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Verification of RESRAD-BUILD Code Version 4

Environmental Science Division

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Verification of RESRAD-BUILD Code Version 4

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by
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1 INTRODUCTION

This report documents the verification of the RESRAD-BUILD code, Version 4.0, which was released on December 22, 2022. Two earlier reports verifying Versions 3.0 and 3.1, respectively, were published in 2001 (Kamboj, et al. 2001) and 2003 (Tetra Tech NUS 2003). Version 4.0 of the RESRAD-BUILD code has many new features and modeling enhancements over the earlier versions, including the previously released Version 3.5. The major new features and modeling enhancements include:

1. Provision of a choice between ICRP-107 and ICRP-38 radiological transformation databases, along with an input of cut-off half-life, for use in constructing radiological decay chains and choosing compatible dose and risk coefficient libraries for dose and risk calculations.

2. An ability to model complete decay chains, including branches, and evaluate each progeny separately for their contributions to direct external radiation.

3. Implementation of a new dynamic ventilation model that forgoes the steady-state assumption as used in previous versions, to conserve mass balance and improve accuracy in the predicted radionuclide concentrations in the air and on the floor over time.

4. Increments in the number of compartments (rooms) in a building from 3 to 9 with allowance for air exchange between any pair of rooms and between any room and the outdoor.

5. Consideration of periodical vacuuming and its efficiency to remove floor deposition of contaminated materials.

6. Consideration of up to 10 release phases with user-defined begin time, end time, and source removal fraction for each phase for point, line, and area sources, to account for different source removal rates and intermittent releases.

7. Implementation of both analytical and numerical solutions to time integration and use of the analytical solutions to reduce calculation time whenever feasible or per user's choice.

8. A redefined basis for volume source coordinates, as the center of the contaminated region, and the addition of a new direction of erosion parameter, for precise determination of the receptor-source distance at any time.

9. Generation of output files containing intermediate calculation results per user's choice, for obtaining insights to the modeling.

10. Addition of new appearances for several input forms, to facilitate input data collection, while maintaining the traditional appearances (as in Version 3.5), which can continue to be used, if preferred by users.

11. Linking the code to Version 3.3 of the Dose Conversion Factor (DCF) Editor that has an expanded database (including air submersion dose and risk coefficients) and is equipped with improved interactive help entries.

12. Provision of context-specific help entries and the User's Manual (including User's Guide) in pdf format to guide the use of the code.

13. Streamlining the selection of DCF libraries to ensure proper pairing of external and internal dose coefficient libraries.

Chapter 2 of this report focuses on verifying the external dose and risk modeling for point, line, area, and volume sources, as well as for floor deposition. Besides verification, the external radiation doses calculated by RESRAD-BUILD were also benchmarked with those calculated by the MCNP code (Briemeister 1993). Section J.3 of the RESRAD-BUILD User's Manual Vol. 1 (Yu et al. 2022) documents the results of that benchmarking effort. Chapter 3 of this report focuses on verifying the ventilation modeling, from checking the remaining source inventory, releases of radionuclides to the air, air concentrations and deposited floor concentrations over time, to the radiation dose and risk associated with inhalation, ingestion, and air submersion, with and without vacuuming. The verification efforts involve designing spreadsheets to perform calculations the same as or like those performed by the RESRAD-BUILD code and then comparing the spreadsheet results with those produced by the code. When the results agree or the differences are within acceptable range, the accuracy of model implementation in the code is verified.

In addition to model implementation, the implementation of key functions and features that facilitate the modeling or the use of the code were also verified during the release testing of the code. Appendix A presents the test cases developed for these verification testing, and Appendix B presents the testing results that verify proper implementation of key functions and features.

2 VERIFICATION OF THE EXTERNAL RADIATION MODELING

RESRAD-BUILD User's Manual (Yu et al. 2022) Appendix C describes the modeling of external dose and risk from different types of radiation sources implemented in the code. To verify that the external radiation model was correctly implemented, several Excel® spreadsheets were designed to calculate external radiation dose and risk for comparison with the RESRAD-BUILD results. In addition to the external radiation dose coefficients taken from FGR 12 (Eckerman and Ryman 1993), the data needed for the estimates of attenuation factors, buildup factors, and mass absorption fractions in the spreadsheets were taken from Trubey 1991. The comparisons showed that for most cases, the RESRAD-BUILD results and the spreadsheet results were in good agreement; when the results were different, the difference was less than 10% and was judged to be acceptable, considering the approximate nature of the estimated attenuation factors, buildup factors, and mass absorption fractions in the spreadsheets.

2.1 EXTERNAL RADIATION OF POINT SOURCES

External radiation doses from C-14, Mn-54, Co-60, Nb-94, and Tc-99 were calculated for comparison. It was assumed a point source containing 1 pCi of radioactivity of each radionuclide was located at (0 m, 0 m, 0 m). The removable fraction of the source was zero, and there was no release of radioactivity into the indoor air. Three receptors located at (0 m, 0 m, 0.3 m), (1 m, 1 m, 1 m), and (0 m, 0 m, 4 m) would incur external radiation emitted by the source. Each of them was assumed to spend 50% of the time in a year inside the building.

The average annual external dose and risk without shielding materials between the source and each receptor for the first year were calculated and compared. To verify the attenuation modeling of external radiation due to shielding, water and concrete were assumed to be the shielding materials, both with effective thicknesses of 1 cm, 5 cm, and 50 cm. The attenuated dose and risk received by the receptor located at (1 m, 1 m, 1 m) were then calculated and compared.

Table 2.1 lists literature data of the mass energy absorption coefficients and the absorbed-to-effective dose conversion factors used in the spreadsheet. The mass energy absorption coefficients were obtained from Trubey 1991. The ICRP Publication 51 (ICRP 1987) was the source of the absorbed-to-effective dose conversion factors. The mass absorption fraction and the absorbed-to-effective dose conversion factor for the photon energy associated with the decay of the individual radionuclides were calculated by interpolation.

Table 2.2 lists data of the mass attenuation coefficients for air, water, and concrete from Trubey 1991. Like the mass absorption fraction and the absorbed-to-effective dose conversion factor, the mass attenuation coefficients needed for the photon energy associated with the decay of the individual radionuclides were calculated by interpolation.

Tables 2.3 to 2.5 list the data of the buildup factors in air, water, and concrete, respectively, and the estimates based on the data for C-14, Tc-99, Nb-94, Mn-54, and Co-60, the five radionuclides selected for this comparison.

Table 2.1 Literature Data of Mass Energy Absorption Coefficients and Absorbed-to-Effective Dose Conversion Factors

Energy (MeV)	Mass Energy Absorption Coefficient from Trubey 1991 Air (cm^2/g)	Absorbed-to-Effective Dose Conversion Factor from ICRP 51 (Sv/Gy)
0.01	4.64	0.0039
0.015	1.3	0.023
0.02	0.5255	0.065
0.03	0.1501	0.23
0.04	0.06694	0.464
0.05	0.04031	0.687
0.06	0.03004	0.83
0.08	0.02393	0.954
0.1	0.02318	0.962
0.15	0.02494	0.891
0.2	0.02672	0.854
0.3	0.02872	0.826
0.4	0.02949	0.82
0.5	0.02966	0.824
0.6	0.02953	0.824
0.8	0.02882	0.832
1	0.02787	0.839
1.5	0.02545	0.856
2	0.02342	0.875
3	0.02054	0.902
4	0.01866	0.917
5	0.01737	0.935
6	0.01644	0.943
8	0.01521	0.969
10	0.01446	0.991

Table 2.2 Literature Data of Mass Attenuation Coefficients in Air, Water, and Concrete

Energy (MeV)	Mass Attenuation Coefficient (cm^2/g) from Trubey 1991		
	Air	Water	NBS Concrete
0.01	5.123	5.33	26.56
0.015	1.615	1.673	8.297
0.02	0.7784	0.8098	3.651
0.03	0.3539	0.3756	1.214
0.04	0.2485	0.2683	0.6122
0.05	0.208	0.2269	0.3944
0.06	0.1875	0.2058	0.2957
0.08	0.1663	0.1837	0.2125
0.1	0.1541	0.1707	0.1783
0.15	0.1356	0.1505	0.1434
0.2	0.1234	0.137	0.127
0.3	0.1068	0.1187	0.1082
0.4	0.09549	0.1061	0.09628
0.5	0.08712	0.09678	0.08768
0.6	0.08055	0.08956	0.08098
0.8	0.07074	0.07866	0.07103
1	0.06358	0.07071	0.06382
1.5	0.05175	0.05754	0.05197
2	0.04447	0.04941	0.04482
3	0.03581	0.03969	0.03654
4	0.03079	0.03403	0.03189
5	0.02751	0.03031	0.02895
6	0.02522	0.0277	0.02696
8	0.02225	0.02429	0.0245
10	0.02045	0.02219	0.02311

Table 2.3 Estimates of Buildup Factors in Air of Different Thicknesses

Thickness in Mean Free Path	Data of Buildup Factors in Air									C-14	Tc-99	Nb-94	Mn-54	Co-60
	0.015 MeV	0.04 MeV	0.05 MeV	0.1 MeV	0.15 MeV	0.6 MeV	0.8 MeV	1 MeV	1.5 MeV	0.049 MeV	0.101 MeV	0.787 MeV	0.835 MeV	1.25 MeV
0.5	1.12	2.20	2.48	2.35	2.16	1.56	1.50	1.47	1.42	2.45	2.35	1.50	1.49	1.45
1	1.17	3.38	4.28	4.46	3.83	2.33	2.17	2.08	1.92	4.19	4.45	2.18	2.15	2.00
2	1.25	5.85	8.72	11.40	9.21	4.46	3.94	3.60	3.09	8.43	11.36	3.97	3.88	3.35
3	1.31	8.47	14.10	22.50	18.20	7.34	6.19	5.46	4.42	13.54	22.41	6.26	6.06	4.94
4	1.36	11.20	20.50	38.40	31.50	10.90	8.88	7.60	5.86	19.57	38.26	9.01	8.66	6.73
5	1.39	14.10	27.60	59.90	49.90	15.30	12.00	10.00	7.42	26.25	59.70	12.21	11.65	8.71
6	1.43	17.00	35.70	87.80	74.20	20.30	15.50	12.70	9.08	33.83	87.53	15.81	15.01	10.89
7	1.46	20.10	44.60	123.00	105.00	26.00	19.40	15.60	10.80	42.15	122.64	19.83	18.74	13.20
8	1.48	23.30	54.40	166.00	144.00	32.50	23.70	18.80	12.70	51.29	165.56	24.27	22.84	15.75
10	1.53	30.00	76.80	282.00	249.00	47.90	33.50	25.80	16.70	72.12	281.34	34.44	32.15	21.25
15	1.62	49.00	151.00	800.00	735.00	100.00	64.90	47.00	27.70	140.80	798.70	67.18	61.77	37.35
20	1.68	71.40	256.00	1810.00	1700.00	173.00	105.00	72.80	40.20	237.54	1807.80	109.42	99.37	56.50
25	1.74	97.20	395.00	3570.00	3410.00	266.00	154.00	103.00	53.90	365.22	3566.80	161.28	145.08	78.45
30	1.78	126.00	574.00	6430.00	6210.00	379.00	210.00	136.00	68.50	529.20	6425.60	220.99	197.05	102.25
35	1.82	159.00	798.00	1.06E+04	1.05E+04	512.00	274.00	173.00	84.00	734.10	1.06E+04	289.47	256.33	128.50
40	1.85	195.00	1070.00	1.57E+04	1.70E+04	665.00	345.00	212.00	100.00	982.50	1.57E+04	365.80	321.73	156.00

Table 2.4 Estimates of Buildup Factors in Water of Different Thicknesses

Thickness in Mean Free Path	Data of Buildup Factors in Water									C-14	Tc-99	Nb-94	Mn-54	Co-60
	0.015 MeV	0.04 MeV	0.05 MeV	0.1 MeV	0.15 MeV	0.6 MeV	0.8 MeV	1 MeV	1.5 MeV	0.049 MeV	0.101 MeV	0.787 MeV	0.835 MeV	1.25 MeV
0.5	1.13	2.22	2.52	2.37	2.07	1.56	1.50	1.47	1.41	2.49	2.36	1.50	1.49	1.44
1	1.18	3.47	4.42	4.55	3.89	2.33	2.17	2.08	1.91	4.33	4.54	2.18	2.15	2.00
2	1.27	6.18	9.25	11.80	9.49	4.49	3.96	3.62	3.10	8.94	11.75	3.99	3.90	3.36
3	1.33	9.14	15.30	23.80	19.00	7.44	6.26	5.50	4.43	14.68	23.70	6.34	6.13	4.97
4	1.38	12.30	22.60	41.30	33.30	11.20	9.00	7.68	5.88	21.57	41.14	9.14	8.77	6.78
5	1.43	15.70	31.00	65.20	53.40	15.60	12.20	10.10	7.44	29.47	64.96	12.42	11.83	8.77
6	1.46	19.20	40.50	96.70	80.10	20.80	15.80	12.80	9.11	38.37	96.37	16.13	15.28	10.96
7	1.50	22.90	51.30	137.00	115.00	26.70	19.80	15.80	10.90	48.46	136.56	20.25	19.10	13.35
8	1.53	26.80	63.20	187.00	158.00	33.50	24.20	19.00	12.70	59.56	186.42	24.80	23.29	15.85
10	1.58	35.10	90.90	321.00	277.00	49.30	34.20	26.10	16.70	85.32	320.12	35.18	32.78	21.40
15	1.68	59.20	185.00	938.00	834.00	104.00	66.30	47.70	27.80	172.42	935.92	68.75	63.05	37.75
20	1.75	88.50	323.00	2170.00	1960.00	179.00	108.00	74.00	40.40	299.55	2165.80	112.62	102.05	57.20
25	1.82	123.00	511.00	4360.00	3980.00	276.00	157.00	104.00	54.00	472.20	4352.40	164.74	147.73	79.00
30	1.87	163.00	759.00	7970.00	7320.00	395.00	215.00	139.00	68.70	699.40	7957.00	226.70	201.70	103.85
35	1.91	208.00	1080.00	1.35E+04	1.25E+04	534.00	281.00	177.00	84.30	992.80	1.35E+04	297.45	262.80	130.65
40	1.94	259.00	1470.00	2.11E+04	2.03E+04	695.00	353.00	218.00	101.00	1348.90	2.11E+04	375.23	329.38	159.50

Table 2.5 Estimates of Buildup Factors in Concrete of Different Thicknesses

Thickness in Mean Free Path	Data of Buildup Factors in Concrete									C-14	Tc-99	Nb-94	Mn-54	Co-60
	0.015 MeV	0.04 MeV	0.05 MeV	0.1 MeV	0.15 MeV	0.6 MeV	0.8 MeV	1 MeV	1.5 MeV	0.049 MeV	0.101 MeV	0.787 MeV	0.835 MeV	1.25 MeV
0.5	1.02	1.30	1.42	1.89	1.84	1.53	1.48	1.45	1.39	1.41	1.89	1.48	1.47	1.42
1	1.03	1.46	1.74	2.78	2.82	2.18	2.06	1.98	1.85	1.71	2.78	2.07	2.05	1.92
2	1.04	1.69	2.26	4.63	5.13	3.80	3.47	3.24	2.86	2.20	4.64	3.49	3.43	3.05
3	1.05	1.87	2.63	6.63	7.92	5.82	5.18	4.72	4.00	2.55	6.66	5.22	5.10	4.36
4	1.05	2.01	2.95	8.80	11.20	8.25	7.18	6.42	5.25	2.86	8.85	7.25	7.05	5.84
5	1.06	2.14	3.25	11.10	15.00	11.10	9.47	8.33	6.60	3.14	11.18	9.58	9.27	7.47
6	1.06	2.25	3.53	13.60	19.30	14.30	12.00	10.40	8.05	3.40	13.71	12.15	11.72	9.23
7	1.07	2.35	3.79	16.30	24.20	18.00	14.90	12.70	9.58	3.65	16.46	15.10	14.52	11.14
8	1.07	2.45	4.04	19.20	29.70	22.20	18.10	15.20	11.20	3.88	19.41	18.37	17.59	13.20
10	1.08	2.62	4.51	25.60	42.70	31.80	25.10	20.70	14.60	4.32	25.94	25.54	24.33	17.65
15	1.09	2.98	5.57	44.90	87.60	63.60	47.40	37.20	24.20	5.31	45.75	48.45	45.62	30.70
20	1.10	3.27	6.52	69.10	153.00	107.00	75.70	57.10	35.00	6.20	70.78	77.73	72.45	46.05
25	1.10	3.51	7.38	87.90	240.00	161.00	110.00	80.10	46.90	6.99	90.94	113.32	104.77	63.50
30	1.11	3.73	8.18	131.00	353.00	226.00	149.00	106.00	59.60	7.74	135.44	154.01	141.48	82.80
35	1.11	3.91	8.87	170.00	494.00	302.00	193.00	134.00	73.00	8.37	176.48	200.09	182.68	103.50
40	1.11	4.03	9.44	214.00	664.00	389.00	242.00	164.00	87.10	8.90	223.00	251.56	228.35	125.55

2.1.1 Dose Results without Shielding

Tables 2.6-2.8 show the estimations of the external radiation dose incurred by each receptor when there was no shielding between the radiation source and the receptor. Table 2.9 compares the dose estimates between the spreadsheets and the RESRAD-BUILD code. The comparison shows good agreement in the dose estimates.

2.1.2 Risk Results without Shielding

In RESRAD-BUILD, cancer risks associated with external radiation are calculated by multiplying the estimated external doses with a radionuclide-specific dose-to-risk conversion factor, which is the ratio of the slope factor (SF) for external radiation to the dose conversion factor/dose coefficient (DCF) for external radiation for an infinite volume source. To verify the external risk results from RESRAD-BUILD, the external dose results from RESRAD-BUILD were multiplied by the radionuclide-specific dose-to-risk conversion factor in the spreadsheets, and the multiplication products were compared with the cancer risk results reported by the code.

Table 2.10 presents the radionuclide-specific dose-to-risk conversion factors for external radiation for the radionuclides selected for this comparison. The dose coefficients are from FGR 12 (Eckerman and Ryman 1993), and the slope factors are the FGR 13 (Eckerman et al. 1999) morbidity risk numbers. Table 2.11 compares the cancer risks calculated by the RESRAD-BUILD code and by the spreadsheets. The two sets of calculation results agree with each other.

2.1.3 Dose Results with Water Shielding

Table 2.12 shows the estimation of the attenuation factor and buildup factor when there is shielding of water with a thickness of 1 cm, 5 cm, and 50 cm between the source and the receptor at (1 m, 1 m, 1 m).

Table 2.13 compares the dose estimates between the spreadsheets and the RESRAD-BUILD code. Except for the dose results with a shielding thickness of 1 cm for Tc-99 that show a difference of 13%, the other dose results of RESRAD-BUILD and the spreadsheets are in good agreement.

2.1.4 Risk Results with Water Shielding

Table 2.14 compares the cancer risks calculated by the RESRAD-BUILD code and by the spreadsheets. The spreadsheet results were the multiplication products of the RESRAD-BUILD dose results and the radionuclide-specific dose-to-risk conversion factors presented in Table 2.10. The two sets of calculation results agree with each other.

Table 2.6 Estimates of External Dose from a Point Source at (0, 0, 0) at the Receptor Location (1, 1, 1) (m) without Shielding

Indoor Time Fraction =	0.5											
1 MeV of energy =	1.60E-06	ergs										
100 erg of energy absorbed in 1 g of medium = 1 rad dose												
Total energy in 1 year for 1 MeV photon emitted by 1 Bq of activity =	50.49216	erg										
Total energy in 1 year for 1 Mev photon emitted by 1 pCi of activity =	1.86821	erg										
Yearly dose for the energy absorption in one gram of medium, imparted by 1 MeV photons emitted by 1 pCi of activity =									0.0186821	rad/yr per pCi		
4 π area associated with the distance between source and receptor	3.77E+05	cm^2										

Nuclide	Half-life (yr)	Average Source Activity in 1st Year (pCi)	# photons	Energy (MeV)	Yield	FE	Absorbed-to-Effective Dose Conversion Factor (Sv/Gy)	Energy Absorption Coefficient in Air (cm^2/g)	Mass Attenuation Coefficient for Air (cm^{-1})	Distance in Mean Free Path in Air	Estimated Buildup Factor in Air	Estimated Attenuation Factor with Air	Calculated External Dose (mrem/yr)
C-14	5.73E+03	1.00E+00	1	0.049	8.65E-04	0.1	0.665	4.30E-02	2.59E-04	4.48E-02	1.07E+00	9.56E-01	3.06E-11
Mn-54	8.56E-01	6.85E-01	1	0.835	1	0.825	0.833	2.87E-02	8.48E-05	1.47E-02	1.01E+00	9.85E-01	3.36E-07
CO-60	5.27E+00	9.37E-01	1	1.25286	2	0.49428	0.848	2.66E-02	7.03E-05	1.22E-02	1.01E+00	9.88E-01	1.30E-06
Nb-94	2.03E+04	1.00E+00	1	0.787	2	0.065	0.831	2.89E-02	8.71E-05	1.51E-02	1.01E+00	9.85E-01	9.29E-07
Tc-99	2.13E+05	1.00E+00	1	0.101	1.77E-03	0.98	0.961	2.32E-02	1.88E-04	3.25E-02	1.04E+00	9.68E-01	9.99E-11

Table 2.7 Estimates of External Dose from a Point Source at (0, 0, 0) at the Receptor Location (0, 0, 4) (m) without Shielding

Indoor Time Fraction =	0.5											
1 MeV of energy =	1.60E-06	ergs										
100 erg of energy absorbed in 1 g of medium = 1 rad dose												
Total energy in 1 year for 1 MeV photons emitted by 1 Bq of activity =					50.49216	erg						
Total energy in 1 year for 1 Mev photons emitted by 1 pCi of activity					1.86821	erg						
Yearly dose for the energy absorption in one gram of medium, imparted by 1 MeV photons emitted by 1 pCi of activity =									0.0186821	rad/yr per pCi		
4 π area associated with the distance between source and receptor					2.01E+06	cm^2						

Nuclide	Half-life (yr)	Average Source Activity in 1st Year (pCi)	# photons	Energy (MeV)	Yield	FE	Absorbed-to-Effective Dose Conversion Factor (Sv/Gy)	Mass Energy Absorption Coefficient in Air (cm^2/g)	Mass Attenuation Coefficient for Air (cm^{-1})	Distance in Mean Free Path in Air	Estimated Buildup Factor in Air	Estimated Attenuation Factor with Air	Calculated External Dose (mrem/yr)
C-14	5.73E+03	1.00E+00	1	0.049	8.65E-04	0.1	0.665	4.30E-02	2.59E-04	1.03E-01	1.15E+00	9.02E-01	5.83E-12
Mn-54	8.56E-01	6.85E-01	1	0.835	1	0.825	0.833	2.87E-02	8.48E-05	3.39E-02	1.02E+00	9.67E-01	6.24E-08
CO-60	5.27E+00	9.37E-01	1	1.25286	2	0.49428	0.848	2.66E-02	7.03E-05	2.81E-02	1.01E+00	9.72E-01	2.42E-07
Nb-94	2.03E+04	1.00E+00	1	0.787	2	0.065	0.831	2.89E-02	8.71E-05	3.48E-02	1.02E+00	9.66E-01	1.72E-07
Tc-99	2.13E+05	1.00E+00	1	0.101	1.77E-03	0.98	0.961	2.32E-02	1.88E-04	7.50E-02	1.10E+00	9.28E-01	1.89E-11

Table 2.8 Estimates of External Dose from a Point Source at (0, 0, 0) at the Receptor Location (0, 0, 0.3) (m) without Shielding

Indoor Time Fraction =	0.5											
1 MeV of energy =	1.60E-06	ergs										
100 erg of energy absorbed in 1 g of medium = 1 rad dose												
Total energy in 1 year for 1 MeV photons emitted by 1 Bq of activity =					50.49216	erg						
Total energy in 1 year for 1 Mev photons emitted by 1 pCi of activity					1.86821	erg						
Yearly dose for the energy absorption in one gram of medium, imparted by 1 MeV photons emitted by 1 pCi of activity =									0.0186821	rad/yr per pCi		
4 π area associated with the distance between source and receptor					1.13E+04	cm^2						

Nuclide	Half-life (yr)	Average Source Activity in 1st Year (pCi)	# photons	Energy (MeV)	Yield	FE	Absorbed-to-Effective Dose Conversion Factor (Sv/Gy)	Mass Energy Absorption Coefficient in Air (cm^2/g)	Mass Attenuation Coefficient for Air (cm^{-1})	Distance in Mean Free Path in Air	Estimated Buildup Factor in Air	Estimated Attenuation Factor with Air	Calculated External Dose (mrem/yr)
C-14	5.73E+03	1.00E+00	1	0.049	8.65E-04	0.1	0.665	4.30E-02	2.59E-04	7.76E-03	1.01E+00	9.92E-01	1.00E-09
Mn-54	8.56E-01	6.85E-01	1	0.835	1	0.825	0.833	2.87E-02	8.48E-05	2.54E-03	1.00E+00	9.97E-01	1.13E-05
CO-60	5.27E+00	9.37E-01	1	1.25286	2	0.49428	0.848	2.66E-02	7.03E-05	2.11E-03	1.00E+00	9.98E-01	4.36E-05
Nb-94	2.03E+04	1.00E+00	1	0.787	2	0.065	0.831	2.89E-02	8.71E-05	2.61E-03	1.00E+00	9.97E-01	3.11E-05
Tc-99	2.13E+05	1.00E+00	1	0.101	1.77E-03	0.98	0.961	2.32E-02	1.88E-04	5.63E-03	1.01E+00	9.94E-01	3.30E-09

Table 2.9 Comparison of Estimates of External Dose (mrem/yr) from a Point Source at Different Receptor Locations without Shielding

Nuclide	RESRAD-BUILD Code Version 4 Results			Spreadsheet Results			Ratio (RESRAD-BUILD/Spreadsheet)		
	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)
C-14	1.01E-09	3.17E-11	6.41E-12	1.00E-09	3.06E-11	5.83E-12	1.01	1.04	1.10
Mn-54	1.13E-05	3.36E-07	6.28E-08	1.13E-05	3.36E-07	6.24E-08	1.00	1.00	1.01
CO-60	4.36E-05	1.31E-06	2.44E-07	4.36E-05	1.30E-06	2.42E-07	1.00	1.00	1.01
Nb-94	3.10E-05	9.28E-07	1.73E-07	3.11E-05	9.29E-07	1.72E-07	1.00	1.00	1.00
Tc-99	3.31E-09	1.01E-10	1.97E-11	3.30E-09	9.99E-11	1.89E-11	1.00	1.01	1.04

Table 2.10 Calculation of Radionuclide-Specific Dose-to-Risk Conversion Factors

Nuclides	External DCF (mrem/yr per	External SF (Risk/yr per	Ratio (Risk/Dose)
C-14	1.34E-05	7.83E-12	5.84E-07
Mn-54	5.16E+00	3.89E-06	7.54E-07
Co-60	16.2	1.24E-05	7.65E-07
Nb-94	9.68	7.29E-06	7.53E-07
Tc-99	1.26E-04	8.14E-11	6.46E-07

Table 2.11 Comparison of Estimates of External Radiation Cancer Risks (1/yr) from a Point Source at Different Receptor Locations without Shielding

Nuclide	RESRAD-BUILD Code Version 4 Results			Spreadsheet Results			Ratio (RESRAD-BUILD/Spreadsheet)		
	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)
C-14	5.85E-16	1.85E-17	3.73E-18	5.90E-16	1.85E-17	3.75E-18	0.99	1.00	1.00
Mn-54	8.49E-12	2.54E-13	4.74E-14	8.52E-12	2.53E-13	4.73E-14	1.00	1.00	1.00
CO-60	3.34E-11	9.99E-13	1.87E-13	3.34E-11	1.00E-12	1.87E-13	1.00	1.00	1.00
Nb-94	2.34E-11	6.99E-13	1.31E-13	2.33E-11	6.99E-13	1.30E-13	1.00	1.00	1.01
Tc-99	2.15E-15	6.56E-17	1.28E-17	2.14E-15	6.52E-17	1.27E-17	1.01	1.01	1.01

Table 2.12 Estimates of Attenuation (Shielding) Factor and Buildup Factor at the Receptor Location (1, 1, 1) (m) with Water Shielding

Nuclide	# photons	Energy (MeV)	Yield	FE	Mass Attenuation Coefficient (cm^{-1})		Distance in Mean Free Path				Estimated Buildup Factor			Estimated Attenuation Factor		
					Air	Water	In Air [Between (0, 0, 0) to (1, 1, 1) (m)]	In Water of 1 cm Thickness	In Water of 5 cm Thickness	In Water of 50 cm Thickness	In Water of 1 cm	In Water of 5 cm	In Water of 50 cm	With Water of 1 cm	With Water of 5 cm	With Water of 50 cm
C-14	1	0.049	8.65E-04	0.1	2.59E-04	2.31E-01	4.48E-02	2.31E-01	1.16E+00	1.16E+01	1.77E+00	5.04E+00	1.12E+02	7.94E-01	3.15E-01	9.62E-06
Mn-54	1	0.835	1	0.825	8.48E-05	7.73E-02	1.47E-02	7.73E-02	3.86E-01	3.86E+00	1.09E+00	1.45E+00	8.41E+00	9.26E-01	6.80E-01	2.10E-02
CO-60	1	1.25	2	0.5	7.04E-05	6.41E-02	1.22E-02	6.41E-02	3.21E-01	3.21E+00	1.06E+00	1.32E+00	5.34E+00	9.38E-01	7.26E-01	4.05E-02
Nb-94	1	0.787	2	0.065	8.71E-05	7.94E-02	1.51E-02	7.94E-02	3.97E-01	3.97E+00	1.09E+00	1.47E+00	9.05E+00	9.24E-01	6.72E-01	1.89E-02
Tc-99	1	0.101	1.77E-03	0.98	1.88E-04	1.70E-01	3.25E-02	1.70E-01	8.51E-01	8.51E+00	1.60E+00	3.90E+00	2.21E+02	8.43E-01	4.27E-01	2.00E-04

Table 2.13 Comparison of Estimates of External Radiation Dose (mrem/yr) from a Point Source at the Receptor Location (1, 1, 1) (m) with Water Shielding of Different Thicknesses

Nuclide	Spreadsheet Results (Without Shielding)	RESRAD-BUILD Results with Water Shielding			Spreadsheet Results with Water Shielding			Ratio (RESRAD-BUILD/Spreadsheet)		
		1 cm	5 cm	50 cm	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	3.06E-11	4.04E-11	4.72E-11	3.36E-14	4.29E-11	4.85E-11	3.30E-14	0.94	0.97	1.02
Mn-54	3.36E-07	3.32E-07	3.18E-07	5.79E-08	3.39E-07	3.30E-07	5.93E-08	0.98	0.96	0.98
CO-60	1.30E-06	1.29E-06	1.22E-06	2.77E-07	1.30E-06	1.25E-06	2.82E-07	0.99	0.98	0.98
Nb-94	9.29E-07	9.18E-07	8.81E-07	1.55E-07	9.38E-07	9.17E-07	1.59E-07	0.98	0.96	0.98
Tc-99	9.99E-11	1.18E-10	1.66E-10	4.24E-12	1.35E-10	1.66E-10	4.42E-12	0.87	1.00	0.96

Table 2.14 Comparison of Estimates of External Radiation Cancer Risks (1/yr) from a Point Source at the Receptor Location (1, 1, 1) (m) with Water Shielding of Different Thicknesses

	RESRAD-BUILD Results with Water Shielding			Spreadsheet Results with Water Shielding			Ratio (RESRAD-BUILD/Spreadsheet)		
Nuclide	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	2.35E-17	2.75E-17	1.96E-20	2.36E-17	2.76E-17	1.96E-20	1.00	1.00	1.00
Mn-54	2.51E-13	2.40E-13	4.37E-14	2.50E-13	2.40E-13	4.36E-14	1.00	1.00	1.00
CO-60	9.85E-13	9.32E-13	2.11E-13	9.87E-13	9.34E-13	2.12E-13	1.00	1.00	1.00
Nb-94	6.91E-13	6.64E-13	1.17E-13	6.91E-13	6.63E-13	1.17E-13	1.00	1.00	1.00
Tc-99	7.64E-17	1.08E-16	2.75E-18	7.62E-17	1.07E-16	2.74E-18	1.00	1.01	1.00

2.1.5 Dose Results with Concrete Shielding

Table 2.15 shows the estimation of the attenuation factor and buildup factor when there is shielding of concrete with a thickness of 1 cm, 5 cm, and 50 cm between the source and the receptor at (1 m, 1 m, 1 m).

Table 2.16 compares the dose estimates between the spreadsheets and the RESRAD-BUILD code. Except for the dose results with a shielding thickness of 50 cm for C-14 that show a difference of almost 500%, the other dose results of RESRAD-BUILD and the spreadsheets show good agreement. The difference of almost 500% in the C-14 results are ignored because of the extremely small magnitude of both dose estimates, which are essentially zero.

