba-137m	1.4E-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.2E-14
Bi-210	5.5E-14	1.6E-09	1.2E-10	5.4E-09	7.9E-10	1.9E-09	1.0E-10	2.8E-09
Bi-211	1.0E-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.3E-15
Bi-212	6.7E-12	1.3E-10	6.5E-14	4.6E-20	1.5E-26	0.0E+00	8.9E-16	1.2E-10
Bi-213	7.8E-13	9.2E-11	1.5E-13	7.2E-16	1.4E-18	7.6E-30	6.9E-16	8.7E-11
Bi-214	2.4E-12	3.1E-11	5.7E-12	1.7E-12	1.9E-13	2.5E-13	7.2E-13	3.0E-11
Bk-249	6.8E-09	1.5E-09	8.6E-10	1.8E-09	1.4E-12	4.2E-12	1.1E-09	3.4E-09
C-14	0.0E+00	4.5E-10	5.6E-07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-08
Ca-41	1.7E-11	2.1E-10	5.3E-09	2.5E-09	1.9E-09	3.1E-10	1.7E-10	8.9E-10
Ca-45	4.5E-18	6.8E-10	1.4E-08	9.4E-10	9.3E-10	1.5E-10	1.3E-11	1.2E-09
Cd-109	5.5E-11	1.8E-09	8.3E-09	3.4E-09	1.6E-09	1.9E-10	9.7E-11	2.6E-09
Cd-113	0.0E+00	2.0E-08	9.9E-08	2.3E-07	3.6E-08	4.5E-09	1.6E-08	6.9E-08
Cd-113m	0.0E+00	1.9E-08	9.3E-08	1.3E-07	2.5E-08	3.2E-09	7.8E-09	4.7E-08
Ce-139	3.1E-08	2.9E-10	1.8E-10	3.2E-10	3.4E-12	5.6E-13	4.8E-12	7.5E-09
Ce-142	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table I-2. Calculation of Groundwater Screening Factors (continued)

Nuclide	Garden & Shoreline	Water	Fish	Vegetable	Milk	Meat	Soil	Adjusted Total
Ce-144	1.9E-08	6.6E-09	4.4E-09	7.5E-09	7.9E-11	1.3E-11	2.2E-10	1.2E-08
Cf-249	2.9E-06	5.6E-07	3.5E-07	6.8E-07	5.2E-10	3.9E-09	4.3E-07	1.4E-06
Cf-250	3.0E-09	2.6E-07	1.6E-07	3.1E-07	2.2E-10	1.7E-09	1.0E-07	3.2E-07
Cf-251	1.1E-06	5.7E-07	3.6E-07	7.0E-07	5.3E-10	4.0E-09	4.4E-07	9.6E-07
Cf-252	7.5E-10	1.4E-07	8.4E-08	1.6E-07	1.2E-10	8.7E-10	1.5E-08	1.7E-07
Cl-36	3.9E-15	6.7E-10	1.7E-08	2.8E-07	6.8E-07	3.4E-07	5.3E-10	1.0E-07
Cm-242	2.2E-10	1.8E-08	1.2E-08	2.1E-08	1.5E-11	3.9E-11	1.8E-09	2.2E-08
Cm-243	9.0E-07	3.2E-07	2.4E-07	3.9E-07	2.9E-10	7.3E-10	1.8E-07	6.0E-07
Cm-244	4.2E-09	2.6E-07	1.9E-07	3.1E-07	2.3E-10	5.8E-10	1.3E-07	3.2E-07
Cm-245	7.2E-07	4.7E-07	3.6E-07	5.8E-07	4.4E-10	1.1E-09	3.8E-07	7.5E-07
Cm-246	6.1E-09	4.7E-07	3.5E-07	5.7E-07	4.4E-10	1.1E-09	3.7E-07	5.8E-07
Cm-247	3.1E-06	4.3E-07	3.3E-07	5.3E-07	4.0E-10	1.0E-09	3.4E-07	1.2E-06
Cm-248	5.0E-09	1.7E-06	1.3E-06	2.1E-06	1.6E-09	4.0E-09	1.4E-06	2.1E-06
Co-58	8.9E-09	7.9E-10	4.1E-09	8.1E-10	5.9E-10	2.1E-09	6.7E-12	3.3E-09
Co-60	5.2E-07	5.7E-09	4.2E-08	9.3E-09	7.7E-09	2.9E-08	1.2E-09	1.3E-07
Cs-134	1.5E-07	1.6E-08	7.5E-07	2.6E-08	7.2E-08	9.1E-08	1.4E-09	8.3E-08
Cs-135	0.0E+00	1.5E-09	7.7E-08	8.3E-09	1.4E-08	1.8E-08	1.2E-09	7.0E-09
Cs-137	3.5E-07	1.1E-08	5.4E-07	4.6E-08	8.5E-08	1.1E-07	6.2E-09	1.3E-07
Eu-150	9.9E-07	1.4E-09	1.7E-09	1.7E-09	3.7E-11	3.1E-10	8.2E-10	2.3E-07
Eu-152	4.9E-07	1.5E-09	1.9E-09	1.9E-09	4.0E-11	3.4E-10	6.3E-10	1.1E-07
Eu-154	4.1E-07	2.4E-09	3.0E-09	2.9E-09	6.2E-11	5.2E-10	7.6E-10	9.7E-08
Eu-155	1.5E-08	4.0E-10	4.9E-10	4.8E-10	1.0E-11	8.6E-11	8.1E-11	3.9E-09
Fe-55	2.6E-10	1.2E-10	5.9E-10	1.4E-10	1.5E-11	3.8E-10	1.4E-11	2.5E-10
Fr-221	2.3E-13	1.1E-11	1.4E-14	7.6E-17	1.3E-19	7.0E-31	7.3E-17	1.0E-11
Fr-223	2.7E-12	8.0E-10	2.9E-11	7.3E-11	2.8E-11	5.2E-12	1.9E-13	7.7E-10
Gd-152	0.0E+00	2.1E-08	1.6E-08	2.6E-08	5.8E-10	4.9E-09	1.7E-08	2.7E-08
Gd-153	3.9E-09	3.1E-10	2.1E-10	3.6E-10	7.6E-12	6.3E-11	9.0E-12	1.3E-09
H-3	0.0E+00	1.4E-11	3.4E-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-11
Ho-166m	1.4E-06	1.8E-09	5.3E-07	2.2E-09	4.9E-11	4.1E-10	1.4E-09	3.4E-07
I-129	1.8E-09	9.9E-08	9.9E-08	1.6E-07	4.6E-07	4.6E-07	7.8E-08	1.8E-07
In-113m	2.4E-11	1.5E-11	8.5E-12	5.0E-18	1.5E-22	1.3E-43	1.5E-16	2.0E-11
K-40	1.1E-08	4.0E-09	1.0E-06	3.0E-08	5.4E-08	3.9E-08	3.2E-09	4.1E-08
Kr-85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
La-138	9.6E-07	1.2E-09	9.2E-10	1.5E-09	3.4E-11	2.9E-10	9.6E-10	2.2E-07
Mn-54	3.3E-07	5.7E-10	6.5E-09	8.2E-10	1.1E-10	9.0E-11	2.1E-11	7.7E-08
Mo-93	8.9E-10	1.9E-10	4.7E-11	6.4E-10	2.3E-10	2.9E-11	2.0E-10	5.3E-10
Nb-91	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nb-93m	4.6E-10	1.5E-10	1.1E-09	2.0E-10	1.3E-13	5.1E-15	6.4E-11	3.2E-10
Nb-94	1.4E-06	1.7E-09	1.3E-08	2.4E-09	1.6E-12	6.1E-14	1.4E-09	3.2E-07
Nb-95	3.5E-09	5.9E-10	2.4E-09	5.1E-10	3.8E-13	1.3E-14	2.5E-12	1.5E-09
Nb-95m	3.9E-10	6.6E-10	5.3E-10	1.8E-10	1.4E-13	2.6E-15	5.4E-13	7.6E-10
Nd-144	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ni-59	3.5E-10	5.2E-11	1.3E-10	1.2E-10	9.6E-10	6.0E-11	4.1E-11	1.8E-10
Ni-63	0.0E+00	1.5E-10	3.8E-10	3.2E-10	2.6E-09	1.6E-10	1.1E-10	2.7E-10

Table I-2. Calculation of Groundwater Screening Factors (continued)

Nuclide	Garden & Shoreline	Water	Fish	Vegetable	Milk	Meat	Soil	Adjusted Total
Np-235	2.4E-10	6.8E-11	4.7E-11	8.0E-11	2.7E-13	6.9E-12	3.2E-12	1.4E-10
Np-236a	1.4E-07	1.9E-07	1.4E-07	3.0E-07	9.2E-10	2.2E-08	1.6E-07	2.8E-07
Np-237	2.2E-07	5.1E-07	3.8E-07	8.3E-07	2.4E-09	5.9E-08	4.0E-07	7.3E-07
Np-238	1.5E-10	1.0E-09	4.9E-11	1.5E-10	4.7E-13	2.6E-12	1.9E-11	1.0E-09
Np-239	5.7E-11	9.0E-10	4.9E-11	1.2E-10	4.8E-13	2.8E-12	3.5E-13	8.8E-10
Pa-231	5.9E-07	1.1E-06	2.8E-07	1.6E-06	5.8E-09	1.4E-09	1.4E-06	1.6E-06
Pa-233	7.9E-10	1.1E-09	1.3E-10	8.5E-10	1.6E-12	3.6E-13	3.4E-12	1.4E-09
Pa-234	7.2E-11	4.2E-10	9.7E-13	9.2E-13	5.0E-16	6.1E-18	1.5E-14	4.1E-10
Pa-234m	1.5E-15	1.6E-15	3.7E-18	3.5E-18	1.8E-21	2.0E-27	5.6E-20	1.8E-15
Pb-209	0.0E+00	3.8E-11	1.3E-12	3.1E-15	1.2E-17	6.6E-29	6.9E-16	3.6E-11
Pb-210	1.7E-08	6.4E-07	4.8E-06	8.2E-07	8.9E-08	6.7E-08	4.2E-07	9.1E-07
Pb-211	1.9E-12	7.4E-11	4.6E-13	2.9E-25	5.1E-37	0.0E+00	3.9E-16	7.0E-11
Pb-212	1.6E-10	6.5E-09	7.0E-10	5.4E-11	3.3E-12	9.4E-16	3.6E-13	6.2E-09
Pb-214	9.7E-12	9.3E-11	2.9E-12	2.3E-12	2.6E-13	3.3E-13	9.7E-13	9.0E-11
Pd-107	0.0E+00	4.7E-11	1.2E-11	1.5E-10	3.1E-12	1.6E-12	3.7E-11	7.7E-11
Pm-145	1.5E-07	1.2E-10	8.9E-11	1.5E-10	3.2E-12	2.7E-11	5.7E-11	3.5E-08
Pm-146	1.8E-08	9.2E-10	6.8E-10	1.1E-09	2.3E-11	2.0E-10	2.0E-10	5.3E-09
Pm-147	4.8E-12	3.2E-10	2.3E-10	3.8E-10	7.9E-12	6.6E-11	3.5E-11	3.9E-10
Po-210	1.5E-12	1.7E-07	3.5E-07	1.9E-07	2.7E-08	8.2E-08	2.8E-09	2.1E-07
Po-211	6.0E-17	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-17
Po-212	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Po-213	1.9E-24	1.4E-20	4.6E-22	1.1E-24	4.1E-27	2.4E-38	2.5E-25	1.3E-20
Po-214	2.0E-22	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.6E-23
Po-215	1.5E-18	6.1E-17	3.8E-19	2.4E-31	4.2E-43	0.0E+00	3.2E-22	5.8E-17
Po-216	6.4E-16	2.6E-14	2.8E-15	2.1E-16	1.3E-17	3.7E-21	1.4E-18	2.5E-14
Po-218	1.1E-12	1.1E-11	2.8E-13	2.6E-13	2.9E-14	3.7E-14	1.1E-13	1.1E-11
Pr-144	4.6E-13	1.2E-11	1.2E-14	3.5E-39	0.0E+00	0.0E+00	5.7E-17	1.1E-11
Pr-144m	2.5E-13	6.9E-12	6.8E-15	1.5E-39	0.0E+00	0.0E+00	2.4E-17	6.5E-12
Pt-193	3.8E-10	3.6E-11	3.1E-11	1.1E-10	2.2E-12	1.1E-12	2.3E-11	1.5E-10
Pu-236	6.6E-08	1.5E-07	1.1E-07	1.8E-07	2.4E-10	1.6E-09	2.3E-08	2.0E-07
Pu-238	6.4E-09	4.1E-07	3.1E-07	5.0E-07	1.9E-10	4.7E-09	2.9E-07	5.1E-07
Pu-239	3.2E-09	4.5E-07	3.4E-07	5.5E-07	2.1E-10	5.2E-09	3.5E-07	5.6E-07
Pu-240	6.9E-09	4.5E-07	3.4E-07	5.5E-07	2.1E-10	5.2E-09	3.5E-07	5.6E-07
Pu-241	3.7E-09	8.6E-09	6.4E-09	1.1E-08	4.5E-12	9.9E-11	9.1E-09	1.2E-08
Pu-242	5.7E-09	4.3E-07	3.2E-07	5.2E-07	2.0E-10	5.0E-09	3.4E-07	5.3E-07
Pu-243	7.5E-12	6.5E-11	3.3E-13	8.7E-14	3.3E-17	1.9E-16	2.9E-14	6.3E-11
Ra-223	1.2E-09	1.0E-07	3.5E-08	5.5E-08	2.2E-08	4.1E-09	1.4E-10	1.1E-07
Ra-224	1.3E-09	5.9E-08	8.0E-09	1.3E-08	5.2E-09	5.1E-10	2.9E-11	5.9E-08
Ra-225	1.3E-09	5.7E-08	2.3E-08	4.6E-08	1.4E-08	2.8E-09	1.5E-10	6.4E-08
Ra-226	3.4E-06	1.8E-07	2.2E-07	3.9E-07	9.7E-08	2.9E-08	3.5E-07	1.1E-06
Ra-228	2.9E-06	2.2E-07	2.7E-07	3.3E-07	9.9E-08	2.5E-08	7.6E-08	9.5E-07
Rb-87	0.0E+00	1.0E-09	5.2E-08	5.6E-09	1.5E-08	1.1E-08	8.1E-10	4.7E-09
Rh-102	2.8E-08	2.2E-09	1.6E-08	2.8E-09	4.6E-10	4.7E-10	2.7E-10	9.5E-09
Rh-106	9.6E-16	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.2E-16

