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User's Guide for the Simplified Risk Model (SRM)

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User's Guide for the Simplified Risk Model (SRM)

**R. G. Peatross
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Published October 1996

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CONTENTS

1.	INTRODUCTION	1
2.	REST STATE—LOOKUP TABLES	9
2.1	Element 1—Waste Characteristics	9
2.1.1	Element 1a—Quantities of Radiological Material	9
2.1.2	Element 1a—Quantities of Hazardous Chemicals	9
2.1.3	Element 1b—Specific Toxicity for Radionuclides	9
2.1.4	Element 1b—Specific Toxicity for Typical Hazardous Chemicals	11
2.2	Element 2—Susceptibility of Contaminants to Release and Movement	15
2.2.1	Element 2a—Mobility of Waste Form	15
2.2.2	Element 2b—Confinement Capability	15
2.3	Element 3—Severity and Likelihood of Challenges to Contaminant Confinement	16
2.3.1	Element 3a—Confinement Challenges from Environmental Events	16
2.3.2	Element 3b—Confinement Challenges from Operational Events	17
2.4	Element 4—Environmental Transport Effectiveness	17
2.5	Element 5—Presence of Human Receptors	18
2.5.1	Element 5a—Workers	21
2.5.2	Element 5b—Public	22
2.6	Elements $4 \times (5a + 5b)$ —Recommended Values	23
2.7	Element 6—Time in the Rest State	23
3.	TRANSITION STATE—LOOKUP TABLES	26
3.1	Element 1—Waste Characteristics	26
3.2	Element 2—Susceptibility of Contaminants to Movement	26
3.2.1	Element 2a—Mobility of Waste Form	26
3.2.2	Element 2b—Confinement Capability	26
3.3	Element 3—Challenges to Contaminant Confinement	26
3.3.1	Element 3a—Confinement Challenges from Environmental Events	26

3.3.2	Element 3b—Confinement Challenges from Operational Events	26
3.4	Element 4—Environmental Transport Effectiveness	29
3.5	Element 5—Presence of Human Receptors	29
3.5.1	Element 5a for Nonshipment Transition States—Workers	29
3.5.2	Element 5b for Nonshipment Transition States—Public	29
3.5.3	Element 5a for Shipment—Workers	30
3.5.4	Element 5b for Shipment—Public	30
3.6	Elements $4 \times (5a + 5b)$ —Recommended Values	30
4.	REFERENCES	33

TABLES

1-1.	SRM risk equation state inputs (radiological risk and airborne pathway)	4
2-1.	Adjustment factors for radioactive decay (including progeny ingrowth) for actinides	10
2-2.	Adjustment factors for radioactive decay (including progeny) for nonactinides	10
2-3.	Element 1b lookup table—specific toxicity for radionuclides	11
2-4.	Element 1b lookup table—specific toxicity for hazardous chemicals	12
2-5.	Element 2a lookup table—mobility	16
2-6.	Element 2b lookup table—confinement capability	17
2-7.	Element 3a lookup table—environmental challenges to confinement	18
2-8.	Element 3b lookup table—operational challenges to confinement	19
2-9.	Element 4 lookup table—relative air transportabilities	19
2-10.	Element 4 lookup table—relative groundwater transportabilities	20
2-11.	Approximate times of water transport through the vadose zone for major DOE Environmental Management sites	20
2-12.	Combined Elements $4 \times (5a + 5b)$ lookup table—recommended values	24
2-13.	Combined Elements $(4 \times 5a)_{\text{facility}}$ lookup table—recommended values for airborne releases	25

2-14.	Element 6—recommended time values based on barrier life.	25
3-1.	Element 2b lookup table—confinement capability.	27
3-2.	Element 3a lookup table—environmental challenges to confinement (nonshipping states).	27
3-3.	Element 3b lookup table—operational challenges to confinement: nonshipping states.	28
3-4.	Element 3b lookup table—frequency-severity values for operational challenges to confinement: shipping states.	29
3-5.	Combined Elements $4 \times (5a + 5b)$ lookup table—recommended values.	31
3-6.	Combined Elements $(4 \times 5_{a_{\text{facility}}})$ lookup table—recommended values.	32
3-7.	Combined Elements $4 \times (5a + 5b)$ lookup table—recommended values for transportation.	32

User's Guide for the Simplified Risk Model (SRM)

1. INTRODUCTION

This is the user's guide for the Simplified Risk Model (SRM). The SRM can be used to quickly compare relative values relating to risk for many environmental management (EM) activities or alternatives at U.S. Department of Energy (DOE) sites. The purpose of this guide is to provide the user with the essential values and decision points for each model variable. The technical bases for the model and the values and decision points are documented in Eide et al. (1996).

The numerical results are useful for ranking and screening purposes and should not be compared directly against absolute risk numerical results such as those calculated for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) baseline risk assessments or Safety Analysis Reports.

Implementing the SRM entails (a) performing several preliminary steps, (b) selecting values of the risk elements, (c) calculating the risk equations, and (d) checking the results. Technical persons experienced with the methods used in health and safety risk assessments and trained on the SRM should be able to apply the method without difficulty.

The SRM considers two types of waste management states: (1) a rest state and (2) a transition state. A rest state is an inactive management state. Storage and disposal are rest states. A transition state is an active management state, one in which an operation is performed on the waste type. Examples of transition states are retrieval, treatment, handling, and shipping.

The SRM considers risk from exposures to radionuclides and hazardous chemicals, as well as industrial hazards. For exposures to radionuclides and hazardous chemicals, the SRM covers both accidents and normal, incident-free operation. The accident risk of a rest state is given by Equation (1-1), and the accident risk of a transition state is given by Equation (1-2).

$$R_{acc} = V_{1a} \times V_{1b} \times V_{2a} \times V_{2b} \times (V_{3a} + V_{3b}) \times V_4 \times (V_{5a} + V_{5b}) \times \quad (1-1)$$

$$R_{acc} = V_{1a} \times V_{1b} \times V_{2a} \times V_{2b} \times (V_{3a} + V_{3b}) \times V_4 \times (V_{5a} + V_{5b}) \quad (1-2)$$

Each V entry is the value selected for a numbered element (e.g., V_{1a} is the value for Element 1a).

Element 1 is the characteristics of the waste type. There are two subelements:

- Element 1a is the quantity of contaminants in the waste type [curies of radioactivity, divided into actinide and nonactinide categories, and/or kilograms of hazardous chemicals].

- Element 1b is the specific radiotoxicity of the radionuclide category (per curie) and/or the specific chemical toxicity (per kilogram) of the hazardous chemicals.

Element 2 expresses the ease with which the contaminants in the waste type could escape confinement, as a result of events or conditions that cause the controls to fail, and become mobile in environmental transport to the receptors. There are two subelements:

- Element 2a is the mobility of the waste type (e.g., liquid, powder, or sludge); this term reflects the confinement provided by the waste form itself
- Element 2b is the capability of the external confinement barriers to contain the contaminants.

Element 3 expresses the frequency and severity of accidents. There are two subelements:

- Element 3a is the nature, severity, and frequency of environmental stresses (e.g., floods and seismic events) to which the confinement might be subjected
- Element 3b is the nature, severity, and frequency of operations-related stresses (e.g., fires and container drops) to which the confinement might be subjected.

Element 4 expresses how effectively the released contaminants could be moved by environmental transport processes (e.g., atmospheric transport and groundwater transport) to receptors.

Element 5 relates to the presence of human receptors. It has two subelements:

- Element 5a expresses how frequently workers would be located around the waste type, how many workers would be involved, and how closely they would be involved.
- Element 5b represents how many members of the public are in the vicinity of the site that manages the waste type and how close they are located.

Element 6 of Equation (1-1) represents the length of time, in years, for which the waste type is assumed to be in the rest state.

The risk from normal, incident-free operations is divided into two components: exposure to off-gas or fugitive emissions, and direct radiation (not applicable to chemical risk). The off-gas or fugitive emissions risk equation is the following:

$$R_{\text{off-gas}} = V_{1a} \times V_{1b} \times V_{2a} \times V_{2b} \times V_4 \times (V_{5a} + V_{5b}) \quad (1-3)$$

This equation applies only to certain transition states. Finally, the direct radiation risk equation is the following:

$$R_{\text{direct-radiation}} = V_{DR} \times V_6 \quad (1-4)$$

The total risk for a state is the sum of the accident, off-gas, and direct radiation risks.

The total radiological risk model for airborne dispersion is summarized in Table 1-1. That table is also applicable for hazardous chemicals, except that the direct radiation component is not applicable, and some of the table numbers are different. For groundwater dispersion, the individual tables in Section 2 of this document should be used.

Section 2 of this users manual gives the lookup tables for rest states and Section 3 gives the lookup tables for transition states. The lookup tables contain numbers from among which the user selects the most appropriate value for each element in the risk equation.