2.1.6 Risk Results with Concrete Shielding

Table 2.17 compares the cancer risks calculated by the RESRAD-BUILD code and by the spreadsheets. The spreadsheet results were the multiplication products of the RESRAD-BUILD dose results and the radionuclide-specific dose-to-risk conversion factors presented in Table 1.10. The two sets of calculation results agree with each other.

2.2 EXTERNAL RADIATION OF LINE SOURCES

To verify the RESRAD-BUILD results of external radiation modeling for line sources, a line source of 1 m located at (0, 0, 0) with a total radioactivity of 1 pCi was considered. The same receptors, at (1 m, 1 m, 1 m), (0 m, 0 m, 0.3 m), and (0 m, 0 m, 4 m), as considered in the verification of point source modeling, were selected for estimating radiation doses and cancer risks. The receptors were assumed to spend 50% of the time in a year inside the building. There was no release of contamination from the line source and no erosion of source materials. Radiation doses and cancer risks were estimated for C-14, Mn-54, Co-60, Nb-94, and Tc-99. The comparison of results between RESRAD-BUILD and the spreadsheets focused on the exposures incurred during the 1^{st} year.

In the spreadsheets designed for this verification, the 1-m line source was evenly divided into 20 segments, and each segment was modeled as a point source. The radiation dose and cancer risk incurred by a receptor from the line source was the sum of doses and risks from each segment. External radiation dose and cancer risk without shielding materials to attenuate the radiation were estimated for each receptor. External radiation dose and cancer risk with water as shielding material of 1 cm, 5 cm, and 50 cm effective thickness were estimated for the receptor at (1 m, 1 m, 1 m). For the same receptor, radiation dose and cancer risk attenuated by concrete of 1 m, 5 cm, and 50 cm effective thickness were also estimated.

Table 2.15 Estimates of Attenuation (Shielding) Factor and Buildup Factor at the Receptor Location (1, 1, 1) (m) with Concrete Shielding

Nuclide	# photons	Energy (MeV)	Yield	FE	Mass Attenuation Coefficient (cm^{-1})		Distance in Mean Free Path				Estimated Buildup Factor			Estimated Attenuation Factor		
					Air	Concrete	In Air [Between (0, 0, 0) to (1, 1, 1) (m)]	In Concrete of 1 cm Thickness	In Concrete of 5 cm Thickness	In Concrete of 50 cm Thickness	In Concrete of 1 cm	In Concrete of 5 cm	In Concrete of 50 cm	With Concrete of 1 cm	With Concrete of 5 cm	With Concrete of 50 cm
C-14	1	0.049	8.65E-04	0.1	2.59E-04	9.99E-01	4.48E-02	9.99E-01	4.99E+00	4.99E+01	1.71E+00	3.14E+00	8.90E+00	3.68E-01	6.78E-03	2.04E-22
Mn-54	1	0.835	1	0.825	8.48E-05	1.67E-01	1.47E-02	1.67E-01	8.37E-01	8.37E+00	1.18E+00	1.86E+00	1.88E+01	8.46E-01	4.33E-01	2.31E-04
CO-60	1	1.25	2	0.5	7.04E-05	1.39E-01	1.22E-02	1.39E-01	6.95E-01	6.95E+00	1.13E+00	1.61E+00	1.10E+01	8.70E-01	4.99E-01	9.61E-04
Nb-94	1	0.787	2	0.065	8.71E-05	1.72E-01	1.51E-02	1.72E-01	8.60E-01	8.60E+00	1.18E+00	1.90E+00	2.05E+01	8.42E-01	4.23E-01	1.84E-04
Tc-99	1	0.101	1.77E-03	0.98	1.88E-04	4.26E-01	3.25E-02	4.26E-01	2.13E+00	2.13E+01	1.76E+00	4.90E+00	7.61E+01	6.53E-01	1.19E-01	5.55E-10

Table 2.16 Comparison of Estimates of External Radiation Dose (mrem/yr) from a Point Source at the Receptor Location (1, 1, 1) (m) with Concrete Shielding of Different Thicknesses

Nuclide	Spreadsheet Calculated Dose (No Shield)	RESRAD-BUILD Code Version 4 Results with Concrete Shielding			Spreadsheet Results with Concrete Shielding			Ratio (Code/Spreadsheet)		
		1 cm	5 cm	50 cm	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	3.06E-11	1.87E-11	7.13E-13	2.77E-31	1.93E-11	6.50E-13	5.56E-32	0.97	1.10	4.98
Mn-54	3.36E-07	3.26E-07	2.70E-07	1.46E-09	3.34E-07	2.70E-07	1.46E-09	0.98	1.00	1.00
CO-60	1.30E-06	1.26E-06	1.05E-06	1.39E-08	1.28E-06	1.05E-06	1.38E-08	0.98	1.00	1.00
Nb-94	9.29E-07	9.01E-07	7.46E-07	3.57E-09	9.26E-07	7.48E-07	3.50E-09	0.97	1.00	1.02
Tc-99	9.99E-11	1.12E-10	5.66E-11	3.96E-18	1.15E-10	5.81E-11	4.22E-18	0.98	0.97	0.94

Table 2.17 Comparison of Estimates of External Radiation Cancer Risk (1/yr) from a Point Source at the Receptor Location (1, 1, 1) (m) with Concrete Shielding of Different Thicknesses

	RESRAD-BUILD Results with Concrete Shielding			Spreadsheet Results with Concrete Shielding			Ratio (RESRAD-BUILD/Spreadsheet)		
Nuclide	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	1.09E-17	4.15E-19	1.61E-37	1.09E-17	4.17E-19	1.62E-37	1.00	1.00	0.99
Mn-54	2.46E-13	2.04E-13	1.10E-15	2.46E-13	2.04E-13	1.10E-15	1.00	1.00	1.00
CO-60	9.63E-13	8.01E-13	1.06E-14	9.64E-13	8.04E-13	1.06E-14	1.00	1.00	1.00
Nb-94	6.79E-13	5.62E-13	2.69E-15	6.79E-13	5.62E-13	2.69E-15	1.00	1.00	1.00
Tc-99	7.29E-17	3.67E-17	2.57E-24	7.24E-17	3.66E-17	2.56E-24	1.01	1.00	1.00

2.2.1 Dose Results without Shielding

Table 2.18 shows the calculations of distance between the receptor at (1 m, 1 m, 1 m) and the center of each segment of the line source, the 4π area corresponding to the distance, and the geometrical factor for each line segment (G_L) [see Equation C.13 in the RESRAD-BUILD User's Manual (Yu et al., 2022)]. Table 2.19 shows the estimations of the external radiation dose incurred by the receptor when there was no shielding between the line source and the receptor. Likewise, Tables 2.20 and 2.21 show the same calculations/estimations as Tables 2.18 and 2.19, respectively, for the receptor at (0 m, 0 m, 0.3 m), and Tables 2.22 and 2.23 show the same calculations/estimations as Tables 2.18 and 2.19, respectively, for the receptor at (0 m, 0 m, 4 m).

Table 2.24 compares the dose estimates between the spreadsheets and the RESRAD-BUILD code. The comparison shows good agreement in the dose estimates.

2.2.2 Risk Results without Shielding

Table 2.25 compares the cancer risks calculated by the RESRAD-BUILD code and by the spreadsheets. The spreadsheet results were the multiplication products of the RESRAD-BUILD dose results and the radionuclide-specific dose-to-risk conversion factors presented in Table 2.10. The two sets of calculation results agree with each other.

2.2.3 Dose Results with Water Shielding

The estimations of buildup and attenuation factors when there is shielding of water with a thickness of 1 cm, 5 cm, and 50 cm between the source and the receptor at (1 m, 1 m, 1 m) are presented in Table 2.12.

Table 2.26 compares the dose estimates between the spreadsheets and the RESRAD-BUILD code. Except for the dose results with a shielding thickness of 1 cm for Tc-99 that show a difference of 13%, the other dose results of RESRAD-BUILD and the spreadsheets are in good agreement.

2.2.4 Risk Results with Water Shielding

Table 2.27 compares the cancer risks calculated by the RESRAD-BUILD code and by the spreadsheets. The spreadsheet results were the multiplication products of the RESRAD-BUILD dose results and the radionuclide-specific dose-to-risk conversion factors presented in Table 2.10. The two sets of calculation results agree with each other.

Table 2.18 Calculations of Distance, 4π Area, and Geometrical Factor at the Receptor Location (1, 1, 1) (m)

No. of line segment	Coordinate of line segment center, cm			Coordinate of receptor location, cm			Distance (cm)	4π Area based on Distance (cm^2)	G_L ($1/cm^2$)				
	x	y	z	x	y	z			C-14	Mn-54	Co-60	Nb-94	Tc-99
1	0	2.5	0	100	100	100	1.72E+02	3.71E+05	2.58E-06	2.66E-06	2.66E-06	2.66E-06	2.61E-06
2	0	7.5	0	100	100	100	1.69E+02	3.59E+05	2.67E-06	2.75E-06	2.75E-06	2.74E-06	2.70E-06
3	0	12.5	0	100	100	100	1.66E+02	3.48E+05	2.76E-06	2.84E-06	2.84E-06	2.83E-06	2.79E-06
4	0	17.5	0	100	100	100	1.64E+02	3.37E+05	2.84E-06	2.93E-06	2.93E-06	2.93E-06	2.88E-06
5	0	22.5	0	100	100	100	1.61E+02	3.27E+05	2.93E-06	3.02E-06	3.02E-06	3.02E-06	2.97E-06
6	0	27.5	0	100	100	100	1.59E+02	3.18E+05	3.02E-06	3.11E-06	3.11E-06	3.11E-06	3.06E-06
7	0	32.5	0	100	100	100	1.57E+02	3.09E+05	3.11E-06	3.20E-06	3.20E-06	3.20E-06	3.15E-06
8	0	37.5	0	100	100	100	1.55E+02	3.01E+05	3.20E-06	3.28E-06	3.29E-06	3.28E-06	3.23E-06
9	0	42.5	0	100	100	100	1.53E+02	2.93E+05	3.28E-06	3.37E-06	3.38E-06	3.37E-06	3.32E-06
10	0	47.5	0	100	100	100	1.51E+02	2.86E+05	3.36E-06	3.45E-06	3.46E-06	3.45E-06	3.40E-06
11	0	-2.5	0	100	100	100	1.75E+02	3.84E+05	2.49E-06	2.57E-06	2.58E-06	2.57E-06	2.52E-06
12	0	-7.5	0	100	100	100	1.78E+02	3.97E+05	2.41E-06	2.48E-06	2.49E-06	2.48E-06	2.44E-06
13	0	-12.5	0	100	100	100	1.81E+02	4.11E+05	2.32E-06	2.40E-06	2.41E-06	2.40E-06	2.35E-06
14	0	-17.5	0	100	100	100	1.84E+02	4.25E+05	2.24E-06	2.32E-06	2.32E-06	2.32E-06	2.27E-06
15	0	-22.5	0	100	100	100	1.87E+02	4.40E+05	2.16E-06	2.24E-06	2.24E-06	2.24E-06	2.19E-06
16	0	-27.5	0	100	100	100	1.90E+02	4.56E+05	2.09E-06	2.16E-06	2.16E-06	2.16E-06	2.12E-06
17	0	-32.5	0	100	100	100	1.94E+02	4.72E+05	2.01E-06	2.08E-06	2.09E-06	2.08E-06	2.04E-06
18	0	-37.5	0	100	100	100	1.97E+02	4.89E+05	1.94E-06	2.01E-06	2.02E-06	2.01E-06	1.97E-06
19	0	-42.5	0	100	100	100	2.01E+02	5.07E+05	1.87E-06	1.94E-06	1.95E-06	1.94E-06	1.90E-06
20	0	-47.5	0	100	100	100	2.04E+02	5.25E+05	1.81E-06	1.87E-06	1.88E-06	1.87E-06	1.83E-06
Average								3.88E+05	2.56E-06	2.63E-06	2.64E-06	2.63E-06	2.59E-06

Table 2.19 Estimates of External Radiation Dose from a Line Source at (0, 0, 0) at the Receptor Location (1, 1, 1) (m) without Shielding

Indoor Time Fraction =	0.5												
1 MeV of energy =	1.60E-06	ergs											
100 erg of energy absorbed in 1 g of medium = 1 rad dose													
Total energy in 1 year for 1 MeV photon emitted by 1 Bq of activity =					50.49216	erg							
Total energy in 1 year for 1 Mev photon emitted by 1 pCi of activity =					1.86820992	erg							
Yearly dose for the energy absorption in one gram of medium, imparted by 1 MeV photons emitted by 1 pCi of activity =										0.0186821	rad/yr per pCi		

Nuclide	Half-life (yr)	Average Source Activity in 1st Year (pCi)	# photons	Energy (MeV)	Yield	FE	Absorbed-to-Effective Dose Conversion Factor (Sv/Gy)	Mass Energy Absorption Coefficient in Air (cm^2/g)	Distance in Mean Free Path in Air	Estimated Buildup Factor in Air	Mass Attenuation Coeff for Air (cm^{-1})	Ratio of Attenuation Factor/ 4π Area for Air ($1/cm^2$)	Calculated External Dose (mrem/yr)
C-14	5.73E+03	1.00E+00	1	0.049	8.65E-04	0.1	0.665	4.30E-02	4.48E-02	1.07E+00	2.59E-04	2.56E-06	3.08E-11
Mn-54	8.56E-01	6.85E-01	1	0.835	1	0.825	0.833	2.87E-02	1.47E-02	1.01E+00	8.48E-05	2.63E-06	3.38E-07
CO-60	5.27E+00	9.37E-01	1	1.25286	2	0.49428	0.848	2.66E-02	1.22E-02	1.01E+00	7.04E-05	2.64E-06	1.31E-06
Nb-94	2.03E+04	1.00E+00	1	0.787	2	0.065	0.831	2.89E-02	1.51E-02	1.01E+00	8.71E-05	2.63E-06	9.36E-07
Tc-99	2.13E+05	1.00E+00	1	0.101	1.77E-03	0.98	0.961	2.32E-02	3.25E-02	1.04E+00	1.88E-04	2.59E-06	1.01E-10

Table 2.20 Calculations of Distance, 4π Area, and Geometrical Factor at the Receptor Location (0, 0, 0.3) (m)

No. of line segment	Coordinate of line segment center, cm			Coordinate of receptor location, cm			Distance (cm)	based on Distance	G_L (1/cm^2)				
	x	y	z	x	y	z			C-14	Mn-54	Co-60	Nb-94	Tc-99
1	0	2.5	0	0	0	30	3.01E+01	1.14E+04	8.71E-05	8.76E-05	8.76E-05	8.75E-05	8.73E-05
2	0	7.5	0	0	0	30	3.09E+01	1.20E+04	8.25E-05	8.30E-05	8.30E-05	8.30E-05	8.27E-05
3	0	12.5	0	0	0	30	3.25E+01	1.33E+04	7.47E-05	7.51E-05	7.51E-05	7.51E-05	7.49E-05
4	0	17.5	0	0	0	30	3.47E+01	1.52E+04	6.54E-05	6.58E-05	6.58E-05	6.57E-05	6.55E-05
5	0	22.5	0	0	0	30	3.75E+01	1.77E+04	5.60E-05	5.64E-05	5.64E-05	5.64E-05	5.62E-05
6	0	27.5	0	0	0	30	4.07E+01	2.08E+04	4.75E-05	4.79E-05	4.79E-05	4.79E-05	4.77E-05
7	0	32.5	0	0	0	30	4.42E+01	2.46E+04	4.02E-05	4.05E-05	4.05E-05	4.05E-05	4.03E-05
8	0	37.5	0	0	0	30	4.80E+01	2.90E+04	3.41E-05	3.44E-05	3.44E-05	3.43E-05	3.42E-05
9	0	42.5	0	0	0	30	5.20E+01	3.40E+04	2.90E-05	2.93E-05	2.93E-05	2.93E-05	2.91E-05
10	0	47.5	0	0	0	30	5.62E+01	3.97E+04	2.48E-05	2.51E-05	2.51E-05	2.51E-05	2.49E-05
11	0	-2.5	0	0	0	30	3.01E+01	1.14E+04	8.71E-05	8.76E-05	8.76E-05	8.75E-05	8.73E-05
12	0	-7.5	0	0	0	30	3.09E+01	1.20E+04	8.25E-05	8.30E-05	8.30E-05	8.30E-05	8.27E-05
13	0	-12.5	0	0	0	30	3.25E+01	1.33E+04	7.47E-05	7.51E-05	7.51E-05	7.51E-05	7.49E-05
14	0	-17.5	0	0	0	30	3.47E+01	1.52E+04	6.54E-05	6.58E-05	6.58E-05	6.57E-05	6.55E-05
15	0	-22.5	0	0	0	30	3.75E+01	1.77E+04	5.60E-05	5.64E-05	5.64E-05	5.64E-05	5.62E-05
16	0	-27.5	0	0	0	30	4.07E+01	2.08E+04	4.75E-05	4.79E-05	4.79E-05	4.79E-05	4.77E-05
17	0	-32.5	0	0	0	30	4.42E+01	2.46E+04	4.02E-05	4.05E-05	4.05E-05	4.05E-05	4.03E-05
18	0	-37.5	0	0	0	30	4.80E+01	2.90E+04	3.41E-05	3.44E-05	3.44E-05	3.43E-05	3.42E-05
19	0	-42.5	0	0	0	30	5.20E+01	3.40E+04	2.90E-05	2.93E-05	2.93E-05	2.93E-05	2.91E-05
20	0	-47.5	0	0	0	30	5.62E+01	3.97E+04	2.48E-05	2.51E-05	2.51E-05	2.51E-05	2.49E-05
Average								2.18E+04	5.41E-05	5.45E-05	5.45E-05	5.45E-05	5.43E-05

Table 2.21 Estimates of External Dose from a Line Source at (0, 0, 0) at the Receptor Location (0, 0, 0.3) (m) without Shielding

Indoor Time Fraction =	0.5												
1 MeV of energy =	1.60E-06	ergs											
100 erg of energy absorbed in 1 g of medium = 1 rad dose													
Total energy in 1 year for 1 MeV photon emitted by 1 Bq of activity =					50.49216	erg							
Total energy in 1 year for 1 Mev photon emitted by 1 pCi of activity =					1.86820992	erg							
Yearly dose for the energy absorption in one gram of medium, imparted by 1 MeV photons emitted by 1 pCi of activity =										0.0186821	rad/yr per pCi		

Nuclide	Half-life (yr)	Average Source Activity in 1st Year (pCi)	# photons	Energy (MeV)	Yield	FE	Absorbed-to-Effective Dose Conversion Factor (Sv/Gy)	Mass Energy Absorption Coefficient in Air (cm^2/g)	Distance in Mean Free Path in Air	Estimated Buildup Factor in Air	Mass Attenuation Coeff for Air (cm^{-1})	Ratio of Attenuation Factor/ 4π Area in Air ($1/cm^2$)	Calculated External Dose (mrem/yr)
C-14	5.73E+03	1.00E+00	1	0.049	8.65E-04	0.1	0.665	4.30E-02	7.76E-03	1.01E+00	2.59E-04	5.41E-05	6.19E-10
Mn-54	8.56E-01	6.85E-01	1	0.835	1	0.825	0.833	2.87E-02	2.54E-03	1.00E+00	8.48E-05	5.45E-05	6.96E-06
CO-60	5.27E+00	9.37E-01	1	1.25286	2	0.49428	0.848	2.66E-02	2.11E-03	1.00E+00	7.04E-05	5.45E-05	2.70E-05
Nb-94	2.03E+04	1.00E+00	1	0.787	2	0.065	0.831	2.89E-02	2.61E-03	1.00E+00	8.71E-05	5.45E-05	1.92E-05
Tc-99	2.13E+05	1.00E+00	1	0.101	1.77E-03	0.98	0.961	2.32E-02	5.63E-03	1.01E+00	1.88E-04	5.43E-05	2.04E-09

Table 2.22 Calculations of Distance, 4π Area, and Geometrical Factor at the Receptor Location (0, 0, 4) (m)

No. of line segment	Coordinate of line segment center, cm			Coordinate of receptor location, cm			Distance (cm)	based on Distance	G_L (1/cm^2)				
	x	y	z	x	y	z			C-14	Mn-54	Co-60	Nb-94	Tc-99
1	0	2.5	0	0	0	400	4.00E+02	2.01E+06	4.48E-07	4.81E-07	4.83E-07	4.80E-07	4.61E-07
2	0	7.5	0	0	0	400	4.00E+02	2.01E+06	4.48E-07	4.80E-07	4.83E-07	4.80E-07	4.61E-07
3	0	12.5	0	0	0	400	4.00E+02	2.01E+06	4.48E-07	4.80E-07	4.83E-07	4.80E-07	4.61E-07
4	0	17.5	0	0	0	400	4.00E+02	2.02E+06	4.47E-07	4.80E-07	4.82E-07	4.79E-07	4.60E-07
5	0	22.5	0	0	0	400	4.01E+02	2.02E+06	4.47E-07	4.79E-07	4.82E-07	4.79E-07	4.60E-07
6	0	27.5	0	0	0	400	4.01E+02	2.02E+06	4.46E-07	4.78E-07	4.81E-07	4.78E-07	4.59E-07
7	0	32.5	0	0	0	400	4.01E+02	2.02E+06	4.45E-07	4.77E-07	4.80E-07	4.77E-07	4.58E-07
8	0	37.5	0	0	0	400	4.02E+02	2.03E+06	4.44E-07	4.76E-07	4.79E-07	4.76E-07	4.57E-07
9	0	42.5	0	0	0	400	4.02E+02	2.03E+06	4.43E-07	4.75E-07	4.78E-07	4.75E-07	4.56E-07
10	0	47.5	0	0	0	400	4.03E+02	2.04E+06	4.42E-07	4.74E-07	4.77E-07	4.73E-07	4.55E-07
11	0	-2.5	0	0	0	400	4.00E+02	2.01E+06	4.48E-07	4.81E-07	4.83E-07	4.80E-07	4.61E-07
12	0	-7.5	0	0	0	400	4.00E+02	2.01E+06	4.48E-07	4.80E-07	4.83E-07	4.80E-07	4.61E-07
13	0	-12.5	0	0	0	400	4.00E+02	2.01E+06	4.48E-07	4.80E-07	4.83E-07	4.80E-07	4.61E-07
14	0	-17.5	0	0	0	400	4.00E+02	2.02E+06	4.47E-07	4.80E-07	4.82E-07	4.79E-07	4.60E-07
15	0	-22.5	0	0	0	400	4.01E+02	2.02E+06	4.47E-07	4.79E-07	4.82E-07	4.79E-07	4.60E-07
16	0	-27.5	0	0	0	400	4.01E+02	2.02E+06	4.46E-07	4.78E-07	4.81E-07	4.78E-07	4.59E-07
17	0	-32.5	0	0	0	400	4.01E+02	2.02E+06	4.45E-07	4.77E-07	4.80E-07	4.77E-07	4.58E-07
18	0	-37.5	0	0	0	400	4.02E+02	2.03E+06	4.44E-07	4.76E-07	4.79E-07	4.76E-07	4.57E-07
19	0	-42.5	0	0	0	400	4.02E+02	2.03E+06	4.43E-07	4.75E-07	4.78E-07	4.75E-07	4.56E-07
20	0	-47.5	0	0	0	400	4.03E+02	2.04E+06	4.42E-07	4.74E-07	4.77E-07	4.73E-07	4.55E-07
Average								2.02E+06	4.46E-07	4.78E-07	4.81E-07	4.78E-07	4.59E-07

Table 2.23 Estimates of External Dose from a Line Source at (0, 0, 0) at the Receptor Location (0, 0, 4) (m) without Shielding

Indoor Time Fraction =	0.5												
1 MeV of energy =	1.60E-06	ergs											
100 erg of energy absorbed in 1 g of medium = 1 rad dose													
Total energy in 1 year for 1 MeV photon emitted by 1 Bq of activity =					50.49216	erg							
Total energy in 1 year for 1 Mev photon emitted by 1 pCi of activity =					1.86820992	erg							
Yearly dose for the energy absorption in one gram of medium, imprated by 1 MeV photons emitted by 1 pCi of activity =										0.0186821	rad/yr per pCi		

Nuclide	Half-life (yr)	Average Source Activity in 1st Year (pCi)	# photons	Energy (MeV)	Yield	FE	Absorbed-to-Effective Dose Conversion Factor (Sv/Gy)	Mass Energy Absorption Coefficient in Air (cm^2/g)	Distance in Mean Free Path in Air	Estimated Buildup Factor in Air	Mass Attenuation Coeff for Air (cm^{-1})	Ratio of Attenuation Factor/ 4π Area in Air ($1/cm^2$)	Calculated External Dose (mrem/yr)
C-14	5.73E+03	1.00E+00	1	0.049	8.65E-04	0.1	0.665	4.30E-02	1.03E-01	1.15E+00	2.59E-04	4.46E-07	5.80E-12
Mn-54	8.56E-01	6.85E-01	1	0.835	1	0.825	0.833	2.87E-02	3.39E-02	1.02E+00	8.48E-05	4.78E-07	6.20E-08
CO-60	5.27E+00	9.37E-01	1	1.25286	2	0.49428	0.848	2.66E-02	2.81E-02	1.01E+00	7.04E-05	4.81E-07	2.41E-07
Nb-94	2.03E+04	1.00E+00	1	0.787	2	0.065	0.831	2.89E-02	3.48E-02	1.02E+00	8.71E-05	4.78E-07	1.72E-07
Tc-99	2.13E+05	1.00E+00	1	0.101	1.77E-03	0.98	0.961	2.32E-02	7.50E-02	1.10E+00	1.88E-04	4.59E-07	1.88E-11

Table 2.24 Comparison of Estimates of External Radiation Dose (mrem/yr) from a Line Source at Different Receptor Locations without Shielding

	RESRAD-BUILD Code Version 4 Results			Spreadsheet Results			Ratio (RESRAD-BUILD/Spreadsheet)		
Nuclide	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)
C-14	6.20E-10	3.20E-11	6.38E-12	6.19E-10	3.08E-11	5.80E-12	1.00	1.04	1.10
Mn-54	6.95E-06	3.39E-07	6.25E-08	6.96E-06	3.38E-07	6.20E-08	1.00	1.00	1.01
CO-60	2.70E-05	1.32E-06	2.43E-07	2.70E-05	1.31E-06	2.41E-07	1.00	1.01	1.01
Nb-94	1.92E-05	9.35E-07	1.73E-07	1.92E-05	9.36E-07	1.72E-07	1.00	1.00	1.01
Tc-99	2.04E-09	1.02E-10	1.96E-11	2.04E-09	1.01E-10	1.88E-11	1.00	1.01	1.04

Table 2.25 Comparison of Estimates of External Radiation Risks (1/yr) from a Line Source at Different Receptor Locations without Shielding

	RESRAD-BUILD Code Version 4 Results			Spreadsheet Results			Ratio (RESRAD-BUILD/Spreadsheet)		
Nuclide	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)	Receptor (0,0,0.3)(m)	Receptor (1,1,1)(m)	Receptor (0,0,4)(m)
C-14	3.61E-16	1.86E-17	3.71E-18	3.62E-16	1.87E-17	3.73E-18	1.00	0.99	1.00
Mn-54	5.24E-12	2.56E-13	4.72E-14	5.24E-12	2.56E-13	4.71E-14	1.00	1.00	1.00
CO-60	2.06E-11	1.01E-12	1.86E-13	2.07E-11	1.01E-12	1.86E-13	1.00	1.00	1.00
Nb-94	1.45E-11	7.04E-13	1.30E-13	1.45E-11	7.04E-13	1.30E-13	1.00	1.00	1.00
Tc-99	1.32E-15	6.61E-17	1.27E-17	1.32E-15	6.59E-17	1.27E-17	1.00	1.00	1.00

Table 2.26 Comparison of Estimates of External Radiation Dose (mrem/yr) from a Line Source at the Receptor Location (1, 1, 1) (m) with Water Shielding of Different Thicknesses

	Spreadsheet Results (Without Shielding)	RESRAD-BUILD Results with Water Shielding			Spreadsheet Results with Water Shielding			Ratio (RESRAD-BUILD/Spreadsheet)		
Nuclide		1 cm	5 cm	50 cm	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	3.08E-11	4.07E-11	4.76E-11	3.39E-14	4.32E-11	4.89E-11	3.33E-14	0.94	0.97	1.02
Mn-54	3.38E-07	3.35E-07	3.20E-07	5.83E-08	3.41E-07	3.33E-07	5.98E-08	0.98	0.96	0.98
CO-60	1.31E-06	1.30E-06	1.23E-06	2.79E-07	1.31E-06	1.26E-06	2.84E-07	0.99	0.98	0.98
Nb-94	9.36E-07	9.25E-07	8.88E-07	1.57E-07	9.45E-07	9.24E-07	1.60E-07	0.98	0.96	0.98
Tc-99	1.01E-10	1.19E-10	1.67E-10	4.27E-12	1.36E-10	1.68E-10	4.46E-12	0.87	1.00	0.96

Table 2.27 Comparison of Estimates of External Radiation Cancer Risks (1/yr) from a Line Source at the Receptor Location (1, 1, 1) (m) with Water Shielding of Different Thicknesses

	RESRAD-BUILD Results with Water Shielding			Spreadsheet Results with Water Shielding			Ratio (RESRAD-BUILD/Spreadsheet)		
Nuclide	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	2.37E-17	2.77E-17	1.97E-20	2.38E-17	2.78E-17	1.98E-20	1.00	1.00	0.99
Mn-54	2.53E-13	2.42E-13	4.40E-14	2.53E-13	2.41E-13	4.40E-14	1.00	1.00	1.00
CO-60	9.93E-13	9.39E-13	2.13E-13	9.95E-13	9.41E-13	2.14E-13	1.00	1.00	1.00
Nb-94	6.97E-13	6.69E-13	1.18E-13	6.97E-13	6.69E-13	1.18E-13	1.00	1.00	1.00
Tc-99	7.69E-17	1.08E-16	2.77E-18	7.69E-17	1.08E-16	2.76E-18	1.00	1.00	1.00

2.2.5 Dose Results with Concrete Shielding

The estimations of buildup and attenuation factors when there is shielding of concrete with a thickness of 1 cm, 5 cm, and 50 cm between the source and the receptor at (1 m, 1 m, 1 m) are presented in Table 2.15.

Table 2.28 compares the dose estimates between the spreadsheets and the RESRAD-BUILD code. Except for the dose results with a shielding thickness of 1 cm for Tc-99 that show a difference of 13%, the other dose results of RESRAD-BUILD and the spreadsheets are in good agreement.

2.2.6 Risk Results with Concrete Shielding

Table 2.29 compares the cancer risks calculated by the RESRAD-BUILD code and by the spreadsheets. The spreadsheet results were the multiplication products of the RESRAD-BUILD dose results and the radionuclide-specific dose-to-risk conversion factors presented in Table 2.10. The two sets of calculation results agree with each other.

2.3 EXTERNAL RADIATION OF AREA SOURCES

In RESRAD-BUILD, an area source is modeled as a volume source with a very small thickness, 0.001 cm. The modeling of external radiation for volume sources is described in Section C.1 of the User's Manual for RESRAD-BUILD Code Version 4.0 Vol. 1 (Yu et al. 2022). The radiation dose and cancer risk incurred by a receptor from a volume source is calculated as the radiation dose and cancer risk from a standard source, a source of contaminated soil that has an infinite depth and infinite lateral extent with no cover, corrected by F_{AM}, the area and material factor described by Equation (C.4), F_{CD}, the cover and depth factor described by Equation (C.3), and $F_{OFF\text{-}SET}$, the offset factor described by Equation (C.9). F_{AM}, the area and material factor, is a function of the buildup factor and attenuation factor.

Table 2.30 lists literature data of the mass attenuation coefficients in air, soil, and concrete and the fluence to the effective dose equivalent conversion factors used in the spreadsheets. The mass attenuation coefficients in air, soil, and concrete were obtained from Trubey 1991, while the fluence to effective dose equivalent conversion factors were obtained from ICRP 51 (ICRP 1987).

Tables 2.31 lists the buildup factors in soil; data from Trubey 1991 were used to estimate buildup factors in soil for C-14, Tc-99, and Mn-54. Buildup factors in air and concrete for C-14, Tc-99, and Mn-54 were presented previously, in Tables 2.3 and 2.5, respectively.