Table I-2. Calculation of Groundwater Screening Factors (continued)

Nuclide	Garden & Shoreline	Water	Fish	Vegetable	Milk	Meat	Soil	Adjusted Total
Rn-219	3.4E-15	1.3E-13	8.4E-16	5.3E-28	9.4E-40	0.0E+00	7.2E-19	1.2E-13
Rn-220	2.4E-13	9.5E-12	1.0E-12	7.9E-14	4.8E-15	1.4E-18	5.3E-16	9.0E-12
Rn-222	2.0E-09	7.5E-11	8.3E-13	3.7E-10	3.9E-11	5.0E-11	2.0E-10	6.2E-10
Ru-106	1.0E-09	8.0E-09	1.8E-09	9.5E-09	6.5E-11	1.6E-09	3.5E-10	9.9E-09
Sb-125	6.2E-09	7.4E-10	1.8E-09	9.9E-10	4.3E-11	1.2E-10	1.1E-10	2.4E-09
Sb-126	4.5E-10	2.6E-09	1.9E-09	1.4E-09	5.8E-11	1.1E-10	3.8E-12	2.9E-09
Sb-126m	3.4E-13	9.5E-12	2.0E-13	2.2E-13	8.3E-15	1.6E-14	6.1E-16	9.1E-12
Se-79	0.0E+00	1.2E-09	6.2E-09	4.1E-09	8.3E-09	2.1E-08	9.7E-10	4.4E-09
Sm-145	3.8E-08	2.4E-10	1.4E-10	2.8E-10	5.9E-12	4.9E-11	1.3E-11	9.0E-09
Sm-146	0.0E+00	2.8E-08	1.7E-08	3.4E-08	7.7E-10	6.4E-09	2.2E-08	3.5E-08
Sm-147	0.0E+00	2.5E-08	1.6E-08	3.1E-08	7.0E-10	5.9E-09	2.0E-08	3.2E-08
Sm-148	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sm-149	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sm-151	3.9E-11	1.1E-10	6.7E-11	1.3E-10	3.0E-12	2.5E-11	7.6E-11	1.5E-10
Sn-113	4.0E-08	8.7E-10	5.2E-08	1.0E-09	3.4E-10	8.3E-10	1.2E-11	1.2E-08
Sn-119m	2.2E-10	4.2E-10	2.8E-08	6.0E-10	1.8E-10	4.4E-10	1.4E-11	1.3E-09
Sn-121	0.0E+00	2.4E-10	6.4E-10	1.2E-11	4.2E-12	5.1E-13	3.2E-14	2.4E-10
Sn-121m	3.2E-09	4.8E-10	3.6E-08	3.8E-09	4.4E-10	1.0E-09	4.4E-10	2.9E-09
Sn-123	1.1E-10	2.6E-09	1.6E-07	3.2E-09	1.0E-09	2.5E-09	4.0E-11	7.2E-09
Sn-126	2.2E-07	5.3E-09	3.9E-07	4.0E-08	4.8E-09	1.2E-08	4.4E-09	7.4E-08
Sr-90	0.0E+00	2.5E-08	3.7E-08	1.5E-07	9.3E-08	1.2E-07	1.6E-08	6.8E-08
Tb-160	9.7E-08	1.8E-09	8.0E-10	1.8E-09	4.0E-11	3.2E-10	1.6E-11	2.4E-08
Tc-98	1.2E-07	1.5E-09	7.3E-10	1.6E-07	3.0E-08	7.5E-10	1.2E-09	6.2E-08
Tc-99	5.2E-14	5.3E-10	2.7E-10	5.7E-08	1.1E-08	2.7E-10	4.2E-10	1.2E-08
Te-123m	2.5E-09	9.6E-10	7.7E-09	1.1E-09	1.9E-10	6.5E-10	1.4E-11	2.0E-09
Te-125m	1.6E-10	7.2E-10	4.8E-09	7.2E-10	1.3E-10	4.4E-10	5.0E-12	1.0E-09
Te-127	2.6E-13	1.4E-10	1.8E-11	8.5E-13	7.4E-14	3.8E-17	6.9E-15	1.3E-10
Te-127m	1.6E-10	1.8E-09	1.4E-08	2.0E-09	3.6E-10	1.2E-09	2.6E-11	2.6E-09
Th-227	4.7E-09	1.0E-08	9.8E-09	4.5E-08	1.1E-08	2.2E-09	2.5E-10	2.0E-08
Th-228	2.5E-07	5.3E-08	1.3E-07	1.1E-07	1.2E-08	1.7E-09	9.6E-09	1.3E-07
Th-229	1.5E-06	3.8E-07	9.6E-07	5.5E-07	1.4E-08	7.0E-09	3.7E-07	8.5E-07
Th-230	2.9E-08	6.2E-08	1.5E-07	7.7E-08	2.8E-10	7.8E-10	5.1E-08	8.7E-08
Th-231	2.6E-11	3.5E-10	3.0E-11	1.6E-11	2.8E-14	5.6E-15	1.7E-13	3.4E-10
Th-232	6.9E-06	2.9E-07	7.4E-07	5.2E-07	1.9E-08	7.8E-09	4.1E-07	2.0E-06
Th-234	3.7E-10	4.2E-09	4.7E-09	3.3E-09	6.2E-12	2.7E-11	1.2E-11	4.8E-09
Tl-206	4.4E-17	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E-17
Tl-207	9.2E-16	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.1E-16
Tl-208	8.1E-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.9E-13
Tl-209	4.0E-13	4.4E-13	1.5E-14	3.5E-17	1.3E-19	7.5E-31	7.8E-18	5.1E-13
Tm-171	7.0E-10	1.3E-10	7.9E-11	1.5E-10	3.3E-12	2.7E-11	1.1E-11	3.2E-10
U-232	1.9E-06	1.0E-07	2.6E-08	1.6E-07	2.3E-08	1.0E-08	1.5E-07	5.7E-07
U-233	2.4E-09	2.3E-08	5.8E-09	2.9E-08	4.3E-09	2.1E-09	1.9E-08	2.9E-08
U-234	6.8E-10	2.3E-08	5.6E-09	2.8E-08	4.2E-09	2.1E-09	1.8E-08	2.9E-08
U-235	3.1E-07	2.2E-08	5.5E-09	2.7E-08	4.0E-09	2.0E-09	1.8E-08	9.9E-08

Table I-2. Calculation of Groundwater Screening Factors (continued)

<b>Nuclide</b>	<b>Garden &amp; Shoreline</b>	<b>Water</b>	<b>Fish</b>	<b>Vegetable</b>	<b>Milk</b>	<b>Meat</b>	<b>Soil</b>	<b>Adjusted Total</b>
U-236	6.1E-10	2.1E-08	5.3E-09	2.6E-08	4.0E-09	2.0E-09	1.7E-08	2.6E-08
U-237	1.4E-10	9.2E-10	4.2E-11	3.4E-10	5.5E-11	1.7E-11	7.5E-13	9.7E-10
U-238	1.0E-07	2.1E-08	5.2E-09	2.7E-08	3.8E-09	1.9E-09	2.0E-08	5.0E-08
Y-90	0.0E+00	3.1E-09	1.9E-10	4.9E-10	1.2E-11	2.7E-11	1.0E-12	3.0E-09
Y-91	2.4E-10	3.0E-09	1.5E-09	2.9E-09	6.4E-11	5.0E-10	2.1E-11	3.5E-09
Zn-65	1.7E-08	3.0E-09	6.6E-08	4.3E-09	1.2E-08	3.1E-08	8.6E-11	1.2E-08
Zr-93	4.0E-10	2.4E-10	1.8E-09	3.1E-10	7.5E-14	2.9E-14	2.5E-10	4.4E-10
Zr-95	6.7E-08	9.7E-10	4.9E-09	1.1E-09	2.9E-13	8.6E-14	1.2E-11	1.7E-08

NOTE: The adjusted total screening factor in  $(\text{Sv} / \text{y}) / (\text{Bq} / \text{m}^3)$  is the sum of the products of the components (from NCRP 1996, Table C.1; or Assumption 5.10) and the adjustment factors in Table I-1 above. Multiplication and summation operators in Microsoft Excel were used for the computations.

## ATTACHMENT II.

### SCREENING FACTORS FOR THE ERUPTIVE SCENARIO

(6 pages)

#### DEVELOPMENT OF ERUPTIVE SCREENING FACTORS

As stated in Assumption 5.2, adjusted air screening factors from NCRP (1996) are used as screening factors in the screening analysis. The following sections develop adjustment factors (Table I-1) for each component represented in the NCRP report (NCRP 1996, Table B.1). The adjusted total screening factor (Table II-1) is the sum of the products of the components and their adjustment factors. Table II-1 provides a complete list of the radionuclides considered in the screening calculation along with the corresponding eruptive screening factors.

#### **Inhalation**

The screening factor for inhalation is a simple multiple of the usage factor for inhalation (NCRP 1996, Equation 8.2). Therefore, the adjustment factor is simply the ratio of project-generated to generic usage factors. The best estimate of the project-generated usage factor is given by the product of the inhalation exposure time 6073.5 h/y (Section 4.1.1) and the chronic breathing rate 23 m<sup>3</sup>/d (Section 4.1.1):  $6073.5 \text{ h/y} \times (23 \text{ m}^3/\text{d}) / (24 \text{ h/d}) = 5820 \text{ m}^3/\text{y}$ . The generic value is 8000 m<sup>3</sup>/y (NCRP 1996, Table 7.1). The adjustment factor for inhalation is  $5820 / 8000 = 0.73$ . The appropriateness of the relative weight assigned to the inhalation pathway by the screening factors developed in this attachment is addressed in Assumption 5.2.

#### **External exposure to the ash plume**

External exposure to the ash plume is not considered in the development of biosphere dose conversion factors (CRWMS M&O 2001a, Table 10, Section 6.3.2), so it is not considered in this screening analysis. In effect, the adjustment factor for external exposure to the ash plume is zero.

#### **External exposure to the contaminated ground surface**

The screening factor for ground exposure is a simple multiple of the usage factor for ground exposure (NCRP 1996, Equation 8.2). Therefore, the adjustment factor is simply the ratio of project-generated to NCRP usage factors. The best estimate of the project-generated usage factor is 3387 h/y (Section 4.1.1), while the NCRP value is 8000 h/y (NCRP 1996, Table 7.1). The adjustment factor for external exposure to contaminated ground is  $3387 / 8000 = 0.42$ .

#### **Consumption of terrestrial food and soil**

The screening factors for consumption of vegetables, milk, meat, and soil are simple multiples of the corresponding usage factors (NCRP 1996, Equation 8.5 through 8.6c). Therefore, the adjustment factors are simply the ratios of project-generated to NCRP generic usage factors. The

resulting adjustment factors are the same as the corresponding ones from Attachment I (Table I-1).

### CORRECTING THE GROUND-EXPOSURE COMPONENT FOR Np-236a

As noted in Assumption 5.2, the value of the air screening factor for Np-236a from the NCRP report is erroneously high. The error can be traced to an erroneously high effective dose factor for ground irradiation:  $1.19 \times 10^{-6} \text{ (Sv/y) / (Bq/m}^3\text{)}$ . The source cited by the NCRP report (Kocher 1983, Table 3) gives a value of  $4.35 \times 10^{-5} \text{ (Sv/y) / (Bq/m}^3\text{) / (365.25 d/y) / (100}^2\text{ cm}^2\text{/m}^2\text{)} = 1.19 \times 10^{-11} \text{ (Sv/d)/(Bq/m}^2\text{)}$ , which is a factor of  $10^5$  lower than the value given in the NCRP report. Because the dose coefficient is a simple multiplier for each radionuclide (NCRP 1996, Equation 8.2), the corrected value for the ground exposure component is a factor of  $10^5$  less than the value provided in the NCRP report (1996, Table B.1):  $3.8 \times 10^3 / 10^5 = 3.8 \times 10^{-2} \text{ (Sv/y) / (Bq/m}^3\text{)}$ .