Selecting a value for a risk element is usually quick and straightforward, although some judgment is required. The risk analyst turns to the lookup table for the risk element; compares the collected information on the state, waste type, and site location against the information in the lookup table; and selects the most appropriate value of the risk element. Interpolation between entries in the lookup table may be necessary, and some engineering and safety judgment is needed to perform the interpolation.

Finally, this user's guide does not cover risk from industrial hazards. The user must refer to Section 10 of Eide et al. (1996) for guidance in that area.

Table 1-1. SRM risk equation state inputs (radiological risk and airborne pathway).

SRM State Type	Accident Exposure ¹						Accident Exposure and Normal, Incident-Free Exposure (off-gas or fugitive emissions)				Normal, Incident-Free Exposure (off-gas or fugitive emissions) ²	Normal, Incident-Free Exposure (direct radiation) ³
	1a (Ci)	1b	2a	2b	3a (1/yr)	3b (1/yr)	4*5a (facility)	4*5a (site)	4*5b	6 (yr)	2b	DR (person-rem/y)
Storage (above ground)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-4 (noncompliant facility) 2E-5 (Haz. Cat. 3) 2E-6 (Haz. Cat. 2) (Table 2-7)	1E-3 (poorly characterized, unvented waste) 1E-4 (inadequate fire protection or natural gas or fuel lines present) 1E-5 (adequate fire protection) (Table 2-8)	4 (small) 10 (medium) 17 (large) (Table 2-13)	Table 2-12 (DOE site)	Table 2-12 (DOE site)	User input	0	0.1 (small) 0.3 (medium) 0.5 (large)
Storage (below ground)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-6 (similar to above ground disposal) (Table 2-7)	3E-5 (disposal state times 10, no intrusion) (Table 2-8)	1 (small) 3 (medium) 6 (large) (Table 2-13)	Table 2-12 (DOE site)	Table 2-12 (DOE site)	User input	0	0.05 (small) 0.15 (medium) 0.3 (large)
Retrieval (from storage)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	0 (natural phenomena covered under storage)	1E-4 (handling accident under optimal conditions) (Table 3-3)	10 (small) 30 (medium) 60 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	0	0.4 (small) 1.0 (medium) 2.0 (large)
Retrieval (from berm/trench storage)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	0 (natural phenomena covered under storage)	1E-3 (handling accident under suboptimal conditions) (Table 3-3)	60 (small) 110 (medium) 230 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	0	2.0 (small) 4.0 (medium) 8.0 (large)

Table 1-1. (continued).

SRM State Type	Accident Exposure ¹						Accident Exposure and Normal, Incident-Free Exposure (off-gas or fugitive emissions)				Normal, Incident-Free Exposure (off-gas or fugitive emissions) ²	Normal, Incident-Free Exposure (direct radiation) ³
	1a (Ci)	1b	2a	2b	3a (1/yr)	3b (1/yr)	4*5a (facility)	4*5a (site)	4*5b	6 (yr)	2b	DR (person-rem/y)
Venting	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-4 (noncompliant facility) 2E-5 (Haz. Cat. 3) 2E-6 (Haz. Cat. 2) (Table 3-2)	1E-4 (Table 3-3)	10 (small) 30 (medium) 60 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	0	0.4 (small) 1.0 (medium) 2.0 (large)
Waste Preparation ⁴	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-4 (noncompliant facility) 2E-5 (Haz. Cat. 3) 2E-6 (Haz. Cat. 2) (Table 3-2)	1E-3 (torch cutting) 1E-4 (criticality concerns or significant combustibles present) 1E-5 (waste form difficult to combust) (Table 3-3)	10 (small) 30 (medium) 60 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	0	0.4 (small) 1.0 (medium) 2.0 (large)
Sorting/ Repackaging	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-4 (noncompliant facility) 2E-5 (Haz. Cat. 3) 2E-6 (Haz. Cat. 2) (Table 3-2)	1E-4 (criticality concerns or poorly characterized waste) 1E-5 (well characterized waste) (Table 3-3)	70 (small) 150 (medium) 300 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	0	2.4 (small) 5.0 (medium) 10.0 (large)
Treatment (high energy) ⁵	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-4 (noncompliant facility) 2E-5 (Haz. Cat. 3) 2E-6 (Haz. Cat. 2) (Table 3-2)	2E-3 (Table 3-3)	30 (large) 60 (medium) 120 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	5E-4	1.0 (small) 2.0 (medium) 4.0 (large)

Table 1-1. (continued).

SRM State Type	Accident Exposure ¹						Accident Exposure and Normal, Incident-Free Exposure (off-gas or fugitive emissions)				Normal, Incident-Free Exposure (off-gas or fugitive emissions) ²	Normal, Incident-Free Exposure (direct radiation) ³
	1a (Ci)	1b	2a	2b	3a (1/yr)	3b (1/yr)	4*5a (facility)	4*5a (site)	4*5b	6 (yr)	2b	DR (person-rem/y)
Treatment (moderate energy) ⁶	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-4 (noncompliant facility) 2E-5 (Haz. Cat. 3) 2E-6 (Haz. Cat. 2) (Table 3-2)	1E-4 (Table 3-3)	30 (small) 60 (medium) 120 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	1E-4	1.0 (small) 2.0 (medium) 4.0 (large)
Treatment (low energy) ⁷	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-4 (noncompliant facility) 2E-5 (Haz. Cat. 3) 2E-6 (Haz. Cat. 2) (Table 3-2)	1E-5 (Table 3-3)	30 (small) 60 (medium) 120 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	1E-4	1.0 (small) 2.0 (medium) 4.0 (large)
Certification	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-4 (noncompliant facility) 2E-5 (Haz. Cat. 3) 2E-6 (Haz. Cat. 2) (Table 3-2)	1E-5 (Table 3-3)	10 (small) 30 (medium) 60 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	0	0.4 (small) 1.0 (medium) 2.0 (large)
Load/Unload (shipping)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	0 (assumed to be performed outside)	1E-4 (Table 3-3)	10 (small) 30 (medium) 60 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	0	0.4 (small) 1.0 (medium) 2.0 (large)
Shipping	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	0 (covered in accident rate in element 3b)	4E-7 * route length (mi) (truck) ⁸ 1E-7 * route length (mi) (train) ⁸	0 (Table 3-7)	0 (Table 3-7)	5 (Table 3-7)	1	0	5.0E-5 person-rem/mi * X (mrem/h at 1 m) ⁹

Table 1-1. (continued).

SRM State Type	Accident Exposure ¹						Accident Exposure and Normal, Incident-Free Exposure (off-gas or fugitive emissions)				Normal, Incident-Free Exposure (off-gas or fugitive emissions) ²	Normal, Incident-Free Exposure (direct radiation) ³
	1a (Ci)	1b	2a	2b	3a (1/yr)	3b (1/yr)	4*5a (facility)	4*5a (site)	4*5b	6 (yr)	2b	DR (person-rem/y)
Placement (into storage or disposal)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	0 (natural phenomena covered in storage or disposal)	1E-4 (handling accident under optimal conditions) (Table 3-3)	10 (small) 30 (medium) 60 (large) (Table 3-6)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	User input (1 for accident)	0	0.4 (small) 1.0 (medium) 2.0 (large)
Disposal (below ground vault)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-6 (similar to above ground disposal) (Table 2-7)	4E-6 (Table 2-8)	1 (small) 3 (medium) 6 (large) (Table 2-13)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	Table 2-14	0	0
Disposal (above ground, tumulus)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	2E-6 (Table 2-7)	4E-6 (Table 2-8)	1 (small) 3 (medium) 6 (large) (Table 2-13)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	Table 2-14	0	0
Disposal (near surface)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	1E-7 (Table 2-7)	1E-6 (Table 2-8)	1 (small) 3 (medium) 6 (large) (Table 2-13)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	Table 2-14	0	0
Disposal (deep geological)	User input and Tables 2-1, 2-2	Table 2-3	Table 2-5	Table 2-6	1E-7 (Table 2-7)	1E-6 (Table 2-8)	1 (small) 3 (medium) 6 (large) (Table 2-13)	Table 3-5 (DOE site)	Table 3-5 (DOE site)	Table 2-14	0	0

Table 1-1. (continued).

Notes

1. The equation for accident risk is: $R_{acc} = 1a * 1b * 2a * 2b * (3a + 3b) * (4 * 5a, \text{ facility} + 4 * 5a, \text{ site} + 4 * 5b) * 6$.
2. The equation for normal, incident-free risk (off-gas or fugitive emissions) is: $R_{off-gas} = 1a * 1b * 2a * 2b * (4 * 5a, \text{ facility} + 4 * 5a, \text{ site} + 4 * 5b)$.
3. The equation for normal, incident-free risk (direct radiation) is (except for shipping): $R_{direct-radiation} = DR * 6$.
For shipping, the equation is: $R_{direct-radiation} = DR * (\text{mi/shipment}) * (\text{number of shipments})$.
4. Shredding (including torch cutting), compaction, or supercompaction.
5. Wet-air oxidation, vitrification, incineration, metal melting, thermal desorption, or mercury separation.
6. Evaporation, neutralization, ion exchange, lead recovery, reactive metals recovery, or polymer stabilization.
7. Solidification, grouting, soil washing, decontamination, debris washing, or sludge washing.
8. Route length (one way) in miles for a single shipment.
9. Total miles traveled for all shipments (one way).