Table 2.28 Comparison of Estimates of External Radiation Dose (mrem/yr) from a Line Source at the Receptor Location (1, 1, 1) (m) with Concrete Shielding of Different Thicknesses

Nuclide	Spreadsheet Results (Without Shielding)	RESRAD-BUILD Results with Concrete Shielding			Spreadsheet Results with Concrete Shielding			Ratio (Code/Spreadsheet)		
		1 cm	5 cm	50 cm	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	3.08E-11	1.89E-11	7.18E-13	2.79E-31	1.94E-11	6.55E-13	5.60E-32	0.97	1.10	4.98
Mn-54	3.38E-07	3.28E-07	2.72E-07	1.47E-09	3.36E-07	2.73E-07	1.47E-09	0.97	1.00	1.00
CO-60	1.31E-06	1.27E-06	1.06E-06	1.40E-08	1.29E-06	1.06E-06	1.39E-08	0.99	1.00	1.01
Nb-94	9.36E-07	9.08E-07	7.52E-07	3.60E-09	9.33E-07	7.54E-07	3.53E-09	0.97	1.00	1.02
Tc-99	1.01E-10	1.13E-10	5.70E-11	3.99E-18	1.16E-10	5.86E-11	4.25E-18	0.98	0.97	0.94

Table 2.29 Comparison of Estimates of External Radiation Cancer Risks from a Line Source at the Receptor Location (1, 1, 1) (m) with Concrete Shielding of Different Thicknesses

Nuclide	RESRAD-BUILD Results with Concrete Shielding			Spreadsheet Results with Concrete Shielding			Ratio (RESRAD-BUILD/Spreadsheet)		
	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	1.10E-17	4.18E-19	1.62E-37	1.10E-17	4.20E-19	1.63E-37	1.00	1.00	0.99
Mn-54	2.48E-13	2.05E-13	1.11E-15	2.47E-13	2.05E-13	1.11E-15	1.00	1.00	1.00
CO-60	9.71E-13	8.07E-13	1.07E-14	9.72E-13	8.11E-13	1.07E-14	1.00	0.99	1.00
Nb-94	6.84E-13	5.66E-13	2.71E-15	6.84E-13	5.66E-13	2.71E-15	1.00	1.00	1.00
Tc-99	7.35E-17	3.70E-17	2.59E-24	7.30E-17	3.68E-17	2.58E-24	1.01	1.00	1.00

Table 2.30 Literature Data of Mass Attenuation Coefficients for Air, Concrete, and Soil and Fluence to Effective Dose Equivalent Conversion Factors

Energy (MeV)	Mass Attenuation Coefficient (cm^2/g)			Fluence to Effective Dose Equivalent Conversion (pSv cm2)
	Air	NBS Concrete	Soil	
0.01	5.123	26.56	20.7	0.029
0.015	1.615	8.297	6.45	0.071
0.02	0.7784	3.651	2.86	0.11
0.03	0.3539	1.214	0.977	0.166
0.04	0.2485	0.6122	0.513	0.199
0.05	0.208	0.3944	0.345	0.222
0.06	0.1875	0.2957	0.268	0.24
0.08	0.1663	0.2125	0.202	0.293
0.1	0.1541	0.1783	0.174	0.357
0.15	0.1356	0.1434	0.143	0.534
0.2	0.1234	0.127	0.128	0.731
0.3	0.1068	0.1082	0.11	1.14
0.4	0.09549	0.09628	0.0977	1.55
0.5	0.08712	0.08768	0.089	1.96
0.6	0.08055	0.08098	0.0822	2.34
0.8	0.07074	0.07103	0.0721	3.07
1	0.06358	0.06382	0.0648	3.75
1.5	0.05175	0.05197	0.0528	5.24
2	0.04447	0.04482	0.0455	6.56
3	0.03581	0.03654	0.0369	8.9
4	0.03079	0.03189	0.0321	11
5	0.02751	0.02895	0.029	13
6	0.02522	0.02696	0.0269	14.9
8	0.02225	0.0245	0.0243	18.9
10	0.02045	0.02311	0.0227	22.9

Table 2.31 Estimates of Buildup Factors in Soil of Different Thicknesses

Thickness	Data of Buildup Factors in Soil								C-14	Tc-99	Mn-54
in Mean Free Path	0.04 MeV	0.05 MeV	0.1 MeV	0.15 MeV	0.5 MeV	0.6 MeV	0.8 MeV	1 MeV	0.049 MeV	0.101 MeV	0.835 MeV
0.5	1.38	1.67	1.99	1.9	1.58	1.54	1.49	1.45	1.64	1.99	1.48
1	1.62	2.13	3.10	3.01	2.31	2.21	2.09	2	2.08	3.10	2.07
2	1.99	2.80	5.61	5.83	4.18	3.92	3.56	3.3	2.72	5.61	3.51
3	2.27	3.39	8.51	9.41	6.58	6.08	5.35	4.85	3.28	8.53	5.26
4	2.49	3.95	11.80	13.8	9.53	8.67	7.45	6.62	3.80	11.84	7.30
5	2.7	4.48	15.50	19	13	11.7	9.87	8.6	4.30	15.57	9.65
6	2.89	4.97	19.50	25.2	17.1	15.2	12.6	10.8	4.76	19.61	12.29
7	3.06	5.44	24.10	32.3	21.9	19.2	15.6	13.2	5.20	24.26	15.18
8	3.22	5.90	29.00	40.4	27.2	23.7	18.9	15.8	5.63	29.23	18.36
10	3.52	6.80	40.40	60.2	39.9	34.2	26.5	21.6	6.47	40.80	25.64
15	4.18	8.95	77.80	133	83.9	69	50.1	38.8	8.47	78.90	48.12
20	4.73	10.90	129.00	247	147	116	80.3	59.8	10.28	131.36	76.71
25	5.22	13.00	196.00	412	229	176	116	84	12.22	200.32	110.40
30	5.66	15.30	279.00	637	331	249	158	111	14.34	286.16	149.78
35	6.03	17.50	380.00	930	454	334	206	141	16.35	391.00	194.63
40	6.3	19.70	499.00	1300	598	430	258	173	18.36	515.02	243.13

2.3.1 Circular Area Sources

To verify the RESRAD-BUILD results of external radiation modeling for circular area sources, six area sources of 4 m^2, 10 m^2, 36 m^2, 100 m^2, 1,000 m^2, and 10,000 m^2 centered at (0, 0, 0) with z-direction were considered. Three receptors, located at (0, 0, 0.3) (m), (0, 0, 1) (m), and (0, 0, 4) (m) with distances of 0.3 m, 1 m, and 4 m, respectively, from the sources, were selected for estimating radiation doses and cancer risks. The receptors were assumed to spend 100% of the time in a year inside the building. There was no release of contamination from the area sources and no erosion of source materials. Each area source was assumed to contain C-14, Mn-54, and Tc-99, with a concentration of 1 pCi/m^2 for each radionuclide. The comparison of results between RESRAD-BUILD and the spreadsheets focused on the exposures incurred during the 1st year.

In the spreadsheets designed for this verification, the area sources were divided into multiple annuli for the calculation of effective F_{AM} for each source. External radiation dose and cancer risk without shielding materials to attenuate the radiation were estimated at the three receptor locations (0, 0, 0.3) (m), (0, 0, 1) (m), and (0, 0, 4) (m). External radiation dose and cancer risk with concrete as shielding material of 1 cm and 5 cm effective thicknesses were also estimated for the receptor location at (0, 0, 1) (m).

2.3.1.1 Dose Results without Shielding

Results for C-14. Radiation dose at the receptor location (0, 0, 1) (m) from each area source considered was estimated first. Table 2.32 shows the calculation of F_{CD}, the cover and depth factor, for C-14. Table 2.33 shows the estimation of $F_{AM\text{-}ref}$ for the reference area source, which is made of soil to an infinite extent. In the estimation, an area of nearly 3,000,000 m^2 was used for the reference source. Tables 2.34 to 2.39 show the estimation of F_{AM}'s for the six circular area sources considered in this comparison. After F_{CD} and F_{AM}'s were available, external radiation dose resulting from C-14 in each of the six circular area sources were estimated by adjusting the external radiation dose conversion factor for an infinite volume source from FGR 12, as shown in Table 2.40.

Radiation doses at the receptor location (0, 0, 0.3) (m) were estimated with the same procedure used for estimating the dose at the receptor location (0, 0, 1) (m). Because the source thickness (assumed to be 0.001 cm) and cover thickness (0 cm) did not change, the value of F_{CD} stayed the same, as shown in Table 2.32. The value of F_{AM} for each of the six circular area sources was estimated as the sum of the F_{AM}'s for the individual annuli that constitute the area source. Because the design of the tables used for estimating F_{AM}'s were the same as that of Tables 2.34 to 2.39, these estimation tables are not presented here; only the final values of F_{AM} for each area source are listed, in Table 2.41, which shows the calculation of radiation doses at the receptor location. Table 2.42 shows the calculation of radiation doses at the receptor location (0, 0, 4) (m).

Table 2.32 Calculation of F_{CD} for C-14 in an Area Source without Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.642	0.358	0.294	3.39				
Reference source –		Cover material =	none	Cover thickness, cm =			0	Density of cover, g/cm3 =			1.6
		Source density , g/cm3 =		1.6	Source thickness, cm =			0.001			
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625							
$F_{CD} = \frac{D(T_c=t_c, T_S=t_s)}{D(T_c=0, T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,											
FCD-surf=	0.00013990		(Note: FCD-surf = FCD × Surface activity conversion factor)								

Table 2.33 Calculation of F_{AM} for C-14 in a Reference Area Source without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu=\frac{(t_a\mu_a+t_c\mu_c+t\mu_s)}{(t_a+t_c+t)}$					
1	0.049	8.65E-04	0.1	0.220	2.59E-04	2.59E-04	3.62E-01	9.99E-01	2.59E-04						
ta (cm) =	100		tc (cm) =	0		Source area (m2) =	4		Source-ref area (m2) =	3.36E+06					
exp(-ux)/x2 - ref	dist. in -ref-air (cm)	dist. in-ref-cover (cm)	mfp-dist. in -ref-air	mfp-dist. in-ref-cover	BF-ref-air	BF-ref-cover	Vol-source-ref	F_{AM}-ref	4π x dist-ref^2 (cm2)	distance-ref (cm)	r - ref (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.75E-06	1.00E+02	0.00E+00	2.59E-02	0.00E+00	1.08E+00	1.00E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	1.00		
7.67E-06	1.00E+02	0.00E+00	2.60E-02	0.00E+00	1.08E+00	1.00E+00	3.14E-02	2.59E-07	1.27E+05	1.00E+02	1.00E-01	1	1.00		
7.67E-06	1.01E+02	0.00E+00	2.60E-02	0.00E+00	1.08E+00	1.00E+00	1.91E-03	1.58E-08	1.27E+05	1.01E+02	1.03E-01	1	1.00		
7.66E-06	1.01E+02	0.00E+00	2.60E-02	0.00E+00	1.08E+00	1.00E+00	2.03E-03	1.67E-08	1.27E+05	1.01E+02	1.06E-01	1	1.00		
7.66E-06	1.01E+02	0.00E+00	2.60E-02	0.00E+00	1.08E+00	1.00E+00	2.15E-03	1.77E-08	1.27E+05	1.01E+02	1.09E-01	1	1.00		
7.65E-06	1.01E+02	0.00E+00	2.60E-02	0.00E+00	1.08E+00	1.00E+00	2.29E-03	1.88E-08	1.27E+05	1.01E+02	1.13E-01	1	1.00		
7.65E-06	1.01E+02	0.00E+00	2.60E-02	0.00E+00	1.08E+00	1.00E+00	2.42E-03	1.99E-08	1.27E+05	1.01E+02	1.16E-01	1	1.00		
7.64E-06	1.01E+02	0.00E+00	2.61E-02	0.00E+00	1.08E+00	1.00E+00	2.57E-03	2.11E-08	1.28E+05	1.01E+02	1.19E-01	1	1.00	0	100
7.63E-06	1.01E+02	0.00E+00	2.61E-02	0.00E+00	1.08E+00	1.00E+00	2.73E-03	2.24E-08	1.28E+05	1.01E+02	1.23E-01	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.78E-09	3.43E+03	0.00E+00	8.88E-01	0.00E+00	3.80E+00	1.00E+00	1.44E+02	1.52E-06	1.48E+08	3.43E+03	3.43E+01	1	1.00		
2.63E-09	3.50E+03	0.00E+00	9.05E-01	0.00E+00	3.86E+00	1.00E+00	1.49E+02	1.51E-06	1.54E+08	3.50E+03	3.50E+01	1	1.00		
2.48E-09	3.57E+03	0.00E+00	9.23E-01	0.00E+00	3.92E+00	1.00E+00	1.55E+02	1.51E-06	1.60E+08	3.57E+03	3.57E+01	1	1.00		
2.34E-09	3.64E+03	0.00E+00	9.42E-01	0.00E+00	3.99E+00	1.00E+00	1.62E+02	1.51E-06	1.67E+08	3.64E+03	3.64E+01	1	1.00		
2.21E-09	3.71E+03	0.00E+00	9.61E-01	0.00E+00	4.05E+00	1.00E+00	1.68E+02	1.50E-06	1.73E+08	3.71E+03	3.71E+01	1	1.00		
2.08E-09	3.79E+03	0.00E+00	9.80E-01	0.00E+00	4.12E+00	1.00E+00	1.75E+02	1.50E-06	1.80E+08	3.79E+03	3.79E+01	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
5.51E-23	9.94E+04	0.00E+00	2.57E+01	0.00E+00	3.88E+02	1.00E+00	1.21E+05	2.58E-15	1.24E+11	9.94E+04	9.94E+02	1	1.00		
3.17E-23	1.01E+05	0.00E+00	2.62E+01	0.00E+00	4.05E+02	1.00E+00	1.25E+05	1.61E-15	1.29E+11	1.01E+05	1.01E+03	1	1.00		
1.80E-23	1.03E+05	0.00E+00	2.67E+01	0.00E+00	4.22E+02	1.00E+00	1.30E+05	9.93E-16	1.34E+11	1.03E+05	1.03E+03	1	1.00		
							∑ F_{AM}-ref =	3.08E-04							

Table 2.34 Calculation of F_{AM} for C-14 in an Area Source of 4 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu=\frac{(t_a\mu_a+t_c\mu_c+t\mu_s)}{(t_a+t_c+t)}$					
1	0.049	8.65E-04	0.1	0.220	2.59E-04	2.59E-04	3.62E-01	9.99E-01	2.59E-04						
ta (cm) =	100		tc (cm) =	0		Source area (m2) =	4		Source-ref area (m2) =	3.36E+06					
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.75E-06	2.59E-02	0.00E+00	1.00E+02	0.00E+00	1.08E+00	1.00E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	1.00		
7.67E-06	2.60E-02	0.00E+00	1.00E+02	0.00E+00	1.08E+00	1.00E+00	3.14E-02	2.59E-07	1.27E+05	1.00E+02	1.00E-01	1	1.00		
7.67E-06	2.60E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	1.91E-03	1.58E-08	1.27E+05	1.01E+02	1.03E-01	1	1.00		
7.66E-06	2.60E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	2.03E-03	1.67E-08	1.27E+05	1.01E+02	1.06E-01	1	1.00		
7.66E-06	2.60E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	2.15E-03	1.77E-08	1.27E+05	1.01E+02	1.09E-01	1	1.00		
7.65E-06	2.60E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	2.29E-03	1.88E-08	1.27E+05	1.01E+02	1.13E-01	1	1.00		
7.65E-06	2.60E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	2.42E-03	1.99E-08	1.27E+05	1.01E+02	1.16E-01	1	1.00		
7.64E-06	2.61E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	2.57E-03	2.11E-08	1.28E+05	1.01E+02	1.19E-01	1	1.00		
7.63E-06	2.61E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	2.73E-03	2.24E-08	1.28E+05	1.01E+02	1.23E-01	1	1.00		
7.63E-06	2.61E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	2.90E-03	2.38E-08	1.28E+05	1.01E+02	1.27E-01	1	1.00		
7.62E-06	2.61E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	3.07E-03	2.52E-08	1.28E+05	1.01E+02	1.30E-01	1	1.00		
7.61E-06	2.61E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	3.26E-03	2.67E-08	1.28E+05	1.01E+02	1.34E-01	1	1.00		
7.60E-06	2.61E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	3.46E-03	2.83E-08	1.28E+05	1.01E+02	1.38E-01	1	1.00		
7.59E-06	2.61E-02	0.00E+00	1.01E+02	0.00E+00	1.08E+00	1.00E+00	3.67E-03	3.00E-08	1.28E+05	1.01E+02	1.43E-01	1	1.00	0	100
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
3.82E-06	3.66E-02	0.00E+00	1.42E+02	0.00E+00	1.11E+00	1.00E+00	1.81E-01	7.68E-07	2.52E+05	1.42E+02	1.00E+00	1	1.00		
3.71E-06	3.72E-02	0.00E+00	1.44E+02	0.00E+00	1.11E+00	1.00E+00	1.93E-01	7.91E-07	2.60E+05	1.44E+02	1.03E+00	1	1.00		
3.59E-06	3.78E-02	0.00E+00	1.46E+02	0.00E+00	1.11E+00	1.00E+00	2.04E-01	8.14E-07	2.68E+05	1.46E+02	1.06E+00	1	1.00		
3.48E-06	3.84E-02	0.00E+00	1.48E+02	0.00E+00	1.11E+00	1.00E+00	2.17E-01	8.38E-07	2.77E+05	1.48E+02	1.10E+00	1	1.00		
3.36E-06	3.90E-02	0.00E+00	1.51E+02	0.00E+00	1.11E+00	1.00E+00	2.30E-01	8.61E-07	2.86E+05	1.51E+02	1.13E+00	1	1.00		
							∑ F_{AM}-source =	2.15E-05							
							F_{AM} =	7.00E-02							

Table 2.35 Calculation of F_{AM} for C-14 in an Area Source of 10 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{\left(t_a\mu_a + t_c\mu_c + t\mu_s\right)}{\left(t_a + t_c + t\right)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.049	8.65E-04	0.1	0.220	2.59E-04	2.59E-04	3.62E-01	9.99E-01	2.59E-04

ta (cm) =	100		tc (cm) =	0		Source area (m2) =	10		Source-ref area (m2) =	3.36E+06

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
3.25E-06	3.97E-02	0.00E+00	1.53E+02	0.00E+00	1.12E+00	1.00E+00	2.44E-01	8.84E-07	2.96E+05	1.53E+02	1.16E+00	1	1.00		
3.14E-06	4.04E-02	0.00E+00	1.56E+02	0.00E+00	1.12E+00	1.00E+00	2.59E-01	9.07E-07	3.06E+05	1.56E+02	1.20E+00	1	1.00		
3.03E-06	4.11E-02	0.00E+00	1.59E+02	0.00E+00	1.12E+00	1.00E+00	2.75E-01	9.30E-07	3.17E+05	1.59E+02	1.23E+00	1	1.00		
2.92E-06	4.18E-02	0.00E+00	1.62E+02	0.00E+00	1.12E+00	1.00E+00	2.91E-01	9.53E-07	3.29E+05	1.62E+02	1.27E+00	1	1.00		
2.81E-06	4.26E-02	0.00E+00	1.65E+02	0.00E+00	1.12E+00	1.00E+00	3.09E-01	9.76E-07	3.41E+05	1.65E+02	1.31E+00	1	1.00		
2.70E-06	4.34E-02	0.00E+00	1.68E+02	0.00E+00	1.13E+00	1.00E+00	3.28E-01	9.98E-07	3.54E+05	1.68E+02	1.35E+00	1	1.00		
2.60E-06	4.43E-02	0.00E+00	1.71E+02	0.00E+00	1.13E+00	1.00E+00	3.48E-01	1.02E-06	3.68E+05	1.71E+02	1.39E+00	1	1.00		
2.50E-06	4.51E-02	0.00E+00	1.75E+02	0.00E+00	1.13E+00	1.00E+00	3.69E-01	1.04E-06	3.83E+05	1.75E+02	1.43E+00	1	1.00		
2.40E-06	4.61E-02	0.00E+00	1.78E+02	0.00E+00	1.13E+00	1.00E+00	3.91E-01	1.06E-06	3.98E+05	1.78E+02	1.47E+00	1	1.00	0	100
2.30E-06	4.70E-02	0.00E+00	1.82E+02	0.00E+00	1.14E+00	1.00E+00	4.15E-01	1.08E-06	4.15E+05	1.82E+02	1.52E+00	1	1.00		
2.20E-06	4.80E-02	0.00E+00	1.86E+02	0.00E+00	1.14E+00	1.00E+00	4.41E-01	1.11E-06	4.33E+05	1.86E+02	1.56E+00	1	1.00		
2.11E-06	4.90E-02	0.00E+00	1.89E+02	0.00E+00	1.14E+00	1.00E+00	4.67E-01	1.13E-06	4.51E+05	1.89E+02	1.61E+00	1	1.00		
2.02E-06	5.01E-02	0.00E+00	1.94E+02	0.00E+00	1.15E+00	1.00E+00	4.96E-01	1.15E-06	4.71E+05	1.94E+02	1.66E+00	1	1.00		
1.93E-06	5.12E-02	0.00E+00	1.98E+02	0.00E+00	1.15E+00	1.00E+00	5.26E-01	1.17E-06	4.92E+05	1.98E+02	1.71E+00	1	1.00		
1.84E-06	5.23E-02	0.00E+00	2.02E+02	0.00E+00	1.15E+00	1.00E+00	5.58E-01	1.19E-06	5.15E+05	2.02E+02	1.76E+00	1	1.00		
1.79E-06	5.31E-02	0.00E+00	2.05E+02	0.00E+00	1.15E+00	1.00E+00	3.93E-01	8.11E-07	5.30E+05	2.05E+02	1.79E+00	1	1.00		
							∑ F_{AM}-source =	3.79E-05							
							F_{AM} =	1.23E-01							

Table 2.36 Calculation of F_{AM} for C-14 in an Area Source of 36 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.049	8.65E-04	0.1	0.220	2.59E-04	2.59E-04	3.62E-01	9.99E-01	2.59E-04						
ta (cm) =	100		tc (cm) =	0			Source area (m2) =	36		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.68E-06	5.48E-02	0.00E+00	2.12E+02	0.00E+00	1.16E+00	1.00E+00	4.25E-01	8.28E-07	5.64E+05	2.12E+02	1.87E+00	1	1.00		
1.63E-06	5.56E-02	0.00E+00	2.15E+02	0.00E+00	1.16E+00	1.00E+00	4.42E-01	8.36E-07	5.81E+05	2.15E+02	1.90E+00	1	1.00		
1.58E-06	5.65E-02	0.00E+00	2.18E+02	0.00E+00	1.16E+00	1.00E+00	4.60E-01	8.44E-07	6.00E+05	2.18E+02	1.94E+00	1	1.00		
1.53E-06	5.74E-02	0.00E+00	2.22E+02	0.00E+00	1.17E+00	1.00E+00	4.79E-01	8.52E-07	6.19E+05	2.22E+02	1.98E+00	1	1.00		
1.48E-06	5.83E-02	0.00E+00	2.25E+02	0.00E+00	1.17E+00	1.00E+00	4.98E-01	8.60E-07	6.39E+05	2.25E+02	2.02E+00	1	1.00		
1.43E-06	5.93E-02	0.00E+00	2.29E+02	0.00E+00	1.17E+00	1.00E+00	5.18E-01	8.68E-07	6.60E+05	2.29E+02	2.06E+00	1	1.00		
1.38E-06	6.02E-02	0.00E+00	2.33E+02	0.00E+00	1.17E+00	1.00E+00	5.39E-01	8.76E-07	6.81E+05	2.33E+02	2.10E+00	1	1.00		
1.34E-06	6.12E-02	0.00E+00	2.37E+02	0.00E+00	1.18E+00	1.00E+00	5.61E-01	8.83E-07	7.04E+05	2.37E+02	2.14E+00	1	1.00		
1.29E-06	6.22E-02	0.00E+00	2.40E+02	0.00E+00	1.18E+00	1.00E+00	5.84E-01	8.91E-07	7.27E+05	2.40E+02	2.19E+00	1	1.00		
1.25E-06	6.32E-02	0.00E+00	2.44E+02	0.00E+00	1.18E+00	1.00E+00	6.07E-01	8.98E-07	7.51E+05	2.44E+02	2.23E+00	1	1.00	0	100
1.21E-06	6.43E-02	0.00E+00	2.49E+02	0.00E+00	1.19E+00	1.00E+00	6.32E-01	9.05E-07	7.76E+05	2.49E+02	2.28E+00	1	1.00		
1.17E-06	6.54E-02	0.00E+00	2.53E+02	0.00E+00	1.19E+00	1.00E+00	6.57E-01	9.13E-07	8.03E+05	2.53E+02	2.32E+00	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
7.60E-07	8.04E-02	0.00E+00	3.11E+02	0.00E+00	1.23E+00	1.00E+00	1.06E+00	9.91E-07	1.21E+06	3.11E+02	2.94E+00	1	1.00		
7.32E-07	8.19E-02	0.00E+00	3.16E+02	0.00E+00	1.24E+00	1.00E+00	1.10E+00	9.97E-07	1.26E+06	3.16E+02	3.00E+00	1	1.00		
7.05E-07	8.33E-02	0.00E+00	3.22E+02	0.00E+00	1.24E+00	1.00E+00	1.14E+00	1.00E-06	1.30E+06	3.22E+02	3.06E+00	1	1.00		
6.79E-07	8.48E-02	0.00E+00	3.28E+02	0.00E+00	1.25E+00	1.00E+00	1.19E+00	1.01E-06	1.35E+06	3.28E+02	3.12E+00	1	1.00		
6.54E-07	8.64E-02	0.00E+00	3.34E+02	0.00E+00	1.25E+00	1.00E+00	1.24E+00	1.01E-06	1.40E+06	3.34E+02	3.19E+00	1	1.00		
6.30E-07	8.80E-02	0.00E+00	3.40E+02	0.00E+00	1.26E+00	1.00E+00	1.29E+00	1.02E-06	1.45E+06	3.40E+02	3.25E+00	1	1.00		
6.07E-07	8.96E-02	0.00E+00	3.46E+02	0.00E+00	1.26E+00	1.00E+00	1.34E+00	1.03E-06	1.51E+06	3.46E+02	3.31E+00	1	1.00		
							∑ F_{AM}-source =	6.78E-05							
							F_{AM} =	2.20E-01							

Table 2.37 Calculation of F_{AM} for C-14 in an Area Source of 100 m^2 without Cover at the Receptor Location of (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.049	8.65E-04	0.1	0.220	2.59E-04	2.59E-04	3.62E-01	9.99E-01	2.59E-04

ta (cm) =	100		tc (cm) =	0			Source area (m2) =	100		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
5.62E-07	9.29E-02	0.00E+00	3.59E+02	0.00E+00	1.27E+00	1.00E+00	1.45E+00	1.04E-06	1.62E+06	3.59E+02	3.45E+00	1	1.00		
5.41E-07	9.46E-02	0.00E+00	3.66E+02	0.00E+00	1.27E+00	1.00E+00	1.51E+00	1.04E-06	1.68E+06	3.66E+02	3.52E+00	1	1.00		
5.21E-07	9.64E-02	0.00E+00	3.72E+02	0.00E+00	1.28E+00	1.00E+00	1.57E+00	1.05E-06	1.74E+06	3.72E+02	3.59E+00	1	1.00		
5.01E-07	9.81E-02	0.00E+00	3.79E+02	0.00E+00	1.29E+00	1.00E+00	1.63E+00	1.05E-06	1.81E+06	3.79E+02	3.66E+00	1	1.00		
4.82E-07	1.00E-01	0.00E+00	3.86E+02	0.00E+00	1.29E+00	1.00E+00	1.70E+00	1.06E-06	1.88E+06	3.86E+02	3.73E+00	1	1.00		
4.64E-07	1.02E-01	0.00E+00	3.94E+02	0.00E+00	1.30E+00	1.00E+00	1.77E+00	1.06E-06	1.95E+06	3.94E+02	3.81E+00	1	1.00		
4.46E-07	1.04E-01	0.00E+00	4.01E+02	0.00E+00	1.30E+00	1.00E+00	1.84E+00	1.07E-06	2.02E+06	4.01E+02	3.88E+00	1	1.00		
4.29E-07	1.06E-01	0.00E+00	4.09E+02	0.00E+00	1.31E+00	1.00E+00	1.91E+00	1.07E-06	2.10E+06	4.09E+02	3.96E+00	1	1.00		
4.12E-07	1.08E-01	0.00E+00	4.16E+02	0.00E+00	1.31E+00	1.00E+00	1.99E+00	1.08E-06	2.18E+06	4.16E+02	4.04E+00	1	1.00		
3.96E-07	1.10E-01	0.00E+00	4.24E+02	0.00E+00	1.32E+00	1.00E+00	2.07E+00	1.08E-06	2.26E+06	4.24E+02	4.12E+00	1	1.00		
3.81E-07	1.12E-01	0.00E+00	4.32E+02	0.00E+00	1.32E+00	1.00E+00	2.16E+00	1.09E-06	2.35E+06	4.32E+02	4.20E+00	1	1.00		
3.66E-07	1.14E-01	0.00E+00	4.40E+02	0.00E+00	1.33E+00	1.00E+00	2.24E+00	1.09E-06	2.44E+06	4.40E+02	4.29E+00	1	1.00		
3.52E-07	1.16E-01	0.00E+00	4.49E+02	0.00E+00	1.34E+00	1.00E+00	2.33E+00	1.10E-06	2.53E+06	4.49E+02	4.37E+00	1	1.00	0	100
3.38E-07	1.18E-01	0.00E+00	4.57E+02	0.00E+00	1.34E+00	1.00E+00	2.43E+00	1.10E-06	2.63E+06	4.57E+02	4.46E+00	1	1.00		
3.25E-07	1.21E-01	0.00E+00	4.66E+02	0.00E+00	1.35E+00	1.00E+00	2.53E+00	1.11E-06	2.73E+06	4.66E+02	4.55E+00	1	1.00		
3.12E-07	1.23E-01	0.00E+00	4.75E+02	0.00E+00	1.36E+00	1.00E+00	2.63E+00	1.11E-06	2.83E+06	4.75E+02	4.64E+00	1	1.00		
3.00E-07	1.25E-01	0.00E+00	4.84E+02	0.00E+00	1.36E+00	1.00E+00	2.73E+00	1.12E-06	2.94E+06	4.84E+02	4.73E+00	1	1.00		
2.88E-07	1.28E-01	0.00E+00	4.93E+02	0.00E+00	1.37E+00	1.00E+00	2.85E+00	1.12E-06	3.06E+06	4.93E+02	4.83E+00	1	1.00		
2.77E-07	1.30E-01	0.00E+00	5.03E+02	0.00E+00	1.38E+00	1.00E+00	2.96E+00	1.13E-06	3.18E+06	5.03E+02	4.93E+00	1	1.00		
2.66E-07	1.33E-01	0.00E+00	5.12E+02	0.00E+00	1.38E+00	1.00E+00	3.08E+00	1.13E-06	3.30E+06	5.12E+02	5.02E+00	1	1.00		
2.55E-07	1.35E-01	0.00E+00	5.22E+02	0.00E+00	1.39E+00	1.00E+00	3.20E+00	1.14E-06	3.43E+06	5.22E+02	5.12E+00	1	1.00		
2.45E-07	1.38E-01	0.00E+00	5.32E+02	0.00E+00	1.40E+00	1.00E+00	3.33E+00	1.14E-06	3.56E+06	5.32E+02	5.23E+00	1	1.00		
2.35E-07	1.40E-01	0.00E+00	5.42E+02	0.00E+00	1.41E+00	1.00E+00	3.47E+00	1.15E-06	3.70E+06	5.42E+02	5.33E+00	1	1.00		
2.26E-07	1.43E-01	0.00E+00	5.53E+02	0.00E+00	1.42E+00	1.00E+00	3.61E+00	1.15E-06	3.84E+06	5.53E+02	5.44E+00	1	1.00		
2.16E-07	1.46E-01	0.00E+00	5.64E+02	0.00E+00	1.42E+00	1.00E+00	3.75E+00	1.16E-06	3.99E+06	5.64E+02	5.55E+00	1	1.00		
2.08E-07	1.49E-01	0.00E+00	5.75E+02	0.00E+00	1.43E+00	1.00E+00	3.91E+00	1.16E-06	4.15E+06	5.75E+02	5.66E+00	1	1.00		
							∑ F_{AM}-source =	9.64E-05							
							F_{AM} =	3.13E-01							