Table II-1. Calculation of Igneous Eruptive Screening Factors

Nuclide	Inhalation	Ground Surface	Vegetable	Milk	Meat	Soil	Adjusted Total
Ac-225	1.7E-02	8.6E-05	7.5E-03	5.4E-06	9.6E-06	1.8E-05	1.4E-02
Ac-227	8.6E+00	6.7E-02	1.1E+00	6.0E-03	2.9E-03	5.0E-01	6.6E+00
Ac-228	4.0E-04	2.1E-05	2.0E-05	2.1E-06	3.0E-07	1.8E-06	3.0E-04
Ag-108	0.0E+00	1.0E-09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.2E-10
Ag-108m	5.7E-04	3.5E-01	1.0E-03	2.2E-03	2.7E-04	6.0E-04	1.5E-01
Ag-109m	0.0E+00	1.5E-10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.3E-11
Ag-110	0.0E+00	3.1E-10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-10
Ag-110m	1.7E-04	2.4E-02	1.3E-03	2.6E-03	3.2E-04	3.4E-05	1.1E-02
Am-241	5.7E-01	6.8E-03	2.8E-01	2.0E-04	1.3E-03	1.8E-01	4.8E-01
Am-242	9.6E-05	4.4E-07	3.7E-05	2.3E-08	5.9E-08	3.0E-06	7.8E-05
Am-242m	5.4E-01	5.2E-03	2.7E-01	2.0E-04	1.2E-03	1.8E-01	4.6E-01
Am-243	5.6E-01	6.0E-02	2.8E-01	2.0E-04	1.3E-03	1.8E-01	5.0E-01
Ar-39	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
At-217	3.2E-10	2.6E-12	4.3E-15	3.1E-18	1.6E-29	4.1E-15	2.3E-10
Ba-133	1.5E-05	4.5E-02	4.9E-04	7.8E-05	7.8E-06	1.4E-04	1.9E-02
Ba-137m	0.0E+00	3.8E-08	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E-08
Bi-210	4.1E-04	1.5E-09	2.7E-03	3.8E-04	9.4E-04	5.2E-05	9.4E-04
Bi-211	0.0E+00	2.8E-09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-09
Bi-212	3.4E-05	1.9E-06	2.3E-14	6.4E-22	0.0E+00	4.4E-10	2.6E-05
Bi-213	2.7E-05	2.2E-07	3.6E-10	2.6E-13	1.4E-24	3.5E-10	2.0E-05
Bi-214	9.6E-06	6.7E-07	8.6E-07	9.4E-08	1.2E-07	3.6E-07	7.5E-06
Bk-249	1.6E-03	1.9E-04	9.2E-04	6.6E-07	2.0E-06	5.4E-04	1.5E-03
C-14	4.5E-06	0.0E+00	1.3E-04	6.3E-05	7.2E-05	3.4E-08	3.7E-05
Ca-41	2.3E-06	4.7E-06	1.3E-03	9.3E-04	1.6E-04	8.4E-05	3.0E-04
Ca-45	1.4E-05	1.2E-12	4.7E-04	4.4E-04	7.2E-05	6.6E-06	1.2E-04

Table II-1. Calculation of Igneous Eruptive Screening Factors (continued)

Nuclide	Inhalation	Ground Surface	Vegetable	Milk	Meat	Soil	Adjusted Total
Cd-109	1.3E-04	1.5E-04	1.7E-03	7.4E-04	9.2E-05	4.8E-05	5.2E-04
Cd-113	1.9E-03	0.0E+00	1.2E-01	1.8E-02	2.2E-03	7.8E-03	2.6E-02
Cd-113m	1.7E-03	0.0E+00	6.3E-02	1.2E-02	1.5E-03	3.9E-03	1.4E-02
Ce-139	2.0E-05	8.6E-04	1.6E-04	1.6E-06	2.6E-07	2.4E-06	4.1E-04
Ce-142	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ce-144	8.1E-04	5.2E-04	3.8E-03	3.7E-05	6.1E-06	1.1E-04	1.6E-03
Cf-249	6.9E-01	8.0E-02	3.4E-01	2.5E-04	1.9E-03	2.1E-01	6.2E-01
Cf-250	3.6E-01	8.4E-05	1.5E-01	1.1E-04	8.0E-04	5.2E-02	3.0E-01
Cf-251	7.0E-01	3.1E-02	3.5E-01	2.5E-04	1.9E-03	2.2E-01	6.1E-01
Cf-252	3.2E-01	2.1E-05	8.2E-02	5.4E-05	4.1E-04	7.7E-03	2.5E-01
Cl-36	4.7E-05	1.1E-08	1.4E-01	3.4E-01	1.7E-01	2.6E-04	5.0E-02
Cm-242	2.8E-02	6.3E-06	1.0E-02	6.9E-06	1.8E-05	8.9E-04	2.2E-02
Cm-243	4.0E-01	2.5E-02	2.0E-01	1.4E-04	3.4E-04	9.2E-02	3.5E-01
Cm-244	3.2E-01	1.2E-04	1.6E-01	1.1E-04	2.7E-04	6.3E-02	2.7E-01
Cm-245	5.8E-01	2.0E-02	2.9E-01	2.1E-04	5.3E-04	1.9E-01	5.0E-01
Cm-246	5.8E-01	1.7E-04	2.9E-01	2.1E-04	5.2E-04	1.9E-01	4.9E-01
Cm-247	5.3E-01	8.6E-02	2.6E-01	1.9E-04	4.8E-04	1.7E-01	4.8E-01
Cm-248	2.1E+00	1.4E-04	1.1E+00	7.7E-04	1.9E-03	6.8E-01	1.8E+00
Co-58	2.3E-05	2.5E-03	4.1E-04	2.8E-04	1.0E-03	3.3E-06	1.3E-03
Co-60	4.5E-04	1.4E-01	4.7E-03	3.7E-03	1.4E-02	6.0E-04	6.2E-02
Cs-134	9.9E-05	4.2E-02	1.3E-02	3.4E-02	4.3E-02	6.8E-04	2.5E-02
Cs-135	9.8E-06	0.0E+00	4.2E-03	6.9E-03	8.6E-03	6.0E-04	1.8E-03
Cs-137	6.8E-05	9.9E-02	2.3E-02	4.1E-02	5.1E-02	3.1E-03	5.2E-02
Eu-150	5.8E-04	2.8E-01	8.4E-04	1.8E-05	1.5E-04	4.1E-04	1.2E-01
Eu-152	3.7E-04	1.4E-01	9.3E-04	1.9E-05	1.6E-04	3.2E-04	5.9E-02
Eu-154	4.7E-04	1.1E-01	1.4E-03	2.9E-05	2.4E-04	3.8E-04	4.7E-02
Eu-155	6.1E-05	4.3E-03	2.4E-04	4.8E-06	4.0E-05	4.0E-05	1.9E-03
Fe-55	5.1E-06	7.3E-06	7.2E-05	7.2E-06	1.8E-04	6.9E-06	4.0E-05
Fr-221	2.1E-06	2.7E-08	3.8E-11	2.7E-14	1.4E-25	3.6E-11	1.5E-06
Fr-223	1.5E-05	2.0E-07	3.6E-05	1.3E-05	2.4E-06	9.5E-08	1.9E-05
Gd-152	3.0E-01	0.0E+00	1.3E-02	2.8E-04	2.3E-03	8.3E-03	2.2E-01
Gd-153	3.3E-05	1.1E-03	1.8E-04	3.6E-06	2.9E-05	4.5E-06	5.3E-04
H-3	1.4E-07	0.0E+00	5.8E-07	8.6E-07	2.9E-07	1.1E-10	2.6E-07
Ho-166m	1.1E-03	3.8E-01	1.1E-03	2.3E-05	1.9E-04	6.8E-04	1.6E-01
I-129	6.2E-04	5.1E-03	8.0E-02	2.2E-01	2.2E-01	3.9E-02	4.6E-02
In-113m	7.8E-08	6.6E-07	2.5E-12	8.7E-18	7.1E-39	7.5E-11	3.3E-07
K-40	2.7E-05	3.2E-02	1.5E-02	2.7E-02	1.9E-02	1.6E-03	1.9E-02
Kr-85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
La-138	2.3E-03	2.7E-01	7.6E-04	1.6E-05	1.3E-04	4.8E-04	1.2E-01
Mn-54	1.4E-05	9.2E-03	4.1E-04	5.2E-05	4.3E-05	1.0E-05	4.0E-03
Mo-93	6.1E-05	1.5E-03	3.2E-04	1.1E-04	1.4E-05	1.0E-04	7.5E-04
Nb-91	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nb-93m	6.3E-05	1.3E-04	1.0E-04	6.4E-08	2.4E-09	3.2E-05	1.2E-04

Table II-1. Calculation of Igneous Eruptive Screening Factors (continued)

Nuclide	Inhalation	Ground Surface	Vegetable	Milk	Meat	Soil	Adjusted Total
Nb-94	8.6E-04	3.8E-01	1.2E-03	7.7E-07	2.9E-08	6.8E-04	1.6E-01
Nb-95	1.3E-05	9.6E-04	2.6E-04	1.8E-07	6.1E-09	1.2E-06	4.6E-04
Nb-95m	6.0E-06	1.1E-04	9.2E-05	6.0E-08	1.1E-09	2.7E-07	6.9E-05
Nd-144	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ni-59	5.8E-06	9.8E-05	5.9E-05	4.7E-04	2.9E-05	2.0E-05	6.8E-05
Ni-63	1.4E-05	0.0E+00	1.6E-04	1.3E-03	8.0E-05	5.3E-05	7.1E-05
Np-235	6.2E-06	6.6E-05	4.0E-05	1.3E-07	3.2E-06	1.6E-06	4.1E-05
Np-236a	2.2E-01	3.8E-02	1.5E-01	4.4E-04	1.0E-02	7.9E-02	2.1E-01
Np-237	6.2E-01	6.1E-02	4.1E-01	1.1E-03	2.8E-02	2.0E-01	5.7E-01
Np-238	4.6E-05	4.1E-05	7.4E-05	1.8E-07	9.7E-07	9.6E-06	6.6E-05
Np-239	5.8E-06	1.6E-05	6.1E-05	1.8E-07	1.0E-06	1.7E-07	2.3E-05
Pa-231	1.4E+00	4.3E-02	8.2E-01	2.8E-03	6.8E-04	7.0E-01	1.2E+00
Pa-233	2.2E-05	2.2E-04	4.3E-04	7.5E-07	1.7E-07	1.7E-06	1.9E-04
Pa-234	1.6E-06	2.0E-05	4.6E-07	8.3E-11	3.0E-12	7.5E-09	9.7E-06
Pa-234m	6.1E-12	4.0E-10	1.7E-12	2.9E-16	2.9E-22	2.8E-14	1.7E-10
Pb-209	1.8E-07	0.0E+00	1.5E-09	1.1E-12	5.8E-24	3.4E-10	1.3E-07
Pb-210	1.6E-02	4.6E-04	4.1E-01	4.3E-02	3.2E-02	2.1E-01	1.1E-01
Pb-211	1.6E-05	9.5E-08	1.5E-19	1.7E-32	0.0E+00	2.0E-10	1.2E-05
Pb-212	2.9E-04	2.2E-05	2.7E-05	6.8E-07	1.8E-10	1.8E-07	2.3E-04
Pb-214	1.6E-05	1.1E-06	1.2E-06	1.3E-07	1.6E-07	4.9E-07	1.2E-05
Pd-107	2.8E-05	0.0E+00	7.7E-05	1.5E-06	7.5E-07	1.8E-05	3.7E-05
Pm-145	5.9E-05	4.2E-03	7.3E-05	1.5E-06	1.3E-05	2.8E-05	1.8E-03
Pm-146	3.0E-04	5.0E-02	5.5E-04	1.1E-05	9.2E-05	1.0E-04	2.1E-02
Pm-147	8.2E-05	1.3E-07	1.9E-04	3.8E-06	3.1E-05	1.8E-05	1.0E-04
Po-210	1.4E-02	4.2E-08	9.4E-02	1.3E-02	3.8E-02	1.4E-03	3.3E-02
Po-211	0.0E+00	1.7E-12	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.1E-13
Po-212	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Po-213	6.3E-17	5.4E-20	5.5E-19	4.0E-22	2.1E-33	1.2E-19	4.6E-17
Po-214	0.0E+00	5.7E-18	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.4E-18
Po-215	1.3E-11	7.8E-14	1.2E-25	1.4E-38	0.0E+00	1.6E-16	9.5E-12
Po-216	1.1E-09	8.7E-11	1.1E-10	2.7E-12	7.2E-16	7.1E-13	8.6E-10
Po-218	1.6E-06	1.2E-07	1.3E-07	1.4E-08	1.8E-08	5.5E-08	1.2E-06
Pr-144	6.8E-08	1.3E-08	1.7E-33	0.0E+00	0.0E+00	2.8E-11	5.5E-08
Pr-144m	1.8E-08	7.1E-09	7.3E-34	0.0E+00	0.0E+00	1.2E-11	1.6E-08
Pt-193	3.1E-07	1.1E-04	5.3E-05	1.1E-06	5.4E-07	1.2E-05	5.8E-05
Pu-236	2.4E-01	8.9E-03	9.0E-02	1.2E-04	7.7E-04	1.2E-02	2.0E-01
Pu-238	5.0E-01	1.8E-04	2.5E-01	8.9E-05	2.2E-03	1.4E-01	4.2E-01
Pu-239	5.5E-01	8.8E-05	2.7E-01	9.9E-05	2.5E-03	1.8E-01	4.6E-01
Pu-240	5.5E-01	1.9E-04	2.7E-01	9.9E-05	2.5E-03	1.8E-01	4.6E-01
Pu-241	1.0E-02	1.0E-04	5.3E-03	2.1E-06	4.7E-05	4.5E-03	8.6E-03
Pu-242	5.2E-01	1.6E-04	2.6E-01	9.4E-05	2.3E-03	1.7E-01	4.4E-01
Pu-243	3.2E-07	2.1E-07	4.3E-08	1.6E-11	9.6E-11	1.5E-08	3.3E-07
Ra-223	1.7E-02	1.3E-04	2.8E-02	1.0E-02	1.8E-03	7.1E-05	1.8E-02