2. REST STATE—LOOKUP TABLES

2.1 Element 1—Waste Characteristics

Element 1 characterizes the quantity and toxicity of the radiological and nonradiological contaminants in the waste. Element 1a addresses the quantity of contaminants. Element 1b addresses the specific toxicity of the contaminants, that is, the toxicity per unit quantity.

At least two separate risk calculations may be required for a mixed radioactive waste. At least one calculation is needed to address the radioactive material portion of the waste and at least one other calculation is needed to address the risk dominant hazardous material portion of the waste.

2.1.1 Element 1a—Quantities of Radiological Material

Determine the radiological values for element 1a as follows:

- For Element 1a_i with $i=1$, use the total curies of long-lived, alpha-emitting actinides and any existing (not future) decay products of actinides.
- For the value of Element 1a_i with $i=2$, use the remaining total curies of other radionuclides (nonactinides).
- Adjust the two values to account for radioactive decay, as follows. First, determine the beginning and end times of the state. Calculate the midpoint time. Then, for that midpoint time, select from Table 2-1 (actinides) and Table 2-2 (nonactinides) the appropriate adjustment factor for radioactive decay for the waste types indicated across the top of the tables.

2.1.2 Element 1a—Quantities of Hazardous Chemicals

The approach for handling the quantity of nonradiological contaminants is to use the quantity of several risk dominant chemicals for the value of Element 1a. In practice, only a few hazardous chemicals from among the large number that may exist in a waste type, will generally dominate the risk contribution. Therefore, quantities and specific toxicities usually need be determined for a limited number of hazardous chemicals (e.g., three to five) in any situation.

2.1.3 Element 1b—Specific Toxicity for Radionuclides

Select the value in Table 2-3 that corresponds to the pathway listed across the top of the table and the radionuclide class of interest down the left side. If the radionuclide distribution in the waste type being evaluated is radically different from the typical distributions given in Section 5.1.2.1 of Eide et al. (1996), better accuracy may be achieved by referring to the basic toxicity data given in Section 5.1.3.1 of Eide et al. (1996), and deriving more specific and appropriate values for Element 1b.

Table 2-1. Adjustment factors for radioactive decay (including progeny ingrowth) for actinides.

Time (yr)	SNF ^a	HLW ^b	CH TRU ^c	RH TRU ^c	CH α -LLW ^c	RH α -LLW ^c	LLW ^d
0	1.0E0	1.0E0	1.0E0	1.0E0	1.0E0	1.0E0	1.0E0
10	9.2E-1	9.3E-1	9.5E-1	9.8E-1	9.7E-1	9.7E-1	1.6E0
30	7.9E-1	8.0E-1	9.0E-1	9.2E-1	9.2E-1	9.2E-1	1.4E0
50	6.8E-1	6.9E-1	8.5E-1	8.6E-1	8.7E-1	8.7E-1	1.4E0
100	4.6E-1	4.7E-1	7.5E-1	7.8E-1	7.7E-1	7.7E-1	1.2E0
200	2.1E-1	2.3E-1	6.1E-1	6.6E-1	6.5E-1	6.5E-1	9.7E-1
500	2.8E-2	4.7E-2	4.4E-1	5.1E-1	4.6E-1	4.6E-1	7.8E-1
1,000	8.7E-3	2.7E-2	3.1E-1	4.4E-1	3.3E-1	3.3E-1	6.8E-1

a. For spent nuclear fuel (SNF), time zero corresponds to 1 year after removal from a reactor.

b. For high-level waste (HLW), time zero corresponds to 1 year after removal from a reactor.

c. For TRU waste and α -LLW, time zero corresponds to 10 years after the waste was generated.

d. For LLW, time zero corresponds to the time of waste generation.

Table 2-2. Adjustment factors for radioactive decay (including progeny) for nonactinides.

Time (yr)	SNF ^a	HLW ^b	CH TRU ^c	RH TRU ^c	CH α -LLW ^c	RH α -LLW ^c	LLW ^d
0	1.0E0	1.0E0	1.0E0	1.0E0	1.0E0	1.0E0	1.0E0
10	1.4E0	7.7E-1	6.2E-1	7.3E-1	6.5E-1	7.8E-1	3.8E-1
30	8.8E-1	4.8E-1	2.6E-1	4.4E-1	3.0E-1	4.9E-1	1.9E-1
50	5.4E-1	3.0E-1	1.2E-1	2.8E-1	1.5E-1	3.0E-1	1.5E-1
100	1.7E-1	9.3E-2	3.7E-2	8.6E-2	4.6E-2	9.3E-2	1.0E-1
200	1.6E-2	9.1E-3	2.5E-2	8.4E-3	2.2E-2	1.1E-2	5.0E-2
500	4.0E-4	8.9E-5	1.5E-2	1.3E-4	1.3E-2	1.9E-3	6.7E-3
1,000	2.1E-4	6.4E-5	6.9E-3	5.3E-5	6.1E-3	1.8E-3	6.1E-4

a. For SNF, time zero corresponds to 1 year after removal from a reactor.

b. For HLW, time zero corresponds to 1 year after removal from a reactor.

c. For TRU waste and α -LLW, time zero corresponds to 10 years after the waste was generated.

d. For LLW, time zero corresponds to the time of waste generation.

Table 2-3. Element 1b lookup table—specific toxicity for radionuclides.

Radionuclide Class	Airborne Pathway	Waterborne Pathway
Actinides		
TRU		
(CH)	150	2
(RH)	100	1
SNF		
SRS production reactor, graphite reactor	150	2
Other reactors	30	0.5
HLW	350	3
LLW		
INEL, SRS	200	2.5
Disposal sites	600	1.5
Nonactinides	0.15	0.1

2.1.4 Element 1b—Specific Toxicity for Typical Hazardous Chemicals

In Table 2-4 for the specific toxicity for hazardous chemicals,

- Locate each hazardous chemical known to be in the waste type in substantial quantities.
- Based on the type of pathway (airborne or waterborne) being evaluated, use the value of specific toxicity given for that pathway for the given chemical.
- Some hazardous chemicals not on the list may be present in the waste type in substantial quantities. In that case, refer to the method used in Section 5.1.3.2 of Eide et al. (1996) to derive the values for Element 1b. Using that same method, supply the absolute toxicity values from the various regulatory sources and derive the value of the toxicity element corresponding to those in the lookup table. Unless such additional chemicals are expected to be key risk drivers, however, developing additional relative toxicity values may not be warranted.

Table 2-4. Element 1b lookup table—specific toxicity for hazardous chemicals.

Chemical	Toxicity Group ^a for Ingestion (waterborne pathway)	Value of Element 1b for Waterborne Pathway	Toxicity Group ^a for Inhalation (airborne pathway)	Value of Element 1b for Airborne Pathway
Organics				
1,1,1-trichloroethane	NA ^b	NA	Low	10 ⁻⁵
1,1,2,2-tetrachloroethane	High	10 ⁻³	Mod	10 ⁻³
1,1,2-trichloro- 1,2,2-trifluoroethane	Low	3 × 10 ⁻⁶	Low	10 ⁻⁵
3-methylcholanthrene	NA	NA	NA	NA
Acetic acid	NA	NA	Mod	10 ⁻³
Acetone	Low	3 × 10 ⁻⁶	Low	10 ⁻⁵
Acrylonitrile	High	10 ⁻³	High	0.1
Ammonia	NA	NA	Mod	10 ⁻³
Anthracene	Low	3 × 10 ⁻⁶	NA	NA
Benzene	Mod	3 × 10 ⁻⁵	Mod	10 ⁻³
n-butyl alcohol	Low	3 × 10 ⁻⁶	NA	NA
sec-butyl alcohol	NA	NA	Low	10 ⁻⁵
Carbon disulfide	Low	3 × 10 ⁻⁶	Low	10 ⁻⁵
Carbon tetrachloride	High	10 ⁻³	Mod	10 ⁻³
Cellulose	NA	NA	Mod	10 ⁻³
Chloroform	Mod	3 × 10 ⁻⁵	Mod	10 ⁻³
Ethyl alcohol	NA	NA	Low	10 ⁻⁵
Ethyl ether	Low	3 × 10 ⁻⁶	Low	10 ⁻⁵
Ethyl benzene	Low	3 × 10 ⁻⁶	Mod	10 ⁻³
Ethylene dichloride	Mod	3 × 10 ⁻⁵	Mod	10 ⁻³
Formaldehyde	Low	3 × 10 ⁻⁶	High	0.1
Formic acid	Low	3 × 10 ⁻⁶	High	0.1
Glycerin	NA	NA	Mod	10 ⁻³
Hexane	Mod	3 × 10 ⁻⁵	Low	10 ⁻⁵
Hydrazine	High	10 ⁻³	High	0.1
Isopropyl alcohol	NA	NA	Low	10 ⁻⁵
Mercury (organic)	High	10 ⁻³	NA	NA
Methanol	Low	3 × 10 ⁻⁶	Mod	10 ⁻³

Table 2-4. (continued).