Table 2.38 Calculation of F_{AM} for C-14 in an Area Source of 1,000 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.049	8.65E-04	0.1	0.220	2.59E-04	2.59E-04	3.62E-01	9.99E-01	2.59E-04						
ta (cm) =	100		tc (cm) =	0			Source area (m2) =	1000		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.99E-07	1.52E-01	0.00E+00	5.86E+02	0.00E+00	1.44E+00	1.00E+00	4.06E+00	1.17E-06	4.31E+06	5.86E+02	5.77E+00	1	1.00		
1.91E-07	1.54E-01	0.00E+00	5.97E+02	0.00E+00	1.45E+00	1.00E+00	4.23E+00	1.17E-06	4.48E+06	5.97E+02	5.89E+00	1	1.00		
1.83E-07	1.57E-01	0.00E+00	6.09E+02	0.00E+00	1.46E+00	1.00E+00	4.40E+00	1.18E-06	4.66E+06	6.09E+02	6.00E+00	1	1.00		
1.76E-07	1.61E-01	0.00E+00	6.20E+02	0.00E+00	1.47E+00	1.00E+00	4.58E+00	1.18E-06	4.84E+06	6.20E+02	6.12E+00	1	1.00		
1.69E-07	1.64E-01	0.00E+00	6.33E+02	0.00E+00	1.48E+00	1.00E+00	4.76E+00	1.19E-06	5.03E+06	6.33E+02	6.25E+00	1	1.00		
1.62E-07	1.67E-01	0.00E+00	6.45E+02	0.00E+00	1.48E+00	1.00E+00	4.95E+00	1.19E-06	5.23E+06	6.45E+02	6.37E+00	1	1.00		
1.55E-07	1.70E-01	0.00E+00	6.58E+02	0.00E+00	1.49E+00	1.00E+00	5.15E+00	1.20E-06	5.43E+06	6.58E+02	6.50E+00	1	1.00		
1.49E-07	1.73E-01	0.00E+00	6.70E+02	0.00E+00	1.50E+00	1.00E+00	5.36E+00	1.20E-06	5.65E+06	6.70E+02	6.63E+00	1	1.00		
1.43E-07	1.77E-01	0.00E+00	6.83E+02	0.00E+00	1.51E+00	1.00E+00	5.58E+00	1.20E-06	5.87E+06	6.83E+02	6.76E+00	1	1.00	0	100
1.37E-07	1.80E-01	0.00E+00	6.97E+02	0.00E+00	1.52E+00	1.00E+00	5.80E+00	1.21E-06	6.10E+06	6.97E+02	6.90E+00	1	1.00		
1.31E-07	1.84E-01	0.00E+00	7.11E+02	0.00E+00	1.53E+00	1.00E+00	6.04E+00	1.21E-06	6.35E+06	7.11E+02	7.03E+00	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.00E-08	4.19E-01	0.00E+00	1.62E+03	0.00E+00	2.22E+00	1.00E+00	3.19E+01	1.41E-06	3.30E+07	1.62E+03	1.62E+01	1	1.00		
1.90E-08	4.27E-01	0.00E+00	1.65E+03	0.00E+00	2.24E+00	1.00E+00	3.32E+01	1.41E-06	3.43E+07	1.65E+03	1.65E+01	1	1.00		
1.81E-08	4.36E-01	0.00E+00	1.68E+03	0.00E+00	2.27E+00	1.00E+00	3.45E+01	1.42E-06	3.57E+07	1.68E+03	1.68E+01	1	1.00		
1.73E-08	4.44E-01	0.00E+00	1.72E+03	0.00E+00	2.29E+00	1.00E+00	3.59E+01	1.42E-06	3.71E+07	1.72E+03	1.71E+01	1	1.00		
1.65E-08	4.53E-01	0.00E+00	1.75E+03	0.00E+00	2.32E+00	1.00E+00	3.73E+01	1.42E-06	3.86E+07	1.75E+03	1.75E+01	1	1.00		
1.57E-08	4.62E-01	0.00E+00	1.79E+03	0.00E+00	2.34E+00	1.00E+00	3.88E+01	1.43E-06	4.01E+07	1.79E+03	1.78E+01	1	1.00		
							∑ F_{AM}-source =	1.72E-04							
							F_{AM} =	5.59E-01							

Table 2.39 Calculation of F_{AM} for C-14 in an Area Source of 10,000 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.049	8.65E-04	0.1	0.220	2.59E-04	2.59E-04	3.62E-01	9.99E-01	2.59E-04						
ta (cm) =	100		tc (cm) =	0			Source area (m2) =	10000		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.49E-08	4.72E-01	0.00E+00	1.82E+03	0.00E+00	2.37E+00	1.00E+00	4.04E+01	1.43E-06	4.18E+07	1.82E+03	1.82E+01	1	1.00		
1.42E-08	4.81E-01	0.00E+00	1.86E+03	0.00E+00	2.40E+00	1.00E+00	4.21E+01	1.43E-06	4.34E+07	1.86E+03	1.86E+01	1	1.00		
1.35E-08	4.90E-01	0.00E+00	1.90E+03	0.00E+00	2.42E+00	1.00E+00	4.37E+01	1.44E-06	4.52E+07	1.90E+03	1.89E+01	1	1.00		
1.29E-08	5.00E-01	0.00E+00	1.93E+03	0.00E+00	2.45E+00	1.00E+00	4.55E+01	1.44E-06	4.70E+07	1.93E+03	1.93E+01	1	1.00		
1.23E-08	5.10E-01	0.00E+00	1.97E+03	0.00E+00	2.49E+00	1.00E+00	4.74E+01	1.45E-06	4.89E+07	1.97E+03	1.97E+01	1	1.00		
1.17E-08	5.20E-01	0.00E+00	2.01E+03	0.00E+00	2.52E+00	1.00E+00	4.93E+01	1.45E-06	5.09E+07	2.01E+03	2.01E+01	1	1.00		
1.11E-08	5.31E-01	0.00E+00	2.05E+03	0.00E+00	2.56E+00	1.00E+00	5.13E+01	1.46E-06	5.29E+07	2.05E+03	2.05E+01	1	1.00		
1.06E-08	5.41E-01	0.00E+00	2.09E+03	0.00E+00	2.60E+00	1.00E+00	5.33E+01	1.46E-06	5.51E+07	2.09E+03	2.09E+01	1	1.00		
1.01E-08	5.52E-01	0.00E+00	2.13E+03	0.00E+00	2.63E+00	1.00E+00	5.55E+01	1.47E-06	5.73E+07	2.13E+03	2.13E+01	1	1.00		
9.55E-09	5.63E-01	0.00E+00	2.18E+03	0.00E+00	2.67E+00	1.00E+00	5.77E+01	1.47E-06	5.96E+07	2.18E+03	2.17E+01	1	1.00		
9.08E-09	5.74E-01	0.00E+00	2.22E+03	0.00E+00	2.71E+00	1.00E+00	6.01E+01	1.48E-06	6.20E+07	2.22E+03	2.22E+01	1	1.00	0	100
8.63E-09	5.86E-01	0.00E+00	2.26E+03	0.00E+00	2.75E+00	1.00E+00	6.25E+01	1.48E-06	6.45E+07	2.26E+03	2.26E+01	1	1.00		
8.20E-09	5.98E-01	0.00E+00	2.31E+03	0.00E+00	2.79E+00	1.00E+00	6.50E+01	1.49E-06	6.71E+07	2.31E+03	2.31E+01	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
8.19E-10	1.32E+00	0.00E+00	5.10E+03	0.00E+00	5.54E+00	1.00E+00	3.17E+02	1.44E-06	3.27E+08	5.10E+03	5.10E+01	1	1.00		
7.67E-10	1.34E+00	0.00E+00	5.20E+03	0.00E+00	5.65E+00	1.00E+00	3.30E+02	1.43E-06	3.40E+08	5.20E+03	5.20E+01	1	1.00		
7.17E-10	1.37E+00	0.00E+00	5.30E+03	0.00E+00	5.77E+00	1.00E+00	3.43E+02	1.42E-06	3.54E+08	5.30E+03	5.30E+01	1	1.00		
6.71E-10	1.40E+00	0.00E+00	5.41E+03	0.00E+00	5.88E+00	1.00E+00	3.57E+02	1.41E-06	3.68E+08	5.41E+03	5.41E+01	1	1.00		
6.27E-10	1.43E+00	0.00E+00	5.52E+03	0.00E+00	6.00E+00	1.00E+00	3.71E+02	1.40E-06	3.83E+08	5.52E+03	5.52E+01	1	1.00		
5.86E-10	1.46E+00	0.00E+00	5.63E+03	0.00E+00	6.12E+00	1.00E+00	3.86E+02	1.39E-06	3.98E+08	5.63E+03	5.63E+01	1	1.00		
							∑ F_{AM}-source =	2.58E-04							
							F_{AM} =	8.38E-01							

Table 2.40 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from C-14 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.35E-05	5.73E+03	1.00E+00	1.40E-04	10,000	8.38E-01	1.58E-09
				1,000	5.59E-01	1.05E-09
				100	3.13E-01	5.90E-10
				36	2.20E-01	4.15E-10
				10	1.23E-01	2.32E-10
				4	7.00E-02	1.32E-10

Table 2.41 Estimation of External Radiation Dose at the Receptor Location (0, 0, 0.3) (m) from C-14 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.35E-05	5.73E+03	1.00E+00	1.40E-04	10,000	1.03E+00	1.94E-09
				1,000	7.54E-01	1.42E-09
				100	5.06E-01	9.52E-10
				36	4.09E-01	7.69E-10
				10	2.98E-01	5.61E-10
				4	2.23E-01	4.20E-10

Table 2.42 Estimation of External Radiation Dose at the Receptor Location (0, 0, 4) (m) from C-14 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.35E-05	5.73E+03	1.00E+00	1.40E-04	10,000	5.97E-01	1.12E-09
				1,000	3.22E-01	6.06E-10
				100	1.08E-01	2.03E-10
				36	5.21E-02	9.80E-11
				10	1.75E-02	3.30E-11
				4	7.31E-03	1.38E-11

Comparison of the dose results for C-14 between the spreadsheets and RESRAD-BUILD are presented in Table 2.43. Because of the limited number of annuli used in the spreadsheets to approximate the area of the circular sources, it is expected that the estimations of external radiation doses are not as precise by spreadsheets as by the RESRAD-BUILD code. In general, the differences are less than 3%. Based on the comparison, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Results for Mn-54. Radiation dose at the receptor location (0, 0, 1) (m) from each area source considered was estimated first. Table 2.44 shows the calculation of F_{CD}, the cover and depth factor, for Mn-54. Table 2.45 shows the estimation of $F_{AM\text{-}ref}$ for the reference area source, which is made of soil having an infinite extent. In the estimation, an area of about 3,000,000 m^2 was used for the reference source. Tables 2.46 to 2.51 show the estimation of F_{AM}'s for the six circular area sources considered in this comparison. After F_{CD} and F_{AM}'s were available, external radiation doses resulting from Mn-54 in each of the six circular area sources were estimated by adjusting the external radiation dose conversion factor for an infinite volume source from FGR 12, as shown in Table 2.52.

Radiation doses at the receptor location (0, 0, 0.3) (m) were estimated with the same procedure used for estimating the doses at the receptor location (0, 0, 1) (m). Because the source thickness (assumed to be 0.001 cm) and cover thickness (0 cm) did not change, the value of F_{CD} stayed the same, as shown in Table 2.44. The values of F_{AM} for each of the six circular area sources were estimated as the sum of the F_{AM}'s for individual annuli that constitute the area source. Because the design of tables used for estimating F_{AM}'s were the same as that of Tables 2.46 to 2.51, these estimation tables are not presented here; only the final values of F_{AM} for each area source are presented, in Table 2.53, which shows the calculation of radiation doses at the receptor location. Table 2.54 shows the calculation of radiation doses at the receptor location (0, 0, 4) (m).

Comparison of the dose results for Mn-54 between the spreadsheets and RESRAD-BUILD are presented in Table 2.55. Because of the limited number of annuli used in the spreadsheets to approximate the area of the circular sources, it is expected that the estimation of external radiation doses is not as precise by spreadsheets as by the RESRAD-BUILD code. In general, the largest differences are about 3%. Based on the comparison, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Results for Tc-99. Radiation dose at the receptor location (0, 0, 1) (m) from each area source considered was estimated first. Table 2.56 shows the calculation of F_{CD}, the cover and depth factor, for Tc-99. Table 2.57 shows the estimation of $F_{AM\text{-}ref}$ for the reference area source, which is made of soil having an infinite extent. In the estimation, an area of about 3,000,000 m^2 was used for the reference source. Tables 2.58 to 2.63 show the estimation of F_{AM}'s for the six circular area sources considered in this comparison. After F_{CD} and F_{AM}'s were available, external radiation doses resulting from Tc-99 in each of the six circular area sources were estimated by adjusting the external radiation dose conversion factor for an infinite volume source from FGR 12, as shown in Table 2.64.

Table 2.43 Comparison of Radiation Dose (mrem/yr) Estimated by RESRAD-BUILD and Spreadsheets from C-14 in Six Area Sources without Cover

Area of Source (m^2)	Receptor Location (0, 0, 1) (m)			Receptor Location (0, 0, 0.3) (m)			Receptor Location (0, 0, 4) (m)		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	1.58E-09	1.58E-09	1.00	1.96E-09	1.94E-09	1.01	1.13E-09	1.12E-09	1.01
1,000	1.04E-09	1.05E-09	0.99	1.42E-09	1.42E-09	1.00	6.00E-10	6.06E-10	0.99
100	5.83E-10	5.90E-10	0.99	9.52E-10	9.52E-10	1.00	1.98E-10	2.03E-10	0.97
36	4.11E-10	4.15E-10	0.99	7.72E-10	7.69E-10	1.00	9.56E-11	9.80E-11	0.98
10	2.29E-10	2.32E-10	0.99	5.62E-10	5.61E-10	1.00	3.17E-11	3.30E-11	0.96
4	1.30E-10	1.32E-10	0.99	4.22E-10	4.20E-10	1.01	1.34E-11	1.38E-11	0.97

Table 2.44 Calculation of F_{CD} for Mn-54 in an Area Source without Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.085	0.915	1.22	0.088			
Reference source –		Cover material =	none	Cover thickness, cm =			0	Density of cover, g/cm3 =		1.6
		Source density , g/cm3 =		1.6	Source thickness, cm =			0.001		
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625						
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$										
FCD-surf=	0.00001841		(Note: FCD-surf = FCD × Surface activity conversion factor)							

Table 2.45 Calculation of F_{AM} for Mn-54 in a Reference Area Source without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1	0.825	3.189	8.48E-05	8.48E-05	7.08E-02	1.67E-01	8.48E-05						
ta (cm) =	100	tc (cm) =	0	Source-ref area (m2) =		3.36E+06									
exp(-ux)/x2 - ref	dist. in -ref-air (cm)	dist. in-ref-cover (cm)	mfp-dist. in -ref-air	mfp-dist. in-ref-cover	BF-ref-air	BF-ref-cover	Vol-source-ref	F_{AM}-ref	4π x dist-ref^2 (cm2)	distance-ref (cm)	r - ref (m)	ta + tc (m)	ta (m)	Receptor location y, cm	Receptor location z, cm
7.89E-06	1.00E+02	0.00E+00	8.48E-03	0.00E+00	1.01E+00	1.00E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	1.00E+00	0	1		
7.81E-06	1.00E+02	0.00E+00	8.52E-03	0.00E+00	1.01E+00	1.00E+00	3.14E-02	2.47E-07	1.27E+05	1.00E+02	1.00E+00	0	1		
7.80E-06	1.01E+02	0.00E+00	8.52E-03	0.00E+00	1.01E+00	1.00E+00	1.91E-03	1.51E-08	1.27E+05	1.01E+02	1.00E+00	0	1		
7.80E-06	1.01E+02	0.00E+00	8.52E-03	0.00E+00	1.01E+00	1.00E+00	2.03E-03	1.60E-08	1.27E+05	1.01E+02	1.00E+00	0	1		
7.79E-06	1.01E+02	0.00E+00	8.53E-03	0.00E+00	1.01E+00	1.00E+00	2.15E-03	1.69E-08	1.27E+05	1.01E+02	1.00E+00	0	1		
7.79E-06	1.01E+02	0.00E+00	8.53E-03	0.00E+00	1.01E+00	1.00E+00	2.29E-03	1.79E-08	1.27E+05	1.01E+02	1.00E+00	0	1		
7.78E-06	1.01E+02	0.00E+00	8.53E-03	0.00E+00	1.01E+00	1.00E+00	2.42E-03	1.90E-08	1.27E+05	1.01E+02	1.00E+00	0	1		
7.78E-06	1.01E+02	0.00E+00	8.54E-03	0.00E+00	1.01E+00	1.00E+00	2.57E-03	2.02E-08	1.28E+05	1.01E+02	1.00E+00	0	1	0	100
7.77E-06	1.01E+02	0.00E+00	8.54E-03	0.00E+00	1.01E+00	1.00E+00	2.73E-03	2.14E-08	1.28E+05	1.01E+02	1.00E+00	0	1		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
5.05E-09	3.43E+03	0.00E+00	2.91E-01	0.00E+00	1.29E+00	1.00E+00	1.44E+02	9.34E-07	1.48E+08	3.43E+03	1.00E+00	34	1		
4.83E-09	3.50E+03	0.00E+00	2.97E-01	0.00E+00	1.29E+00	1.00E+00	1.49E+02	9.33E-07	1.54E+08	3.50E+03	1.00E+00	35	1		
4.61E-09	3.57E+03	0.00E+00	3.03E-01	0.00E+00	1.30E+00	1.00E+00	1.55E+02	9.31E-07	1.60E+08	3.57E+03	1.00E+00	36	1		
4.41E-09	3.64E+03	0.00E+00	3.09E-01	0.00E+00	1.31E+00	1.00E+00	1.62E+02	9.30E-07	1.67E+08	3.64E+03	1.00E+00	36	1		
4.21E-09	3.71E+03	0.00E+00	3.15E-01	0.00E+00	1.31E+00	1.00E+00	1.68E+02	9.29E-07	1.73E+08	3.71E+03	1.00E+00	37	1		
4.02E-09	3.79E+03	0.00E+00	3.21E-01	0.00E+00	1.32E+00	1.00E+00	1.75E+02	9.27E-07	1.80E+08	3.79E+03	1.00E+00	38	1		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
1.77E-15	9.94E+04	0.00E+00	8.42E+00	0.00E+00	2.48E+01	1.00E+00	1.21E+05	5.29E-09	1.24E+11	9.94E+04	1.00E+00	994	1		
1.44E-15	1.01E+05	0.00E+00	8.59E+00	0.00E+00	2.56E+01	1.00E+00	1.25E+05	4.61E-09	1.29E+11	1.01E+05	1.00E+00	1014	1		
1.16E-15	1.03E+05	0.00E+00	8.76E+00	0.00E+00	2.64E+01	1.00E+00	1.30E+05	4.00E-09	1.34E+11	1.03E+05	1.00E+00	1034	1		
							∑ F_{AM}-ref =	1.83E-04							

Table 2.46 Calculation of F_{AM} for Mn-54 in an Area Source of 4 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1	0.825	3.189	8.48E-05	8.48E-05	7.08E-02	1.67E-01	8.48E-05						
ta (cm) =	100		tc (cm) =	0		Source area (m2) =		4		Source-ref area (m2) =		3.36E+06			
exp(-ux)/x2 - source	mfp-dist. in -source-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.89E-06	8.48E-03	0.00E+00	1.00E+02	0.00E+00	1.01E+00	1.00E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	1		
7.81E-06	8.52E-03	0.00E+00	1.00E+02	0.00E+00	1.01E+00	1.00E+00	3.14E-02	2.47E-07	1.27E+05	1.00E+02	1.00E-01	1	1		
7.80E-06	8.52E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	1.91E-03	1.51E-08	1.27E+05	1.01E+02	1.03E-01	1	1		
7.80E-06	8.52E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	2.03E-03	1.60E-08	1.27E+05	1.01E+02	1.06E-01	1	1		
7.79E-06	8.53E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	2.15E-03	1.69E-08	1.27E+05	1.01E+02	1.09E-01	1	1		
7.79E-06	8.53E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	2.29E-03	1.79E-08	1.27E+05	1.01E+02	1.13E-01	1	1		
7.78E-06	8.53E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	2.42E-03	1.90E-08	1.27E+05	1.01E+02	1.16E-01	1	1		
7.78E-06	8.54E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	2.57E-03	2.02E-08	1.28E+05	1.01E+02	1.19E-01	1	1		
7.77E-06	8.54E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	2.73E-03	2.14E-08	1.28E+05	1.01E+02	1.23E-01	1	1		
7.76E-06	8.55E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	2.90E-03	2.27E-08	1.28E+05	1.01E+02	1.27E-01	1	1		
7.75E-06	8.55E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	3.07E-03	2.40E-08	1.28E+05	1.01E+02	1.30E-01	1	1		
7.75E-06	8.55E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	3.26E-03	2.55E-08	1.28E+05	1.01E+02	1.34E-01	1	1		
7.74E-06	8.56E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	3.46E-03	2.70E-08	1.28E+05	1.01E+02	1.38E-01	1	1		
7.73E-06	8.56E-03	0.00E+00	1.01E+02	0.00E+00	1.01E+00	1.00E+00	3.67E-03	2.86E-08	1.28E+05	1.01E+02	1.43E-01	1	1	0	100
..	..	..	..	..	..	..	..	..	..	..	..	..	0		
3.92E-06	1.20E-02	0.00E+00	1.42E+02	0.00E+00	1.01E+00	1.00E+00	1.81E-01	7.20E-07	2.52E+05	1.42E+02	1.00E+00	1	1		
3.80E-06	1.22E-02	0.00E+00	1.44E+02	0.00E+00	1.01E+00	1.00E+00	1.93E-01	7.41E-07	2.60E+05	1.44E+02	1.03E+00	1	1		
3.68E-06	1.24E-02	0.00E+00	1.46E+02	0.00E+00	1.01E+00	1.00E+00	2.04E-01	7.62E-07	2.68E+05	1.46E+02	1.06E+00	1	1		
3.57E-06	1.26E-02	0.00E+00	1.48E+02	0.00E+00	1.01E+00	1.00E+00	2.17E-01	7.83E-07	2.77E+05	1.48E+02	1.10E+00	1	1		
3.45E-06	1.28E-02	0.00E+00	1.51E+02	0.00E+00	1.01E+00	1.00E+00	2.30E-01	8.04E-07	2.86E+05	1.51E+02	1.13E+00	1	1		
						∑FAM-source=		2.03E-05							
							FAM=	7.73E-02							

Table 2.47 Calculation of F_{AM} for Mn-54 in an Area Source of 10 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.835	1	0.825	3.189	8.48E-05	8.48E-05	7.08E-02	1.67E-01	8.48E-05

ta (cm) =	100	tc (cm) =	0	Source area (m2) =	10	Siource-ref area (m2) =	3.36E+06

exp(-ux)/x2 - source	mfp-dist. in -source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
3.34E-06	1.30E-02	0.00E+00	1.53E+02	0.00E+00	1.01E+00	1.00E+00	2.44E-01	8.25E-07	2.96E+05	1.53E+02	1.16E+00	1	1		
3.22E-06	1.32E-02	0.00E+00	1.56E+02	0.00E+00	1.01E+00	1.00E+00	2.59E-01	8.45E-07	3.06E+05	1.56E+02	1.20E+00	1	1		
3.11E-06	1.35E-02	0.00E+00	1.59E+02	0.00E+00	1.01E+00	1.00E+00	2.75E-01	8.66E-07	3.17E+05	1.59E+02	1.23E+00	1	1		
3.00E-06	1.37E-02	0.00E+00	1.62E+02	0.00E+00	1.01E+00	1.00E+00	2.91E-01	8.86E-07	3.29E+05	1.62E+02	1.27E+00	1	1		
2.89E-06	1.40E-02	0.00E+00	1.65E+02	0.00E+00	1.01E+00	1.00E+00	3.09E-01	9.06E-07	3.41E+05	1.65E+02	1.31E+00	1	1		
2.78E-06	1.42E-02	0.00E+00	1.68E+02	0.00E+00	1.01E+00	1.00E+00	3.28E-01	9.25E-07	3.54E+05	1.68E+02	1.35E+00	1	1		
2.68E-06	1.45E-02	0.00E+00	1.71E+02	0.00E+00	1.01E+00	1.00E+00	3.48E-01	9.45E-07	3.68E+05	1.71E+02	1.39E+00	1	1		
2.57E-06	1.48E-02	0.00E+00	1.75E+02	0.00E+00	1.01E+00	1.00E+00	3.69E-01	9.64E-07	3.83E+05	1.75E+02	1.43E+00	1	1		
2.47E-06	1.51E-02	0.00E+00	1.78E+02	0.00E+00	1.01E+00	1.00E+00	3.91E-01	9.82E-07	3.98E+05	1.78E+02	1.47E+00	1	1	0	100
2.37E-06	1.54E-02	0.00E+00	1.82E+02	0.00E+00	1.02E+00	1.00E+00	4.15E-01	1.00E-06	4.15E+05	1.82E+02	1.52E+00	1	1		
2.28E-06	1.57E-02	0.00E+00	1.86E+02	0.00E+00	1.02E+00	1.00E+00	4.41E-01	1.02E-06	4.33E+05	1.86E+02	1.56E+00	1	1		
2.18E-06	1.61E-02	0.00E+00	1.89E+02	0.00E+00	1.02E+00	1.00E+00	4.67E-01	1.04E-06	4.51E+05	1.89E+02	1.61E+00	1	1		
2.09E-06	1.64E-02	0.00E+00	1.94E+02	0.00E+00	1.02E+00	1.00E+00	4.96E-01	1.05E-06	4.71E+05	1.94E+02	1.66E+00	1	1		
2.00E-06	1.68E-02	0.00E+00	1.98E+02	0.00E+00	1.02E+00	1.00E+00	5.26E-01	1.07E-06	4.92E+05	1.98E+02	1.71E+00	1	1		
1.91E-06	1.72E-02	0.00E+00	2.02E+02	0.00E+00	1.02E+00	1.00E+00	5.58E-01	1.08E-06	5.15E+05	2.02E+02	1.76E+00	1	1		
1.85E-06	1.74E-02	0.00E+00	2.05E+02	0.00E+00	1.02E+00	1.00E+00	3.93E-01	7.40E-07	5.30E+05	2.05E+02	1.79E+00	1	1		
						∑FAM-source=		3.55E-05							
							FAM=	1.35E-01							

Table 2.48 Calculation of F_{AM} for Mn-54 in an Area Source of 36 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1	0.825	3.189	8.48E-05	8.48E-05	7.08E-02	1.67E-01	8.48E-05						
ta (cm) =	100		tc (cm) =	0		Source area (m2) =		36		Siource-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in -source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.74E-06	1.80E-02	0.00E+00	2.12E+02	0.00E+00	1.02E+00	1.00E+00	4.25E-01	7.54E-07	5.64E+05	2.12E+02	1.87E+00	1	1		
1.69E-06	1.82E-02	0.00E+00	2.15E+02	0.00E+00	1.02E+00	1.00E+00	4.42E-01	7.61E-07	5.81E+05	2.15E+02	1.90E+00	1	1		
1.64E-06	1.85E-02	0.00E+00	2.18E+02	0.00E+00	1.02E+00	1.00E+00	4.60E-01	7.67E-07	6.00E+05	2.18E+02	1.94E+00	1	1		
1.59E-06	1.88E-02	0.00E+00	2.22E+02	0.00E+00	1.02E+00	1.00E+00	4.79E-01	7.73E-07	6.19E+05	2.22E+02	1.98E+00	1	1		
1.54E-06	1.91E-02	0.00E+00	2.25E+02	0.00E+00	1.02E+00	1.00E+00	4.98E-01	7.79E-07	6.39E+05	2.25E+02	2.02E+00	1	1		
1.49E-06	1.94E-02	0.00E+00	2.29E+02	0.00E+00	1.02E+00	1.00E+00	5.18E-01	7.85E-07	6.60E+05	2.29E+02	2.06E+00	1	1		
1.44E-06	1.97E-02	0.00E+00	2.33E+02	0.00E+00	1.02E+00	1.00E+00	5.39E-01	7.91E-07	6.81E+05	2.33E+02	2.10E+00	1	1		
1.39E-06	2.01E-02	0.00E+00	2.37E+02	0.00E+00	1.02E+00	1.00E+00	5.61E-01	7.97E-07	7.04E+05	2.37E+02	2.14E+00	1	1		
1.35E-06	2.04E-02	0.00E+00	2.40E+02	0.00E+00	1.02E+00	1.00E+00	5.84E-01	8.03E-07	7.27E+05	2.40E+02	2.19E+00	1	1		
1.30E-06	2.07E-02	0.00E+00	2.44E+02	0.00E+00	1.02E+00	1.00E+00	6.07E-01	8.08E-07	7.51E+05	2.44E+02	2.23E+00	1	1	0	100
1.26E-06	2.11E-02	0.00E+00	2.49E+02	0.00E+00	1.02E+00	1.00E+00	6.32E-01	8.13E-07	7.76E+05	2.49E+02	2.28E+00	1	1		
1.22E-06	2.14E-02	0.00E+00	2.53E+02	0.00E+00	1.02E+00	1.00E+00	6.57E-01	8.18E-07	8.03E+05	2.53E+02	2.32E+00	1	1		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
8.02E-07	2.64E-02	0.00E+00	3.11E+02	0.00E+00	1.03E+00	1.00E+00	1.06E+00	8.70E-07	1.21E+06	3.11E+02	2.94E+00	1	1		
7.73E-07	2.68E-02	0.00E+00	3.16E+02	0.00E+00	1.03E+00	1.00E+00	1.10E+00	8.73E-07	1.26E+06	3.16E+02	3.00E+00	1	1		
7.46E-07	2.73E-02	0.00E+00	3.22E+02	0.00E+00	1.03E+00	1.00E+00	1.14E+00	8.77E-07	1.30E+06	3.22E+02	3.06E+00	1	1		
7.19E-07	2.78E-02	0.00E+00	3.28E+02	0.00E+00	1.03E+00	1.00E+00	1.19E+00	8.80E-07	1.35E+06	3.28E+02	3.12E+00	1	1		
6.94E-07	2.83E-02	0.00E+00	3.34E+02	0.00E+00	1.03E+00	1.00E+00	1.24E+00	8.83E-07	1.40E+06	3.34E+02	3.19E+00	1	1		
6.69E-07	2.88E-02	0.00E+00	3.40E+02	0.00E+00	1.03E+00	1.00E+00	1.29E+00	8.86E-07	1.45E+06	3.40E+02	3.25E+00	1	1		
6.44E-07	2.93E-02	0.00E+00	3.46E+02	0.00E+00	1.03E+00	1.00E+00	1.34E+00	8.89E-07	1.51E+06	3.46E+02	3.31E+00	1	1		
						∑FAM-source=		6.20E-05							
							FAM=	2.36E-01							

Table 2.49 Calculation of F_{AM} for Mn-54 in an Area Source of 100 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1	0.825	3.189	8.48E-05	8.48E-05	7.08E-02	1.67E-01	8.48E-05						
ta (cm) =	100		tc (cm) =	0		Source area (m2) =		100		Siource-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in -source-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
5.99E-07	3.04E-02	0.00E+00	3.59E+02	0.00E+00	1.03E+00	1.00E+00	1.45E+00	8.95E-07	1.62E+06	3.59E+02	3.45E+00	1	1		
5.77E-07	3.10E-02	0.00E+00	3.66E+02	0.00E+00	1.03E+00	1.00E+00	1.51E+00	8.97E-07	1.68E+06	3.66E+02	3.52E+00	1	1		
5.56E-07	3.16E-02	0.00E+00	3.72E+02	0.00E+00	1.03E+00	1.00E+00	1.57E+00	9.00E-07	1.74E+06	3.72E+02	3.59E+00	1	1		
5.35E-07	3.22E-02	0.00E+00	3.79E+02	0.00E+00	1.03E+00	1.00E+00	1.63E+00	9.03E-07	1.81E+06	3.79E+02	3.66E+00	1	1		
5.16E-07	3.28E-02	0.00E+00	3.86E+02	0.00E+00	1.03E+00	1.00E+00	1.70E+00	9.05E-07	1.88E+06	3.86E+02	3.73E+00	1	1		
4.96E-07	3.34E-02	0.00E+00	3.94E+02	0.00E+00	1.03E+00	1.00E+00	1.77E+00	9.07E-07	1.95E+06	3.94E+02	3.81E+00	1	1		
4.78E-07	3.40E-02	0.00E+00	4.01E+02	0.00E+00	1.03E+00	1.00E+00	1.84E+00	9.10E-07	2.02E+06	4.01E+02	3.88E+00	1	1		
4.60E-07	3.46E-02	0.00E+00	4.09E+02	0.00E+00	1.03E+00	1.00E+00	1.91E+00	9.12E-07	2.10E+06	4.09E+02	3.96E+00	1	1		
4.43E-07	3.53E-02	0.00E+00	4.16E+02	0.00E+00	1.03E+00	1.00E+00	1.99E+00	9.14E-07	2.18E+06	4.16E+02	4.04E+00	1	1		
4.27E-07	3.60E-02	0.00E+00	4.24E+02	0.00E+00	1.04E+00	1.00E+00	2.07E+00	9.16E-07	2.26E+06	4.24E+02	4.12E+00	1	1		
4.11E-07	3.66E-02	0.00E+00	4.32E+02	0.00E+00	1.04E+00	1.00E+00	2.16E+00	9.18E-07	2.35E+06	4.32E+02	4.20E+00	1	1		
3.95E-07	3.73E-02	0.00E+00	4.40E+02	0.00E+00	1.04E+00	1.00E+00	2.24E+00	9.20E-07	2.44E+06	4.40E+02	4.29E+00	1	1		
3.80E-07	3.80E-02	0.00E+00	4.49E+02	0.00E+00	1.04E+00	1.00E+00	2.33E+00	9.22E-07	2.53E+06	4.49E+02	4.37E+00	1	1	0	100
3.66E-07	3.88E-02	0.00E+00	4.57E+02	0.00E+00	1.04E+00	1.00E+00	2.43E+00	9.23E-07	2.63E+06	4.57E+02	4.46E+00	1	1		
3.52E-07	3.95E-02	0.00E+00	4.66E+02	0.00E+00	1.04E+00	1.00E+00	2.53E+00	9.25E-07	2.73E+06	4.66E+02	4.55E+00	1	1		
3.39E-07	4.02E-02	0.00E+00	4.75E+02	0.00E+00	1.04E+00	1.00E+00	2.63E+00	9.27E-07	2.83E+06	4.75E+02	4.64E+00	1	1		
3.26E-07	4.10E-02	0.00E+00	4.84E+02	0.00E+00	1.04E+00	1.00E+00	2.73E+00	9.28E-07	2.94E+06	4.84E+02	4.73E+00	1	1		
3.14E-07	4.18E-02	0.00E+00	4.93E+02	0.00E+00	1.04E+00	1.00E+00	2.85E+00	9.30E-07	3.06E+06	4.93E+02	4.83E+00	1	1		
3.02E-07	4.26E-02	0.00E+00	5.03E+02	0.00E+00	1.04E+00	1.00E+00	2.96E+00	9.31E-07	3.18E+06	5.03E+02	4.93E+00	1	1		
2.90E-07	4.34E-02	0.00E+00	5.12E+02	0.00E+00	1.04E+00	1.00E+00	3.08E+00	9.33E-07	3.30E+06	5.12E+02	5.02E+00	1	1		
2.79E-07	4.43E-02	0.00E+00	5.22E+02	0.00E+00	1.04E+00	1.00E+00	3.20E+00	9.34E-07	3.43E+06	5.22E+02	5.12E+00	1	1		
2.69E-07	4.51E-02	0.00E+00	5.32E+02	0.00E+00	1.04E+00	1.00E+00	3.33E+00	9.35E-07	3.56E+06	5.32E+02	5.23E+00	1	1		
2.58E-07	4.60E-02	0.00E+00	5.42E+02	0.00E+00	1.05E+00	1.00E+00	3.47E+00	9.36E-07	3.70E+06	5.42E+02	5.33E+00	1	1		
2.48E-07	4.69E-02	0.00E+00	5.53E+02	0.00E+00	1.05E+00	1.00E+00	3.61E+00	9.38E-07	3.84E+06	5.53E+02	5.44E+00	1	1		
2.39E-07	4.78E-02	0.00E+00	5.64E+02	0.00E+00	1.05E+00	1.00E+00	3.75E+00	9.39E-07	3.99E+06	5.64E+02	5.55E+00	1	1		
2.30E-07	4.87E-02	0.00E+00	5.75E+02	0.00E+00	1.05E+00	1.00E+00	3.91E+00	9.40E-07	4.15E+06	5.75E+02	5.66E+00	1	1		
						∑FAM-source=		8.60E-05							
							FAM=	3.27E-01							