Table II-1. Calculation of Igneous Eruptive Screening Factors (continued)

Nuclide	Inhalation	Ground Surface	Vegetable	Milk	Meat	Soil	Adjusted Total
Ra-224	6.6E-03	1.8E-04	6.6E-03	2.1E-03	2.1E-04	1.4E-05	6.3E-03
Ra-225	1.7E-02	1.4E-04	2.3E-02	6.3E-03	1.3E-03	7.7E-05	1.7E-02
Ra-226	1.7E-02	3.8E-01	1.9E-01	4.6E-02	1.4E-02	1.8E-01	2.2E-01
Ra-228	9.3E-03	1.5E-01	1.7E-01	4.7E-02	1.2E-02	3.8E-02	1.1E-01
Rb-87	6.7E-06	0.0E+00	2.8E-03	7.2E-03	5.4E-03	4.1E-04	1.2E-03
Rh-102	2.4E-04	7.8E-02	1.4E-03	2.2E-04	2.2E-04	1.3E-04	3.3E-02
Rh-106	0.0E+00	2.7E-09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-09
Rn-219	2.9E-08	1.7E-10	2.7E-22	3.1E-35	0.0E+00	3.6E-13	2.1E-08
Rn-220	4.2E-07	3.2E-08	3.9E-08	9.9E-10	2.7E-13	2.6E-10	3.3E-07
Rn-222	1.9E-06	2.2E-04	1.9E-04	1.9E-05	2.5E-05	1.0E-04	1.4E-04
Ru-106	1.0E-03	2.8E-03	4.8E-03	3.1E-05	7.7E-04	1.7E-04	3.0E-03
Sb-125	2.7E-05	1.6E-02	4.9E-04	2.1E-05	5.6E-05	5.3E-05	6.8E-03
Sb-126	2.7E-05	1.3E-03	7.2E-04	2.6E-05	5.0E-05	1.9E-06	7.2E-04
Sb-126m	6.0E-08	9.5E-07	1.1E-07	3.9E-09	7.4E-09	3.1E-10	4.7E-07
Se-79	1.5E-05	0.0E+00	2.0E-03	4.0E-03	1.0E-02	4.9E-04	1.5E-03
Sm-145	1.9E-05	1.0E-03	1.4E-04	2.8E-06	2.3E-05	6.3E-06	4.6E-04
Sm-146	1.1E-01	0.0E+00	1.7E-02	3.7E-04	3.1E-03	1.1E-02	8.5E-02
Sm-147	9.9E-02	0.0E+00	1.6E-02	3.3E-04	2.8E-03	9.9E-03	7.6E-02
Sm-148	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sm-149	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sm-151	4.0E-05	1.1E-06	6.7E-05	1.4E-06	1.2E-05	3.8E-05	4.6E-05
Sn-113	2.4E-05	1.2E-03	5.2E-04	1.6E-04	3.9E-04	6.1E-06	6.7E-04
Sn-119m	1.4E-05	6.1E-05	3.0E-04	8.4E-05	2.1E-04	7.2E-06	1.2E-04
Sn-121	1.2E-06	0.0E+00	6.2E-06	1.3E-06	1.5E-07	1.6E-08	2.2E-06
Sn-121m	2.5E-05	8.9E-04	1.9E-03	2.2E-04	4.9E-04	2.2E-04	8.4E-04
Sn-123	7.4E-05	3.0E-05	1.6E-03	4.9E-04	1.2E-03	2.0E-05	5.1E-04
Sn-126	2.2E-04	4.9E-01	2.0E-02	2.3E-03	5.9E-03	2.2E-03	2.1E-01
Sr-90	2.8E-03	0.0E+00	7.3E-02	4.6E-02	5.8E-02	8.0E-03	2.3E-02
Tb-160	5.1E-05	2.7E-03	9.2E-04	1.9E-05	1.5E-04	7.8E-06	1.4E-03
Tc-98	5.1E-05	3.5E-01	7.8E-02	1.5E-02	3.8E-04	5.8E-04	1.6E-01
Tc-99	1.9E-05	1.5E-07	2.8E-02	5.5E-03	1.4E-04	2.1E-04	5.7E-03
Te-123m	2.0E-05	6.9E-04	5.4E-04	9.0E-05	3.0E-04	6.8E-06	4.4E-04
Te-125m	1.5E-05	4.5E-05	3.6E-04	6.2E-05	2.0E-04	2.5E-06	1.2E-04
Te-127	6.8E-07	7.1E-08	4.3E-07	1.4E-08	6.9E-12	3.4E-09	6.1E-07
Te-127m	4.5E-05	4.5E-05	1.0E-03	1.7E-04	5.7E-04	1.3E-05	3.1E-04
Th-227	3.5E-02	2.9E-04	2.3E-02	5.7E-03	1.1E-03	1.3E-04	3.0E-02
Th-228	7.0E-01	3.4E-02	5.6E-02	6.0E-03	8.3E-04	4.8E-03	5.4E-01
Th-229	2.8E+00	8.5E-02	2.8E-01	6.8E-03	3.4E-03	1.9E-01	2.1E+00
Th-230	4.3E-01	2.6E-03	3.8E-02	1.3E-04	3.7E-04	2.5E-02	3.2E-01
Th-231	2.0E-06	7.2E-07	8.2E-06	8.6E-09	1.7E-09	8.4E-08	3.4E-06
Th-232	1.8E+00	3.6E-01	2.6E-01	9.7E-03	3.8E-03	2.1E-01	1.5E+00
Th-234	8.2E-05	2.4E-05	1.6E-03	2.9E-06	1.3E-05	6.1E-06	3.9E-04
Tl-206	0.0E+00	1.2E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.0E-12

Table II-1. Calculation of Igneous Eruptive Screening Factors (continued)

<b>Nuclide</b>	<b>Inhalation</b>	<b>Ground Surface</b>	<b>Vegetable</b>	<b>Milk</b>	<b>Meat</b>	<b>Soil</b>	<b>Adjusted Total</b>
Ti-207	0.0E+00	2.5E-10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-10
Ti-208	0.0E+00	2.3E-07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.7E-08
Ti-209	1.9E-09	1.1E-07	1.7E-11	1.3E-14	6.6E-26	3.9E-12	4.8E-08
Tm-171	1.2E-05	1.9E-05	7.7E-05	1.5E-06	1.3E-05	5.4E-06	3.4E-05
U-232	1.4E+00	2.6E-01	8.2E-02	1.1E-02	4.7E-03	7.3E-02	1.2E+00
U-233	2.9E-01	2.3E-04	1.4E-02	2.0E-03	1.0E-03	9.3E-03	2.2E-01
U-234	2.9E-01	1.9E-04	1.4E-02	2.0E-03	9.9E-04	8.9E-03	2.2E-01
U-235	2.6E-01	4.6E-02	1.4E-02	1.9E-03	9.6E-04	9.1E-03	2.1E-01
U-236	2.7E-01	1.7E-04	1.3E-02	1.9E-03	9.4E-04	8.4E-03	2.0E-01
U-237	8.7E-06	3.9E-05	1.7E-04	2.4E-05	7.3E-06	3.7E-07	5.8E-05
U-238	2.6E-01	6.7E-03	1.4E-02	1.8E-03	9.2E-04	9.8E-03	2.0E-01
Y-90	2.1E-05	0.0E+00	2.4E-04	4.5E-06	1.0E-05	5.0E-07	6.4E-05
Y-91	1.1E-04	6.7E-06	1.5E-03	3.0E-05	2.3E-04	1.0E-05	4.1E-04
Zn-65	4.2E-05	4.8E-03	2.2E-03	5.9E-03	1.4E-02	4.3E-05	4.0E-03
Zr-93	3.4E-04	1.1E-04	1.6E-04	3.6E-08	1.3E-08	1.2E-04	3.3E-04
Zr-95	5.1E-05	3.4E-03	5.6E-04	1.4E-07	4.0E-08	6.0E-06	1.6E-03

NOTE: The adjusted total screening factor in  $(\text{Sv} / \text{y}) / (\text{Bq} / \text{m}^3)$  is the sum of the products of the components (from NCRP 1996, Table B.1; or Assumption 5.10) and the adjustment factors in Table I-1 above. Multiplication and summation operators in Microsoft Excel were used for the computations.

### ATTACHMENT III.

#### EVALUATION OF DOSE COEFFICIENTS FROM NCRP (1996)

(15 pages)

#### EVALUATION OF NCRP DOSE COEFFICIENTS FOR GROUND IRRADIATION

The error in the Np-236a dose coefficient raises the possibility that there may be other errors in the inputs used in the NCRP report (1996). Also, there are methodological differences in the way dose coefficients were computed in the original source (Kocher 1983) and in the source that provides the most recent federal guidance available at the time of this analysis on external dose coefficients (Eckerman & Ryman 1993). To increase confidence in the ground irradiation dose coefficients from the NCRP report, Table III-1 provides the basis for a comparison of the dose coefficients for irradiation by contaminated ground from NCRP (1996) to the comparable values provided by Eckerman and Ryman (1993). The ratios of dose coefficients (Table III-1, fifth column) are mostly near 1, which indicates a favorable comparison. Cases where the ratio is greater than two or less than one-half are discussed in the following paragraphs.

Wherever the NCRP dose coefficient is equal to zero the ratio is undefined. Where Eckerman and Ryman's coefficient is also zero, the comparison is favorable. Generally, where the NCRP coefficient is zero and Eckerman and Ryman's coefficient is not zero, it may be seen that Eckerman and Ryman's coefficient is less than  $10^{-13}$ , which is small by comparison to typical values, so that precise agreement is not important; therefore, the comparison is favorable. The only exception to this rule is for Y-90. NCRP (1996) did not carry over the nonzero coefficient from Kocher (1983). Yttrium-90 has such a short half-life (Table 2) that it is not directly included in the groundwater screening (Assumption 5.9), so there is no direct impact. Yttrium-90 is the decay product of Sr-90, so it is included indirectly in the groundwater screening. Because Sr-90 is screened in anyway (Section 7), there is no impact on the results of the screening analysis.

There are large differences in dose coefficients between the NCRP report and the latest federal guidance for two radionuclides: Ca-45 and Cl-36. The values that appear in NCRP (1996, Table A.1) do not agree with those listed in the original source (Kocher 1983). The differences appear to be due to an error of omission on the part of NCRP, in which they removed the skin-dose contribution without indicating that they had done so. The Ca-45 dose coefficient given by Kocher is  $6.35 \times 10^{-14} \text{ (Sv/y)/(Bq/cm}^2) / (365 \text{ d/y}) / (100^2 \text{ cm}^2/\text{m}^2) = 1.74 \times 10^{-20} \text{ (Sv/d)/(Bq/m}^2)$ , which is slightly greater than the value given by NCRP and reproduced here in Table III-1. Thus, the NCRP report provides a Ca-45 dose coefficient that differs little from the original source, but there remains an extremely large difference between the NCRP report and Eckerman and Ryman's work. The reason for the large difference is unknown, but the Ca-45 dose coefficient is less than  $10^{-14}$ , which is very small compared to typical values, so that precise agreement is not important. Therefore, the dose coefficient for Ca-45 is judged acceptable.

The Cl-36 dose coefficient given by Kocher (1983) is  $2.23 \times 10^{-6} \text{ (Sv/y)/(Bq/cm}^2) / (365 \text{ d/y}) / (100^2 \text{ cm}^2/\text{m}^2) = 6.11 \times 10^{-13} \text{ (Sv/d)/(Bq/m}^2)$ , which is about a factor of  $10^5$  greater than the

value given by NCRP and reproduced in Table III-1. Chlorine-36 is not a gamma emitter (Parrington et al. 1996), so it is not expected to be a significant contributor to dose from exposure to direct irradiation from contaminated ground. Indeed, the contributions to the unadjusted screening factors from terrestrial food consumption are at least eight orders of magnitude greater than the ground irradiation contributions (NCRP 1996, Tables B.1 and C.1). Therefore, no correction is made for the questionable Cl-36 dose coefficient for ground irradiation.

For Cd-109, Pm-147, Pt-193, Sn-119m, Tl-206, and Y-91 there are differences of more than a factor of two between the NCRP report and the latest federal guidance. Of these, all but Pt-193 have a half-lives less than 10 y (Table 2), so they are not used in the groundwater screening. For the eruptive screening, the short-lived radionuclides are included as contributors to the screening factors for the parent radionuclides, so their particular screening factors are not important. The Pt-193 dose coefficient given by Kocher (1983) is  $1.69 \times 10^{-7} \text{ (Sv/y)/(Bq/cm}^2) / (365 \text{ d/y}) / (100^2 \text{ cm}^2/\text{m}^2) = 4.63 \times 10^{-14} \text{ (Sv/d)/(Bq/m}^2)$ , which is slightly larger than the value given by NCRP and reproduced in Table III-1. The Pt-193 dose coefficient from NCRP is judged acceptable because it is in reasonable agreement with Kocher (1983) and is less than  $10^{-13}$ , which is small compared to typical values, so that precise agreement is not important.