Chemical	Toxicity group ^a for ingestion (waterborne pathway)	Value of Element 1b for waterborne pathway	Toxicity group ^a for inhalation (airborne pathway)	Value of Element 1b for airborne pathway
Organics (continued)				
Methyl isobutyl ketone	Mod	3×10^{-5}	Mod	10^{-3}
Methyl ethyl ketone (2-butanone)	Low	3×10^{-6}	Mod	10^{-3}
Methylene chloride	Mod	3×10^{-5}	Low	10^{-5}
Naphthalene	Mod	3×10^{-5}	Mod	10^{-3}
Nitrobenzene	High	10^{-3}	Mod	10^{-3}
Nitrocellulose	NA	NA	NA	NA
Nonane	NA	NA	Low	10^{-5}
Oxalic acid	NA	NA	High	0.1
PCBs	High	10^{-3}	High	0.1
PCBs-aroclor 1016	High	10^{-3}	High	0.1
PCBs-aroclor 1254	High	10^{-3}	High	0.1
Pentane	NA	NA	Low	10^{-5}
Phenanthrene	NA	NA	NA	NA
Pyrene	Mod	3×10^{-5}	NA	NA
Terphenyls	NA	NA	Mod	10^{-3}
Tetrachloroethylene	Mod	3×10^{-5}	Mod	10^{-3}
Toluene	Low	3×10^{-6}	Low	10^{-5}
Tributyl phosphate	NA	NA	Mod	10^{-3}
Trichloroethylene	Mod	3×10^{-5}	Mod	10^{-3}
Trimethyl benzene	NA	NA	Low	10^{-5}
Versene disodium salt	NA	NA	NA	NA
Xylene, mixed	Low	3×10^{-6}	Mod	10^{-3}
Inorganics				
Aluminum	NA	NA	Mod	10^{-3}
Antimony	High	10^{-3}	High	0.1
Arsenic	High	10^{-3}	High	0.1
Barium	Mod	3×10^{-5}	High	0.1
Barium sulfate	NA	NA	Mod	10^{-3}

Table 2-4. (continued).

Chemical	Toxicity group ^a for ingestion (waterborne pathway)	Value of Element 1b for waterborne pathway	Toxicity group ^a for inhalation (airborne pathway)	Value of Element 1b for airborne pathway
Beryllium	High	10^{-3}	High	0.1
Bromine	NA	NA	High	0.1
Cadmium	Mod	3×10^{-5}	High	0.1
Calcium hydroxide	NA	NA	Mod	10^{-3}
Calcium oxide	NA	NA	Mod	10^{-3}
Cerium chloride	NA	NA	NA	NA
Chromium-3	Low	3×10^{-6}	High	0.1
Chromium-6	Mod	3×10^{-5}	High	0.1
Cobalt	NA	NA	High	0.1
Copper	Mod	3×10^{-5}	High	0.1
Cyanide, free	Mod	3×10^{-5}	Mod	10^{-3}
Hydrochloric acid	NA	NA	Mod	10^{-3}
Hydrogen fluoride	NA	NA	Mod	10^{-3}
Hydrogen peroxide	NA	NA	Mod	10^{-3}
Lead	NA	NA	High	0.1
Lithium hydride	NA	NA	High	0.1
Lithium oxide	NA	NA	NA	NA
Magnesium fluoride	NA	NA	NA	NA
Magnesium oxide	NA	NA	Mod	10^{-3}
Manganese	Low	3×10^{-6}	High	0.1
Mercury	NA	NA	High	0.1
Mercury nitrate	NA	NA	NA	NA
Nickel	Mod	3×10^{-5}	High	0.1
Nitrate	Low	3×10^{-6}	NA	NA
Nitric acid	NA	NA	High	0.1
Phosphoric acid	NA	NA	High	0.1
Platinum	NA	NA	High	0.1
Selenium	Mod	3×10^{-5}	High	0.1
Silver	Mod	3×10^{-5}	High	0.1
Sodium cyanide	Mod	3×10^{-5}	NA	NA
Sodium hydroxide	NA	NA	NA	NA

Chemical	Toxicity group ^a for ingestion (waterborne pathway)	Value of Element 1b for waterborne pathway	Toxicity group ^a for inhalation (airborne pathway)	Value of Element 1b for airborne pathway
Sulfuric acid	NA	NA	High	0.1
Tantalum	NA	NA	Mod	10 ⁻³
Thallium	High	10 ⁻³	High	0.1
Tungsten	NA	NA	High	0.1
Uranium (chemical toxicity)	Mod	3 × 10 ⁻⁵	High	0.1
Zinc	Low	3 × 10 ⁻⁶	Mod	10 ⁻³
Zirconium	Low	3 × 10 ⁻⁶	High	0.1
Explosives	DNA ^c	DNA ^c	DNA ^c	0.1 ^c

a. If the toxicity groups differed among the various toxicity measures, the higher (more conservative) group was used.

b. NA = toxicity data not available in regulatory sources consulted. The toxicity of the given chemical in the given exposure route may not be negligible, however. Lack of toxicity data should be included in the qualitative uncertainty discussion of the risk assessment.

c. For explosives, the toxicity value was taken to be that corresponding to the high toxicity value in the inhalation exposure route (airborne pathway) because of the hazard represented by the explosiveness characteristic. For waterborne pathways, the value was taken to be DNA (does not apply).

2.2 Element 2—Susceptibility of Contaminants to Release and Movement

2.2.1 Element 2a—Mobility of Waste Form

Element 2a addresses the confinement provided by the waste form itself (i.e., the tendency of an unconfined waste form to disperse as a result of conditions associated with a release). From Table 2-5, select the mobility value for the physical form that corresponds most closely to the waste form of interest and for the type of transport pathway expected to predominate.

2.2.2 Element 2b—Confinement Capability

Element 2b represents the relative strength of the set of barriers between the waste and the transport pathways (the air and/or groundwater). For aboveground facilities, the barriers between the waste and the atmosphere include the waste containers and any additional engineered barriers. For belowground facilities, the barriers include the subsurface geologic formation separating the waste from the groundwater and the air, as well as any additional engineered barriers.

Table 2-5. Element 2a lookup table—mobility.

Physical Form of Waste	Mobility for Airborne Releases (transition or storage)	Mobility for Waterborne Release (disposal)
Gas or vapor from a highly volatile liquid	1	1
Low-volatility liquid or bulk quantity of volatile liquid	3×10^{-3}	10^{-1}
Loose contamination on surface of solids	10^{-3}	10^{-3}
Powder	10^{-3}	8×10^{-4}
Calcine (a granular solid)	6×10^{-4}	6×10^{-4}
Sludge	3×10^{-4}	3×10^{-4}
Cement and concrete	10^{-4}	10^{-4}
Glass and ceramic	10^{-5}	10^{-5}
Metals (nonpyrophoric)	10^{-5}	2×10^{-6}

The lookup table for Element 2b is presented in Table 2-6. The values represent the conditional probability of confinement failure for states with various confinement barriers. The conditional probabilities assume that the barriers are in a series configuration rather than parallel. The values should be reduced by a factor of 3 to 10 if a barrier is massive (e.g., steel or concrete that is several inches thick, as in SNF shipping casks). If a barrier does not satisfy the applicable standards (e.g., a facility whose ventilation system has numerous noncompliances with standards), the value of Element 2b should be increased by a factor of 3 to 10.

For aboveground facilities, credit can be taken for various numbers of engineered barriers. For belowground facilities, multiplicative credit can be taken for both engineered barriers and geologic barriers, although the life that can be assumed for engineered barriers is typically limited to 50 years for barriers such as metal drums and 500 years for massive barriers such as concrete and steel calcine bins. For example, the value of Element 2b for waste in a massive concrete container in near surface burial would be $[(1E-1)/3] \times 1E-2 = 3E-4$ for the first 500 years and $1E-2$ thereafter.

2.3 Element 3—Severity and Likelihood of Challenges to Contaminant Confinement

2.3.1 Element 3a—Confinement Challenges from Environmental Events

The Element 3a lookup table for environmental challenges is Table 2-7. The value for Element 3a is the sum of the frequency-severity values from seismic events, strong winds and tornadoes, and floods, as applicable.