Table 2.50 Calculation of F_{AM} for Mn-54 in an Area Source of 1,000 m^2 without Cover at the Receptor Location of (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1	0.825	3.189	8.48E-05	8.48E-05	7.08E-02	1.67E-01	8.48E-05						
ta (cm) =	100		tc (cm) =	0		Source area (m2) =		1000		Siource-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in- source-cover	dist. in -source- air (cm)	dist. in- source- cover (cm)	BF-source-air	BF-source- cover	Vol-source	F_{AM}-source	4π x dist- source^2 (cm2)	distance- source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
2.21E-07	4.96E-02	0.00E+00	5.86E+02	0.00E+00	1.05E+00	1.00E+00	4.06E+00	9.41E-07	4.31E+06	5.86E+02	5.77E+00	1	1		
2.12E-07	5.06E-02	0.00E+00	5.97E+02	0.00E+00	1.05E+00	1.00E+00	4.23E+00	9.42E-07	4.48E+06	5.97E+02	5.89E+00	1	1		
2.04E-07	5.16E-02	0.00E+00	6.09E+02	0.00E+00	1.05E+00	1.00E+00	4.40E+00	9.43E-07	4.66E+06	6.09E+02	6.00E+00	1	1		
1.96E-07	5.26E-02	0.00E+00	6.20E+02	0.00E+00	1.05E+00	1.00E+00	4.58E+00	9.44E-07	4.84E+06	6.20E+02	6.12E+00	1	1		
1.88E-07	5.36E-02	0.00E+00	6.33E+02	0.00E+00	1.05E+00	1.00E+00	4.76E+00	9.45E-07	5.03E+06	6.33E+02	6.25E+00	1	1		
1.81E-07	5.47E-02	0.00E+00	6.45E+02	0.00E+00	1.05E+00	1.00E+00	4.95E+00	9.46E-07	5.23E+06	6.45E+02	6.37E+00	1	1		
1.74E-07	5.57E-02	0.00E+00	6.58E+02	0.00E+00	1.06E+00	1.00E+00	5.15E+00	9.46E-07	5.43E+06	6.58E+02	6.50E+00	1	1		
1.67E-07	5.68E-02	0.00E+00	6.70E+02	0.00E+00	1.06E+00	1.00E+00	5.36E+00	9.47E-07	5.65E+06	6.70E+02	6.63E+00	1	1		
1.61E-07	5.79E-02	0.00E+00	6.83E+02	0.00E+00	1.06E+00	1.00E+00	5.58E+00	9.48E-07	5.87E+06	6.83E+02	6.76E+00	1	1	0	100
1.54E-07	5.91E-02	0.00E+00	6.97E+02	0.00E+00	1.06E+00	1.00E+00	5.80E+00	9.49E-07	6.10E+06	6.97E+02	6.90E+00	1	1		
1.48E-07	6.02E-02	0.00E+00	7.11E+02	0.00E+00	1.06E+00	1.00E+00	6.04E+00	9.49E-07	6.35E+06	7.11E+02	7.03E+00	1	1		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.65E-08	1.37E-01	0.00E+00	1.62E+03	0.00E+00	1.14E+00	1.00E+00	3.19E+01	9.58E-07	3.30E+07	1.62E+03	1.62E+01	1	1		
2.54E-08	1.40E-01	0.00E+00	1.65E+03	0.00E+00	1.14E+00	1.00E+00	3.32E+01	9.57E-07	3.43E+07	1.65E+03	1.65E+01	1	1		
2.43E-08	1.43E-01	0.00E+00	1.68E+03	0.00E+00	1.14E+00	1.00E+00	3.45E+01	9.57E-07	3.57E+07	1.68E+03	1.68E+01	1	1		
2.33E-08	1.46E-01	0.00E+00	1.72E+03	0.00E+00	1.14E+00	1.00E+00	3.59E+01	9.57E-07	3.71E+07	1.72E+03	1.71E+01	1	1		
2.23E-08	1.49E-01	0.00E+00	1.75E+03	0.00E+00	1.15E+00	1.00E+00	3.73E+01	9.57E-07	3.86E+07	1.75E+03	1.75E+01	1	1		
2.14E-08	1.51E-01	0.00E+00	1.79E+03	0.00E+00	1.15E+00	1.00E+00	3.88E+01	9.56E-07	4.01E+07	1.79E+03	1.78E+01	1	1		
						∑FAM-source=		1.41E-04							
							FAM=	5.37E-01							

Table 2.51 Calculation of F_{AM} for Mn-54 in an Area Source of 10,000 m^2 without Cover at the Receptor Location of (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1	0.825	3.189	8.48E-05	8.48E-05	7.08E-02	1.67E-01	8.48E-05						
ta (cm) =	100		tc (cm) =	0		Source area (m2) =		10000		Siource-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in -source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
2.05E-08	1.55E-01	0.00E+00	1.82E+03	0.00E+00	1.15E+00	1.00E+00	4.04E+01	9.56E-07	4.18E+07	1.82E+03	1.82E+01	1	1		
1.97E-08	1.58E-01	0.00E+00	1.86E+03	0.00E+00	1.16E+00	1.00E+00	4.21E+01	9.56E-07	4.34E+07	1.86E+03	1.86E+01	1	1		
1.88E-08	1.61E-01	0.00E+00	1.90E+03	0.00E+00	1.16E+00	1.00E+00	4.37E+01	9.55E-07	4.52E+07	1.90E+03	1.89E+01	1	1		
1.81E-08	1.64E-01	0.00E+00	1.93E+03	0.00E+00	1.16E+00	1.00E+00	4.55E+01	9.55E-07	4.70E+07	1.93E+03	1.93E+01	1	1		
1.73E-08	1.67E-01	0.00E+00	1.97E+03	0.00E+00	1.17E+00	1.00E+00	4.74E+01	9.55E-07	4.89E+07	1.97E+03	1.97E+01	1	1		
1.66E-08	1.71E-01	0.00E+00	2.01E+03	0.00E+00	1.17E+00	1.00E+00	4.93E+01	9.54E-07	5.09E+07	2.01E+03	2.01E+01	1	1		
1.59E-08	1.74E-01	0.00E+00	2.05E+03	0.00E+00	1.17E+00	1.00E+00	5.13E+01	9.54E-07	5.29E+07	2.05E+03	2.05E+01	1	1		
1.52E-08	1.77E-01	0.00E+00	2.09E+03	0.00E+00	1.18E+00	1.00E+00	5.33E+01	9.53E-07	5.51E+07	2.09E+03	2.09E+01	1	1		
1.46E-08	1.81E-01	0.00E+00	2.13E+03	0.00E+00	1.18E+00	1.00E+00	5.55E+01	9.53E-07	5.73E+07	2.13E+03	2.13E+01	1	1		
1.40E-08	1.85E-01	0.00E+00	2.18E+03	0.00E+00	1.18E+00	1.00E+00	5.77E+01	9.53E-07	5.96E+07	2.18E+03	2.17E+01	1	1		
1.34E-08	1.88E-01	0.00E+00	2.22E+03	0.00E+00	1.19E+00	1.00E+00	6.01E+01	9.52E-07	6.20E+07	2.22E+03	2.22E+01	1	1	0	100
1.28E-08	1.92E-01	0.00E+00	2.26E+03	0.00E+00	1.19E+00	1.00E+00	6.25E+01	9.52E-07	6.45E+07	2.26E+03	2.26E+01	1	1		
1.23E-08	1.96E-01	0.00E+00	2.31E+03	0.00E+00	1.19E+00	1.00E+00	6.50E+01	9.51E-07	6.71E+07	2.31E+03	2.31E+01	1	1		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
1.99E-09	4.32E-01	0.00E+00	5.10E+03	0.00E+00	1.43E+00	1.00E+00	3.17E+02	8.99E-07	3.27E+08	5.10E+03	5.10E+01	1	1		
1.89E-09	4.41E-01	0.00E+00	5.20E+03	0.00E+00	1.44E+00	1.00E+00	3.30E+02	8.97E-07	3.40E+08	5.20E+03	5.20E+01	1	1		
1.80E-09	4.50E-01	0.00E+00	5.30E+03	0.00E+00	1.44E+00	1.00E+00	3.43E+02	8.94E-07	3.54E+08	5.30E+03	5.30E+01	1	1		
1.72E-09	4.59E-01	0.00E+00	5.41E+03	0.00E+00	1.45E+00	1.00E+00	3.57E+02	8.92E-07	3.68E+08	5.41E+03	5.41E+01	1	1		
1.64E-09	4.68E-01	0.00E+00	5.52E+03	0.00E+00	1.46E+00	1.00E+00	3.71E+02	8.89E-07	3.83E+08	5.52E+03	5.52E+01	1	1		
1.56E-09	4.77E-01	0.00E+00	5.63E+03	0.00E+00	1.47E+00	1.00E+00	3.86E+02	8.87E-07	3.98E+08	5.63E+03	5.63E+01	1	1		
						∑FAM-source=		1.95E-04							
							FAM=	7.42E-01							

Table 2.52 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	1.84E-05	10,000	7.42E-01	4.83E-05
				1,000	5.37E-01	3.49E-05
				100	3.27E-01	2.12E-05
				36	2.36E-01	1.53E-05
				10	1.35E-01	8.77E-06
				4	7.73E-02	5.03E-06

Table 2.53 Estimation of External Radiation Dose at the Receptor Location (0, 0, 0.3) (m) from Mn-54 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	1.84E-05	10,000	9.64E-01	6.28E-05
				1,000	7.58E-01	4.94E-05
				100	5.46E-01	3.55E-05
				36	4.51E-01	2.93E-05
				10	3.34E-01	2.18E-05
				4	2.53E-01	1.65E-05

Table 2.54 Estimation of External Radiation Dose at the Receptor Location (0, 0, 4) (m) from Mn-54 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	1.84E-05	10,000	4.85E-01	3.16E-05
				1,000	2.83E-01	1.85E-05
				100	1.03E-01	6.73E-06
				36	5.09E-02	3.31E-06
				10	1.73E-02	1.13E-06
				4	7.26E-03	4.73E-07

Table 2.55 Comparison of Radiation Doses (mrem/yr) Estimated by RESRAD-BUILD and Spreadsheets from Mn-54 in Six Area Sources without Cover

Area of Source (m^2)	Receptor Location (0, 0, 1) (m)			Receptor Location (0, 0, 0.3) (m)			Receptor Location (0, 0, 4) (m)		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	4.80E-05	4.83E-05	0.99	6.25E-05	6.28E-05	1.00	3.13E-05	3.16E-05	0.99
1,000	3.46E-05	3.49E-05	0.99	4.92E-05	4.94E-05	1.00	1.82E-05	1.85E-05	0.99
100	2.10E-05	2.12E-05	0.99	3.55E-05	3.55E-05	1.00	6.58E-06	6.73E-06	0.98
36	1.52E-05	1.53E-05	0.99	2.94E-05	2.93E-05	1.00	3.25E-06	3.31E-06	0.98
10	8.65E-06	8.77E-06	0.99	2.17E-05	2.18E-05	1.00	1.09E-06	1.13E-06	0.97
4	4.97E-06	5.03E-06	0.99	1.65E-05	1.65E-05	1.00	4.61E-07	4.73E-07	0.97

Table 2.56 Calculation of F_{CD} for Tc-99 in an Area Source without Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.787	0.213	0.211	2.63			
Reference source –		Cover material =	none	Cover thickness, cm =			0	Density of cover, g/cm3 =		1.6
		Source density , g/cm3 =		1.6	Source thickness, cm =			0.001		
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625						
				$F_{CD} = \frac{D(T_c=t_c, T_S=t_s)}{D(T_c=0, T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,						
FCD-surf=	0.00007250		(Note: FCD-surf = FCD × Surface activity conversion factor)							

Table 2.57 Calculation of F_{AM} for Tc-99 in a Reference Area Source without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	0.001772	0.98	0.361	1.88E-04	1.88E-04	2.77E-01	4.26E-01	1.88E-04

ta (cm) =	100		tc (cm) =	0		Source-ref area (m2) =		3.36E+06	

exp(-ux)/x2 - ref	dist. in -ref-air (cm)	dist. in-ref-cover (cm)	mfp-dist. in -ref-air	mfp-dist. in-ref-cover	BF-ref-air	BF-ref-cover	Vol-source-ref	F_{AM}-ref	4π x dist-ref^2 (cm2)	distance-ref (cm)	r - ref (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.81E-06	1.00E+02	0.00E+00	1.88E-02	0.00E+00	1.05E+00	1.00E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	1.00		
7.73E-06	1.00E+02	0.00E+00	1.88E-02	0.00E+00	1.05E+00	1.00E+00	3.14E-02	2.55E-07	1.27E+05	1.00E+02	1.00E-01	1	1.00		
7.72E-06	1.01E+02	0.00E+00	1.89E-02	0.00E+00	1.05E+00	1.00E+00	1.91E-03	1.55E-08	1.27E+05	1.01E+02	1.03E-01	1	1.00		
7.72E-06	1.01E+02	0.00E+00	1.89E-02	0.00E+00	1.05E+00	1.00E+00	2.03E-03	1.65E-08	1.27E+05	1.01E+02	1.06E-01	1	1.00		
7.71E-06	1.01E+02	0.00E+00	1.89E-02	0.00E+00	1.05E+00	1.00E+00	2.15E-03	1.75E-08	1.27E+05	1.01E+02	1.09E-01	1	1.00		
7.71E-06	1.01E+02	0.00E+00	1.89E-02	0.00E+00	1.05E+00	1.00E+00	2.29E-03	1.85E-08	1.27E+05	1.01E+02	1.13E-01	1	1.00		
7.70E-06	1.01E+02	0.00E+00	1.89E-02	0.00E+00	1.05E+00	1.00E+00	2.42E-03	1.96E-08	1.27E+05	1.01E+02	1.16E-01	1	1.00		
7.70E-06	1.01E+02	0.00E+00	1.89E-02	0.00E+00	1.05E+00	1.00E+00	2.57E-03	2.08E-08	1.28E+05	1.01E+02	1.19E-01	1	1.00	0	100
7.69E-06	1.01E+02	0.00E+00	1.89E-02	0.00E+00	1.05E+00	1.00E+00	2.73E-03	2.21E-08	1.28E+05	1.01E+02	1.23E-01	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
3.55E-09	3.43E+03	0.00E+00	6.43E-01	0.00E+00	2.95E+00	1.00E+00	1.44E+02	1.50E-06	1.48E+08	3.43E+03	3.43E+01	1	1.00		
3.37E-09	3.50E+03	0.00E+00	6.56E-01	0.00E+00	3.00E+00	1.00E+00	1.49E+02	1.51E-06	1.54E+08	3.50E+03	3.50E+01	1	1.00		
3.20E-09	3.57E+03	0.00E+00	6.69E-01	0.00E+00	3.06E+00	1.00E+00	1.55E+02	1.52E-06	1.60E+08	3.57E+03	3.57E+01	1	1.00		
3.03E-09	3.64E+03	0.00E+00	6.83E-01	0.00E+00	3.11E+00	1.00E+00	1.62E+02	1.53E-06	1.67E+08	3.64E+03	3.64E+01	1	1.00		
2.87E-09	3.71E+03	0.00E+00	6.96E-01	0.00E+00	3.17E+00	1.00E+00	1.68E+02	1.53E-06	1.73E+08	3.71E+03	3.71E+01	1	1.00		
2.72E-09	3.79E+03	0.00E+00	7.10E-01	0.00E+00	3.23E+00	1.00E+00	1.75E+02	1.54E-06	1.80E+08	3.79E+03	3.79E+01	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
6.49E-20	9.94E+04	0.00E+00	1.86E+01	0.00E+00	1.53E+03	1.00E+00	1.21E+05	1.20E-11	1.24E+11	9.94E+04	9.94E+02	1	1.00		
4.29E-20	1.01E+05	0.00E+00	1.90E+01	0.00E+00	1.61E+03	1.00E+00	1.25E+05	8.66E-12	1.29E+11	1.01E+05	1.01E+03	1	1.00		
2.82E-20	1.03E+05	0.00E+00	1.94E+01	0.00E+00	1.68E+03	1.00E+00	1.30E+05	6.20E-12	1.34E+11	1.03E+05	1.03E+03	1	1.00		
							∑ F_{AM}-ref =	3.52E-04							

Table 2.58 Calculation of F_{AM} for Tc-99 in an Area Source of 4 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	0.001772	0.98	0.361	1.88E-04	1.88E-04	2.77E-01	4.26E-01	1.88E-04

ta (cm) =	100		tc (cm) =	0		Source area (m2) =	4	Source-ref area (m2) =	3.36E+06

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.81E-06	1.88E-02	0.00E+00	1.00E+02	0.00E+00	1.05E+00	1.00E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	1.00		
7.73E-06	1.88E-02	0.00E+00	1.00E+02	0.00E+00	1.05E+00	1.00E+00	3.14E-02	2.55E-07	1.27E+05	1.00E+02	1.00E-01	1	1.00		
7.72E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	1.91E-03	1.55E-08	1.27E+05	1.01E+02	1.03E-01	1	1.00		
7.72E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	2.03E-03	1.65E-08	1.27E+05	1.01E+02	1.06E-01	1	1.00		
7.71E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	2.15E-03	1.75E-08	1.27E+05	1.01E+02	1.09E-01	1	1.00		
7.71E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	2.29E-03	1.85E-08	1.27E+05	1.01E+02	1.13E-01	1	1.00		
7.70E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	2.42E-03	1.96E-08	1.27E+05	1.01E+02	1.16E-01	1	1.00		
7.70E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	2.57E-03	2.08E-08	1.28E+05	1.01E+02	1.19E-01	1	1.00		
7.69E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	2.73E-03	2.21E-08	1.28E+05	1.01E+02	1.23E-01	1	1.00		
7.68E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	2.90E-03	2.34E-08	1.28E+05	1.01E+02	1.27E-01	1	1.00		
7.67E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	3.07E-03	2.48E-08	1.28E+05	1.01E+02	1.30E-01	1	1.00		
7.67E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	3.26E-03	2.63E-08	1.28E+05	1.01E+02	1.34E-01	1	1.00		
7.66E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	3.46E-03	2.78E-08	1.28E+05	1.01E+02	1.38E-01	1	1.00		
7.65E-06	1.89E-02	0.00E+00	1.01E+02	0.00E+00	1.05E+00	1.00E+00	3.67E-03	2.95E-08	1.28E+05	1.01E+02	1.43E-01	1	1.00	1	100
..	..	..	..	..	..	..	..	..	..	..	..	..	0.00		
3.86E-06	2.66E-02	0.00E+00	1.42E+02	0.00E+00	1.07E+00	1.00E+00	1.81E-01	7.51E-07	2.52E+05	1.42E+02	1.00E+00	1	1.00		
3.75E-06	2.70E-02	0.00E+00	1.44E+02	0.00E+00	1.07E+00	1.00E+00	1.93E-01	7.74E-07	2.60E+05	1.44E+02	1.03E+00	1	1.00		
3.63E-06	2.74E-02	0.00E+00	1.46E+02	0.00E+00	1.07E+00	1.00E+00	2.04E-01	7.96E-07	2.68E+05	1.46E+02	1.06E+00	1	1.00		
3.51E-06	2.78E-02	0.00E+00	1.48E+02	0.00E+00	1.07E+00	1.00E+00	2.17E-01	8.19E-07	2.77E+05	1.48E+02	1.10E+00	1	1.00		
3.40E-06	2.83E-02	0.00E+00	1.51E+02	0.00E+00	1.08E+00	1.00E+00	2.30E-01	8.41E-07	2.86E+05	1.51E+02	1.13E+00	1	1.00		
						∑ FAM-source =		2.11E-05							
						FAM =		6.00E-02							

Table 2.59 Calculation of F_{AM} for Tc-99 in an Area Source of 10 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	0.001772	0.98	0.361	1.88E-04	1.88E-04	2.77E-01	4.26E-01	1.88E-04

ta (cm) =	100		tc (cm) =	0		Source area (m2) =		10	Source-ref area (m2) =		3359362				
exp(-ux)/x2 - source	mfp-dist. - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
3.29E-06	2.88E-02	0.00E+00	1.53E+02	0.00E+00	1.08E+00	1.00E+00	2.44E-01	8.64E-07	2.96E+05	1.53E+02	1.16E+00	1	1.00		
3.17E-06	2.93E-02	0.00E+00	1.56E+02	0.00E+00	1.08E+00	1.00E+00	2.59E-01	8.86E-07	3.06E+05	1.56E+02	1.20E+00	1	1.00		
3.06E-06	2.98E-02	0.00E+00	1.59E+02	0.00E+00	1.08E+00	1.00E+00	2.75E-01	9.08E-07	3.17E+05	1.59E+02	1.23E+00	1	1.00		
2.95E-06	3.03E-02	0.00E+00	1.62E+02	0.00E+00	1.08E+00	1.00E+00	2.91E-01	9.30E-07	3.29E+05	1.62E+02	1.27E+00	1	1.00		
2.84E-06	3.09E-02	0.00E+00	1.65E+02	0.00E+00	1.08E+00	1.00E+00	3.09E-01	9.52E-07	3.41E+05	1.65E+02	1.31E+00	1	1.00		
2.74E-06	3.15E-02	0.00E+00	1.68E+02	0.00E+00	1.08E+00	1.00E+00	3.28E-01	9.73E-07	3.54E+05	1.68E+02	1.35E+00	1	1.00		
2.63E-06	3.21E-02	0.00E+00	1.71E+02	0.00E+00	1.09E+00	1.00E+00	3.48E-01	9.94E-07	3.68E+05	1.71E+02	1.39E+00	1	1.00		
2.53E-06	3.27E-02	0.00E+00	1.75E+02	0.00E+00	1.09E+00	1.00E+00	3.69E-01	1.01E-06	3.83E+05	1.75E+02	1.43E+00	1	1.00		
2.43E-06	3.34E-02	0.00E+00	1.78E+02	0.00E+00	1.09E+00	1.00E+00	3.91E-01	1.04E-06	3.98E+05	1.78E+02	1.47E+00	1	1.00	0	100
2.33E-06	3.41E-02	0.00E+00	1.82E+02	0.00E+00	1.09E+00	1.00E+00	4.15E-01	1.06E-06	4.15E+05	1.82E+02	1.52E+00	1	1.00		
2.23E-06	3.48E-02	0.00E+00	1.86E+02	0.00E+00	1.09E+00	1.00E+00	4.41E-01	1.08E-06	4.33E+05	1.86E+02	1.56E+00	1	1.00		
2.14E-06	3.55E-02	0.00E+00	1.89E+02	0.00E+00	1.10E+00	1.00E+00	4.67E-01	1.09E-06	4.51E+05	1.89E+02	1.61E+00	1	1.00		
2.05E-06	3.63E-02	0.00E+00	1.94E+02	0.00E+00	1.10E+00	1.00E+00	4.96E-01	1.11E-06	4.71E+05	1.94E+02	1.66E+00	1	1.00		
1.96E-06	3.71E-02	0.00E+00	1.98E+02	0.00E+00	1.10E+00	1.00E+00	5.26E-01	1.13E-06	4.92E+05	1.98E+02	1.71E+00	1	1.00		
1.87E-06	3.79E-02	0.00E+00	2.02E+02	0.00E+00	1.10E+00	1.00E+00	5.58E-01	1.15E-06	5.15E+05	2.02E+02	1.76E+00	1	1.00		
1.81E-06	3.85E-02	0.00E+00	2.05E+02	0.00E+00	1.10E+00	1.00E+00	3.93E-01	7.87E-07	5.30E+05	2.05E+02	1.79E+00	1	1.00		
							∑ F_{AM}-source =	3.71E-05							
							F_{AM} =	1.05E-01							

Table 2.60 Calculation of F_{AM} for Tc-99 in an Area Source of 36 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	0.001772	0.98	0.361	1.88E-04	1.88E-04	2.77E-01	4.26E-01	1.88E-04

ta (cm) =	100		tc (cm) =	0		Source area (m2) =	36		Source-ref area (m2) =	3359362				

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.71E-06	3.97E-02	0.00E+00	2.12E+02	0.00E+00	1.11E+00	1.00E+00	4.25E-01	8.02E-07	5.64E+05	2.12E+02	1.87E+00	1	1.00		
1.65E-06	4.03E-02	0.00E+00	2.15E+02	0.00E+00	1.11E+00	1.00E+00	4.42E-01	8.10E-07	5.81E+05	2.15E+02	1.90E+00	1	1.00		
1.60E-06	4.10E-02	0.00E+00	2.18E+02	0.00E+00	1.11E+00	1.00E+00	4.60E-01	8.18E-07	6.00E+05	2.18E+02	1.94E+00	1	1.00		
1.55E-06	4.16E-02	0.00E+00	2.22E+02	0.00E+00	1.11E+00	1.00E+00	4.79E-01	8.25E-07	6.19E+05	2.22E+02	1.98E+00	1	1.00		
1.50E-06	4.23E-02	0.00E+00	2.25E+02	0.00E+00	1.11E+00	1.00E+00	4.98E-01	8.33E-07	6.39E+05	2.25E+02	2.02E+00	1	1.00		
1.45E-06	4.30E-02	0.00E+00	2.29E+02	0.00E+00	1.12E+00	1.00E+00	5.18E-01	8.40E-07	6.60E+05	2.29E+02	2.06E+00	1	1.00		
1.41E-06	4.37E-02	0.00E+00	2.33E+02	0.00E+00	1.12E+00	1.00E+00	5.39E-01	8.47E-07	6.81E+05	2.33E+02	2.10E+00	1	1.00		
1.36E-06	4.44E-02	0.00E+00	2.37E+02	0.00E+00	1.12E+00	1.00E+00	5.61E-01	8.54E-07	7.04E+05	2.37E+02	2.14E+00	1	1.00		
1.32E-06	4.51E-02	0.00E+00	2.40E+02	0.00E+00	1.12E+00	1.00E+00	5.84E-01	8.61E-07	7.27E+05	2.40E+02	2.19E+00	1	1.00		
1.27E-06	4.58E-02	0.00E+00	2.44E+02	0.00E+00	1.12E+00	1.00E+00	6.07E-01	8.67E-07	7.51E+05	2.44E+02	2.23E+00	1	1.00	0	100
1.23E-06	4.66E-02	0.00E+00	2.49E+02	0.00E+00	1.13E+00	1.00E+00	6.32E-01	8.74E-07	7.76E+05	2.49E+02	2.28E+00	1	1.00		
1.19E-06	4.74E-02	0.00E+00	2.53E+02	0.00E+00	1.13E+00	1.00E+00	6.57E-01	8.80E-07	8.03E+05	2.53E+02	2.32E+00	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
7.77E-07	5.83E-02	0.00E+00	3.11E+02	0.00E+00	1.16E+00	1.00E+00	1.06E+00	9.50E-07	1.21E+06	3.11E+02	2.94E+00	1	1.00		
7.49E-07	5.93E-02	0.00E+00	3.16E+02	0.00E+00	1.16E+00	1.00E+00	1.10E+00	9.55E-07	1.26E+06	3.16E+02	3.00E+00	1	1.00		
7.22E-07	6.04E-02	0.00E+00	3.22E+02	0.00E+00	1.16E+00	1.00E+00	1.14E+00	9.60E-07	1.30E+06	3.22E+02	3.06E+00	1	1.00		
6.95E-07	6.15E-02	0.00E+00	3.28E+02	0.00E+00	1.17E+00	1.00E+00	1.19E+00	9.65E-07	1.35E+06	3.28E+02	3.12E+00	1	1.00		
6.70E-07	6.26E-02	0.00E+00	3.34E+02	0.00E+00	1.17E+00	1.00E+00	1.24E+00	9.70E-07	1.40E+06	3.34E+02	3.19E+00	1	1.00		
6.46E-07	6.38E-02	0.00E+00	3.40E+02	0.00E+00	1.17E+00	1.00E+00	1.29E+00	9.75E-07	1.45E+06	3.40E+02	3.25E+00	1	1.00		
6.22E-07	6.49E-02	0.00E+00	3.46E+02	0.00E+00	1.17E+00	1.00E+00	1.34E+00	9.80E-07	1.51E+06	3.46E+02	3.31E+00	1	1.00		
							∑ F_{AM}-source =	6.58E-05							
							F_{AM} =	1.87E-01							