Table III-1. Comparison of Ground Irradiation Dose Coefficients from Two Sources

Nuclide	Dose Coefficient for Exposure to Contaminated Ground			Ratio FGR-12 : NCRP-123 (dimensionless) <sup>c</sup>
	FGR-12 <sup>a</sup> (Sv/s)/(Bq/m <sup>2</sup> )	FGR-12 (Sv/d)/(Bq/m <sup>2</sup> )	NCRP-123 <sup>b</sup> (Sv/d)/(Bq/m <sup>2</sup> )	
Ac-225	1.58E-17	1.37E-12 <sup>e</sup>	1.20E-12	1.14E+00
Ac-227	1.57E-19	1.36E-14	1.60E-14	8.48E-01
Ac-228	9.28E-16	8.02E-11	6.70E-11	1.20E+00
Ag-108	1.99E-17	1.72E-12	1.30E-12	1.32E+00
Ag-108m	1.60E-15	1.38E-10	1.20E-10	1.15E+00
Ag-109m	9.71E-18	8.39E-13	6.60E-13	1.27E+00
Ag-110	3.82E-17	3.30E-12	2.30E-12	1.43E+00
Ag-110m	2.65E-15	2.29E-10	2.00E-10	1.14E+00
Am-241	2.75E-17	2.38E-12	2.20E-12	1.08E+00
Am-242	1.57E-17	1.36E-12	1.30E-12	1.04E+00
Am-242m	3.02E-18	2.61E-13	2.00E-13	1.30E+00
Am-243	5.35E-17	4.62E-12	4.90E-12	9.43E-01
Ar-39	3.38E-19	2.92E-14	0.00E+00	Undefined <sup>c</sup>
At-217	3.03E-19	2.62E-14	1.80E-14	1.45E+00
Ba-133	3.97E-16	3.43E-11	3.10E-11	1.11E+00
Ba-137m	5.86E-16	5.06E-11	4.50E-11	1.13E+00
Bi-210	1.05E-18	9.07E-14	0.00E+00	Undefined
Bi-211	4.58E-17	3.96E-12	3.80E-12	1.04E+00
Bi-212	1.79E-16	1.55E-11	1.30E-11	1.19E+00
Bi-213	1.32E-16	1.14E-11	1.10E-11	1.04E+00
Bi-214	1.41E-15	1.22E-10	1.00E-10	1.22E+00
Bk-249	6.85E-21	5.92E-16	0.00E+00	Undefined
C-14	1.61E-20	1.39E-15	0.00E+00	Undefined

Table III-1. Comparison of Ground Irradiation Dose Coefficients from Two Sources (continued)

Nuclide	Dose Coefficient for Exposure to Contaminated Ground			Ratio FGR-12 : NCRP-123 (dimensionless) <sup>c</sup>
	FGR-12 <sup>a</sup> (Sv/s)/(Bq/m <sup>2</sup> )	FGR-12 (Sv/d)/(Bq/m <sup>2</sup> )	NCRP-123 <sup>b</sup> (Sv/d)/(Bq/m <sup>2</sup> )	
Ca-41	0.00E+00	0.00E+00	1.50E-15	0.00E+00
Ca-45	4.61E-20	3.98E-15	1.60E-20	2.49E+05 <sup>d</sup>
Cd-109	2.25E-17	1.94E-12	7.00E-13	2.78E+00 <sup>d</sup>
Cd-113	6.99E-20	6.04E-15	0.00E+00	Undefined
Cd-113m	2.63E-19	2.27E-14	0.00E+00	Undefined
Ce-139	1.56E-16	1.35E-11	1.30E-11	1.04E+00
Ce-142	Not listed	Not listed	Not listed	Undefined
Ce-144	2.03E-17	1.75E-12	1.60E-12	1.10E+00
Cf-249	3.28E-16	2.83E-11	2.60E-11	1.09E+00
Cf-250	7.37E-19	6.37E-14	5.10E-14	1.25E+00
Cf-251	1.22E-16	1.05E-11	1.00E-11	1.05E+00
Cf-252	7.22E-19	6.24E-14	4.70E-14	1.33E+00
Cl-36	6.73E-19	5.81E-14	3.40E-18	1.71E+04 <sup>d</sup>
Cm-242	9.56E-19	8.26E-14	6.90E-14	1.20E+00
Cm-243	1.25E-16	1.08E-11	1.10E-11	9.82E-01
Cm-244	8.78E-19	7.59E-14	6.10E-14	1.24E+00
Cm-245	8.70E-17	7.52E-12	6.30E-12	1.19E+00
Cm-246	7.85E-19	6.78E-14	5.40E-14	1.26E+00
Cm-247	3.10E-16	2.68E-11	2.50E-11	1.07E+00
Cm-248	6.00E-19	5.18E-14	4.40E-14	1.18E+00
Co-58	9.50E-16	8.21E-11	7.30E-11	1.12E+00
Co-60	2.35E-15	2.03E-10	1.70E-10	1.19E+00
Cs-134	1.52E-15	1.31E-10	1.20E-10	1.09E+00
Cs-135	3.33E-20	2.88E-15	0.00E+00	Undefined
Cs-137	2.85E-19	2.46E-14	0.00E+00	Undefined
Eu-150	1.46E-15	1.26E-10	1.15E-10	1.10E+00
Eu-152	1.10E-15	9.50E-11	8.20E-11	1.16E+00
Eu-154	1.19E-15	1.03E-10	9.00E-11	1.14E+00
Eu-155	5.90E-17	5.10E-12	5.30E-12	9.62E-01
Fe-55	0.00E+00	0.00E+00	1.60E-14	0.00E+00 <sup>c</sup>
Fr-221	2.98E-17	2.57E-12	2.50E-12	1.03E+00
Fr-223	5.65E-17	4.88E-12	4.40E-12	1.11E+00
Gd-152	0.00E+00	0.00E+00	0.00E+00	Undefined
Gd-153	1.06E-16	9.16E-12	9.40E-12	9.74E-01
H-3	0.00E+00	0.00E+00	0.00E+00	Undefined
Ho-166m	1.70E-15	1.47E-10	1.20E-10	1.22E+00
I-129	2.58E-17	2.23E-12	1.60E-12	1.39E+00
In-113m	2.54E-16	2.19E-11	2.00E-11	1.10E+00
K-40	1.46E-16	1.26E-11	1.00E-11	1.26E+00
Kr-85	2.64E-18	2.28E-13	1.70E-13	1.34E+00
La-138	1.16E-15	1.00E-10	8.44E-11	1.19E+00
Mn-54	8.12E-16	7.02E-11	6.20E-11	1.13E+00

Table III-1. Comparison of Ground Irradiation Dose Coefficients from Two Sources (continued)

Nuclide	Dose Coefficient for Exposure to Contaminated Ground			Ratio FGR-12 : NCRP-123 (dimensionless) <sup>c</sup>
	FGR-12 <sup>a</sup> (Sv/s)/(Bq/m <sup>2</sup> )	FGR-12 (Sv/d)/(Bq/m <sup>2</sup> )	NCRP-123 <sup>b</sup> (Sv/d)/(Bq/m <sup>2</sup> )	
Mo-93	5.34E-18	4.61E-13	4.30E-13	1.07E+00
Nb-91	Not listed	Not listed	Not listed	Undefined
Nb-93m	9.39E-19	8.11E-14	7.60E-14	1.07E+00
Nb-94	1.53E-15	1.32E-10	1.20E-10	1.10E+00
Nb-95	7.48E-16	6.46E-11	5.70E-11	1.13E+00
Nb-95m	6.26E-17	5.41E-12	5.10E-12	1.06E+00
Nd-144	Not listed	Not listed	Not listed	Undefined
Ni-59	0.00E+00	0.00E+00	3.10E-14	0.00E+00 <sup>c</sup>
Ni-63	0.00E+00	0.00E+00	0.00E+00	Undefined
Np-235	3.65E-18	3.15E-13	3.50E-13	9.01E-01
Np-236a	1.20E-16	1.04E-11	1.19E-11	8.71E-01
Np-237	2.87E-17	2.48E-12	2.40E-12	1.03E+00
Np-238	5.29E-16	4.57E-11	4.00E-11	1.14E+00
Np-239	1.63E-16	1.41E-11	1.40E-11	1.01E+00
Pa-231	4.07E-17	3.52E-12	2.60E-12	1.35E+00
Pa-233	1.95E-16	1.68E-11	1.70E-11	9.91E-01
Pa-234	1.84E-15	1.59E-10	1.50E-10	1.06E+00
Pa-234m	1.53E-17	1.32E-12	8.40E-13	1.57E+00
Pb-209	3.01E-19	2.60E-14	0.00E+00	Undefined
Pb-210	2.48E-18	2.14E-13	2.20E-13	9.74E-01
Pb-211	5.08E-17	4.39E-12	3.90E-12	1.13E+00
Pb-212	1.43E-16	1.24E-11	1.20E-11	1.03E+00
Pb-214	2.44E-16	2.11E-11	2.00E-11	1.05E+00
Pd-107	0.00E+00	0.00E+00	0.00E+00	Undefined
Pm-145	3.26E-17	2.82E-12	2.20E-12	1.28E+00
Pm-146	7.41E-16	6.40E-11	5.70E-11	1.12E+00
Pm-147	3.41E-20	2.95E-15	3.00E-16	9.82E+00 <sup>d</sup>
Po-210	8.29E-21	7.16E-16	6.40E-16	1.12E+00
Po-211	7.61E-18	6.58E-13	5.80E-13	1.13E+00
Po-212	0.00E+00	0.00E+00	0.00E+00	Undefined
Po-213	0.00E+00	0.00E+00	2.30E-15	0.00E+00 <sup>c</sup>
Po-214	8.13E-20	7.02E-15	6.20E-15	1.13E+00
Po-215	1.74E-19	1.50E-14	1.20E-14	1.25E+00
Po-216	1.65E-20	1.43E-15	1.10E-15	1.30E+00
Po-218	8.88E-21	7.67E-16	0.00E+00	Undefined
Pr-144	3.78E-17	3.27E-12	2.20E-12	1.48E+00
Pr-144m	1.30E-17	1.12E-12	7.50E-13	1.50E+00
Pt-193	1.19E-19	1.03E-14	4.10E-14	2.51E-01 <sup>d</sup>
Pu-236	9.81E-19	8.48E-14	7.30E-14	1.16E+00
Pu-238	8.38E-19	7.24E-14	6.30E-14	1.15E+00
Pu-239	3.67E-19	3.17E-14	2.80E-14	1.13E+00
Pu-240	8.03E-19	6.94E-14	6.10E-14	1.14E+00

Table III-1. Comparison of Ground Irradiation Dose Coefficients from Two Sources (continued)

Nuclide	Dose Coefficient for Exposure to Contaminated Ground			Ratio FGR-12 : NCRP-123 (dimensionless) <sup>c</sup>
	FGR-12 <sup>a</sup> (Sv/s)/(Bq/m <sup>2</sup> )	FGR-12 (Sv/d)/(Bq/m <sup>2</sup> )	NCRP-123 <sup>b</sup> (Sv/d)/(Bq/m <sup>2</sup> )	
Pu-241	1.93E-21	1.67E-16	0.00E+00	Undefined
Pu-242	6.67E-19	5.76E-14	5.00E-14	1.15E+00
Pu-243	2.41E-17	2.08E-12	2.10E-12	9.92E-01
Ra-223	1.28E-16	1.11E-11	1.10E-11	1.01E+00
Ra-224	9.57E-18	8.27E-13	8.10E-13	1.02E+00
Ra-225	1.33E-17	1.15E-12	1.10E-12	1.04E+00
Ra-226	6.44E-18	5.56E-13	5.60E-13	9.94E-01
Ra-228	0.00E+00	0.00E+00	4.90E-20	0.00E+00 <sup>c</sup>
Rb-87	8.80E-20	7.60E-15	0.00E+00	Undefined
Rh-102	2.08E-15	1.80E-10	1.59E-10	1.13E+00
Rh-106	2.12E-16	1.83E-11	1.60E-11	1.14E+00
Rn-219	5.49E-17	4.74E-12	4.60E-12	1.03E+00
Rn-220	3.81E-19	3.29E-14	4.00E-14	8.23E-01
Rn-222	3.95E-19	3.41E-14	3.00E-14	1.14E+00
Ru-106	0.00E+00	0.00E+00	0.00E+00	Undefined
Sb-125	4.25E-16	3.67E-11	3.30E-11	1.11E+00
Sb-126	2.78E-15	2.40E-10	2.10E-10	1.14E+00
Sb-126m	1.52E-15	1.31E-10	1.20E-10	1.09E+00
Se-79	2.07E-20	1.79E-15	0.00E+00	Undefined
Sm-145	6.84E-17	5.91E-12	5.15E-12	1.15E+00
Sm-146	0.00E+00	0.00E+00	0.00E+00	Undefined
Sm-147	0.00E+00	0.00E+00	0.00E+00	Undefined
Sm-148	Not listed	Not listed	Not listed	Not listed
Sm-149	Not listed	Not listed	Not listed	Not listed
Sm-151	5.03E-21	4.35E-16	3.80E-16	1.14E+00
Sn-113	2.13E-17	1.84E-12	1.10E-12	1.67E+00
Sn-119m	1.04E-17	8.99E-13	4.40E-13	2.04E+00 <sup>d</sup>
Sn-121	1.05E-19	9.07E-15	0.00E+00	Undefined
Sn-121m	4.89E-18	4.22E-13	3.35E-13	1.26E+00
Sn-123	8.37E-18	7.23E-13	4.80E-13	1.51E+00
Sn-126	5.47E-17	4.73E-12	4.60E-12	1.03E+00
Sr-90	2.84E-19	2.45E-14	0.00E+00	Undefined
Tb-160	1.08E-15	9.33E-11	7.80E-11	1.20E+00
Tc-98	1.38E-15	1.19E-10	1.10E-10	1.08E+00
Tc-99	7.80E-20	6.74E-15	4.60E-17	1.47E+02
Te-123m	1.43E-16	1.24E-11	1.20E-11	1.03E+00
Te-125m	3.61E-17	3.12E-12	1.60E-12	1.95E+00
Te-127	5.18E-18	4.48E-13	3.80E-13	1.18E+00
Te-127m	1.13E-17	9.76E-13	5.00E-13	1.95E+00
Th-227	1.04E-16	8.99E-12	8.70E-12	1.03E+00
Th-228	2.35E-18	2.03E-13	2.00E-13	1.02E+00
Th-229	8.54E-17	7.38E-12	7.80E-12	9.46E-01