Table 2-6. Element 2b lookup table—confinement capability.

Type of Facility	Confinement	Value
Aboveground or belowground	No engineered confinement or flimsy engineered barriers (e.g., cardboard boxes) or severely degraded engineered barriers (e.g., badly rusted drums); groundwater pathway (long-term)	1
	Single engineered barrier in good condition ^a	1E-1 ^b
	Two engineered barriers in good condition ^a	1E-2 ^b
	Three engineered barriers in good condition ^a	3E-3 ^b
Belowground only	Near-surface burial ^c	1E-2
	Near-surface burial with multilayer engineered cap ^{a,c}	1E-3 ^d
	Intermediate-depth burial	1E-4
	Deep geological disposal	1E-5

a. Engineered barriers are generally assumed to last a maximum of 50 years. Multilayered caps over disposal or storage units and very substantial barriers (e.g., calcine bins) may be assumed to last a maximum of 500 years.

b. Additional credit (reduction by a factor of 3 to 10) can be taken if the barrier is massive, such as a SNF shipping cask.

c. These values also apply to abovegrade earth-covered disposal structures such as tumuli.

d. Cap is multilayer (e.g., designed and constructed in accordance with NRC regulations in 10 Code of Federal Regulations (CFR) 61 or with the EPA/NRC guidance on mixed waste disposal facilities).

2.3.2 Element 3b—Confinement Challenges from Operational Events

The Element 3b lookup table is Table 2-8. The user should select the appropriate value of frequency-severity for each relevant operational event. These values are then added to give the value of Element 3b.

2.4 Element 4—Environmental Transport Effectiveness

Tables 2-9 and 2-10 are the lookup tables for Element 4. They contain the relative transportability values for air and groundwater, respectively. Lookup tables that combine Elements 4, 5a, and 5b for airborne transport are provided as a time-saving measure in Section 2.6.

The air transportability values are used for risk calculations for both transition states and aboveground storage states in Table 2-9. The groundwater transportability values in Table 2-10 are used for risk calculations for disposal states and underground storage states. The relative air transportabilities given in Table 2-9 are independent of windspeed.

Table 2-7. Element 3a lookup table—environmental challenges to confinement.

NPH event	Selection criteria	Frequency-severity value (1/yr):
		Element 3a ^a
Seismic (beyond design basis)	Storage facility not meeting NPH design criteria	1E-4
	PC 2 (Hazard Category 3) storage facility	1E-5
	PC 3 (Hazard Category 2) storage facility; aboveground disposal state	1E-6
	Belowground disposal state	1E-7
Strong wind/tornado (beyond design basis)	Storage facility not meeting NPH design criteria	1E-4
	PC 2 (Hazard Category 3) storage facility	1E-5
	PC 3 (Hazard Category 2) storage facility; aboveground disposal state	1E-6
Flood (beyond design basis)	Storage facility not meeting NPH design criteria	1E-5
	PC 2 (Hazard Category 3) storage facility	1E-6
	PC 3 (Hazard Category 2) storage facility; aboveground disposal state	1E-7

a. The total for Element 3a is the sum of the frequency-severity values from seismic events, strong winds and tornadoes, and floods, as applicable.

For determining the relative groundwater transportabilities in Table 2-10, the value of the sorption coefficient (K_d) of the released contaminant is required. As a time-saving measure for the user, generic values for K_d are included in the table. However, if desired, actual site data can be used for the K_d s. To determine values for T (vadose zone transport time decay factor), estimate transport time from Table 2-11 and take the corresponding radioactive decay value from Tables 2-1 and 2-2.

2.5 Element 5—Presence of Human Receptors

Element 5 relates to the presence of humans who are potential receptors for the contaminants in the waste type. Both workers (in Element 5a) and members of the public (in Element 5b) are considered in the method. The values of the two elements are added in the risk equations. If desired, the values can be kept separate so that the risks to workers and to the public can be reported separately.

The human receptors who could be affected by the hazards in the waste type can be thought of as consisting of four groups. Three of these groups consist of workers. The first group is the relatively small number of workers who deal directly with the waste type or are located in the immediate area. Examples are equipment or process operators and health physics technicians.

Table 2-8. Element 3b lookup table—operational challenges to confinement.

Operational Event	Selection Criteria	Frequency-severity Value (1/yr): Element 3b ^a
Fire (unmitigated)	Storage of poorly characterized waste in unvented containers; storage of large amounts of combustible waste with inadequate fire protection	1E-3
	Storage of well-characterized waste with adequate fire protection	1E-4
	Storage of well-characterized waste with adequate fire protection	1E-5
	Storage of waste form that is difficult to combust with adequate fire protection; disposal state	1E-6
Facility explosion	Storage facility with natural gas or fuel lines present	1E-4
	Storage facility with very little explosion potential; disposal state	1E-6
Container explosion	Storage of poorly characterized waste in unvented containers	1E-4
	Storage of well-characterized waste in vented containers; disposal state	1E-6
Intrusion into the waste	Disposal facility only (drilling, excavation, animal/insect transport, or plant uptake)	1E-6
Waste migration into groundwater	Disposal facility	1E-3

a. The total for Element 3b is the sum of the frequency-severity values from fire, facility explosion, container explosion, and waste intrusion, if applicable.

Table 2-9. Element 4 lookup table—relative air transportabilities.^a

Distance (d) to Receptor (m)	Value of Relative Air Transportability
$d \leq 100$	1
$100 < d \leq 300$	3E-1
$300 < d \leq 500$	8E-2
$500 < d \leq 1,000$	3E-2
$1,000 < d \leq 2,000$	1E-2
$2,000 < d \leq 10,000$	1E-3
$10,000 < d \leq 20,000$	4E-4
$20,000 < d$	1E-4

a. See Section 2.6 for recommended values of the combined Element 4 $\times$ (5a + 5b).

Table 2-10. Element 4 lookup table—relative groundwater transportabilities.

Distance (d) to receptor (m)	Value of relative groundwater transportability ^{a,b,c}
$d \leq 100$	$(1E-4) \times T/(K_d \times R_v)$
$100 < d \leq 300$	$(4E-5) \times T/(K_d \times R_v)$
$300 < d \leq 500$	$(2E-5) \times T/(K_d \times R_v)$
$500 < d \leq 1,000$	$(6E-6) \times T/(K_d \times R_v)$
$1,000 < d \leq 2,000$	$(3E-6) \times T/(K_d \times R_v)$
$2,000 < d \leq 10,000$	$(2E-7) \times T/(K_d \times R_v)$
$10,000 < d < 20,000$	$(4E-8) \times T/(K_d \times R_v)$
$20,000 < d$	$(1E-8) \times T/(K_d \times R_v)$

a. The following generic values are suggested for the K_d based on the contaminants present:

Actinides (except uranium), polychlorinated biphenyls (PCBs)	$K_d = 1,000$
Metals, uranium, polyaromatic hydrocarbons, pesticides	$K_d = 100$
Strontium, yttrium, phthalates	$K_d = 10$
Technetium, nonmetals, other organic chemicals	$K_d = 1$

b. Use the following estimated values for the R_v based on the site's groundwater velocity:

Groundwater velocity $> 1E5$ m/yr	$R_v = 100$
$1E3$ m/yr $<$ groundwater velocity $\leq 1E5$ m/yr	$R_v = 10$
Groundwater velocity $\leq 1E3$ m/yr	$R_v = 1$

It is expected that, for most sites, the value of $R_v = 1$. For example, the groundwater velocity values are approximately 570, 7, and 22 m/yr for the INEL, SRS, and Hanford Site, respectively.

c. To determine values for T (vadose zone transport time decay factor), estimate transport time from Table 2-11 and take the corresponding radioactive decay value from Tables 2-1 and 2-2.

Table 2-11. Approximate times of water transport through the vadose zone for major DOE Environmental Management sites.

Site	Representative Approximate Transport Time (yr)
Hanford Site	450
INEL	30–50
Los Alamos National Laboratory	1,000–4,000
Oak Ridge National Laboratory	5–20
Rocky Flats Plant	9–14
Savannah River Site	4.5

These people are located close enough that they could be affected directly by a wide variety of exposure scenarios. The second group is the other workers who are located in the same building or facility but who are in a different work location and do not deal directly with the waste type. These people generally would not be affected in minor accidents but could be affected in major accidents. The third group is workers located still farther away in other facilities at other areas of the same DOE site. The distance from the waste type to these workers can range from a few hundred feet to tens of miles.

The fourth group of receptors is the public who reside offsite. Some members of the public are located close to the site boundary; others are farther away. Only major accidents would be expected to affect the third and fourth groups.

Section 2.5.1 addresses the relative risk that the first three groups (the workers) are subjected to by virtue of their proximity to the waste type. Section 2.5.2 addresses the relative risk that the fourth group (the public) is subjected to by virtue of their proximity to the site.