Table 2.61 Calculation of F_{AM} for Tc-99 in an Area Source of 100 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)							
1	0.101	0.001772	0.98	0.361	1.88E-04	1.88E-04	2.77E-01	4.26E-01	1.88E-04							
ta (cm) =	100		tc (cm) =	0		Source area (m2) =		100	Source-ref area (m2) =		3.4E+06					
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)	
5.77E-07	6.73E-02	0.00E+00	3.59E+02	0.00E+00	1.18E+00	1.00E+00	1.45E+00	9.89E-07	1.62E+06	3.59E+02	3.45E+00	1	1.00			
5.55E-07	6.86E-02	0.00E+00	3.66E+02	0.00E+00	1.18E+00	1.00E+00	1.51E+00	9.94E-07	1.68E+06	3.66E+02	3.52E+00	1	1.00			
5.35E-07	6.99E-02	0.00E+00	3.72E+02	0.00E+00	1.19E+00	1.00E+00	1.57E+00	9.98E-07	1.74E+06	3.72E+02	3.59E+00	1	1.00			
5.15E-07	7.11E-02	0.00E+00	3.79E+02	0.00E+00	1.19E+00	1.00E+00	1.63E+00	1.00E-06	1.81E+06	3.79E+02	3.66E+00	1	1.00			
4.95E-07	7.25E-02	0.00E+00	3.86E+02	0.00E+00	1.20E+00	1.00E+00	1.70E+00	1.01E-06	1.88E+06	3.86E+02	3.73E+00	1	1.00			
4.77E-07	7.38E-02	0.00E+00	3.94E+02	0.00E+00	1.20E+00	1.00E+00	1.77E+00	1.01E-06	1.95E+06	3.94E+02	3.81E+00	1	1.00			
4.59E-07	7.52E-02	0.00E+00	4.01E+02	0.00E+00	1.20E+00	1.00E+00	1.84E+00	1.02E-06	2.02E+06	4.01E+02	3.88E+00	1	1.00			
4.41E-07	7.66E-02	0.00E+00	4.09E+02	0.00E+00	1.21E+00	1.00E+00	1.91E+00	1.02E-06	2.10E+06	4.09E+02	3.96E+00	1	1.00			
4.25E-07	7.81E-02	0.00E+00	4.16E+02	0.00E+00	1.21E+00	1.00E+00	1.99E+00	1.02E-06	2.18E+06	4.16E+02	4.04E+00	1	1.00			
4.08E-07	7.95E-02	0.00E+00	4.24E+02	0.00E+00	1.21E+00	1.00E+00	2.07E+00	1.03E-06	2.26E+06	4.24E+02	4.12E+00	1	1.00			
3.93E-07	8.10E-02	0.00E+00	4.32E+02	0.00E+00	1.22E+00	1.00E+00	2.16E+00	1.03E-06	2.35E+06	4.32E+02	4.20E+00	1	1.00			
3.78E-07	8.26E-02	0.00E+00	4.40E+02	0.00E+00	1.22E+00	1.00E+00	2.24E+00	1.04E-06	2.44E+06	4.40E+02	4.29E+00	1	1.00			
3.63E-07	8.41E-02	0.00E+00	4.49E+02	0.00E+00	1.23E+00	1.00E+00	2.33E+00	1.04E-06	2.53E+06	4.49E+02	4.37E+00	1	1.00	0	100	
3.49E-07	8.57E-02	0.00E+00	4.57E+02	0.00E+00	1.23E+00	1.00E+00	2.43E+00	1.04E-06	2.63E+06	4.57E+02	4.46E+00	1	1.00			
3.36E-07	8.74E-02	0.00E+00	4.66E+02	0.00E+00	1.24E+00	1.00E+00	2.53E+00	1.05E-06	2.73E+06	4.66E+02	4.55E+00	1	1.00			
3.23E-07	8.90E-02	0.00E+00	4.75E+02	0.00E+00	1.24E+00	1.00E+00	2.63E+00	1.05E-06	2.83E+06	4.75E+02	4.64E+00	1	1.00			
3.10E-07	9.07E-02	0.00E+00	4.84E+02	0.00E+00	1.24E+00	1.00E+00	2.73E+00	1.06E-06	2.94E+06	4.84E+02	4.73E+00	1	1.00			
2.98E-07	9.25E-02	0.00E+00	4.93E+02	0.00E+00	1.25E+00	1.00E+00	2.85E+00	1.06E-06	3.06E+06	4.93E+02	4.83E+00	1	1.00			
2.87E-07	9.43E-02	0.00E+00	5.03E+02	0.00E+00	1.25E+00	1.00E+00	2.96E+00	1.06E-06	3.18E+06	5.03E+02	4.93E+00	1	1.00			
2.75E-07	9.61E-02	0.00E+00	5.12E+02	0.00E+00	1.26E+00	1.00E+00	3.08E+00	1.07E-06	3.30E+06	5.12E+02	5.02E+00	1	1.00			
2.65E-07	9.79E-02	0.00E+00	5.22E+02	0.00E+00	1.26E+00	1.00E+00	3.20E+00	1.07E-06	3.43E+06	5.22E+02	5.12E+00	1	1.00			
2.54E-07	9.98E-02	0.00E+00	5.32E+02	0.00E+00	1.27E+00	1.00E+00	3.33E+00	1.08E-06	3.56E+06	5.32E+02	5.23E+00	1	1.00			
2.44E-07	1.02E-01	0.00E+00	5.42E+02	0.00E+00	1.27E+00	1.00E+00	3.47E+00	1.08E-06	3.70E+06	5.42E+02	5.33E+00	1	1.00			
2.35E-07	1.04E-01	0.00E+00	5.53E+02	0.00E+00	1.28E+00	1.00E+00	3.61E+00	1.08E-06	3.84E+06	5.53E+02	5.44E+00	1	1.00			
2.25E-07	1.06E-01	0.00E+00	5.64E+02	0.00E+00	1.28E+00	1.00E+00	3.75E+00	1.09E-06	3.99E+06	5.64E+02	5.55E+00	1	1.00			
2.16E-07	1.08E-01	0.00E+00	5.75E+02	0.00E+00	1.29E+00	1.00E+00	3.91E+00	1.09E-06	4.15E+06	5.75E+02	5.66E+00	1	1.00			
							∑ F_{AM}-source =		9.29E-05							
							F_{AM} =		2.64E-01							

Table 2.62 Calculation of F_{AM} for Tc-99 in an Area Source of 1,000 m^2 without Cover at the Receptor Location (0, 0, 10) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	0.001772	0.98	0.361	1.88E-04	1.88E-04	2.77E-01	4.26E-01	1.88E-04

ta (cm) =	100		tc (cm) =	0		Source area (m2) =	1000	Source-ref area (m2) =	3.36E+06

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
2.08E-07	1.10E-01	0.00E+00	5.86E+02	0.00E+00	1.30E+00	1.00E+00	4.06E+00	1.09E-06	4.31E+06	5.86E+02	5.77E+00	1	1.00		
2.00E-07	1.12E-01	0.00E+00	5.97E+02	0.00E+00	1.30E+00	1.00E+00	4.23E+00	1.10E-06	4.48E+06	5.97E+02	5.89E+00	1	1.00		
1.92E-07	1.14E-01	0.00E+00	6.09E+02	0.00E+00	1.31E+00	1.00E+00	4.40E+00	1.10E-06	4.66E+06	6.09E+02	6.00E+00	1	1.00		
1.84E-07	1.16E-01	0.00E+00	6.20E+02	0.00E+00	1.31E+00	1.00E+00	4.58E+00	1.11E-06	4.84E+06	6.20E+02	6.12E+00	1	1.00		
1.77E-07	1.19E-01	0.00E+00	6.33E+02	0.00E+00	1.32E+00	1.00E+00	4.76E+00	1.11E-06	5.03E+06	6.33E+02	6.25E+00	1	1.00		
1.69E-07	1.21E-01	0.00E+00	6.45E+02	0.00E+00	1.33E+00	1.00E+00	4.95E+00	1.11E-06	5.23E+06	6.45E+02	6.37E+00	1	1.00		
1.63E-07	1.23E-01	0.00E+00	6.58E+02	0.00E+00	1.33E+00	1.00E+00	5.15E+00	1.12E-06	5.43E+06	6.58E+02	6.50E+00	1	1.00		
1.56E-07	1.26E-01	0.00E+00	6.70E+02	0.00E+00	1.34E+00	1.00E+00	5.36E+00	1.12E-06	5.65E+06	6.70E+02	6.63E+00	1	1.00		
1.50E-07	1.28E-01	0.00E+00	6.83E+02	0.00E+00	1.35E+00	1.00E+00	5.58E+00	1.12E-06	5.87E+06	6.83E+02	6.76E+00	1	1.00	0	100
1.44E-07	1.31E-01	0.00E+00	6.97E+02	0.00E+00	1.35E+00	1.00E+00	5.80E+00	1.13E-06	6.10E+06	6.97E+02	6.90E+00	1	1.00		
1.38E-07	1.33E-01	0.00E+00	7.11E+02	0.00E+00	1.36E+00	1.00E+00	6.04E+00	1.13E-06	6.35E+06	7.11E+02	7.03E+00	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.24E-08	3.04E-01	0.00E+00	1.62E+03	0.00E+00	1.82E+00	1.00E+00	3.19E+01	1.30E-06	3.30E+07	1.62E+03	1.62E+01	1	1.00		
2.14E-08	3.10E-01	0.00E+00	1.65E+03	0.00E+00	1.83E+00	1.00E+00	3.32E+01	1.30E-06	3.43E+07	1.65E+03	1.65E+01	1	1.00		
2.04E-08	3.16E-01	0.00E+00	1.68E+03	0.00E+00	1.85E+00	1.00E+00	3.45E+01	1.31E-06	3.57E+07	1.68E+03	1.68E+01	1	1.00		
1.95E-08	3.22E-01	0.00E+00	1.72E+03	0.00E+00	1.87E+00	1.00E+00	3.59E+01	1.31E-06	3.71E+07	1.72E+03	1.71E+01	1	1.00		
1.87E-08	3.29E-01	0.00E+00	1.75E+03	0.00E+00	1.88E+00	1.00E+00	3.73E+01	1.31E-06	3.86E+07	1.75E+03	1.75E+01	1	1.00		
1.78E-08	3.35E-01	0.00E+00	1.79E+03	0.00E+00	1.90E+00	1.00E+00	3.88E+01	1.32E-06	4.01E+07	1.79E+03	1.78E+01	1	1.00		
							∑ F_{AM}-source =	1.63E-04							
							F_{AM} =	4.62E-01							

Table 2.63 Calculation of F_{AM} for Tc-99 in an Area Source of 10,000 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	0.001772	0.98	0.361	1.88E-04	1.88E-04	2.77E-01	4.26E-01	1.88E-04

ta (cm) =	100		tc (cm) =	0		Source area (m2) =	10000	Source-ref area (m2) =	3.36E+06

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.70E-08	3.42E-01	0.00E+00	1.82E+03	0.00E+00	1.92E+00	1.00E+00	4.04E+01	1.32E-06	4.18E+07	1.82E+03	1.82E+01	1	1.00		
1.62E-08	3.49E-01	0.00E+00	1.86E+03	0.00E+00	1.94E+00	1.00E+00	4.21E+01	1.32E-06	4.34E+07	1.86E+03	1.86E+01	1	1.00		
1.55E-08	3.56E-01	0.00E+00	1.90E+03	0.00E+00	1.96E+00	1.00E+00	4.37E+01	1.33E-06	4.52E+07	1.90E+03	1.89E+01	1	1.00		
1.48E-08	3.63E-01	0.00E+00	1.93E+03	0.00E+00	1.98E+00	1.00E+00	4.55E+01	1.33E-06	4.70E+07	1.93E+03	1.93E+01	1	1.00		
1.41E-08	3.70E-01	0.00E+00	1.97E+03	0.00E+00	2.00E+00	1.00E+00	4.74E+01	1.34E-06	4.89E+07	1.97E+03	1.97E+01	1	1.00		
1.35E-08	3.77E-01	0.00E+00	2.01E+03	0.00E+00	2.02E+00	1.00E+00	4.93E+01	1.34E-06	5.09E+07	2.01E+03	2.01E+01	1	1.00		
1.29E-08	3.85E-01	0.00E+00	2.05E+03	0.00E+00	2.04E+00	1.00E+00	5.13E+01	1.34E-06	5.29E+07	2.05E+03	2.05E+01	1	1.00		
1.23E-08	3.93E-01	0.00E+00	2.09E+03	0.00E+00	2.06E+00	1.00E+00	5.33E+01	1.35E-06	5.51E+07	2.09E+03	2.09E+01	1	1.00		
1.17E-08	4.00E-01	0.00E+00	2.13E+03	0.00E+00	2.08E+00	1.00E+00	5.55E+01	1.35E-06	5.73E+07	2.13E+03	2.13E+01	1	1.00		
1.12E-08	4.08E-01	0.00E+00	2.18E+03	0.00E+00	2.10E+00	1.00E+00	5.77E+01	1.35E-06	5.96E+07	2.18E+03	2.17E+01	1	1.00		
1.06E-08	4.16E-01	0.00E+00	2.22E+03	0.00E+00	2.12E+00	1.00E+00	6.01E+01	1.36E-06	6.20E+07	2.22E+03	2.22E+01	1	1.00	0	100
1.01E-08	4.25E-01	0.00E+00	2.26E+03	0.00E+00	2.14E+00	1.00E+00	6.25E+01	1.36E-06	6.45E+07	2.26E+03	2.26E+01	1	1.00		
9.66E-09	4.33E-01	0.00E+00	2.31E+03	0.00E+00	2.17E+00	1.00E+00	6.50E+01	1.36E-06	6.71E+07	2.31E+03	2.31E+01	1	1.00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
1.18E-09	9.56E-01	0.00E+00	5.10E+03	0.00E+00	4.26E+00	1.00E+00	3.17E+02	1.59E-06	3.27E+08	5.10E+03	5.10E+01	1	1.00		
1.11E-09	9.75E-01	0.00E+00	5.20E+03	0.00E+00	4.34E+00	1.00E+00	3.30E+02	1.59E-06	3.40E+08	5.20E+03	5.20E+01	1	1.00		
1.05E-09	9.95E-01	0.00E+00	5.30E+03	0.00E+00	4.42E+00	1.00E+00	3.43E+02	1.59E-06	3.54E+08	5.30E+03	5.30E+01	1	1.00		
9.86E-10	1.01E+00	0.00E+00	5.41E+03	0.00E+00	4.55E+00	1.00E+00	3.57E+02	1.60E-06	3.68E+08	5.41E+03	5.41E+01	1	1.00		
9.29E-10	1.03E+00	0.00E+00	5.52E+03	0.00E+00	4.69E+00	1.00E+00	3.71E+02	1.62E-06	3.83E+08	5.52E+03	5.52E+01	1	1.00		
8.74E-10	1.06E+00	0.00E+00	5.63E+03	0.00E+00	4.83E+00	1.00E+00	3.86E+02	1.63E-06	3.98E+08	5.63E+03	5.63E+01	1	1.00		
							∑ F_{AM}-source =	2.48E-04							
							F_{AM} =	7.04E-01							

Table 2.64 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Tc-99 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	7.25E-05	10,000	7.04E-01	6.40E-09
				1,000	4.62E-01	4.20E-09
				100	2.64E-01	2.40E-09
				36	1.87E-01	1.70E-09
				10	1.05E-01	9.58E-10
				4	6.00E-02	5.46E-10

Radiation doses at the receptor location (0, 0, 0.3) (m) were estimated with the same procedure used for estimating the doses at the receptor location (0, 0, 1) (m). Because the source thickness (assumed to be 0.001 cm) and cover thickness (0 cm) did not change, the value of F_{CD} stayed the same, as shown in Table 2.56. The values of F_{AM} for each of the six circular area sources were estimated as the sum of the F_{AM}'s for individual annuli that constitute the area source. Because the design of tables used for estimating F_{AM}'s was the same as that of Tables 2.58 to 2.63, these estimation tables are not presented here; only the final value of F_{AM} for each area source are presented, in Table 2.65, which shows the calculation of radiation doses at the receptor location (0, 0, 0.3) (m). Table 2.66 shows the calculation of radiation doses at the receptor location (0, 0, 4) (m).

Comparison of the dose results for Tc-99 between the spreadsheets and RESRAD-BUILD are presented in Table 2.67. Because of the limited number of annuli used in the spreadsheets to approximate the area of the circular sources, it is expected that the estimation of external radiation doses is not as precise by spreadsheets as by the RESRAD-BUILD code. In general, the differences are less than 3%. Based on the comparison, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD code.

2.3.1.2 Risk Results without Shielding

In the spreadsheets, estimates of cancer risks were obtained by multiplying the RESRAD-BUILD dose results with the radionuclide-specific dose-to-risk conversion factors presented in Table 2.10. Tables 2.68, 2.69, and 2.70 compare the cancer risk estimates from the spreadsheets and from the RESRAD-BUILD code for C-14, Mn-54, and Tc-99, respectively, at the three receptor locations associated with external radiation from the six circular area sources without cover. The estimates from the spreadsheets and from RESRAD-BUILD agree with each other.

Table 2.65 Estimation of External Radiation Dose at the Receptor Location (0, 0, 0.3) (m) from Tc-99 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	7.25E-05	10,000	8.72E-01	7.94E-09
				1,000	6.31E-01	5.74E-09
				100	4.30E-01	3.92E-09
				36	3.50E-01	3.18E-09
				10	2.57E-01	2.33E-09
				4	1.93E-01	1.75E-09

Table 2.66 Estimation of External Radiation Dose at the Receptor Location (0, 0, 4) (m) from Tc-99 in Six Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	7.25E-05	10,000	4.99E-01	4.54E-09
				1,000	2.61E-01	2.38E-09
				100	8.88E-02	8.08E-10
				36	4.30E-02	3.92E-10
				10	1.45E-02	1.32E-10
				4	6.07E-03	5.52E-11

Table 2.67 Comparison of Radiation Doses (mrem/yr) Estimated by RESRAD-BUILD and Spreadsheets from Tc-99 in Six Area Sources without Cover

Area of Source (m^2)	Receptor Location (0, 0, 1) (m)			Receptor Location (0, 0, 0.3) (m)			Receptor Location (0, 0, 4) (m)		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	6.50E-09	6.40E-09	1.02	8.12E-09	7.94E-09	1.02	4.61E-09	4.54E-09	1.01
1,000	4.19E-09	4.20E-09	1.00	5.80E-09	5.74E-09	1.01	2.34E-09	2.38E-09	0.98
100	2.41E-09	2.40E-09	1.00	3.99E-09	3.92E-09	1.02	7.88E-10	8.08E-10	0.97
36	1.72E-09	1.70E-09	1.01	3.27E-09	3.18E-09	1.03	3.84E-10	3.92E-10	0.98
10	9.66E-10	9.58E-10	1.01	2.41E-09	2.33E-09	1.03	1.28E-10	1.32E-10	0.97
4	5.53E-10	5.46E-10	1.01	1.81E-09	1.75E-09	1.03	5.39E-11	5.52E-11	0.98

Table 2.68 Comparison of Cancer Risks (1/yr) Estimated by Spreadsheets and RESRAD-BUILD from C-14 in Six Area Sources without Cover

Area of Source (m2)	Receptor Location (0, 0, 1) (m)			Receptor Location (0, 0, 0.3) (m)			Receptor Location (0, 0, 4) (m)		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	9.22E-16	9.23E-16	1.00	1.14E-15	1.15E-15	0.99	6.57E-16	6.60E-16	1.00
1,000	6.08E-16	6.08E-16	1.00	8.26E-16	8.30E-16	1.00	3.49E-16	3.51E-16	1.00
100	3.39E-16	3.41E-16	1.00	5.54E-16	5.56E-16	1.00	1.15E-16	1.16E-16	0.99
36	2.39E-16	2.40E-16	1.00	4.49E-16	4.51E-16	1.00	5.57E-17	5.59E-17	1.00
10	1.33E-16	1.34E-16	0.99	3.27E-16	3.28E-16	1.00	1.85E-17	1.85E-17	1.00
4	7.59E-17	7.60E-17	1.00	2.46E-16	2.47E-16	1.00	7.77E-18	7.83E-18	0.99

Table 2.69 Comparison of Cancer Risks (1/yr) Estimated by RESRAD-BUILD and Spreadsheets from Mn-54 in Six Area Sources without Cover

Area of Source (m2)	Receptor Location (0, 0, 1) (m)			Receptor Location (0, 0, 0.3) (m)			Receptor Location (0, 0, 4) (m)		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	3.62E-11	3.62E-11	1.00	4.72E-11	4.71E-11	1.00	2.35E-11	2.36E-11	1.00
1,000	2.61E-11	2.61E-11	1.00	3.71E-11	3.71E-11	1.00	1.37E-11	1.37E-11	1.00
100	1.59E-11	1.58E-11	1.00	2.68E-11	2.68E-11	1.00	4.96E-12	4.96E-12	1.00
36	1.15E-11	1.15E-11	1.00	2.21E-11	2.22E-11	1.00	2.45E-12	2.45E-12	1.00
10	6.52E-12	6.52E-12	1.00	1.64E-11	1.64E-11	1.00	8.23E-13	8.22E-13	1.00
4	3.75E-12	3.75E-12	1.00	1.24E-11	1.24E-11	0.99	3.47E-13	3.48E-13	1.00

Table 2.70 Comparison of Cancer Risks (1/yr) Estimated by RESRAD-BUILD and Spreadsheets from Tc-99 in Six Area Source without Cover

Area of Source (m2)	Receptor Location (0, 0, 1) (m)			Receptor Location (0, 0, 0.3) (m)			Receptor Location (0, 0, 4) (m)		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	4.22E-15	4.20E-15	1.00	5.20E-15	5.25E-15	0.99	2.99E-15	2.98E-15	1.00
1,000	2.61E-15	2.71E-15	0.96	3.76E-15	3.75E-15	1.00	1.52E-15	1.51E-15	1.01
100	1.59E-15	1.56E-15	1.02	2.59E-15	2.58E-15	1.00	5.11E-16	5.09E-16	1.00
36	1.15E-15	1.11E-15	1.03	2.12E-15	2.11E-15	1.00	2.49E-16	2.48E-16	1.00
10	6.27E-16	6.24E-16	1.00	1.56E-15	1.56E-15	1.00	8.30E-17	8.27E-17	1.00
4	3.58E-16	3.57E-16	1.00	1.18E-15	1.17E-15	1.01	3.50E-17	3.48E-17	1.01

2.3.1.3 Dose Results with Concrete Shielding

Results for C-14. To verify external dose modeling when radiation was attenuated by shielding materials in RESRAD-BUILD, the radiation doses at the receptor location (0, 0, 1) (m) from each of the six area sources with a concrete cover of 1-cm thickness were estimated with spreadsheets.

Table 2.71 shows the calculation of F_{CD}, the cover and depth factor, for C-14. Table 2.72 shows the estimation of $F_{AM\text{-}ref}$ for the reference area source, which is made of soil having an infinite extent. In the estimation, an area of about 3,000,000 m^2 was used for the reference source. Tables 2.73 to 2.78 show the estimation of F_{AM}'s for the six circular area sources considered in this comparison. After F_{CD} and F_{AM}'s were available, external radiation doses resulting from C-14 in each of the six circular area sources were estimated by adjusting the external radiation dose conversion factor for an infinite volume source from FGR 12, as shown in Table 2.79.

Radiation doses at the same receptor location (0, 0, 1) (m) but with a concrete cover of 5-cm thickness on each of the six area sources were then estimated. Table 2.80 shows the calculation of F_{CD}, the cover and depth factor, for C-14. The $F_{AM\text{-}ref}$ for the reference source and F_{AM} for each of the six circular area sources were estimated with the same calculations as implemented in Tables 2.72 to 2.78 but for a cover thickness of 5 cm. The final values of F_{AM} for each area source are listed in Table 2.81, which shows the calculation of external radiation doses attenuated by the 5-cm concrete cover at the receptor location.

Comparisons of the dose results for C-14 between the spreadsheets and RESRAD-BUILD are presented in Table 2.82. In general, the differences are less than 7%. Based on the comparison, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Results for Mn-54. To verify external dose modeling when radiation was attenuated by shielding materials in RESRAD-BUILD, the radiation doses at the receptor location (0, 0, 1) (m) from each of the six area sources with a concrete cover of 1-cm thickness were estimated with spreadsheets. Table 2.83 shows the calculation of F_{CD}, the cover and depth factor, for Mn-54. Table 2.84 shows the estimation of $F_{AM\text{-}ref}$ for the reference area source, which is made of soil having an infinite extent. In the estimation, an area of about 3,000,000 m^2 was used for the reference source. Tables 2.85 to 2.90 show the estimation of F_{AM}'s for the six circular area sources considered in this comparison. After F_{CD} and F_{AM}'s were available, external radiation dose resulting from Mn-54 in each of the six circular area sources were estimated by adjusting the external radiation dose conversion factor for an infinite volume source from FGR 12, as shown in Table 2.91.

Table 2.71 Calculation of F_{CD} for C-14 in an Area Source with a Cover of 1 cm

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.642	0.358	0.294	3.39				
Reference source –		Cover material =	none	Cover thickness, cm =			1	Density of cover, g/cm3 =			2.4
		Source density , g/cm3 =		1.6	Source thickness, cm =			0.001			
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625							
FCD-surf=	0.00000935		(Note: FCD-surf = FCD × Surface activity conversion factor)								

$$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$$

Table 2.72 Calculation of F_{AM} for C-14 in a Reference Area Source with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.049	8.65E-04	0.1	0.220	1.02E-02	8.94E-03	8.68E-01	9.99E-01	2.59E-04						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =	4			Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - ref	dist. in -ref-air (cm)	dist. in-ref-cover (cm)	mfp-dist. in -ref-air	mfp-dist. in-ref-cover	BF-ref-air	BF-ref-cover	Vol-source-ref	F_{AM}-ref	4π x dist-ref^2 (cm2)	distance-ref (cm)	r - ref (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
3.25E-06	9.90E+01	1.00E+00	2.56E-02	8.68E-01	1.07E+00	1.96E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	0.99		
3.21E-06	9.95E+01	1.00E+00	2.57E-02	8.73E-01	1.07E+00	1.97E+00	3.14E-02	2.13E-07	1.27E+05	1.00E+02	1.00E-01	1	0.99		
3.20E-06	9.95E+01	1.01E+00	2.57E-02	8.73E-01	1.07E+00	1.97E+00	1.91E-03	1.30E-08	1.27E+05	1.01E+02	1.03E-01	1	0.99		
3.20E-06	9.96E+01	1.01E+00	2.58E-02	8.73E-01	1.07E+00	1.97E+00	2.03E-03	1.37E-08	1.27E+05	1.01E+02	1.06E-01	1	0.99		
3.20E-06	9.96E+01	1.01E+00	2.58E-02	8.73E-01	1.07E+00	1.97E+00	2.15E-03	1.46E-08	1.27E+05	1.01E+02	1.09E-01	1	0.99		
3.19E-06	9.96E+01	1.01E+00	2.58E-02	8.74E-01	1.07E+00	1.97E+00	2.29E-03	1.54E-08	1.27E+05	1.01E+02	1.13E-01	1	0.99		
3.19E-06	9.97E+01	1.01E+00	2.58E-02	8.74E-01	1.07E+00	1.97E+00	2.42E-03	1.64E-08	1.27E+05	1.01E+02	1.16E-01	1	0.99		
3.19E-06	9.97E+01	1.01E+00	2.58E-02	8.74E-01	1.07E+00	1.97E+00	2.57E-03	1.74E-08	1.28E+05	1.01E+02	1.19E-01	1	0.99	0	100
3.18E-06	9.97E+01	1.01E+00	2.58E-02	8.75E-01	1.07E+00	1.97E+00	2.73E-03	1.84E-08	1.28E+05	1.01E+02	1.23E-01	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
3.23E-22	3.40E+03	3.43E+01	8.79E-01	2.98E+01	3.77E+00	1.42E+01	1.44E+02	2.49E-18	1.48E+08	3.43E+03	3.43E+01	1	0.99		
1.68E-22	3.46E+03	3.50E+01	8.96E-01	3.04E+01	3.83E+00	1.45E+01	1.49E+02	1.40E-18	1.54E+08	3.50E+03	3.50E+01	1	0.99		
8.66E-23	3.53E+03	3.57E+01	9.14E-01	3.10E+01	3.89E+00	1.47E+01	1.55E+02	7.72E-19	1.60E+08	3.57E+03	3.57E+01	1	0.99		
4.40E-23	3.60E+03	3.64E+01	9.32E-01	3.16E+01	3.96E+00	1.50E+01	1.62E+02	4.22E-19	1.67E+08	3.64E+03	3.64E+01	1	0.99		
2.21E-23	3.68E+03	3.71E+01	9.51E-01	3.22E+01	4.02E+00	1.52E+01	1.68E+02	2.27E-19	1.73E+08	3.71E+03	3.71E+01	1	0.99		
1.09E-23	3.75E+03	3.79E+01	9.70E-01	3.29E+01	4.09E+00	1.55E+01	1.75E+02	1.21E-19	1.80E+08	3.79E+03	3.79E+01	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
0.00E+00	9.84E+04	9.94E+02	2.55E+01	8.63E+02	3.80E+02	1.84E+01	1.21E+05	0.00E+00	1.24E+11	9.94E+04	9.94E+02	1	0.99		
0.00E+00	1.00E+05	1.01E+03	2.60E+01	8.80E+02	3.97E+02	1.84E+01	1.25E+05	0.00E+00	1.29E+11	1.01E+05	1.01E+03	1	0.99		
0.00E+00	1.02E+05	1.03E+03	2.65E+01	8.98E+02	4.14E+02	1.84E+01	1.30E+05	0.00E+00	1.34E+11	1.03E+05	1.03E+03	1	0.99		
							∑ F_{AM}-ref =	3.50E-05							

Table 2.73 Calculation of F_{AM} for C-14 in an Area Source of 4 m^2 with a Concrete Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$						
1	0.049	8.65E-04	0.1	0.220	1.02E-02	8.94E-03	8.68E-01	9.99E-01	2.59E-04							
ta (cm) =	99		tc (cm) =	1		Source area (m2) =	4			Source-ref area (m2) =	3359362					
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)	
2.86E-06	2.56E-02	9.99E-01	9.90E+01	1.00E+00	1.07E+00	1.71E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	0.99			
2.81E-06	2.57E-02	1.00E+00	9.95E+01	1.00E+00	1.07E+00	1.71E+00	3.14E-02	1.63E-07	1.27E+05	1.00E+02	1.00E-01	1	0.99			
2.81E-06	2.57E-02	1.00E+00	9.95E+01	1.01E+00	1.07E+00	1.71E+00	1.91E-03	9.91E-09	1.27E+05	1.01E+02	1.03E-01	1	0.99			
2.81E-06	2.58E-02	1.00E+00	9.96E+01	1.01E+00	1.07E+00	1.71E+00	2.03E-03	1.05E-08	1.27E+05	1.01E+02	1.06E-01	1	0.99			
2.80E-06	2.58E-02	1.00E+00	9.96E+01	1.01E+00	1.07E+00	1.71E+00	2.15E-03	1.11E-08	1.27E+05	1.01E+02	1.09E-01	1	0.99			
2.80E-06	2.58E-02	1.01E+00	9.96E+01	1.01E+00	1.07E+00	1.71E+00	2.29E-03	1.18E-08	1.27E+05	1.01E+02	1.13E-01	1	0.99			
2.80E-06	2.58E-02	1.01E+00	9.97E+01	1.01E+00	1.07E+00	1.71E+00	2.42E-03	1.25E-08	1.27E+05	1.01E+02	1.16E-01	1	0.99			
2.80E-06	2.58E-02	1.01E+00	9.97E+01	1.01E+00	1.07E+00	1.71E+00	2.57E-03	1.33E-08	1.28E+05	1.01E+02	1.19E-01	1	0.99			
2.79E-06	2.58E-02	1.01E+00	9.97E+01	1.01E+00	1.07E+00	1.72E+00	2.73E-03	1.40E-08	1.28E+05	1.01E+02	1.23E-01	1	0.99			
2.79E-06	2.58E-02	1.01E+00	9.98E+01	1.01E+00	1.07E+00	1.72E+00	2.90E-03	1.49E-08	1.28E+05	1.01E+02	1.27E-01	1	0.99			
2.78E-06	2.58E-02	1.01E+00	9.98E+01	1.01E+00	1.08E+00	1.72E+00	3.07E-03	1.58E-08	1.28E+05	1.01E+02	1.30E-01	1	0.99			
2.78E-06	2.58E-02	1.01E+00	9.99E+01	1.01E+00	1.08E+00	1.72E+00	3.26E-03	1.67E-08	1.28E+05	1.01E+02	1.34E-01	1	0.99			
2.77E-06	2.59E-02	1.01E+00	9.99E+01	1.01E+00	1.08E+00	1.72E+00	3.46E-03	1.77E-08	1.28E+05	1.01E+02	1.38E-01	1	0.99			
2.77E-06	2.59E-02	1.01E+00	1.00E+02	1.01E+00	1.08E+00	1.72E+00	3.67E-03	1.87E-08	1.28E+05	1.01E+02	1.43E-01	1	0.99	0	100	
..	..	..	..	..	..	..	..	..	..	..	..	..	..			
9.29E-07	3.63E-02	1.41E+00	1.40E+02	1.42E+00	1.11E+00	1.92E+00	1.81E-01	3.57E-07	2.52E+05	1.42E+02	1.00E+00	1	0.99			
8.82E-07	3.68E-02	1.44E+00	1.42E+02	1.44E+00	1.11E+00	1.93E+00	1.93E-01	3.62E-07	2.60E+05	1.44E+02	1.03E+00	1	0.99			
8.36E-07	3.74E-02	1.46E+00	1.45E+02	1.46E+00	1.11E+00	1.94E+00	2.04E-01	3.67E-07	2.68E+05	1.46E+02	1.06E+00	1	0.99			
7.90E-07	3.80E-02	1.48E+00	1.47E+02	1.48E+00	1.11E+00	1.95E+00	2.17E-01	3.71E-07	2.77E+05	1.48E+02	1.10E+00	1	0.99			
7.46E-07	3.86E-02	1.51E+00	1.49E+02	1.51E+00	1.11E+00	1.96E+00	2.30E-01	3.74E-07	2.86E+05	1.51E+02	1.13E+00	1	0.99			
							∑ F_{AM}-source =	1.14E-05								
							F_{AM} =	3.27E-01								

Table 2.74 Calculation of F_{AM} for C-14 in an Area Source of 10 m^2 with a Concrete Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.049	8.65E-04	0.1	0.220	1.02E-02	8.94E-03	8.68E-01	9.99E-01	2.59E-04

ta (cm) =	99		tc (cm) =	1		Source area (m2) =	10		Source-ref area (m2) =	3.36E+06