Table III-1. Comparison of Ground Irradiation Dose Coefficients from Two Sources (continued)

Nuclide	Dose Coefficient for Exposure to Contaminated Ground			Ratio FGR-12 : NCRP-123 (dimensionless) <sup>c</sup>
	FGR-12 <sup>a</sup> (Sv/s)/(Bq/m <sup>2</sup> )	FGR-12 (Sv/d)/(Bq/m <sup>2</sup> )	NCRP-123 <sup>b</sup> (Sv/d)/(Bq/m <sup>2</sup> )	
Th-230	7.50E-19	6.48E-14	6.70E-14	9.67E-01
Th-231	1.85E-17	1.60E-12	1.40E-12	1.14E+00
Th-232	5.51E-19	4.76E-14	4.90E-14	9.72E-01
Th-234	8.32E-18	7.19E-13	7.50E-13	9.58E-01
Tl-206	1.99E-18	1.72E-13	8.70E-15	1.98E+01 <sup>d</sup>
Tl-207	3.76E-18	3.25E-13	1.60E-13	2.03E+00
Tl-208	2.98E-15	2.57E-10	2.20E-10	1.17E+00
Tl-209	1.90E-15	1.64E-10	1.50E-10	1.09E+00
Tm-171	6.41E-19	5.54E-14	5.90E-14	9.39E-01
U-232	1.01E-18	8.73E-14	7.60E-14	1.15E+00
U-233	7.16E-19	6.19E-14	3.70E-14	1.67E+00
U-234	7.48E-19	6.46E-14	6.00E-14	1.08E+00
U-235	1.48E-16	1.28E-11	1.30E-11	9.84E-01
U-236	6.50E-19	5.62E-14	5.40E-14	1.04E+00
U-237	1.33E-16	1.15E-11	1.20E-11	9.58E-01
U-238	5.51E-19	4.76E-14	4.80E-14	9.92E-01
Y-90	5.32E-18	4.60E-13	0.00E+00	Undefined
Y-91	5.74E-18	4.96E-13	2.40E-13	2.07E+00 <sup>d</sup>
Zn-65	5.53E-16	4.78E-11	4.10E-11	1.17E+00
Zr-93	0.00E+00	0.00E+00	0.00E+00	Undefined
Zr-95	7.23E-16	6.25E-11	5.50E-11	1.14E+00

NOTES: <sup>a</sup> FGR-12 denotes Eckerman & Ryman 1993 (Table III.3).

<sup>b</sup> NCRP-123 denotes NCRP 1996 (Table A.1).

<sup>c</sup> Division by zero indicates that the NCRP value is zero. See the text for discussion.

<sup>d</sup> Cases where the ratio is greater than 2 or less than 0.5 are discussed in the text.

<sup>e</sup> The computations represented in this table were done using multiplication and division operations in Excel.

## EVALUATION OF NCRP DOSE COEFFICIENTS FOR INHALATION

The errors in the dose coefficients for ground irradiation (Attachment I) raise the possibility that one or more of the inhalation dose coefficients from the NCRP report may be in error in (NCRP 1996, Table A.1). Also, there are methodological differences in the way inhalation dose coefficients were computed in the NCRP report and in the source that provides the most recent federal guidance on internal dose coefficients (Eckerman et al. 1988). To increase confidence in the inhalation dose coefficients from the NCRP report, Table III-2 and Figure III-1 provide the basis for a comparison of the dose coefficients for inhalation of the chemical form that results in the highest dose coefficient from NCRP (1996) to the comparable values provided by Eckerman et al. (1988, Table 2.1). The ratios of dose coefficients for inhalation exposure from Eckerman et al. (1988) to those from NCRP (1996) are near 1 (no greater than about 2 and no less than about 0.6), indicating a favorable comparison (Table III-2).

Table III-2. Comparison of Inhalation Dose Coefficients from Two Sources

Nuclide	FGR-11 <sup>a</sup> Inhalation DCF (Sv/Bq)	NCRP-123 <sup>b</sup> Inhalation DCF (Sv/Bq)	Ratio FGR-11 to NCRP-123 (dimensionless) <sup>c</sup>
Ac-225	2.92E-06	2.18E-06	1.34E+00
Ac-227	1.81E-03	1.08E-03	1.68E+00
Ac-228	8.33E-08	5.01E-08	1.66E+00
Ag-108m	7.66E-08	7.16E-08	1.07E+00
Ag-110m	2.17E-08	2.07E-08	1.05E+00
Am-241	1.20E-04	7.08E-05	1.69E+00
Am-242	1.58E-08	1.20E-08	1.32E+00
Am-242m	1.15E-04	6.71E-05	1.71E+00
Am-243	1.19E-04	7.05E-05	1.69E+00
Bi-210	5.29E-08	5.19E-08	1.02E+00
Bi-212	5.83E-09	4.72E-09	1.24E+00
Bi-213	4.63E-09	3.83E-09	1.21E+00
Bi-214	1.78E-09	1.60E-09	1.11E+00
Bk-249	3.75E-07	2.04E-07	1.84E+00
C-14	5.64E-10	5.64E-10	1.00E+00
Ca-41	3.64E-10	2.93E-10	1.24E+00
Ca-45	1.79E-09	1.75E-09	1.02E+00
Cd-109	3.09E-08	1.62E-08	1.91E+00
Cd-113	4.51E-07	2.34E-07	1.93E+00
Cd-113m	4.13E-07	2.14E-07	1.93E+00
Ce-144	1.01E-07	1.01E-07	1.00E+00
Cf-249	1.56E-04	8.59E-05	1.82E+00
Cf-250	7.08E-05	4.52E-05	1.57E+00
Cf-251	1.59E-04	8.72E-05	1.82E+00
Cf-252	4.24E-05	3.95E-05	1.07E+00
Cl-36	5.93E-09	5.93E-09	1.00E+00
Cm-242	4.67E-06	3.54E-06	1.32E+00
Cm-243	8.30E-05	4.97E-05	1.67E+00
Cm-244	6.70E-05	4.04E-05	1.66E+00
Cm-245	1.23E-04	7.27E-05	1.69E+00
Cm-246	1.22E-04	7.23E-05	1.69E+00
Cm-247	1.12E-04	6.64E-05	1.69E+00
Cm-248	4.47E-04	2.64E-04	1.69E+00
Co-58	2.94E-09	2.93E-09	1.00E+00
Co-60	5.91E-08	5.62E-08	1.05E+00
Cs-134	1.25E-08	1.24E-08	1.01E+00
Cs-135	1.23E-09	1.23E-09	1.00E+00
Cs-137	8.63E-09	8.56E-09	1.01E+00
Eu-150	7.25E-08	7.25E-08	1.00E+00
Eu-152	5.97E-08	4.62E-08	1.29E+00
Eu-154	7.73E-08	5.84E-08	1.32E+00
Eu-155	1.12E-08	7.60E-09	1.47E+00

Table III-2. Comparison of Inhalation Dose Coefficients from Two Sources (continued)

Nuclide	FGR-11 <sup>a</sup> Inhalation DCF (Sv/Bq)	NCRP-123 <sup>b</sup> Inhalation DCF (Sv/Bq)	Ratio FGR-11 to NCRP-123 (dimensionless) <sup>c</sup>
Fe-55	7.26E-10	6.34E-10	1.15E+00
Fr-223	1.68E-09	1.68E-09	1.00E+00
Gd-152	6.58E-05	3.74E-05	1.76E+00
Gd-153	6.43E-09	4.10E-09	1.57E+00
H-3	1.73E-11	1.73E-11	1.00E+00
Ho-166m	2.09E-07	1.36E-07	1.54E+00
I-129	4.69E-08	7.81E-08	6.01E-01
In-113m	1.11E-11	1.04E-11	1.07E+00
K-40	3.34E-09	3.32E-09	1.01E+00
La-138	3.70E-07	2.83E-07	1.31E+00
Mn-54	1.81E-09	1.74E-09	1.04E+00
Mo-93	7.68E-09	7.66E-09	1.00E+00
Nb-93m	7.90E-09	7.90E-09	1.00E+00
Nb-94	1.12E-07	1.07E-07	1.05E+00
Nb-95	1.57E-09	1.60E-09	9.81E-01
Nb-95m	6.59E-10	7.49E-10	8.80E-01
Ni-59	7.31E-10	7.23E-10	1.01E+00
Ni-63	1.70E-09	1.70E-09	1.00E+00
Np-235	1.12E-09	7.79E-10	1.44E+00
Np-236a	2.81E-05	2.81E-05	1.00E+00
Np-237	1.46E-04	7.79E-05	1.87E+00
Np-238	1.00E-08	5.72E-09	1.75E+00
Np-239	6.78E-10	7.23E-10	9.38E-01
Pa-231	3.47E-04	1.73E-04	2.01E+00
Pa-233	2.58E-09	2.74E-09	9.42E-01
Pa-234	2.20E-10	2.04E-10	1.08E+00
Pb-209	2.56E-11	2.27E-11	1.13E+00
Pb-210	3.67E-06	2.03E-06	1.81E+00
Pb-211	2.35E-09	2.33E-09	1.01E+00
Pb-212	4.56E-08	3.66E-08	1.25E+00
Pb-214	2.11E-09	2.03E-09	1.04E+00
Pd-107	3.45E-09	3.46E-09	9.97E-01
Pm-145	8.23E-09	7.43E-09	1.11E+00
Pm-146	3.96E-08	3.74E-08	1.06E+00
Pm-147	1.06E-08	1.02E-08	1.04E+00
Po-210	2.54E-06	1.70E-06	1.49E+00
Pr-144	1.17E-11	1.19E-11	9.83E-01
Pt-193	6.14E-11	3.84E-11	1.60E+00
Pu-236	3.91E-05	2.99E-05	1.31E+00
Pu-238	1.06E-04	6.26E-05	1.69E+00
Pu-239	1.16E-04	6.87E-05	1.69E+00
Pu-240	1.16E-04	6.87E-05	1.69E+00
Pu-241	2.23E-06	1.29E-06	1.73E+00

Table III-2. Comparison of Inhalation Dose Coefficients from Two Sources (continued)

Nuclide	FGR-11 <sup>a</sup> Inhalation DCF (Sv/Bq)	NCRP-123 <sup>b</sup> Inhalation DCF (Sv/Bq)	Ratio FGR-11 to NCRP-123 (dimensionless) <sup>c</sup>
Pu-242	1.11E-04	6.54E-05	1.70E+00
Pu-243	4.44E-11	4.03E-11	1.10E+00
Ra-223	2.12E-06	2.08E-06	1.02E+00
Ra-224	8.53E-07	8.32E-07	1.03E+00
Ra-225	2.10E-06	2.07E-06	1.01E+00
Ra-226	2.32E-06	2.17E-06	1.07E+00
Ra-228	1.29E-06	1.16E-06	1.11E+00
Rb-87	8.74E-10	8.42E-10	1.04E+00
Rh-102	3.24E-08	2.98E-08	1.09E+00
Ru-106	1.29E-07	1.31E-07	9.85E-01
Sb-125	3.30E-09	3.38E-09	9.76E-01
Sb-126	3.17E-09	3.37E-09	9.41E-01
Sb-126m	9.17E-12	1.00E-11	9.17E-01
Se-79	2.66E-09	1.93E-09	1.38E+00
Sm-146	2.23E-05	1.36E-05	1.64E+00
Sm-147	2.02E-05	1.24E-05	1.63E+00
Sm-151	8.10E-09	4.99E-09	1.62E+00
Sn-113	2.88E-09	3.00E-09	9.60E-01
Sn-119m	1.69E-09	1.74E-09	9.71E-01
Sn-121	1.38E-10	1.51E-10	9.14E-01
Sn-121m	3.11E-09	3.14E-09	9.90E-01
Sn-123	8.79E-09	9.20E-09	9.55E-01
Sn-126	2.69E-08	2.70E-08	9.96E-01
Sr-90	3.51E-07	3.51E-07	1.00E+00
Tb-160	6.75E-09	6.36E-09	1.06E+00
Tc-98	6.18E-09	6.39E-09	9.67E-01
Tc-99	2.25E-09	2.42E-09	9.30E-01
Te-123m	2.86E-09	2.46E-09	1.16E+00
Te-125m	1.97E-09	1.82E-09	1.08E+00
Te-127	8.60E-11	8.55E-11	1.01E+00
Te-127m	5.81E-09	5.63E-09	1.03E+00
Th-227	4.37E-06	4.34E-06	1.01E+00
Th-228	9.23E-05	8.77E-05	1.05E+00
Th-229	5.80E-04	3.53E-04	1.64E+00
Th-230	8.80E-05	5.33E-05	1.65E+00
Th-231	2.37E-10	2.56E-10	9.26E-01
Th-232	4.43E-04	2.21E-04	2.00E+00
Th-234	9.47E-09	1.02E-08	9.28E-01
Tm-171	2.47E-09	1.56E-09	1.58E+00
U-232	1.78E-04	1.78E-04	1.00E+00
U-233	3.66E-05	3.65E-05	1.00E+00
U-234	3.58E-05	3.58E-05	1.00E+00
U-235	3.32E-05	3.31E-05	1.00E+00