The products of Element 4 with Elements 5a and 5b are summed for the various groups of receptors located at various distances from the waste type. Section 2.6 includes recommended values for the combined Elements $4 \times (5a + 5b)$ for airborne and groundwater transport. The recommended values can be used as a time-saving measure.

2.5.1 Element 5a—Workers

Element 5a represents the presence of the workers— how many workers are in the vicinity of the waste type, what fraction of their time is spent in that location, and how well they are protected. Protective features can include the presence of engineered work area protection (WAP) features, such as shielding walls, and the use or availability of personal protective equipment (PPE), such as respirators. Emergency procedures, such as evacuation, can also provide protection but are not addressed in the simplified method.

The value of Element 5a for each group i is determined by the following expression (a maximum of the three groups discussed earlier is recommended, but greater than three groups can be used):

$$\text{Element } 5a_i = \frac{N_i \times F_i}{WAP_i \times PPE_i} \quad (2-1)$$

where

i = 1, 2, 3 is an index representing the three groups of workers (those dealing directly with the waste type, others in the same building, and those in other parts of the site).

N_i = the number of workers in group i (persons)

F_i	=	the time fraction of the 24-hour day that the workers in group i are at the location (unitless); normally, the maximum value of F for workers is $1/3$ (i.e., 8 hr/24 hr day)
WAP_i	=	the degree of protection or hazard reduction provided by design features in the work area for group i , based on the entries below (unitless)
WAP_i	=	1 if there are no engineered protective features (i.e., the release or radiation field would not be diminished by protective features)
WAP_i	=	3 if minimal protection is provided by means of controlled airflows, shielding, etc.
WAP_i	=	10 if substantial protection is provided
WAP_i	=	100 if highly reliable control of airflows, massive shielding, etc. are provided
PPE_i	=	the degree of protection or hazard reduction provided to group i by personnel protective equipment, based on the entries below (unitless)
PPE_i	=	1 if no protective equipment is provided
PPE_i	=	3 if protective equipment is not worn but is readily available
PPE_i	=	10 if protective equipment is worn.

Note: WAP values > 1 should be used only if the accidents modeled in Elements 3a and 3b do not affect the design features of interest.

The parameter representing the distance of the workers from the waste type is included in the lookup table (Table 2-9) for airborne transport for Element 4. For distances ≥ 100 m, the corresponding values from the Element 4 lookup table should be used. Thus, the value is 1 for a distance of 100 m. No adjustment to the value of Element 5a for distance is needed in such cases. However, the first two groups of workers are generally located < 100 m from the waste type. For distances D that are < 100 m, use the Element 4 value for 100 m then multiply the value of Element 5a _{i} by the factor $[100/D(m)]^2$.

The Element 5a _{i} values are then multiplied by the corresponding Element 4 _{i} values for the assumed distance to each work group i and summed.

2.5.2 Element 5b—Public

Element 5b represents the presence of the public—how many members of the public are in the vicinity of the site that manages the waste type and how close the public is located.

For each public population group j in the vicinity of the waste type operations, a value should be selected for Element 5b _{j} . The value is simply the number of people in group j . The Element 5b _{j} values

are then multiplied by the corresponding Element 4_i value for the assumed distance to each population group and summed.

$$\text{Element } 5b_i = N_i$$

where

- i = an index representing the various cities, towns, or rural areas that would be the largest contributors for the effects on the public. In practice, use of only three to five groups of members of the public up to a distance of about 50 mi should provide sufficient accuracy.

2.6 Elements 4 x (5a + 5b)—Recommended Values

As a time-saving measure, recommended values have been calculated for the product of Elements 4 x (5a + 5b). In lieu of calculating values for these products by the method discussed in Sections 2.5.1 and 2.5.2, the user can elect to use the precalculated values given in Tables 2-12 and 2-13. It should be noted that the recommended values have been calibrated to result in person-rem risk results. This was done so the accident results could be added to the normal exposure predictions.

Values listed in Table 2-12 and Table 2-13 are for airborne releases. For groundwater releases, multiply by (1E-4) T/(K_a x R_g) (see Table 2-10).

The recommended values are subdivided into three contributions:

- Elements 4 x 5b for the public surrounding a given DOE site
- Elements (4 x 5a)_{site} for DOE site workers not directly associated with the facility being considered
- Elements (4 x 5a)_{facility} for workers and support personnel directly involved with the storage or disposal facility being considered.

The first two contributions are covered in Table 2-12; the last is covered in Table 2-13.

2.7 Element 6—Time in the Rest State

Element 6 is the length of time, in years, for which the waste type is assumed to be in the rest state. The value is, therefore, assumed to be linearly proportional to the length of time in the rest state, allowing for adjustments in other elements for phenomena such as radioactive decay and the time-dependent degradation of confinement barriers.

Table 2-14 lists recommended time values for barrier types (see Section 2.2.2). Note that in most cases at least two calculations will be performed; one for the life of the barrier and another after the life of the barrier. A maximum time of 1000 yr is recommended.

Table 2-12. Combined Elements $4 \times (5a + 5b)$ lookup table—recommended values.

DOE site ^a	Elements $4 \times 5b^b$	Elements $(4 \times 5a)_{\text{site}}^{b,c}$	Elements $(4 \times 5a)_{\text{facility}}^b$	Combined Elements $4 \times (5a + 5b)^{b,d}$
ANL-East	350	10	See Table 2-13	$360 + (4 \times 5a)_{\text{facility}}$
BNL	250	6	See Table 2-13	$256 + (4 \times 5a)_{\text{facility}}$
ETEC	400	0.4	See Table 2-13	$400 + (4 \times 5a)_{\text{facility}}$
FEMP	130	8	See Table 2-13	$138 + (4 \times 5a)_{\text{facility}}$
Hanford	13	1.3	See Table 2-13	$14.3 + (4 \times 5a)_{\text{facility}}$
INEL	5	3	See Table 2-13	$8 + (4 \times 5a)_{\text{facility}}$
KAPL-K	350	13	See Table 2-13	$363 + (4 \times 5a)_{\text{facility}}$
KCP	280	15	See Table 2-13	$295 + (4 \times 5a)_{\text{facility}}$
K-25	35	10	See Table 2-13	$45 + (4 \times 5a)_{\text{facility}}$
LANL	10	6	See Table 2-13	$16 + (4 \times 5a)_{\text{facility}}$
LBL	1,000	13	See Table 2-13	$1013 + (4 \times 5a)_{\text{facility}}$
LLNL	270	30	See Table 2-13	$300 + (4 \times 5a)_{\text{facility}}$
Mound	250	6	See Table 2-13	$256 + (4 \times 5a)_{\text{facility}}$
MSP	830	0	See Table 2-13	$830 + (4 \times 5a)_{\text{facility}}$
NTS	0.5	2	See Table 2-13	$2.5 + (4 \times 5a)_{\text{facility}}$
ORNL	35	12	See Table 2-13	$47 + (4 \times 5a)_{\text{facility}}$
Pantex	9	6	See Table 2-13	$15 + (4 \times 5a)_{\text{facility}}$
PGDP	23	7	See Table 2-13	$30 + (4 \times 5a)_{\text{facility}}$
Pinellas	350	4	See Table 2-13	$354 + (4 \times 5a)_{\text{facility}}$
Portsmouth	27	11	See Table 2-13	$38 + (4 \times 5a)_{\text{facility}}$
RFETS	110	19	See Table 2-13	$129 + (4 \times 5a)_{\text{facility}}$
SNL-NM	320	18	See Table 2-13	$338 + (4 \times 5a)_{\text{facility}}$
SRS	21	3	See Table 2-13	$24 + (4 \times 5a)_{\text{facility}}$
WIPP	3	2	See Table 2-13	$5 + (4 \times 5a)_{\text{facility}}$
WVDP	60	3	See Table 2-13	$63 + (4 \times 5a)_{\text{facility}}$
Y-12	60	25	See Table 2-13	$85 + (4 \times 5a)_{\text{facility}}$

a. ANL—Argonne National Laboratory, BNL—Brookhaven National Laboratory, ETEC—Energy Technology Engineering Center, FEMP—Fernald Environmental Management Project, INEL—Idaho National Engineering Laboratory, KAPL-K—Knolls Atomic Power Laboratory—Kesselring, KCP—Kansas City Plant, LANL—Los Alamos National Laboratory, LBL—Lawrence Berkeley Laboratory, LLNL—Lawrence Livermore National Laboratory, MSP—Middlesox Sampling Plant, NTS—Nevada Test Station, ORNL—Oak Ridge National Laboratory, PGDP—Paducah Gaseous Diffusion Plant, RFETS—Rocky Flats Environmental Technology Site, SNL-NM—Sandia National Laboratory-New Mexico, SRS—Savannah River Site, WIPP—Waste Isolation Pilot Plant, WVDP—West Valley Demonstration Project.

b. Includes the additional factor of 1/3, to calibrate the SRM risk predictions to person-rem.

c. Includes the factor of 1/3, to account for site personnel being at the site 8 h per day.

d. Values listed are for airborne releases. For groundwater releases, multiply by $(1E-4) T/(K_d \times R_p)$.