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.03E-07	3.93E-02	1.53E+00	1.52E+02	1.53E+00	1.11E+00	1.97E+00	2.44E-01	3.77E-07	2.96E+05	1.53E+02	1.16E+00	1	0.99		
6.61E-07	4.00E-02	1.56E+00	1.54E+02	1.56E+00	1.12E+00	1.99E+00	2.59E-01	3.79E-07	3.06E+05	1.56E+02	1.20E+00	1	0.99		
6.20E-07	4.07E-02	1.59E+00	1.57E+02	1.59E+00	1.12E+00	2.00E+00	2.75E-01	3.81E-07	3.17E+05	1.59E+02	1.23E+00	1	0.99		
5.81E-07	4.14E-02	1.62E+00	1.60E+02	1.62E+00	1.12E+00	2.01E+00	2.91E-01	3.82E-07	3.29E+05	1.62E+02	1.27E+00	1	0.99		
5.43E-07	4.22E-02	1.65E+00	1.63E+02	1.65E+00	1.12E+00	2.03E+00	3.09E-01	3.82E-07	3.41E+05	1.65E+02	1.31E+00	1	0.99		
5.06E-07	4.30E-02	1.68E+00	1.66E+02	1.68E+00	1.12E+00	2.04E+00	3.28E-01	3.81E-07	3.54E+05	1.68E+02	1.35E+00	1	0.99		
4.71E-07	4.38E-02	1.71E+00	1.69E+02	1.71E+00	1.13E+00	2.06E+00	3.48E-01	3.80E-07	3.68E+05	1.71E+02	1.39E+00	1	0.99		
4.37E-07	4.47E-02	1.74E+00	1.73E+02	1.75E+00	1.13E+00	2.08E+00	3.69E-01	3.78E-07	3.83E+05	1.75E+02	1.43E+00	1	0.99		
4.05E-07	4.56E-02	1.78E+00	1.76E+02	1.78E+00	1.13E+00	2.09E+00	3.91E-01	3.76E-07	3.98E+05	1.78E+02	1.47E+00	1	0.99	0	100
3.74E-07	4.65E-02	1.81E+00	1.80E+02	1.82E+00	1.14E+00	2.11E+00	4.15E-01	3.73E-07	4.15E+05	1.82E+02	1.52E+00	1	0.99		
3.45E-07	4.75E-02	1.85E+00	1.84E+02	1.86E+00	1.14E+00	2.13E+00	4.41E-01	3.69E-07	4.33E+05	1.86E+02	1.56E+00	1	0.99		
3.18E-07	4.85E-02	1.89E+00	1.88E+02	1.89E+00	1.14E+00	2.15E+00	4.67E-01	3.65E-07	4.51E+05	1.89E+02	1.61E+00	1	0.99		
2.92E-07	4.96E-02	1.93E+00	1.92E+02	1.94E+00	1.14E+00	2.17E+00	4.96E-01	3.60E-07	4.71E+05	1.94E+02	1.66E+00	1	0.99		
2.68E-07	5.07E-02	1.98E+00	1.96E+02	1.98E+00	1.15E+00	2.19E+00	5.26E-01	3.54E-07	4.92E+05	1.98E+02	1.71E+00	1	0.99		
2.45E-07	5.18E-02	2.02E+00	2.00E+02	2.02E+00	1.15E+00	2.21E+00	5.58E-01	3.47E-07	5.15E+05	2.02E+02	1.76E+00	1	0.99		
2.30E-07	5.26E-02	2.05E+00	2.03E+02	2.05E+00	1.15E+00	2.22E+00	3.93E-01	2.31E-07	5.30E+05	2.05E+02	1.79E+00	1	0.99		
							∑ F_{AM}-source =	1.73E-05							
							F_{AM} =	4.93E-01							

Table 2.75 Calculation of F_{AM} for C-14 in an Area Source of 36 m^2 with a Concrete Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.049	8.65E-04	0.1	0.220	1.02E-02	8.94E-03	8.68E-01	9.99E-01	2.59E-04

ta (cm) =	99		tc (cm) =	1		Source area (m2) =	36		Source-ref area (m2) =	3359362					

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
2.03E-07	5.42E-02	2.11E+00	2.10E+02	2.12E+00	1.16E+00	2.24E+00	4.25E-01	2.24E-07	5.64E+05	2.12E+02	1.87E+00	1	0.99		
1.90E-07	5.51E-02	2.15E+00	2.13E+02	2.15E+00	1.16E+00	2.25E+00	4.42E-01	2.20E-07	5.81E+05	2.15E+02	1.90E+00	1	0.99		
1.78E-07	5.59E-02	2.18E+00	2.16E+02	2.18E+00	1.16E+00	2.27E+00	4.60E-01	2.16E-07	6.00E+05	2.18E+02	1.94E+00	1	0.99		
1.66E-07	5.68E-02	2.22E+00	2.20E+02	2.22E+00	1.17E+00	2.28E+00	4.79E-01	2.12E-07	6.19E+05	2.22E+02	1.98E+00	1	0.99		
1.55E-07	5.77E-02	2.25E+00	2.23E+02	2.25E+00	1.17E+00	2.29E+00	4.98E-01	2.07E-07	6.39E+05	2.25E+02	2.02E+00	1	0.99		
1.45E-07	5.87E-02	2.29E+00	2.27E+02	2.29E+00	1.17E+00	2.30E+00	5.18E-01	2.03E-07	6.60E+05	2.29E+02	2.06E+00	1	0.99		
1.35E-07	5.96E-02	2.32E+00	2.30E+02	2.33E+00	1.17E+00	2.32E+00	5.39E-01	1.98E-07	6.81E+05	2.33E+02	2.10E+00	1	0.99		
1.26E-07	6.06E-02	2.36E+00	2.34E+02	2.37E+00	1.18E+00	2.33E+00	5.61E-01	1.94E-07	7.04E+05	2.37E+02	2.14E+00	1	0.99		
1.17E-07	6.16E-02	2.40E+00	2.38E+02	2.40E+00	1.18E+00	2.34E+00	5.84E-01	1.89E-07	7.27E+05	2.40E+02	2.19E+00	1	0.99		
1.09E-07	6.26E-02	2.44E+00	2.42E+02	2.44E+00	1.18E+00	2.36E+00	6.07E-01	1.84E-07	7.51E+05	2.44E+02	2.23E+00	1	0.99	0	100
1.01E-07	6.37E-02	2.48E+00	2.46E+02	2.49E+00	1.18E+00	2.37E+00	6.32E-01	1.79E-07	7.76E+05	2.49E+02	2.28E+00	1	0.99		
9.36E-08	6.47E-02	2.52E+00	2.50E+02	2.53E+00	1.19E+00	2.39E+00	6.57E-01	1.74E-07	8.03E+05	2.53E+02	2.32E+00	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
3.41E-08	7.96E-02	3.10E+00	3.08E+02	3.11E+00	1.23E+00	2.59E+00	1.06E+00	1.15E-07	1.21E+06	3.11E+02	2.94E+00	1	0.99		
3.11E-08	8.10E-02	3.16E+00	3.13E+02	3.16E+00	1.24E+00	2.60E+00	1.10E+00	1.10E-07	1.26E+06	3.16E+02	3.00E+00	1	0.99		
2.83E-08	8.25E-02	3.22E+00	3.19E+02	3.22E+00	1.24E+00	2.62E+00	1.14E+00	1.05E-07	1.30E+06	3.22E+02	3.06E+00	1	0.99		
2.57E-08	8.40E-02	3.28E+00	3.25E+02	3.28E+00	1.24E+00	2.64E+00	1.19E+00	1.00E-07	1.35E+06	3.28E+02	3.12E+00	1	0.99		
2.33E-08	8.55E-02	3.34E+00	3.31E+02	3.34E+00	1.25E+00	2.66E+00	1.24E+00	9.58E-08	1.40E+06	3.34E+02	3.19E+00	1	0.99		
2.11E-08	8.71E-02	3.40E+00	3.37E+02	3.40E+00	1.25E+00	2.67E+00	1.29E+00	9.12E-08	1.45E+06	3.40E+02	3.25E+00	1	0.99		
1.91E-08	8.87E-02	3.46E+00	3.43E+02	3.46E+00	1.26E+00	2.69E+00	1.34E+00	8.68E-08	1.51E+06	3.46E+02	3.31E+00	1	0.99		
							∑ F_{AM}-source =	2.23E-05							
							F_{AM} =	6.36E-01							

Table 2.76 Calculation of F_{AM} for C-14 in an Area Source of 100 m^2 with a Concrete Cover of 1 cm at the Recetpor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.049	8.65E-04	0.1	0.220	1.02E-02	8.94E-03	8.68E-01	9.99E-01	2.59E-04						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =	100			Source-ref area (m2) =	3359362				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.56E-08	9.20E-02	3.59E+00	3.55E+02	3.59E+00	1.27E+00	2.73E+00	1.45E+00	7.83E-08	1.62E+06	3.59E+02	3.45E+00	1	0.99		
1.40E-08	9.37E-02	3.65E+00	3.62E+02	3.66E+00	1.27E+00	2.75E+00	1.51E+00	7.42E-08	1.68E+06	3.66E+02	3.52E+00	1	0.99		
1.26E-08	9.54E-02	3.72E+00	3.69E+02	3.72E+00	1.28E+00	2.77E+00	1.57E+00	7.02E-08	1.74E+06	3.72E+02	3.59E+00	1	0.99		
1.13E-08	9.72E-02	3.79E+00	3.76E+02	3.79E+00	1.28E+00	2.79E+00	1.63E+00	6.64E-08	1.81E+06	3.79E+02	3.66E+00	1	0.99		
1.02E-08	9.90E-02	3.86E+00	3.83E+02	3.86E+00	1.29E+00	2.81E+00	1.70E+00	6.26E-08	1.88E+06	3.86E+02	3.73E+00	1	0.99		
9.10E-09	1.01E-01	3.93E+00	3.90E+02	3.94E+00	1.29E+00	2.84E+00	1.77E+00	5.90E-08	1.95E+06	3.94E+02	3.81E+00	1	0.99		
8.13E-09	1.03E-01	4.01E+00	3.97E+02	4.01E+00	1.30E+00	2.86E+00	1.84E+00	5.55E-08	2.02E+06	4.01E+02	3.88E+00	1	0.99		
7.25E-09	1.05E-01	4.08E+00	4.04E+02	4.09E+00	1.30E+00	2.88E+00	1.91E+00	5.21E-08	2.10E+06	4.09E+02	3.96E+00	1	0.99		
6.46E-09	1.07E-01	4.16E+00	4.12E+02	4.16E+00	1.31E+00	2.90E+00	1.99E+00	4.89E-08	2.18E+06	4.16E+02	4.04E+00	1	0.99		
5.74E-09	1.09E-01	4.24E+00	4.20E+02	4.24E+00	1.32E+00	2.92E+00	2.07E+00	4.57E-08	2.26E+06	4.24E+02	4.12E+00	1	0.99		
5.09E-09	1.11E-01	4.32E+00	4.28E+02	4.32E+00	1.32E+00	2.95E+00	2.16E+00	4.28E-08	2.35E+06	4.32E+02	4.20E+00	1	0.99		
4.51E-09	1.13E-01	4.40E+00	4.36E+02	4.40E+00	1.33E+00	2.97E+00	2.24E+00	3.99E-08	2.44E+06	4.40E+02	4.29E+00	1	0.99		
3.99E-09	1.15E-01	4.48E+00	4.44E+02	4.49E+00	1.33E+00	2.99E+00	2.33E+00	3.72E-08	2.53E+06	4.49E+02	4.37E+00	1	0.99	0	100
3.52E-09	1.17E-01	4.57E+00	4.53E+02	4.57E+00	1.34E+00	3.02E+00	2.43E+00	3.46E-08	2.63E+06	4.57E+02	4.46E+00	1	0.99		
3.10E-09	1.19E-01	4.65E+00	4.61E+02	4.66E+00	1.35E+00	3.04E+00	2.53E+00	3.21E-08	2.73E+06	4.66E+02	4.55E+00	1	0.99		
2.73E-09	1.22E-01	4.74E+00	4.70E+02	4.75E+00	1.35E+00	3.07E+00	2.63E+00	2.97E-08	2.83E+06	4.75E+02	4.64E+00	1	0.99		
2.39E-09	1.24E-01	4.83E+00	4.79E+02	4.84E+00	1.36E+00	3.09E+00	2.73E+00	2.75E-08	2.94E+06	4.84E+02	4.73E+00	1	0.99		
2.09E-09	1.26E-01	4.93E+00	4.88E+02	4.93E+00	1.37E+00	3.12E+00	2.85E+00	2.54E-08	3.06E+06	4.93E+02	4.83E+00	1	0.99		
1.83E-09	1.29E-01	5.02E+00	4.98E+02	5.03E+00	1.37E+00	3.14E+00	2.96E+00	2.34E-08	3.18E+06	5.03E+02	4.93E+00	1	0.99		
1.60E-09	1.31E-01	5.12E+00	5.07E+02	5.12E+00	1.38E+00	3.17E+00	3.08E+00	2.15E-08	3.30E+06	5.12E+02	5.02E+00	1	0.99		
1.39E-09	1.34E-01	5.21E+00	5.17E+02	5.22E+00	1.39E+00	3.20E+00	3.20E+00	1.97E-08	3.43E+06	5.22E+02	5.12E+00	1	0.99		
1.21E-09	1.36E-01	5.32E+00	5.27E+02	5.32E+00	1.40E+00	3.22E+00	3.33E+00	1.81E-08	3.56E+06	5.32E+02	5.23E+00	1	0.99		
1.04E-09	1.39E-01	5.42E+00	5.37E+02	5.42E+00	1.40E+00	3.25E+00	3.47E+00	1.65E-08	3.70E+06	5.42E+02	5.33E+00	1	0.99		
9.02E-10	1.42E-01	5.52E+00	5.47E+02	5.53E+00	1.41E+00	3.28E+00	3.61E+00	1.51E-08	3.84E+06	5.53E+02	5.44E+00	1	0.99		
7.78E-10	1.44E-01	5.63E+00	5.58E+02	5.64E+00	1.42E+00	3.30E+00	3.75E+00	1.37E-08	3.99E+06	5.64E+02	5.55E+00	1	0.99		
6.70E-10	1.47E-01	5.74E+00	5.69E+02	5.75E+00	1.43E+00	3.33E+00	3.91E+00	1.24E-08	4.15E+06	5.75E+02	5.66E+00	1	0.99		
							$\sum F_{AM}$-source =	2.33E-05							
							F_{AM} =	6.66E-01							

Table 2.77 Calculation of F_{AM} for C-14 in an Area Source of 1,000 m^2 with a Concrete Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)						
1	0.049	8.65E-04	0.1	0.220	1.02E-02	8.94E-03	8.68E-01	9.99E-01	2.59E-04						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =		1000		Source-ref area (m2) =		3359362			
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air	dist. in-source-cover	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2	distance-source	r - source, m	ta + tc, m	ta, m	Receptor location y, cm	Receptor location z, cm
5.75E-10	1.50E-01	5.85E+00	5.80E+02	5.86E+00	1.44E+00	3.36E+00	4.06E+00	1.13E-08	4.31E+06	5.86E+02	5.77E+00	1	0.99		
4.92E-10	1.53E-01	5.96E+00	5.91E+02	5.97E+00	1.44E+00	3.39E+00	4.23E+00	1.02E-08	4.48E+06	5.97E+02	5.89E+00	1	0.99		
4.21E-10	1.56E-01	6.08E+00	6.03E+02	6.09E+00	1.45E+00	3.42E+00	4.40E+00	9.20E-09	4.66E+06	6.09E+02	6.00E+00	1	0.99		
3.59E-10	1.59E-01	6.20E+00	6.14E+02	6.20E+00	1.46E+00	3.45E+00	4.58E+00	8.27E-09	4.84E+06	6.20E+02	6.12E+00	1	0.99		
3.05E-10	1.62E-01	6.32E+00	6.26E+02	6.33E+00	1.47E+00	3.48E+00	4.76E+00	7.43E-09	5.03E+06	6.33E+02	6.25E+00	1	0.99		
2.58E-10	1.65E-01	6.44E+00	6.38E+02	6.45E+00	1.48E+00	3.51E+00	4.95E+00	6.65E-09	5.23E+06	6.45E+02	6.37E+00	1	0.99		
2.19E-10	1.68E-01	6.57E+00	6.51E+02	6.58E+00	1.49E+00	3.54E+00	5.15E+00	5.94E-09	5.43E+06	6.58E+02	6.50E+00	1	0.99		
1.84E-10	1.72E-01	6.70E+00	6.64E+02	6.70E+00	1.50E+00	3.57E+00	5.36E+00	5.29E-09	5.65E+06	6.70E+02	6.63E+00	1	0.99		
1.55E-10	1.75E-01	6.83E+00	6.77E+02	6.83E+00	1.51E+00	3.60E+00	5.58E+00	4.70E-09	5.87E+06	6.83E+02	6.76E+00	1	0.99	0	100
1.30E-10	1.78E-01	6.96E+00	6.90E+02	6.97E+00	1.52E+00	3.64E+00	5.80E+00	4.17E-09	6.10E+06	6.97E+02	6.90E+00	1	0.99		
1.09E-10	1.82E-01	7.10E+00	7.03E+02	7.11E+00	1.53E+00	3.67E+00	6.04E+00	3.68E-09	6.35E+06	7.11E+02	7.03E+00	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
1.90E-15	4.15E-01	1.62E+01	1.60E+03	1.62E+01	2.20E+00	5.52E+00	3.19E+01	7.37E-13	3.30E+07	1.62E+03	1.62E+01	1	0.99		
1.31E-15	4.23E-01	1.65E+01	1.63E+03	1.65E+01	2.23E+00	5.58E+00	3.32E+01	5.41E-13	3.43E+07	1.65E+03	1.65E+01	1	0.99		
9.01E-16	4.31E-01	1.68E+01	1.67E+03	1.68E+01	2.25E+00	5.63E+00	3.45E+01	3.94E-13	3.57E+07	1.68E+03	1.68E+01	1	0.99		
6.14E-16	4.40E-01	1.72E+01	1.70E+03	1.72E+01	2.28E+00	5.69E+00	3.59E+01	2.86E-13	3.71E+07	1.72E+03	1.71E+01	1	0.99		
4.16E-16	4.49E-01	1.75E+01	1.73E+03	1.75E+01	2.30E+00	5.75E+00	3.73E+01	2.06E-13	3.86E+07	1.75E+03	1.75E+01	1	0.99		
2.79E-16	4.58E-01	1.78E+01	1.77E+03	1.79E+01	2.33E+00	5.81E+00	3.88E+01	1.47E-13	4.01E+07	1.79E+03	1.78E+01	1	0.99		
							∑ F_{AM}-source =	2.34E-05							
							F_{AM} =	6.69E-01							

Table 2.78 Calculation of F_{AM} for C-14 in an Area Source of 10,000 m^2 with a Concrete Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.049	8.65E-04	0.1	0.220	1.02E-02	8.94E-03	8.68E-01	9.99E-01	2.59E-04						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =		10000		Source-ref area (m2) =		3359362			
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air	dist. in-source-cover	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2	distance-source	r - source, m	ta + tc, m	ta, m	Receptor location y, cm	Receptor location z, cm
1.86E-16	4.67E-01	1.82E+01	1.80E+03	1.82E+01	2.36E+00	5.88E+00	4.04E+01	1.04E-13	4.18E+07	1.82E+03	1.82E+01	1	0.99		
1.23E-16	4.76E-01	1.86E+01	1.84E+03	1.86E+01	2.38E+00	5.94E+00	4.21E+01	7.35E-14	4.34E+07	1.86E+03	1.86E+01	1	0.99		
8.12E-17	4.86E-01	1.89E+01	1.88E+03	1.90E+01	2.41E+00	6.01E+00	4.37E+01	5.14E-14	4.52E+07	1.90E+03	1.89E+01	1	0.99		
5.30E-17	4.95E-01	1.93E+01	1.91E+03	1.93E+01	2.44E+00	6.07E+00	4.55E+01	3.57E-14	4.70E+07	1.93E+03	1.93E+01	1	0.99		
3.43E-17	5.05E-01	1.97E+01	1.95E+03	1.97E+01	2.47E+00	6.14E+00	4.74E+01	2.46E-14	4.89E+07	1.97E+03	1.97E+01	1	0.99		
2.20E-17	5.15E-01	2.01E+01	1.99E+03	2.01E+01	2.50E+00	6.21E+00	4.93E+01	1.69E-14	5.09E+07	2.01E+03	2.01E+01	1	0.99		
1.40E-17	5.26E-01	2.05E+01	2.03E+03	2.05E+01	2.54E+00	6.27E+00	5.13E+01	1.15E-14	5.29E+07	2.05E+03	2.05E+01	1	0.99		
8.87E-18	5.36E-01	2.09E+01	2.07E+03	2.09E+01	2.58E+00	6.34E+00	5.33E+01	7.73E-15	5.51E+07	2.09E+03	2.09E+01	1	0.99		
5.56E-18	5.47E-01	2.13E+01	2.11E+03	2.13E+01	2.61E+00	6.41E+00	5.55E+01	5.17E-15	5.73E+07	2.13E+03	2.13E+01	1	0.99		
3.45E-18	5.58E-01	2.17E+01	2.16E+03	2.18E+01	2.65E+00	6.47E+00	5.77E+01	3.42E-15	5.96E+07	2.18E+03	2.17E+01	1	0.99		
2.13E-18	5.69E-01	2.22E+01	2.20E+03	2.22E+01	2.69E+00	6.54E+00	6.01E+01	2.25E-15	6.20E+07	2.22E+03	2.22E+01	1	0.99	0	100
1.30E-18	5.80E-01	2.26E+01	2.24E+03	2.26E+01	2.73E+00	6.61E+00	6.25E+01	1.47E-15	6.45E+07	2.26E+03	2.26E+01	1	0.99		
7.86E-19	5.92E-01	2.31E+01	2.29E+03	2.31E+01	2.77E+00	6.69E+00	6.50E+01	9.46E-16	6.71E+07	2.31E+03	2.31E+01	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
6.43E-32	1.31E+00	5.09E+01	5.05E+03	5.10E+01	5.49E+00	8.90E+00	3.17E+02	9.95E-28	3.27E+08	5.10E+03	5.10E+01	1	0.99		
2.18E-32	1.33E+00	5.19E+01	5.15E+03	5.20E+01	5.60E+00	8.90E+00	3.30E+02	3.58E-28	3.40E+08	5.20E+03	5.20E+01	1	0.99		
7.21E-33	1.36E+00	5.30E+01	5.25E+03	5.30E+01	5.71E+00	8.90E+00	3.43E+02	1.26E-28	3.54E+08	5.30E+03	5.30E+01	1	0.99		
2.34E-33	1.39E+00	5.40E+01	5.35E+03	5.41E+01	5.82E+00	8.90E+00	3.57E+02	4.33E-29	3.68E+08	5.41E+03	5.41E+01	1	0.99		
7.43E-34	1.41E+00	5.51E+01	5.46E+03	5.52E+01	5.94E+00	8.90E+00	3.71E+02	1.46E-29	3.83E+08	5.52E+03	5.52E+01	1	0.99		
2.31E-34	1.44E+00	5.62E+01	5.57E+03	5.63E+01	6.06E+00	8.90E+00	3.86E+02	4.81E-30	3.98E+08	5.63E+03	5.63E+01	1	0.99		
							∑ F_{AM}-source =	2.34E-05							
							F_{AM} =	6.69E-01							

Table 2.79 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from C-14 in Six Area Sources with a Concrete Cover of 1 cm

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.35E-05	5.73E+03	1.00E+00	9.35E-06	10,000	6.69E-01	8.41E-11
				1,000	6.69E-01	8.41E-11
				100	6.66E-01	8.37E-11
				36	6.36E-01	8.01E-11
				10	4.93E-01	6.21E-11
				4	3.27E-01	4.12E-11

Table 2.80 Calculation of F_{CD} for C-14 in an Area Source with a Cover of 5 cm

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.642	0.358	0.294	3.39			
Reference source –		Cover material =	none	Cover thickness, cm =			5	Density of cover, g/cm3 =		1.6
		Source density , g/cm3 =		1.6	Source thickness, cm =			0.001		
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625						
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$										
FCD-surf=	0.00000055		(Note: FCD-surf = FCD × Surface activity conversion factor)							

Table 2.81 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from C-14 in Six Area Sources with a Concrete Cover of 5 cm

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.35E-05	5.73E+03	1.00E+00	5.54E-07	10,000	3.53E-01	2.63E-12
				1,000	3.53E-01	2.63E-12
				100	3.53E-01	2.63E-12
				36	3.53E-01	2.63E-12
				10	3.52E-01	2.62E-12
				4	3.31E-01	2.47E-12

Table 2.82 Comparison of External Radiation Doses (mrem/yr) at the Receptor Location (0, 0, 1) (m) Estimated by RESRAD-BUILD and Spreadsheets from C-14 in Six Area Sources with Concrete Covers

Area of Source (m^2)	With 1-cm Cover			With 5-cm Cover		
	from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Results from RESRAD-	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	8.54E-11	8.41E-11	1.02	2.81E-12	2.63E-12	1.07
1,000	8.47E-11	8.41E-11	1.01	2.81E-12	2.63E-12	1.07
100	8.53E-11	8.37E-11	1.02	2.81E-12	2.63E-12	1.07
36	8.17E-11	8.01E-11	1.02	2.81E-12	2.63E-12	1.07
10	6.35E-11	6.21E-11	1.02	2.81E-12	2.62E-12	1.07
4	4.23E-11	4.12E-11	1.03	2.63E-12	2.47E-12	1.07

Table 2.83 Calculation of F_{CD} for Mn-54 in an Area Source with a Cover of 1 cm

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.085	0.915	1.22	0.088		
Reference source –		Cover material =	none	Cover thickness, cm =			1	Density of cover, g/cm3 =	2.4
		Source density , g/cm3 =		1.6	Source thickness, cm =			0.001	
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625					
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$									
FCD-surf=	0.00000707		(Note: FCD-surf = FCD × Surface activity conversion factor)						

Table 2.84 Calculation of F_{AM} for Mn-54 in a Reference Area Source with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.835	1.00E+00	0.825	3.189	1.76E-03	1.78E-03	1.70E-01	1.67E-01	8.48E-05

ta (cm) =	99		tc (cm) =	1	Source-ref area (m2) =		3.36E+06		

exp(-ux)/x2 - ref	dist. in -ref-air (cm)	dist. in-ref-cover (cm)	mfp-dist. in -ref-air	mfp-dist. in-ref-cover	BF-ref-air	BF-ref-cover	Vol-source-ref	F_{AM}-ref	4π x dist-ref^2 (cm2)	distance-ref (cm)	r - ref (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
6.66E-06	9.90E+01	1.00E+00	8.39E-03	1.70E-01	1.01E+00	1.16E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	1.00E+00	0	0.99		
6.58E-06	9.95E+01	1.00E+00	8.43E-03	1.71E-01	1.01E+00	1.17E+00	3.14E-02	2.43E-07	1.27E+05	1.00E+02	1.00E+00	0	0.99		
6.58E-06	9.95E+01	1.01E+00	8.44E-03	1.71E-01	1.01E+00	1.17E+00	1.91E-03	1.48E-08	1.27E+05	1.01E+02	1.00E+00	0	0.99		
6.57E-06	9.96E+01	1.01E+00	8.44E-03	1.71E-01	1.01E+00	1.17E+00	2.03E-03	1.57E-08	1.27E+05	1.01E+02	1.00E+00	0	0.99		
6.57E-06	9.96E+01	1.01E+00	8.44E-03	1.71E-01	1.01E+00	1.17E+00	2.15E-03	1.66E-08	1.27E+05	1.01E+02	1.00E+00	0	0.99		
6.56E-06	9.96E+01	1.01E+00	8.45E-03	1.71E-01	1.01E+00	1.17E+00	2.29E-03	1.76E-08	1.27E+05	1.01E+02	1.00E+00	0	0.99		
6.56E-06	9.97E+01	1.01E+00	8.45E-03	1.71E-01	1.01E+00	1.17E+00	2.42E-03	1.87E-08	1.27E+05	1.01E+02	1.00E+00	0	0.99		
6.55E-06	9.97E+01	1.01E+00	8.45E-03	1.71E-01	1.01E+00	1.17E+00	2.57E-03	1.98E-08	1.28E+05	1.01E+02	1.00E+00	0	0.99	0	100
6.55E-06	9.97E+01	1.01E+00	8.46E-03	1.71E-01	1.01E+00	1.17E+00	2.73E-03	2.10E-08	1.28E+05	1.01E+02	1.00E+00	0	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
1.49E-11	3.40E+03	3.43E+01	2.88E-01	5.83E+00	1.28E+00	1.18E+01	1.44E+02	3.25E-08	1.48E+08	3.43E+03	1.00E+00	34	0.99		
1.26E-11	3.46E+03	3.50E+01	2.94E-01	5.95E+00	1.29E+00	1.21E+01	1.49E+02	2.96E-08	1.54E+08	3.50E+03	1.00E+00	35	0.99		
1.07E-11	3.53E+03	3.57E+01	3.00E-01	6.07E+00	1.30E+00	1.25E+01	1.55E+02	2.70E-08	1.60E+08	3.57E+03	1.00E+00	36	0.99		
9.08E-12	3.60E+03	3.64E+01	3.06E-01	6.19E+00	1.30E+00	1.28E+01	1.62E+02	2.45E-08	1.67E+08	3.64E+03	1.00E+00	36	0.99		
7.66E-12	3.68E+03	3.71E+01	3.12E-01	6.31E+00	1.31E+00	1.32E+01	1.68E+02	2.22E-08	1.73E+08	3.71E+03	1.00E+00	37	0.99		
6.45E-12	3.75E+03	3.79E+01	3.18E-01	6.44E+00	1.31E+00	1.36E+01	1.75E+02	2.01E-08	1.80E+08	3.79E+03	1.00E+00	38	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
8.48E-89	9.84E+04	9.94E+02	8.34E+00	1.69E+02	2.44E+01	2.43E+02	1.21E+05	6.07E-80	1.24E+11	9.94E+04	1.00E+00	994	0.99		
2.35E-90	1.00E+05	1.01E+03	8.51E+00	1.72E+02	2.52E+01	2.43E+02	1.25E+05	1.81E-81	1.29E+11	1.01E+05	1.00E+00	1014	0.99		
6.09E-92	1.02E+05	1.03E+03	8.68E+00	1.76E+02	2.60E+01	2.43E+02	1.30E+05	5.02E-83	1.34E+11	1.03E+05	1.00E+00	1034	0.99		
							∑FAM-ref=	1.12E-04							

Table 2.85 Calculation of F_{AM} for Mn-54 in an Area Source of 4 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.835	1.00E+00	0.825	3.189	1.76E-03	1.78E-03	1.70E-01	1.67E-01	8.48E-05

ta (cm) =	99		tc (cm) =	1		Source area (m2) =	4			Source-ref area (m2) =	3.36E+06				

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in- source-cover	dist. in -source- air (cm)	dist. in- source- cover (cm)	BF-source-air	BF-source- cover	Vol-source	F_{AM}-source	4π x dist- source^2 (cm2)	distance- source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
6.67E-06	8.39E-03	1.67E-01	9.90E+01	1.00E+00	1.01E+00	1.16E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	0.99		
6.60E-06	8.43E-03	1.68E-01	9.95E+01	1.00E+00	1.01E+00	1.16E+00	3.14E-02	2.43E-07	1.27E+05	1.00E+02	1.00E-01	1	0.99		
6.60E-06	8.44E-03	1.68E-01	9.95E+01	1.01E+00	1.01E+00	1.16E+00	1.91E-03	1.48E-08	1.27E+05	1.01E+02	1.03E-01	1	0.99		
6.59E-06	8.44E-03	1.68E-01	9.96E+01	1.01E+00	1.01E+00	1.16E+00	2.03E-03	1.57E-08	1.27E+05	1.01E+02	1.06E-01	1	0.99		
6.59E-06	8.44E-03	1.68E-01	9.96E+01	1.01E+00	1.01E+00	1.16E+00	2.15E-03	1.66E-08	1.27E+05	1.01E+02	1.09E-01	1	0.99		
6.58E-06	8.45E-03	1.69E-01	9.96E+01	1.01E+00	1.01E+00	1.16E+00	2.29E-03	1.76E-08	1.27E+05	1.01E+02	1.13E-01	1	0.99		
6.58E-06	8.45E-03	1.69E-01	9.97E+01	1.01E+00	1.01E+00	1.16E+00	2.42E-03	1.86E-08	1.27E+05	1.01E+02	1.16E-01	1	0.99		
6.57E-06	8.45E-03	1.69E-01	9.97E+01	1.01E+00	1.01E+00	1.16E+00	2.57E-03	1.98E-08	1.28E+05	1.01E+02	1.19E-01	1	0.99		
6.56E-06	8.46E-03	1.69E-01	9.97E+01	1.01E+00	1.01E+00	1.16E+00	2.73E-03	2.10E-08	1.28E+05	1.01E+02	1.23E-01	1	0.99		
6.56E-06	8.46E-03	1.69E-01	9.98E+01	1.01E+00	1.01E+00	1.16E+00	2.90E-03	2.22E-08	1.28E+05	1.01E+02	1.27E-01	1	0.99		
6.55E-06	8.46E-03	1.69E-01	9.98E+01	1.01E+00	1.01E+00	1.16E+00	3.07E-03	2.35E-08	1.28E+05	1.01E+02	1.30E-01	1	0.99		
6.54E-06	8.47E-03	1.69E-01	9.99E+01	1.01E+00	1.01E+00	1.16E+00	3.26E-03	2.49E-08	1.28E+05	1.01E+02	1.34E-01	1	0.99		
6.54E-06	8.47E-03	1.69E-01	9.99E+01	1.01E+00	1.01E+00	1.16E+00	3.46E-03	2.64E-08	1.28E+05	1.01E+02	1.38E-01	1	0.99		
6.53E-06	8.48E-03	1.69E-01	1.00E+02	1.01E+00	1.01E+00	1.16E+00	3.67E-03	2.80E-08	1.28E+05	1.01E+02	1.43E-01	1	0.99	0	100
..	..	..	..	..	..	..	..	..	..	..	..	..	0.00		
3.09E-06	1.19E-02	2.37E-01	1.40E+02	1.42E+00	1.01E+00	1.23E+00	1.81E-01	6.95E-07	2.52E+05	1.42E+02	1.00E+00	1	0.99		
2.99E-06	1.21E-02	2.41E-01	1.42E+02	1.44E+00	1.01E+00	1.23E+00	1.93E-01	7.15E-07	2.60E+05	1.44E+02	1.03E+00	1	0.99		
2.89E-06	1.23E-02	2.45E-01	1.45E+02	1.46E+00	1.01E+00	1.23E+00	2.04E-01	7.35E-07	2.68E+05	1.46E+02	1.06E+00	1	0.99		
2.78E-06	1.25E-02	2.48E-01	1.47E+02	1.48E+00	1.01E+00	1.24E+00	2.17E-01	7.55E-07	2.77E+05	1.48E+02	1.10E+00	1	0.99		
2.68E-06	1.27E-02	2.53E-01	1.49E+02	1.51E+00	1.01E+00	1.24E+00	2.30E-01	7.74E-07	2.86E+05	1.51E+02	1.13E+00	1	0.99		
						∑FAM-source=		1.98E-05							
							FAM=	1.76E-01							