Table III-2. Comparison of Inhalation Dose Coefficients from Two Sources (continued)

Nuclide	FGR-11 <sup>a</sup> Inhalation DCF (Sv/Bq)	NCRP-123 <sup>b</sup> Inhalation DCF (Sv/Bq)	Ratio FGR-11 to NCRP-123 (dimensionless) <sup>c</sup>
U-236	3.39E-05	3.39E-05	1.00E+00
U-237	9.54E-10	1.09E-09	8.75E-01
U-238	3.20E-05	3.19E-05	1.00E+00
Y-90	2.28E-09	2.69E-09	8.48E-01
Y-91	1.32E-08	1.37E-08	9.64E-01
Zn-65	5.51E-09	5.27E-09	1.05E+00
Zr-93	8.67E-08	4.31E-08	2.01E+00
Zr-95	6.39E-09	6.35E-09	1.01E+00

NOTES: <sup>a</sup>FGR-11 denotes Eckerman et al. 1988 (Table 2.1).

<sup>b</sup>NCRP-123 denotes NCRP 1996 (Table A.1).

<sup>c</sup>The computations were done using multiplication and summation operations in Excel.

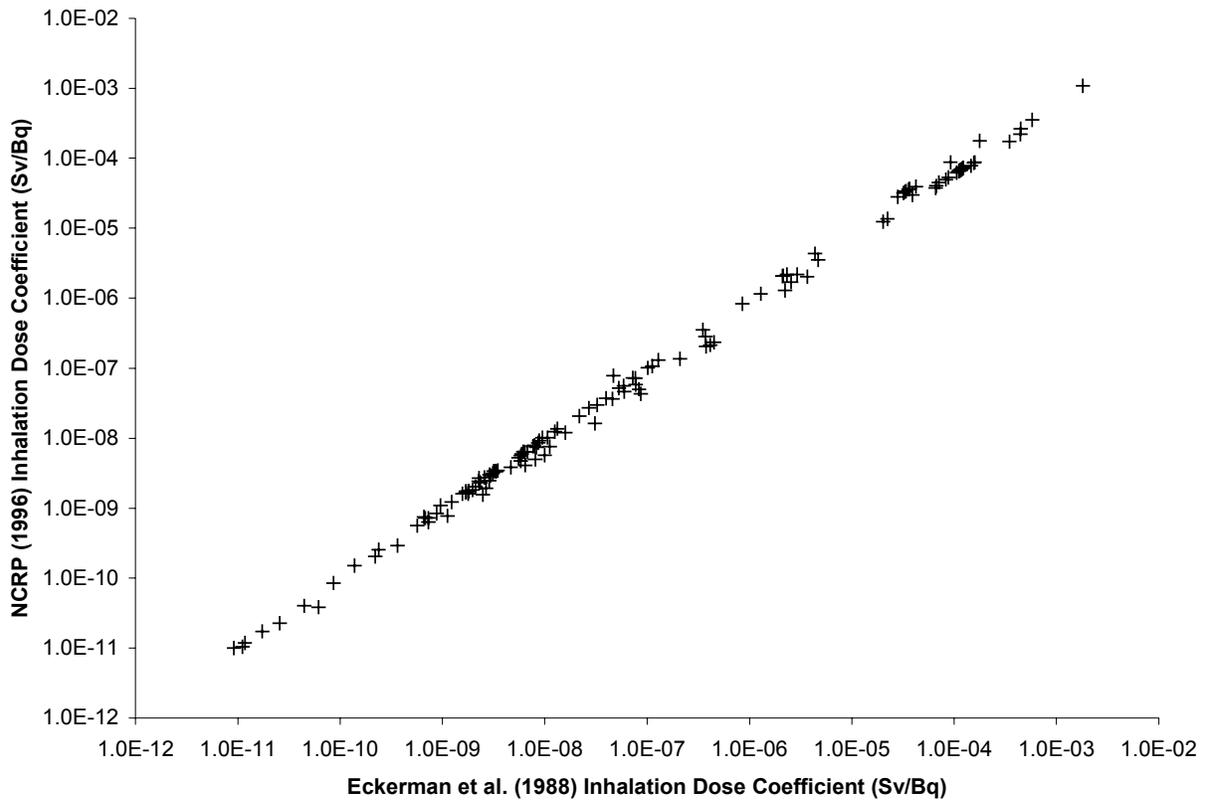


Figure III-1. Graphical Comparison of Inhalation Dose Coefficients from Two Sources

## EVALUATION OF NCRP DOSE COEFFICIENTS FOR INGESTION

The errors in the dose coefficients for ground irradiation (Attachment I) raise the possibility that one or more of the ingestion dose coefficients from the NCRP report may be in error in (NCRP 1996, Table A.1). Also, there are methodological differences in the way ingestion dose coefficients were computed in the NCRP report and in the source that provides the most recent federal guidance on internal dose coefficients (Eckerman et al. 1988). To increase confidence in the ingestion dose coefficients from the NCRP report, Table III-3 and Figure III-2 provide the basis for a comparison of the dose coefficients for ingestion of the chemical form that results in the highest dose coefficient from NCRP (1996) to the comparable values provided by Eckerman et al. (1988, Table 2.1). The ratios of the dose coefficients for ingestion exposure from Eckerman et al. (1988) to those from NCRP (1996) are near 1 (no greater than about 2.7 times and no less than about 0.6 times), indicating a favorable comparison (Table III-3).

Table III-3. Comparison of Ingestion Dose Coefficients from Two Sources

Nuclide	FGR-11 <sup>a</sup> Ingestion DCF (Sv/Bq)	NCRP-123 <sup>b</sup> Ingestion DCF (Sv/Bq)	Ratio FGR-11 to NCRP-123 (dimensionless) <sup>c</sup>
Ac-225	3.00E-08	3.81E-08	7.87E-01
Ac-227	3.80E-06	2.26E-06	1.68E+00
Ac-228	5.85E-10	4.50E-10	1.30E+00
Ag-108m	2.06E-09	2.05E-09	1.00E+00
Ag-110m	2.92E-09	2.89E-09	1.01E+00
Am-241	9.84E-07	5.79E-07	1.70E+00
Am-242	3.81E-10	3.85E-10	9.90E-01
Am-242m	9.50E-07	5.54E-07	1.71E+00
Am-243	9.79E-07	5.75E-07	1.70E+00
Ba-133	9.19E-10	9.50E-10	9.67E-01
Bi-210	1.73E-09	1.93E-09	8.96E-01
Bi-212	2.87E-10	2.21E-10	1.30E+00
Bi-213	1.95E-10	1.75E-10	1.11E+00
Bi-214	7.64E-11	1.07E-10	7.14E-01
Bk-249	3.24E-09	1.89E-09	1.71E+00
C-14	5.64E-10	5.64E-10	1.00E+00
Ca-41	3.44E-10	2.67E-10	1.29E+00
Ca-45	8.55E-10	8.56E-10	9.99E-01
Cd-109	3.55E-09	2.22E-09	1.60E+00
Cd-113	4.70E-08	2.47E-08	1.90E+00
Cd-113m	4.35E-08	2.33E-08	1.87E+00
Ce-139	3.09E-10	3.67E-10	8.42E-01
Ce-144	5.68E-09	8.18E-09	6.94E-01
Cf-249	1.28E-06	7.02E-07	1.82E+00
Cf-250	5.76E-07	3.19E-07	1.81E+00
Cf-251	1.31E-06	7.14E-07	1.83E+00
Cf-252	2.93E-07	1.73E-07	1.69E+00
Cl-36	8.18E-10	8.36E-10	9.78E-01

Table III-3. Comparison of Ingestion Dose Coefficients from Two Sources (continued)

Nuclide	FGR-11 <sup>a</sup> Ingestion DCF (Sv/Bq)	NCRP-123 <sup>b</sup> Ingestion DCF (Sv/Bq)	Ratio FGR-11 to NCRP-123 (dimensionless) <sup>c</sup>
Cm-242	3.10E-08	2.31E-08	1.34E+00
Cm-243	6.79E-07	4.03E-07	1.68E+00
Cm-244	5.45E-07	3.25E-07	1.68E+00
Cm-245	1.01E-06	5.94E-07	1.70E+00
Cm-246	1.00E-06	5.90E-07	1.69E+00
Cm-247	9.24E-07	5.43E-07	1.70E+00
Cm-248	3.68E-06	2.17E-06	1.70E+00
Co-58	9.68E-10	9.86E-10	9.82E-01
Co-60	7.28E-09	7.09E-09	1.03E+00
Cs-134	1.98E-08	1.95E-08	1.02E+00
Cs-135	1.91E-09	1.92E-09	9.95E-01
Cs-137	1.35E-08	1.35E-08	1.00E+00
Eu-150	1.72E-09	1.72E-09	1.00E+00
Eu-152	1.75E-09	1.92E-09	9.11E-01
Eu-154	2.58E-09	2.99E-09	8.63E-01
Eu-155	4.13E-10	5.03E-10	8.21E-01
Fe-55	1.64E-10	1.52E-10	1.08E+00
Fr-223	2.33E-09	2.34E-09	9.96E-01
Gd-152	4.34E-08	2.63E-08	1.65E+00
Gd-153	3.17E-10	3.94E-10	8.05E-01
H-3	1.73E-11	1.73E-11	1.00E+00
Ho-166m	2.18E-09	2.19E-09	9.95E-01
I-129	7.46E-08	1.24E-07	6.02E-01
In-113m	2.83E-11	2.28E-11	1.24E+00
K-40	5.02E-09	5.09E-09	9.86E-01
La-138	1.59E-09	1.53E-09	1.04E+00
Mn-54	7.48E-10	7.09E-10	1.06E+00
Mo-93	3.64E-10	2.36E-10	1.54E+00
Nb-93m	1.41E-10	1.92E-10	7.34E-01
Nb-94	1.93E-09	2.17E-09	8.89E-01
Nb-95	6.95E-10	7.35E-10	9.46E-01
Nb-95m	6.22E-10	8.30E-10	7.49E-01
Ni-59	5.67E-11	6.51E-11	8.71E-01
Ni-63	1.56E-10	1.88E-10	8.30E-01
Np-235	6.56E-11	8.45E-11	7.76E-01
Np-236a	2.34E-07	2.34E-07	1.00E+00
Np-237	1.20E-06	6.38E-07	1.88E+00
Np-238	1.08E-09	1.26E-09	8.57E-01
Np-239	8.82E-10	1.13E-09	7.81E-01
Pa-231	2.86E-06	1.42E-06	2.01E+00
Pa-233	9.81E-10	1.33E-09	7.38E-01
Pa-234	5.84E-10	5.57E-10	1.05E+00
Pb-209	5.75E-11	5.31E-11	1.08E+00

Table III-3. Comparison of Ingestion Dose Coefficients from Two Sources (continued)