Table 2-13. Combined Elements $(4 \times 5a)_{\text{facility}}$ lookup table—recommended values for airborne releases.

Type of Facility or Process	Size of Facility or Process	Number of Involved Workers ^a	Number of Support Personnel ^b	Recommended Value of Elements $(4 \times 5a)_{\text{facility}}$ ^{c,f}
Berm or trench storage	Small	1 ^c	3	1
	Medium	3 ^c	7	3
	Large	6 ^c	10	6
Storage	Small	3 ^d	6	4
	Medium	6 ^d	14	10
	Large	10 ^d	20	17
Disposal	Small	0	10	1
	Medium	0	30	3
	Large	0	50	6

a. Assumed to be 10 m from contaminant 50% of working hours, unless otherwise indicated. The remaining 50% of working hours are at 100 m.

b. Assumed to be 100 m from contaminant 100% of working hours, unless otherwise indicated.

c. Assumed to be 10 m from contaminant 6.25% of working hours (for inspection).

d. Assumed to be 10 m from contaminant 12.5% of working hours (for inspection).

e. Includes the additional factor of 1/3, to calibrate the SRM risk predictions to person-rem.

f. Includes the factor of 1/3, to account for site personnel being at the site 8 h per day.

Table 2-14. Element 6—recommended time values based on barrier life.

Barrier Type	First Calculation	Second Calculation
Nonmassive engineered barrier	Barrier in place up to 50 yr	No barrier after 50 yr
Massive engineered barrier	Barrier in place up to 500 yr	No massive barrier in place after 500 yr
Multi-layered capped	Barrier in place up to 500 yr	No capped barrier in place after 500 yr
Near surface or intermediate depth burial	Time to retrieval	NA
Deep geological disposal	1000 yr	NA

3. TRANSITION STATE—LOOKUP TABLES

This section explains how to select the most appropriate value of each risk element for transition states. The following either (a) provide a lookup table for each risk element or (b) refer the user back to the identical lookup table for the same risk element for rest states.

3.1 Element 1—Waste Characteristics

Elements 1a, contaminant quantities, and 1b, specific toxicity, are identical for transition states and rest states. The lookup tables in Section 2.1 should be used.

3.2 Element 2—Susceptibility of Contaminants to Movement

3.2.1 Element 2a—Mobility of Waste Form

Element 2a, the mobility of the waste form, is identical for transition states and rest states.

If the transition state changes the characteristics of the waste, the value chosen for Element 2a should represent the waste form that exists *during* the transition process. For example, if a transition state involves solidifying a slurry, the waste form during most of the treatment steps is the slurry, not the solidified waste form.

Transition states generally are subject only to airborne releases. Exceptions, such as an accidental release during waste shipment while passing over or beside a body of water, are rare. Therefore, the mobility values for transition states should normally be taken from the airborne column of the Element 2a lookup table.

3.2.2 Element 2b—Confinement Capability

Element 2b, confinement capability, is identical for transition (nontransportation) states and rest states. For transportation, additional guidance is needed. The values in Table 3-1 should be used.

3.3 Element 3—Challenges to Contaminant Confinement

3.3.1 Element 3a—Confinement Challenges from Environmental Events

The lookup table for environmental challenges to confinement for nonshipping transition states is Table 3-2. For shipping states, the value of Element 3a is zero.

3.3.2 Element 3b—Confinement Challenges from Operational Events

Table 3-3 lists the frequency-severity values for Element 3b for nonshipping transition states. To use Table 3-3, determine the operational confinement challenges that apply to the subject operation. Sum the frequency-severity values for each applicable type of challenge. Then use this aggregated value for Element 3b for the transition state.

Table 3-1. Element 2b lookup table—confinement capability.

Type of facility or process	Confinement	Value
Transition (non-transportation)	No engineered confinement or flimsy engineered barriers (e.g., cardboard boxes) or severely degraded engineered barriers (e.g., badly rusted drums)	1
	Single engineered barrier in good condition ^a	1E-1 ^a
	Two engineered barriers in good condition ^a	1E-2 ^a
	Three engineered barriers in good condition ^a	3E-3 ^a
Transportation	Type B (TRUPACT-II or NuPac 72B, assumes 2a = 1E-3)	5E-4
	Type B (vitrified HLW, assumes 2a = 1E-5)	1
	Type A (assumes 2a = 1E-3)	1
	SNF shipping cask (assumes 2a = 1E-5)	1E-1

a. Additional credit (reduction by a factor of 3 to 10) can be taken if the barrier is massive.

Table 3-2. Element 3a lookup table—environmental challenges to confinement (nonshipping states).

NPH Event	Selection Criteria	Frequency-Severity Value: Element 3a ^{a,b}
Seismic (beyond design basis)	Facility not meeting NPH design criteria	1E-4
	Modern PC 2 (Hazard Category 3) facility or process	1E-5
	Modern PC 3 (Hazard Category 2) facility or process	1E-6
Strong wind/tornado (beyond design basis)	Facility not meeting NPH design criteria	1E-4
	PC 2 (Hazard Category 3) facility or process	1E-5
	PC 3 (Hazard Category 2) facility or process	1E-6
Flood (beyond design basis)	Facility not meeting NPH design criteria	1E-5
	PC 2 (Hazard Category 3) facility or process	1E-6
	PC 3 (Hazard Category 2) facility or process	1E-7

a. The total for Element 3a is the sum of the frequency-severity values from seismic events, strong winds and tornadoes, and floods, as applicable.

b. The frequency-severity values have been transformed to unitless values by assuming each transition state lasts 1 year. This transformation is appropriate because the risk from each transition state is based on the entire inventory to be processed during the transition state.

Table 3-3. Element 3b lookup table—operational challenges to confinement: nonshipping states.

Operational Event	Selection Criteria	Frequency-Severity Value: Element 3b ^{b,c}
Criticality	Large potential for criticality (frequent activities or large amounts of material); process difficult to control; or ineffective barriers	1E-4
	Potential for criticality; process easy to control; or effective administrative barriers	1E-6
	Little potential for criticality (infrequent activities or small amounts of material); or effective passive barriers	1E-8
Fire (unmitigated)	Energetic process (high temperature and/or pressure) such as incineration or welding/torch cutting; large amount of combustibles and inadequate fire suppression; retrieval of poorly characterized waste that could contain flammables or pyrophorics	1E-3
	Moderately energetic process such as thermal desorption; moderate amounts of combustibles and adequate fire suppression	1E-4
	Benign process such as grouting or cementation; waste form difficult to combust	1E-5
Facility/process explosion	Energetic process such as rotary kiln incinerator	1E-3
	Moderately energetic process such as thermal desorption with natural gas or fuel sources present	1E-5
	Benign process such as grouting or cementation with no natural gas or fuel sources present	1E-7
Container explosion	Poorly characterized waste in unvented containers; retrieval of poorly characterized waste	1E-4
	Waste in vented containers; movement of waste in vented containers	1E-6
Handling accident (forklift/crane)	Movement of waste containers under suboptimal conditions (unwieldy containers, uneven ground, poor visibility, etc.)	1E-3
	Movement of waste containers under optimal conditions (standardized waste containers, cement floor, good weather/visibility, spotter present)	1E-4

a. For operations that involve technologies that are not proven in full-scale applications, increase the frequency and the frequency-severity by a factor of 3.

b. The total for Element 3b is the sum of the frequency-severity values from criticality, fire, facility and process explosion, container explosion, and handling accident, as applicable.

c. The frequency-severity values have been transformed to unitless values by assuming each transition state lasts 1 year. This transformation is appropriate because the risk from each transition state is based on the entire inventory to be processed during the transition state in question.

Table 3-4 lists the frequency-severity values for Element 3b for shipping states.

3.4 Element 4—Environmental Transport Effectiveness

The relative transportability values of the airborne pathway for transient states are identical to those for rest states in lookup Table 2-9. The groundwater pathway is generally not applicable for transition states.

Recommended values for the combined Elements $4 \times (5a + 5b)$ for airborne transport for transitions states are presented in Section 3.6.

3.5 Element 5—Presence of Human Receptors

Most transition states involve activities that take place in facilities, even if the facility is in the open air. For facility-based transition states, Elements 5a and 5b, the proximity of the workers and the public to the waste is the same as for rest states, except as described in Sections 3.5.1 through 3.5.4.