Nuclide	FGR-11 <sup>a</sup> Ingestion DCF (Sv/Bq)	NCRP-123 <sup>b</sup> Ingestion DCF (Sv/Bq)	Ratio FGR-11 to NCRP-123 (dimensionless) <sup>c</sup>
Pb-210	1.45E-06	8.02E-07	1.81E+00
Pb-211	1.42E-10	1.64E-10	8.66E-01
Pb-212	1.23E-08	8.35E-09	1.47E+00
Pb-214	1.69E-10	1.54E-10	1.10E+00
Pd-107	4.04E-11	5.82E-11	6.94E-01
Pm-145	1.28E-10	1.49E-10	8.59E-01
Pm-146	9.91E-10	1.15E-09	8.62E-01
Pm-147	2.83E-10	3.98E-10	7.11E-01
Po-210	5.14E-07	2.14E-07	2.40E+00
Pr-144	3.15E-11	4.93E-11	6.39E-01
Pt-193	3.21E-11	4.49E-11	7.15E-01
Pu-236	3.15E-07	1.89E-07	1.67E+00
Pu-238	8.65E-07	5.10E-07	1.70E+00
Pu-239	9.56E-07	5.62E-07	1.70E+00
Pu-240	9.56E-07	5.62E-07	1.70E+00
Pu-241	1.85E-08	1.07E-08	1.73E+00
Pu-242	9.08E-07	5.33E-07	1.70E+00
Pu-243	9.02E-11	8.71E-11	1.04E+00
Ra-223	1.78E-07	1.29E-07	1.38E+00
Ra-224	9.89E-08	7.41E-08	1.33E+00
Ra-225	1.04E-07	7.09E-08	1.47E+00
Ra-226	3.58E-07	2.25E-07	1.59E+00
Ra-228	3.88E-07	2.76E-07	1.41E+00
Rb-87	1.33E-09	1.29E-09	1.03E+00
Rh-102	2.82E-09	2.73E-09	1.03E+00
Ru-106	7.40E-09	1.00E-08	7.40E-01
Sb-125	7.59E-10	9.30E-10	8.16E-01
Sb-126	2.89E-09	3.23E-09	8.95E-01
Sb-126m	2.54E-11	3.47E-11	7.32E-01
Se-79	2.35E-09	1.55E-09	1.52E+00
Sm-145	2.46E-10	3.04E-10	8.09E-01
Sm-146	5.51E-08	3.46E-08	1.59E+00
Sm-147	5.01E-08	3.15E-08	1.59E+00
Sm-151	1.05E-10	1.35E-10	7.78E-01
Sn-113	8.33E-10	1.09E-09	7.64E-01
Sn-119m	3.76E-10	5.22E-10	7.20E-01
Sn-121	2.44E-10	3.00E-10	8.13E-01
Sn-121m	4.19E-10	6.01E-10	6.97E-01
Sn-123	2.27E-09	3.25E-09	6.98E-01
Sn-126	5.27E-09	6.55E-09	8.05E-01
Sr-90	3.85E-08	3.10E-08	1.24E+00
Tb-160	1.82E-09	2.26E-09	8.05E-01
Tc-98	1.32E-09	1.83E-09	7.21E-01

Table III-3. Comparison of Ingestion Dose Coefficients from Two Sources (continued)

Nuclide	FGR-11 <sup>a</sup> Ingestion DCF (Sv/Bq)	NCRP-123 <sup>b</sup> Ingestion DCF (Sv/Bq)	Ratio FGR-11 to NCRP-123 (dimensionless) <sup>c</sup>
Tc-99	3.95E-10	6.64E-10	5.95E-01
Te-123m	1.53E-09	1.20E-09	1.28E+00
Te-125m	9.92E-10	9.06E-10	1.09E+00
Te-127	1.87E-10	1.84E-10	1.02E+00
Te-127m	2.23E-09	2.28E-09	9.78E-01
Th-227	1.03E-08	1.27E-08	8.11E-01
Th-228	1.07E-07	6.55E-08	1.63E+00
Th-229	9.54E-07	4.80E-07	1.99E+00
Th-230	1.48E-07	7.75E-08	1.91E+00
Th-231	3.65E-10	4.40E-10	8.30E-01
Th-232	7.38E-07	3.69E-07	2.00E+00
Th-234	3.69E-09	5.30E-09	6.96E-01
Tm-171	1.16E-10	1.64E-10	7.07E-01
U-232	3.54E-07	1.31E-07	2.70E+00
U-233	7.81E-08	2.88E-08	2.71E+00
U-234	7.66E-08	2.82E-08	2.72E+00
U-235	7.19E-08	2.73E-08	2.63E+00
U-236	7.26E-08	2.67E-08	2.72E+00
U-237	8.57E-10	1.15E-09	7.45E-01
U-238	6.88E-08	2.58E-08	2.67E+00
Y-90	2.91E-09	3.93E-09	7.40E-01
Y-91	2.57E-09	3.71E-09	6.93E-01
Zn-65	3.90E-09	3.72E-09	1.05E+00
Zr-93	4.48E-10	3.03E-10	1.48E+00
Zr-95	1.02E-09	1.21E-09	8.43E-01

NOTES: <sup>a</sup>FGR-11 denotes Eckerman et al. 1988 (Table 2.1).

<sup>b</sup>NCRP-123 denotes NCRP 1996 (Table A.1).

<sup>c</sup>The computations were done using multiplication and summation operations in Excel.

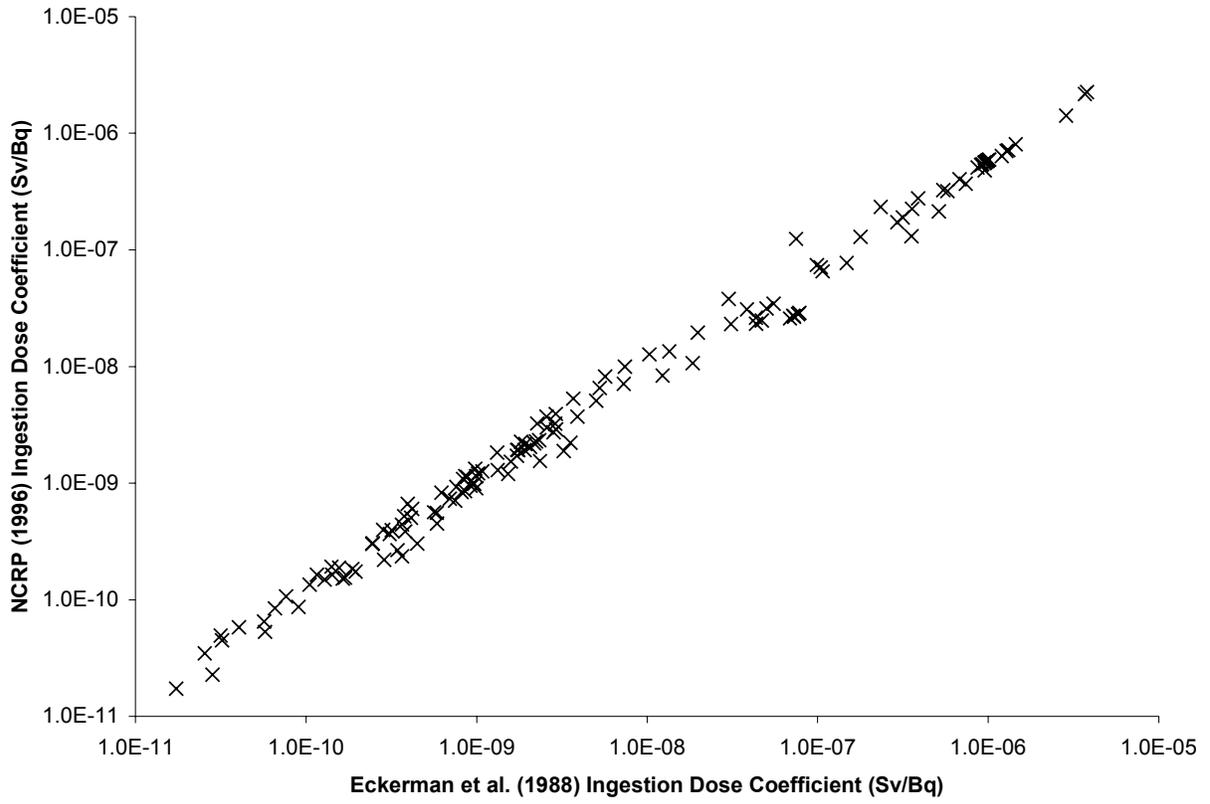


Figure III-2. Graphical Comparison of Ingestion Dose Coefficients from Two Sources

**ATTACHMENT IV.**  
**CORRECTION OF Se-79 ACTIVITIES**

(1 page)

The first section below derives a generic correction factor for an activity calculation that was originally performed with an erroneous half-life or decay constant. The second section applies the generic correction factor to the present screening analysis to compute correction factors for Se-79 activity during the regulatory period and at 1 million years.

**DERIVATION OF THE CORRECTION FACTOR**

Assuming the number of nuclei,  $N_0$ , is correct in the activity calculations at time zero, the old (incorrect) and new (corrected) activities are given by

$$\begin{aligned} A_{\text{old}}(t) &= \lambda_{\text{old}} N_0 \exp(-\lambda_{\text{old}} t) \\ &= \frac{\ln 2}{\tau_{\text{old}}} N_0 \exp\left(-\frac{\ln 2}{\tau_{\text{old}}} t\right) \end{aligned}$$

and

$$\begin{aligned} A_{\text{new}}(t) &= \lambda_{\text{new}} N_0 \exp(-\lambda_{\text{new}} t) \\ &= \frac{\ln 2}{\tau_{\text{new}}} N_0 \exp\left(-\frac{\ln 2}{\tau_{\text{new}}} t\right) , \end{aligned}$$

where  $\lambda_{\text{old}}$  and  $\lambda_{\text{new}}$  are the old and new decay constants,  $\tau_{\text{old}}$  and  $\tau_{\text{new}}$  are the old and new half-lives, and  $t$  is the decay time. The correction factor is

$$\begin{aligned} F(t) &= \frac{A_{\text{new}}(t)}{A_{\text{old}}(t)} \\ &= \frac{\tau_{\text{old}}}{\tau_{\text{new}}} \exp\left[(\ln 2) \left(\frac{1}{\tau_{\text{old}}} - \frac{1}{\tau_{\text{new}}}\right) t\right] . \end{aligned}$$

**APPLICATION TO Se-79 IN THE PRESENT ANALYSIS**

For Se-79 in the present analysis,  $\tau_{\text{old}}$  is 330,000 y and  $\tau_{\text{new}}$  is  $1.1 \times 10^6$  y (Assumption 5.3). At  $t = 0$ , which corresponds approximately to reactor discharge, waste emplacement, or repository closure, application of the correction factor yields  $0.33 \times 10^6 / 1.1 \times 10^6 = 0.30$ . At 10,000 y, the correction factor is still about 0.30 because the exponential term has only grown to about 1.01 (so that a precise definition of  $t = 0$  is unimportant). Thus, the correction reduces the Se-79 activity throughout the regulatory period by a factor of about 0.3. At 1 million years, the exponential term will have grown to about 4.4, so that the correction factor is about 1.3.

**ATTACHMENT V.  
CONTENTS OF ATTACHMENT VI**

(1 page)

Figure V-1 provides a directory listing of the files contained in Attachment VI, which is a compact disk. The filenames indicate the waste form type (BWR, etc.), representativeness (*Av* = average, *Max* = outlying), and the time period (*100-10k* = the 10,000-y regulatory period, *20k* = 20,000 y only, and *20k-1M* = 20,000 y through 1 million y). Except for the Screening Summary file, which is an output summary, the first two worksheets in each workbook file provide the inputs, while the remaining worksheets provide the outputs. The screening summary provides a summary of results by waste form.

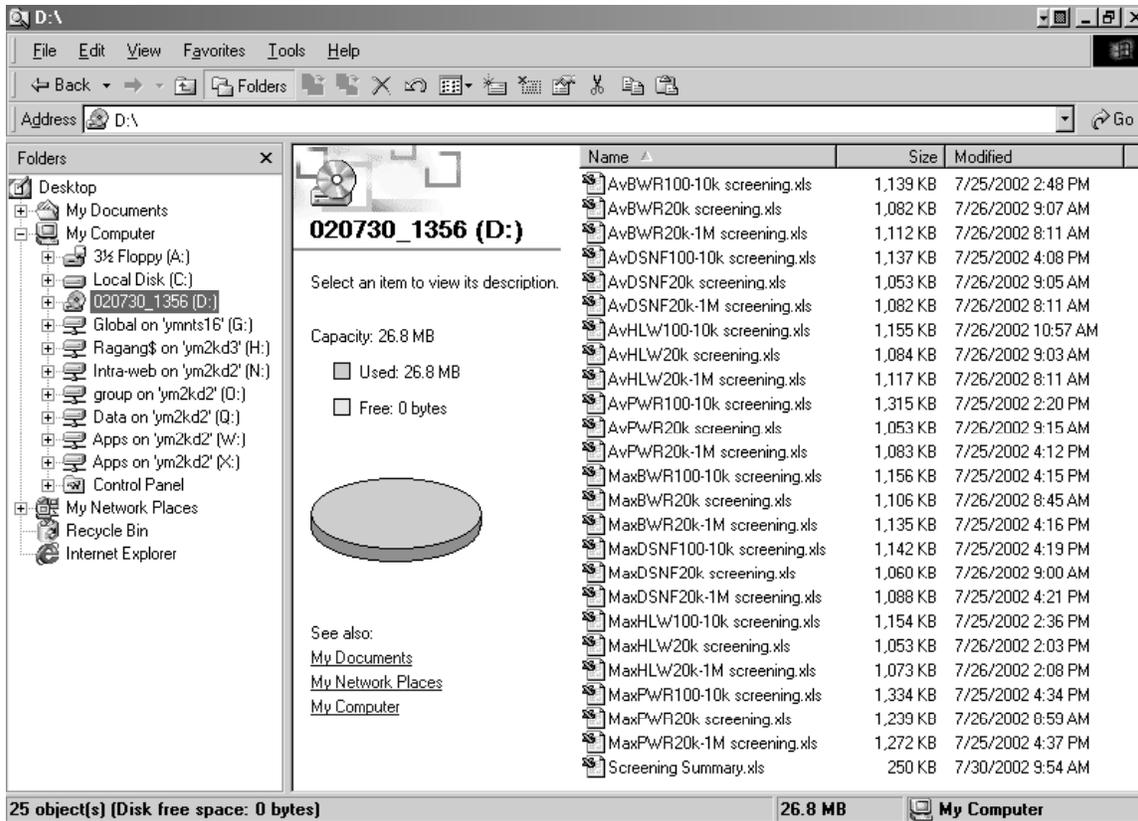


Figure V-1. Contents of Attachment VI