See Sections 3.5.1 and 3.5.2 for values of Elements 5a and 5b for nonshipment transition states. For transition states that involve waste shipment, the methods described in Sections 3.5.3 and 3.5.4 are used to calculate the value of Elements 5a and 5b. The method is a modification of that used for rest states. For shipment activities, one difference between the methods is that the workers are generally transportation personnel such as truck drivers and train brakemen. For offsite shipment, another difference is that members of the public are located along a fixed route that extends many miles in length, rather being located at fixed distances away from a fixed facility.

Section 3.6 includes recommended values for the combined Elements $4 \times (5a + 5b)$ for airborne transport for transition states. The recommended values can be used as a time-saving measure.

3.5.1 Element 5a for Nonshipment Transition States—Workers

For nonshipment transition states, the value of Element 5a is determined by the same method used for rest states (see Section 2.5.1).

3.5.2 Element 5b for Nonshipment Transition States—Public

For nonshipment transition states, the value of Element 5b is determined by the same method used for rest states (see Section 2.5.2).

Table 3-4. Element 3b lookup table—frequency-severity values for operational challenges to confinement: shipping states.

Truck shipment

$$4E-7 \times \text{route length}^a$$

Rail shipment

$$1E-7 \times \text{route length}$$

a. The route length is the one-way travel distance in miles.

3.5.3 Element 5a for Shipment—Workers

This element represents the same basic parameters as the corresponding element for a rest state or a facility-based transition state. The same equation is used, but the factors in the equation are selected based on the route used for the onsite transfer or the offsite shipment. The only exposure routes to the workers are assumed to be direct radiation and inhalation.

The value of Element 5a for each group of workers is determined from Equation (3-1).

$$\text{Element } 5a_i = \frac{N_i \times F_i}{WAP_i \times PPE_i} \quad (3-1)$$

The recommended values for calculating the product of Element 4 and Element 5a for generic offsite shipment are as follows:

- $I = 1$ (transportation crew is only worker group)
- $N = 3$ people in crew
- $F = 1$ (assuming multiple crews operate the transport vehicle 24 hr/day)
- $PPE = WAP = 1$.

If the crew is located at a distance of 100 m during the accident exposure, the value of Element 4 is 1. This produces a value of 3 for the product of Element 4 and Element 5a.

3.5.4 Element 5b for Shipment—Public

This element represents the same basic parameters as the corresponding element for a rest state or a facility-based transition state.

For each public population group k along the shipping route, a value should be selected for Element 5b_k. The value is simply the number of people in group k .

For risk calculations that focus on specific shipping routes, route-specific values can be developed. The same method described for developing the generic values should be used.

3.6 Elements $4 \times (5a + 5b)$ —Recommended Values

If desired, the recommended values for Elements $4 \times (5a + 5b)$ presented in Tables 3-5, 3-6, and 3-7 may be used rather than the process outlined previously for each of the individual elements. Similar to rest states the recommended values are subdivided into three contributions. The recommended values result in a risk measure of person-rem.

Values listed in Table 3-5 are for airborne releases. For groundwater releases, multiply by $(1E-4) T/(K_d \times R_v)$.

Table 3-5. Combined Elements $4 \times (5a + 5b)$ lookup table—recommended values.

DOE site ^a	Elements $4 \times 5b^b$	Elements $(4 \times 5a)_{\text{site}}^{b,c}$	Elements $(4 \times 5a)_{\text{facility}}^b$	Combined Elements $4 \times (5a + 5b)^{b,d}$
ANL-East	350	10	See Table 3-6	$360 + (4 \times 5a)_{\text{facility}}$
BNL	250	6	See Table 3-6	$256 + (4 \times 5a)_{\text{facility}}$
ETEC	400	0.4	See Table 3-6	$400 + (4 \times 5a)_{\text{facility}}$
FEMP	130	8	See Table 3-6	$138 + (4 \times 5a)_{\text{facility}}$
Hanford	13	1.3	See Table 3-6	$14.3 + (4 \times 5a)_{\text{facility}}$
INEL	5	3	See Table 3-6	$8 + (4 \times 5a)_{\text{facility}}$
KAPL-K	350	13	See Table 3-6	$363 + (4 \times 5a)_{\text{facility}}$
KCP	280	15	See Table 3-6	$295 + (4 \times 5a)_{\text{facility}}$
K-25	35	10	See Table 3-6	$45 + (4 \times 5a)_{\text{facility}}$
LANL	10	6	See Table 3-6	$16 + (4 \times 5a)_{\text{facility}}$
LBL	1,000	13	See Table 3-6	$1013 + (4 \times 5a)_{\text{facility}}$
LLNL	270	30	See Table 3-6	$300 + (4 \times 5a)_{\text{facility}}$
Mound	250	6	See Table 3-6	$256 + (4 \times 5a)_{\text{facility}}$
MSP	830	0	See Table 3-6	$830 + (4 \times 5a)_{\text{facility}}$
NTS	0.5	2	See Table 3-6	$2.5 + (4 \times 5a)_{\text{facility}}$
ORNL	35	12	See Table 3-6	$47 + (4 \times 5a)_{\text{facility}}$
Pantex	9	6	See Table 3-6	$15 + (4 \times 5a)_{\text{facility}}$
PGDP	23	7	See Table 3-6	$30 + (4 \times 5a)_{\text{facility}}$
Pinellas	350	4	See Table 3-6	$354 + (4 \times 5a)_{\text{facility}}$
Portsmouth	27	11	See Table 3-6	$38 + (4 \times 5a)_{\text{facility}}$
RFETS	110	19	See Table 3-6	$129 + (4 \times 5a)_{\text{facility}}$
SNL-NM	320	18	See Table 3-6	$338 + (4 \times 5a)_{\text{facility}}$
SRS	21	3	See Table 3-6	$24 + (4 \times 5a)_{\text{facility}}$
WIPP	3	2	See Table 3-6	$5 + (4 \times 5a)_{\text{facility}}$
WVDP	60	3	See Table 3-6	$63 + (4 \times 5a)_{\text{facility}}$
Y-12	60	25	See Table 3-6	$85 + (4 \times 5a)_{\text{facility}}$

a. ANL—Argonne National Laboratory, BNL—Brookhaven National Laboratory, ETEC—Energy Technology Engineering Center, FEMP—Fernald Environmental Management Project, INEL—Idaho National Engineering Laboratory, KAPL-K—Knolls Atomic Power Laboratory—Kesselring, KCP—Kansas City Plant, LANL—Los Alamos National Laboratory, LBL—Lawrence Berkeley Laboratory, LLNL—Lawrence Livermore National Laboratory, MSP—Middlesox Sampling Plant, NTS—Nevada Test Station, ORNL—Oak Ridge National Laboratory, PGDP—Paducah Gaseous Diffusion Plant, RFETS—Rocky Flats Environmental Technology Site, SNL-NM—Sandia National Laboratory-New Mexico, SRS—Savannah River Site, WIPP—Waste Isolation Pilot Plant, WVDP—West Valley Demonstration Project.

b. Includes the additional factor of $1/3$, to calibrate the SRM risk predictions to person-rem.

c. Includes the factor of $1/3$, to account for site personnel being at the site 8 h per day.

d. Values listed are for airborne releases. For groundwater releases, multiply by $(1E-4) T/(K_a \times R_a)$.

Table 3-6. Combined Elements $(4 \times 5a)_{\text{facility}}$ lookup table—recommended values.

Type of facility or process	Size of facility or process	Number of involved workers ^a	Number of support personnel ^b	Recommended Elements $(4 \times 5a)_{\text{facility}}$
Retrieval (from storage), venting, waste preparation, certification, load/unload (shipping), or placement (into storage)	Small	2	2	10
	Medium	5	5	30
	Large	10	10	60
Retrieval (from berm/trench storage)	Small	10	3	60
	Medium	20	7	110
	Large	40	15	230
Sorting	Small	12	38	70
	Medium	25	75	150
	Large	50	150	300
Treatment	Small	5	20	30
	Medium	10	40	60
	Large	20	80	120

a. Assumed to be 10 m from contaminant 50% of working hours, unless otherwise indicated. The remaining 50% of working hours are at 100 m.

b. Assumed to be 100 m from contaminant 100% of working hours, unless otherwise indicated.

Table 3-7. Combined Elements $4 \times (5a + 5b)$ lookup table—recommended values for transportation.

Type of facility or process	Elements $4 \times 5b$	Elements $(4 \times 5a)_{\text{site}}$	Elements $(4 \times 5a)_{\text{facility}}$	Combined Elements $4 \times (5a + 5b)$
Transportation	5	Included in $4 \times 5b$	Included in $4 \times 5b$	5

a. For airborne releases only. Groundwater releases are not modeled.

4. REFERENCES

Eide, S. A., Smith, T. H., Peatross, R. G., Stepan, I. E., *A Simplified Method for Quantitative Assessment of the Relative Health and Safety Risk of Environmental Management Activities*, INEL-95/0645, October 1996.