Table 2.86 Calculation of F_{AM} for Mn-54 in an Area Source of 10 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1.00E+00	0.825	3.189	1.76E-03	1.78E-03	1.70E-01	1.67E-01	8.48E-05						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =		10		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
2.58E-06	1.29E-02	2.57E-01	1.52E+02	1.53E+00	1.01E+00	1.24E+00	2.44E-01	7.94E-07	2.96E+05	1.53E+02	1.16E+00	1	0.99		
2.48E-06	1.31E-02	2.61E-01	1.54E+02	1.56E+00	1.01E+00	1.25E+00	2.59E-01	8.13E-07	3.06E+05	1.56E+02	1.20E+00	1	0.99		
2.39E-06	1.33E-02	2.66E-01	1.57E+02	1.59E+00	1.01E+00	1.25E+00	2.75E-01	8.31E-07	3.17E+05	1.59E+02	1.23E+00	1	0.99		
2.29E-06	1.36E-02	2.71E-01	1.60E+02	1.62E+00	1.01E+00	1.26E+00	2.91E-01	8.50E-07	3.29E+05	1.62E+02	1.27E+00	1	0.99		
2.20E-06	1.38E-02	2.76E-01	1.63E+02	1.65E+00	1.01E+00	1.26E+00	3.09E-01	8.68E-07	3.41E+05	1.65E+02	1.31E+00	1	0.99		
2.10E-06	1.41E-02	2.81E-01	1.66E+02	1.68E+00	1.01E+00	1.27E+00	3.28E-01	8.85E-07	3.54E+05	1.68E+02	1.35E+00	1	0.99		
2.01E-06	1.44E-02	2.87E-01	1.69E+02	1.71E+00	1.01E+00	1.27E+00	3.48E-01	9.02E-07	3.68E+05	1.71E+02	1.39E+00	1	0.99		
1.92E-06	1.46E-02	2.92E-01	1.73E+02	1.75E+00	1.01E+00	1.28E+00	3.69E-01	9.19E-07	3.83E+05	1.75E+02	1.43E+00	1	0.99		
1.84E-06	1.49E-02	2.98E-01	1.76E+02	1.78E+00	1.01E+00	1.28E+00	3.91E-01	9.35E-07	3.98E+05	1.78E+02	1.47E+00	1	0.99	0	100
1.75E-06	1.52E-02	3.04E-01	1.80E+02	1.82E+00	1.02E+00	1.29E+00	4.15E-01	9.51E-07	4.15E+05	1.82E+02	1.52E+00	1	0.99		
1.67E-06	1.56E-02	3.11E-01	1.84E+02	1.86E+00	1.02E+00	1.29E+00	4.41E-01	9.66E-07	4.33E+05	1.86E+02	1.56E+00	1	0.99		
1.59E-06	1.59E-02	3.17E-01	1.88E+02	1.89E+00	1.02E+00	1.30E+00	4.67E-01	9.81E-07	4.51E+05	1.89E+02	1.61E+00	1	0.99		
1.51E-06	1.62E-02	3.24E-01	1.92E+02	1.94E+00	1.02E+00	1.31E+00	4.96E-01	9.95E-07	4.71E+05	1.94E+02	1.66E+00	1	0.99		
1.43E-06	1.66E-02	3.31E-01	1.96E+02	1.98E+00	1.02E+00	1.31E+00	5.26E-01	1.01E-06	4.92E+05	1.98E+02	1.71E+00	1	0.99		
1.36E-06	1.70E-02	3.39E-01	2.00E+02	2.02E+00	1.02E+00	1.32E+00	5.58E-01	1.02E-06	5.15E+05	2.02E+02	1.76E+00	1	0.99		
1.31E-06	1.72E-02	3.44E-01	2.03E+02	2.05E+00	1.02E+00	1.33E+00	3.93E-01	6.96E-07	5.30E+05	2.05E+02	1.79E+00	1	0.99		
						∑FAM-source=		3.42E-05							
							FAM=	3.05E-01							

Table 2.87 Calculation of F_{AM} for Mn-54 in an Area Source of 36 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1.00E+00	0.825	3.189	1.76E-03	1.78E-03	1.70E-01	1.67E-01	8.48E-05						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =		36		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in- source-cover	dist. in -source- air (cm)	dist. in- source- cover (cm)	BF-source-air	BF-source- cover	Vol-source	F_{AM}-source	4π x dist- source^2 (cm2)	distance- source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.22E-06	1.78E-02	3.55E-01	2.10E+02	2.12E+00	1.02E+00	1.34E+00	4.25E-01	7.07E-07	5.64E+05	2.12E+02	1.87E+00	1	0.99		
1.18E-06	1.80E-02	3.60E-01	2.13E+02	2.15E+00	1.02E+00	1.34E+00	4.42E-01	7.12E-07	5.81E+05	2.15E+02	1.90E+00	1	0.99		
1.14E-06	1.83E-02	3.66E-01	2.16E+02	2.18E+00	1.02E+00	1.35E+00	4.60E-01	7.17E-07	6.00E+05	2.18E+02	1.94E+00	1	0.99		
1.09E-06	1.86E-02	3.72E-01	2.20E+02	2.22E+00	1.02E+00	1.35E+00	4.79E-01	7.21E-07	6.19E+05	2.22E+02	1.98E+00	1	0.99		
1.05E-06	1.89E-02	3.77E-01	2.23E+02	2.25E+00	1.02E+00	1.36E+00	4.98E-01	7.26E-07	6.39E+05	2.25E+02	2.02E+00	1	0.99		
1.01E-06	1.92E-02	3.84E-01	2.27E+02	2.29E+00	1.02E+00	1.36E+00	5.18E-01	7.30E-07	6.60E+05	2.29E+02	2.06E+00	1	0.99		
9.75E-07	1.95E-02	3.90E-01	2.30E+02	2.33E+00	1.02E+00	1.37E+00	5.39E-01	7.34E-07	6.81E+05	2.33E+02	2.10E+00	1	0.99		
9.38E-07	1.99E-02	3.96E-01	2.34E+02	2.37E+00	1.02E+00	1.38E+00	5.61E-01	7.38E-07	7.04E+05	2.37E+02	2.14E+00	1	0.99		
9.01E-07	2.02E-02	4.03E-01	2.38E+02	2.40E+00	1.02E+00	1.38E+00	5.84E-01	7.42E-07	7.27E+05	2.40E+02	2.19E+00	1	0.99		
8.66E-07	2.05E-02	4.09E-01	2.42E+02	2.44E+00	1.02E+00	1.39E+00	6.07E-01	7.45E-07	7.51E+05	2.44E+02	2.23E+00	1	0.99	0	100
8.32E-07	2.09E-02	4.16E-01	2.46E+02	2.49E+00	1.02E+00	1.40E+00	6.32E-01	7.48E-07	7.76E+05	2.49E+02	2.28E+00	1	0.99		
7.99E-07	2.12E-02	4.23E-01	2.50E+02	2.53E+00	1.02E+00	1.40E+00	6.57E-01	7.51E-07	8.03E+05	2.53E+02	2.32E+00	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
4.77E-07	2.61E-02	5.20E-01	3.08E+02	3.11E+00	1.03E+00	1.50E+00	1.06E+00	7.74E-07	1.21E+06	3.11E+02	2.94E+00	1	0.99		
4.55E-07	2.66E-02	5.30E-01	3.13E+02	3.16E+00	1.03E+00	1.51E+00	1.10E+00	7.76E-07	1.26E+06	3.16E+02	3.00E+00	1	0.99		
4.35E-07	2.70E-02	5.39E-01	3.19E+02	3.22E+00	1.03E+00	1.52E+00	1.14E+00	7.77E-07	1.30E+06	3.22E+02	3.06E+00	1	0.99		
4.15E-07	2.75E-02	5.49E-01	3.25E+02	3.28E+00	1.03E+00	1.53E+00	1.19E+00	7.78E-07	1.35E+06	3.28E+02	3.12E+00	1	0.99		
3.97E-07	2.80E-02	5.59E-01	3.31E+02	3.34E+00	1.03E+00	1.54E+00	1.24E+00	7.79E-07	1.40E+06	3.34E+02	3.19E+00	1	0.99		
3.78E-07	2.85E-02	5.69E-01	3.37E+02	3.40E+00	1.03E+00	1.55E+00	1.29E+00	7.79E-07	1.45E+06	3.40E+02	3.25E+00	1	0.99		
3.61E-07	2.91E-02	5.80E-01	3.43E+02	3.46E+00	1.03E+00	1.57E+00	1.34E+00	7.80E-07	1.51E+06	3.46E+02	3.31E+00	1	0.99		
							∑ F_{AM}-source =	5.83E-05							
							F_{AM} =	5.19E-01							

Table 2.88 Calculation of F_{AM} for Mn-54 in an Area Source of 100 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_z)}{(t_a + t_c + t)}$					
1	0.835	1.00E+00	0.825	3.189	1.76E-03	1.78E-03	1.70E-01	1.67E-01	8.48E-05						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =	100			Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in- source-cover	dist. in -source- air (cm)	dist. in- source- cover (cm)	BF-source-air	BF-source- cover	Vol-source	F_{AM}-source	4π x dist- source^2 (cm2)	distance- source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
3.28E-07	3.01E-02	6.01E-01	3.55E+02	3.59E+00	1.03E+00	1.59E+00	1.45E+00	7.80E-07	1.62E+06	3.59E+02	3.45E+00	1	0.99		
3.13E-07	3.07E-02	6.12E-01	3.62E+02	3.66E+00	1.03E+00	1.60E+00	1.51E+00	7.80E-07	1.68E+06	3.66E+02	3.52E+00	1	0.99		
2.98E-07	3.13E-02	6.24E-01	3.69E+02	3.72E+00	1.03E+00	1.62E+00	1.57E+00	7.80E-07	1.74E+06	3.72E+02	3.59E+00	1	0.99		
2.84E-07	3.18E-02	6.35E-01	3.76E+02	3.79E+00	1.03E+00	1.63E+00	1.63E+00	7.79E-07	1.81E+06	3.79E+02	3.66E+00	1	0.99		
2.70E-07	3.24E-02	6.47E-01	3.83E+02	3.86E+00	1.03E+00	1.64E+00	1.70E+00	7.78E-07	1.88E+06	3.86E+02	3.73E+00	1	0.99		
2.57E-07	3.30E-02	6.59E-01	3.90E+02	3.94E+00	1.03E+00	1.66E+00	1.77E+00	7.78E-07	1.95E+06	3.94E+02	3.81E+00	1	0.99		
2.44E-07	3.37E-02	6.71E-01	3.97E+02	4.01E+00	1.03E+00	1.67E+00	1.84E+00	7.76E-07	2.02E+06	4.01E+02	3.88E+00	1	0.99		
2.32E-07	3.43E-02	6.84E-01	4.04E+02	4.09E+00	1.03E+00	1.69E+00	1.91E+00	7.75E-07	2.10E+06	4.09E+02	3.96E+00	1	0.99		
2.21E-07	3.49E-02	6.97E-01	4.12E+02	4.16E+00	1.03E+00	1.70E+00	1.99E+00	7.74E-07	2.18E+06	4.16E+02	4.04E+00	1	0.99		
2.10E-07	3.56E-02	7.10E-01	4.20E+02	4.24E+00	1.04E+00	1.71E+00	2.07E+00	7.72E-07	2.26E+06	4.24E+02	4.12E+00	1	0.99		
1.99E-07	3.63E-02	7.24E-01	4.28E+02	4.32E+00	1.04E+00	1.73E+00	2.16E+00	7.70E-07	2.35E+06	4.32E+02	4.20E+00	1	0.99		
1.89E-07	3.70E-02	7.37E-01	4.36E+02	4.40E+00	1.04E+00	1.75E+00	2.24E+00	7.68E-07	2.44E+06	4.40E+02	4.29E+00	1	0.99		
1.80E-07	3.77E-02	7.51E-01	4.44E+02	4.49E+00	1.04E+00	1.76E+00	2.33E+00	7.66E-07	2.53E+06	4.49E+02	4.37E+00	1	0.99	0	100
1.70E-07	3.84E-02	7.65E-01	4.53E+02	4.57E+00	1.04E+00	1.78E+00	2.43E+00	7.64E-07	2.63E+06	4.57E+02	4.46E+00	1	0.99		
1.62E-07	3.91E-02	7.80E-01	4.61E+02	4.66E+00	1.04E+00	1.79E+00	2.53E+00	7.61E-07	2.73E+06	4.66E+02	4.55E+00	1	0.99		
1.53E-07	3.98E-02	7.95E-01	4.70E+02	4.75E+00	1.04E+00	1.81E+00	2.63E+00	7.58E-07	2.83E+06	4.75E+02	4.64E+00	1	0.99		
1.45E-07	4.06E-02	8.10E-01	4.79E+02	4.84E+00	1.04E+00	1.83E+00	2.73E+00	7.55E-07	2.94E+06	4.84E+02	4.73E+00	1	0.99		
1.37E-07	4.14E-02	8.26E-01	4.88E+02	4.93E+00	1.04E+00	1.85E+00	2.85E+00	7.52E-07	3.06E+06	4.93E+02	4.83E+00	1	0.99		
1.30E-07	4.22E-02	8.42E-01	4.98E+02	5.03E+00	1.04E+00	1.86E+00	2.96E+00	7.49E-07	3.18E+06	5.03E+02	4.93E+00	1	0.99		
1.23E-07	4.30E-02	8.58E-01	5.07E+02	5.12E+00	1.04E+00	1.88E+00	3.08E+00	7.45E-07	3.30E+06	5.12E+02	5.02E+00	1	0.99		
1.17E-07	4.38E-02	8.74E-01	5.17E+02	5.22E+00	1.04E+00	1.90E+00	3.20E+00	7.41E-07	3.43E+06	5.22E+02	5.12E+00	1	0.99		
1.10E-07	4.47E-02	8.91E-01	5.27E+02	5.32E+00	1.04E+00	1.92E+00	3.33E+00	7.37E-07	3.56E+06	5.32E+02	5.23E+00	1	0.99		
1.04E-07	4.55E-02	9.08E-01	5.37E+02	5.42E+00	1.05E+00	1.94E+00	3.47E+00	7.33E-07	3.70E+06	5.42E+02	5.33E+00	1	0.99		
9.84E-08	4.64E-02	9.26E-01	5.47E+02	5.53E+00	1.05E+00	1.96E+00	3.61E+00	7.29E-07	3.84E+06	5.53E+02	5.44E+00	1	0.99		
9.30E-08	4.73E-02	9.44E-01	5.58E+02	5.64E+00	1.05E+00	1.98E+00	3.75E+00	7.24E-07	3.99E+06	5.64E+02	5.55E+00	1	0.99		
8.78E-08	4.82E-02	9.62E-01	5.69E+02	5.75E+00	1.05E+00	2.00E+00	3.91E+00	7.19E-07	4.15E+06	5.75E+02	5.66E+00	1	0.99		
						∑FAM-source=		7.80E-05							
							FAM=	6.95E-01							

Table 2.89 Calculation of F_{AM} for Mn-54 in an Area Source of 1,000 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1.00E+00	0.825	3.189	1.76E-03	1.78E-03	1.70E-01	1.67E-01	8.48E-05						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =		1,000		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in -source-air	dist. in-source-cover	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2	distance-source	r - source, m	ta + tc, m	ta, m	Receptor location y, cm	Receptor location z, cm
8.28E-08	4.92E-02	9.81E-01	5.80E+02	5.86E+00	1.05E+00	2.02E+00	4.06E+00	7.14E-07	4.31E+06	5.86E+02	5.77E+00	1	0.99		
7.81E-08	5.01E-02	1.00E+00	5.91E+02	5.97E+00	1.05E+00	2.05E+00	4.23E+00	7.09E-07	4.48E+06	5.97E+02	5.89E+00	1	0.99		
7.36E-08	5.11E-02	1.02E+00	6.03E+02	6.09E+00	1.05E+00	2.07E+00	4.40E+00	7.05E-07	4.66E+06	6.09E+02	6.00E+00	1	0.99		
6.94E-08	5.21E-02	1.04E+00	6.14E+02	6.20E+00	1.05E+00	2.10E+00	4.58E+00	7.01E-07	4.84E+06	6.20E+02	6.12E+00	1	0.99		
6.54E-08	5.31E-02	1.06E+00	6.26E+02	6.33E+00	1.05E+00	2.13E+00	4.76E+00	6.97E-07	5.03E+06	6.33E+02	6.25E+00	1	0.99		
6.15E-08	5.41E-02	1.08E+00	6.38E+02	6.45E+00	1.05E+00	2.16E+00	4.95E+00	6.93E-07	5.23E+06	6.45E+02	6.37E+00	1	0.99		
5.79E-08	5.52E-02	1.10E+00	6.51E+02	6.58E+00	1.05E+00	2.19E+00	5.15E+00	6.88E-07	5.43E+06	6.58E+02	6.50E+00	1	0.99		
5.45E-08	5.63E-02	1.12E+00	6.64E+02	6.70E+00	1.06E+00	2.22E+00	5.36E+00	6.83E-07	5.65E+06	6.70E+02	6.63E+00	1	0.99		
5.12E-08	5.74E-02	1.14E+00	6.77E+02	6.83E+00	1.06E+00	2.25E+00	5.58E+00	6.78E-07	5.87E+06	6.83E+02	6.76E+00	1	0.99	0	100
4.81E-08	5.85E-02	1.17E+00	6.90E+02	6.97E+00	1.06E+00	2.28E+00	5.80E+00	6.73E-07	6.10E+06	6.97E+02	6.90E+00	1	0.99		
4.52E-08	5.96E-02	1.19E+00	7.03E+02	7.11E+00	1.06E+00	2.31E+00	6.04E+00	6.67E-07	6.35E+06	7.11E+02	7.03E+00	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
1.76E-09	1.36E-01	2.71E+00	1.60E+03	1.62E+01	1.13E+00	4.62E+00	3.19E+01	2.94E-07	3.30E+07	1.62E+03	1.62E+01	1	0.99		
1.60E-09	1.39E-01	2.77E+00	1.63E+03	1.65E+01	1.14E+00	4.71E+00	3.32E+01	2.84E-07	3.43E+07	1.65E+03	1.65E+01	1	0.99		
1.45E-09	1.41E-01	2.82E+00	1.67E+03	1.68E+01	1.14E+00	4.80E+00	3.45E+01	2.74E-07	3.57E+07	1.68E+03	1.68E+01	1	0.99		
1.31E-09	1.44E-01	2.88E+00	1.70E+03	1.72E+01	1.14E+00	4.89E+00	3.59E+01	2.64E-07	3.71E+07	1.72E+03	1.71E+01	1	0.99		
1.19E-09	1.47E-01	2.93E+00	1.73E+03	1.75E+01	1.15E+00	4.99E+00	3.73E+01	2.54E-07	3.86E+07	1.75E+03	1.75E+01	1	0.99		
1.08E-09	1.50E-01	2.99E+00	1.77E+03	1.79E+01	1.15E+00	5.09E+00	3.88E+01	2.44E-07	4.01E+07	1.79E+03	1.78E+01	1	0.99		
						∑FAM-source=		1.08E-04							
							FAM=	9.58E-01							

Table 2.90 Calculation of F_{AM} for Mn-54 in an Area Source of 10,000 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.835	1.00E+00	0.825	3.189	1.76E-03	1.78E-03	1.70E-01	1.67E-01	8.48E-05						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =		10,000		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in- source-cover	dist. in -source- air	dist. in- source- cover	BF-source-air	BF-source- cover	Vol-source	F_{AM}-source	4π x dist- source^2	distance- source	r - source, m	ta + tc, m	ta, m	Receptor location y, cm	Receptor location z, cm
9.71E-10	1.53E-01	3.05E+00	1.80E+03	1.82E+01	1.15E+00	5.20E+00	4.04E+01	2.35E-07	4.18E+07	1.82E+03	1.82E+01	1	0.99		
8.76E-10	1.56E-01	3.11E+00	1.84E+03	1.86E+01	1.15E+00	5.32E+00	4.21E+01	2.26E-07	4.34E+07	1.86E+03	1.86E+01	1	0.99		
7.89E-10	1.59E-01	3.17E+00	1.88E+03	1.90E+01	1.16E+00	5.44E+00	4.37E+01	2.17E-07	4.52E+07	1.90E+03	1.89E+01	1	0.99		
7.10E-10	1.62E-01	3.24E+00	1.91E+03	1.93E+01	1.16E+00	5.56E+00	4.55E+01	2.09E-07	4.70E+07	1.93E+03	1.93E+01	1	0.99		
6.37E-10	1.66E-01	3.30E+00	1.95E+03	1.97E+01	1.16E+00	5.69E+00	4.74E+01	2.00E-07	4.89E+07	1.97E+03	1.97E+01	1	0.99		
5.72E-10	1.69E-01	3.37E+00	1.99E+03	2.01E+01	1.17E+00	5.82E+00	4.93E+01	1.91E-07	5.09E+07	2.01E+03	2.01E+01	1	0.99		
5.12E-10	1.72E-01	3.44E+00	2.03E+03	2.05E+01	1.17E+00	5.95E+00	5.13E+01	1.83E-07	5.29E+07	2.05E+03	2.05E+01	1	0.99		
4.58E-10	1.76E-01	3.50E+00	2.07E+03	2.09E+01	1.17E+00	6.08E+00	5.33E+01	1.74E-07	5.51E+07	2.09E+03	2.09E+01	1	0.99		
4.09E-10	1.79E-01	3.57E+00	2.11E+03	2.13E+01	1.18E+00	6.22E+00	5.55E+01	1.66E-07	5.73E+07	2.13E+03	2.13E+01	1	0.99		
3.65E-10	1.83E-01	3.65E+00	2.16E+03	2.18E+01	1.18E+00	6.36E+00	5.77E+01	1.58E-07	5.96E+07	2.18E+03	2.17E+01	1	0.99		
3.25E-10	1.86E-01	3.72E+00	2.20E+03	2.22E+01	1.18E+00	6.50E+00	6.01E+01	1.50E-07	6.20E+07	2.22E+03	2.22E+01	1	0.99	0	100
2.89E-10	1.90E-01	3.79E+00	2.24E+03	2.26E+01	1.19E+00	6.64E+00	6.25E+01	1.43E-07	6.45E+07	2.26E+03	2.26E+01	1	0.99		
2.57E-10	1.94E-01	3.87E+00	2.29E+03	2.31E+01	1.19E+00	6.79E+00	6.50E+01	1.35E-07	6.71E+07	2.31E+03	2.31E+01	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
3.92E-13	4.28E-01	8.53E+00	5.05E+03	5.10E+01	1.42E+00	1.94E+01	3.17E+02	3.43E-09	3.27E+08	5.10E+03	5.10E+01	1	0.99		
3.15E-13	4.36E-01	8.71E+00	5.15E+03	5.20E+01	1.43E+00	2.00E+01	3.30E+02	2.97E-09	3.40E+08	5.20E+03	5.20E+01	1	0.99		
2.52E-13	4.45E-01	8.88E+00	5.25E+03	5.30E+01	1.44E+00	2.06E+01	3.43E+02	2.56E-09	3.54E+08	5.30E+03	5.30E+01	1	0.99		
2.01E-13	4.54E-01	9.06E+00	5.35E+03	5.41E+01	1.45E+00	2.12E+01	3.57E+02	2.20E-09	3.68E+08	5.41E+03	5.41E+01	1	0.99		
1.60E-13	4.63E-01	9.24E+00	5.46E+03	5.52E+01	1.46E+00	2.18E+01	3.71E+02	1.89E-09	3.83E+08	5.52E+03	5.52E+01	1	0.99		
1.27E-13	4.72E-01	9.42E+00	5.57E+03	5.63E+01	1.47E+00	2.24E+01	3.86E+02	1.61E-09	3.98E+08	5.63E+03	5.63E+01	1	0.99		
						∑FAM-source=		1.12E-04							
							FAM=	9.95E-01							

Table 2.91 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six Area Sources with a Concrete Cover of 1 cm

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	7.07E-06	1.00E+04	9.95E-01	2.49E-05
				1.00E+03	9.58E-01	2.40E-05
				1.00E+02	6.95E-01	1.74E-05
				3.60E+01	5.19E-01	1.30E-05
				1.00E+01	3.05E-01	7.62E-06
				4.00E+00	1.76E-01	4.41E-06

Radiation doses at the same receptor location (0, 0, 1) (m) but with a concrete cover of 5-cm thickness on each of the six area sources were then estimated. Table 2.92 shows the calculation of F_{CD}, the cover and depth factor, for Mn-54. The $F_{AM\text{-}ref}$ for the reference source and F_{AM} for each of the six circular area sources were estimated with the same calculations as implemented in Tables 2.84 to 2.90 but for a cover thickness of 5-cm; the final values of F_{AM} for each area source are listed in Table 2.93, which shows the calculation of radiation doses at the receptor location.

Comparison of the dose results for Mn-54 between the spreadsheets and RESRAD-BUILD are presented in Table 2.94. In general, the differences are less than 2%. Based on the comparison, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Results for Tc-99. To verify external dose modeling when radiation was attenuated by shielding materials in RESRAD-BUILD, the radiation doses at the receptor location (0, 0, 1) (m) from each of the six area sources with a concrete cover of 1-cm thickness were estimated with spreadsheets. Table 2.95 shows the calculation of F_{CD}, the cover and depth factor, for Tc-99. Table 2.96 shows the estimation of $F_{AM\text{-}ref}$ for the reference area source, which is made up of soil having an infinite extent. In the estimation, an area of about 3,000,000 m^2 was used for the reference source. Tables 2.97 to 2.102 show the estimation of F_{AM}'s for the six circular area sources considered in this comparison. After F_{CD} and F_{AM}'s were available, external radiation doses resulting from Tc-99 in each of the six circular area sources were estimated by adjusting the external radiation dose conversion factor for an infinite volume source from FGR 12, as shown in Table 2.103.

Radiation doses at the same receptor location (0, 0, 1) (m) but with a concrete cover of 5-cm thickness on each of the six area sources were then estimated. Table 2.104 shows the calculation of F_{CD}, the cover and depth factor, for Tc-99. The $F_{AM\text{-}ref}$ for the reference source and F_{AM} for each of the six circular area sources were estimated with the same calculations as implemented in Tables 2.96 to 2.102 but for a cover thickness of 5-cm; the final values of F_{AM} for each area source are listed in Table 2.105, which shows the calculation of radiation doses at the receptor location.

Comparison of the dose results for Tc-99 between the spreadsheets and RESRAD-BUILD are presented in Table 2.106. In general, the differences are less than 3%. Based on the

comparison, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Table 2.92 Calculation of F_{CD} for Mn-54 in an Area Source with a Cover of 5 cm

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.085	0.915	1.22	0.088		
Reference source –	Cover material =		none	Cover thickness, cm =			5	Density of cover, g/cm3 =	2.4
	Source density , g/cm3 =			1.6	Source thickness, cm =			0.001	
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625					
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho s t_s}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho s t_s})$									
FCD-surf=	0.00000280	(Note: FCD-surf = FCD × Surface activity conversion factor)							

Table 2.93 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six Area Sources with a Concrete Cover of 5 cm

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	2.80E-06	10,000	9.94E-01	9.84E-06
				1,000	9.94E-01	9.84E-06
				100	9.75E-01	9.66E-06
				36	8.82E-01	8.74E-06
				10	6.15E-01	6.09E-06
				4	3.81E-01	3.78E-06

Table 2.94 Comparison of External Radiation Doses (mrem/yr) at the Receptor Location (0, 0, 1) (m) Estimated by RESRAD-BUILD and Spreadsheets from Mn-54 in Six Area Sources with Concrete Covers

	With 1-cm Cover			With 5-cm Cover		
Area of Source (m^2)	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	2.49E-05	2.49E-05	1.00	9.87E-06	9.84E-06	1.00
1,000	2.42E-05	2.40E-05	1.01	9.87E-06	9.84E-06	1.00
100	1.76E-05	1.74E-05	1.01	9.75E-06	9.66E-06	1.01
36	1.32E-05	1.30E-05	1.02	8.82E-06	8.74E-06	1.01
10	7.65E-06	7.62E-06	1.00	6.11E-06	6.09E-06	1.00
4	4.43E-06	4.41E-06	1.00	3.80E-06	3.78E-06	1.01

Table 2.95 Calculation of F_{CD} for Tc-99 in an Area Source with a Cover of 1 cm

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.787	0.213	0.211	2.63		
Reference source –	Cover material =		none	Cover thickness, cm =			1	Density of cover, g/cm3 =	2.4
	Source density , g/cm3 =			1.6	Source thickness, cm =			0.001	
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625					
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho s t_s}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho s t_s})$									
FCD-surf=	0.00001011	(Note: FCD-surf = FCD × Surface activity conversion factor)							

Table 2.96 Calculation of F_{AM} for Tc-99 in a Reference Area Source with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	1.77E-03	0.98	0.361	4.45E-03	4.35E-03	4.16E-01	4.26E-01	1.88E-04

ta (cm) =	99		tc (cm) =	1		Source area (m2) =	4	Source-ref area (m2) =	3.36E+06

exp(-ux)/x2 - ref	dist. in -ref-air (cm)	dist. in-ref-cover (cm)	mfp-dist. in -ref-air	mfp-dist. in-ref-cover	BF-ref-air	BF-ref-cover	Vol-source-ref	F_{AM}-ref	4π x dist-ref^2 (cm2)	distance-ref (cm)	r - ref (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
5.15E-06	9.90E+01	1.00E+00	1.86E-02	4.16E-01	1.05E+00	1.82E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	0.99		
5.09E-06	9.95E+01	1.00E+00	1.87E-02	4.18E-01	1.05E+00	1.83E+00	3.14E-02	3.07E-07	1.27E+05	1.00E+02	1.00E-01	1	0.99		
5.08E-06	9.95E+01	1.01E+00	1.87E-02	4.18E-01	1.05E+00	1.83E+00	1.91E-03	1.87E-08	1.27E+05	1.01E+02	1.03E-01	1	0.99		
5.08E-06	9.96E+01	1.01E+00	1.87E-02	4.18E-01	1.05E+00	1.83E+00	2.03E-03	1.98E-08	1.27E+05	1.01E+02	1.06E-01	1	0.99		
5.08E-06	9.96E+01	1.01E+00	1.87E-02	4.19E-01	1.05E+00	1.83E+00	2.15E-03	2.10E-08	1.27E+05	1.01E+02	1.09E-01	1	0.99		
5.07E-06	9.96E+01	1.01E+00	1.87E-02	4.19E-01	1.05E+00	1.83E+00	2.29E-03	2.23E-08	1.27E+05	1.01E+02	1.13E-01	1	0.99		
5.07E-06	9.97E+01	1.01E+00	1.87E-02	4.19E-01	1.05E+00	1.83E+00	2.42E-03	2.36E-08	1.27E+05	1.01E+02	1.16E-01	1	0.99		
5.06E-06	9.97E+01	1.01E+00	1.87E-02	4.19E-01	1.05E+00	1.83E+00	2.57E-03	2.50E-08	1.28E+05	1.01E+02	1.19E-01	1	0.99	0	100
5.06E-06	9.97E+01	1.01E+00	1.87E-02	4.19E-01	1.05E+00	1.83E+00	2.73E-03	2.65E-08	1.28E+05	1.01E+02	1.23E-01	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.25E-15	3.40E+03	3.43E+01	6.37E-01	1.43E+01	2.92E+00	7.34E+01	1.44E+02	6.94E-11	1.48E+08	3.43E+03	3.43E+01	1	0.99		
1.61E-15	3.46E+03	3.50E+01	6.50E-01	1.46E+01	2.98E+00	7.56E+01	1.49E+02	5.40E-11	1.54E+08	3.50E+03	3.50E+01	1	0.99		
1.14E-15	3.53E+03	3.57E+01	6.63E-01	1.49E+01	3.03E+00	7.78E+01	1.55E+02	4.18E-11	1.60E+08	3.57E+03	3.57E+01	1	0.99		
8.04E-16	3.60E+03	3.64E+01	6.76E-01	1.51E+01	3.09E+00	8.05E+01	1.62E+02	3.23E-11	1.67E+08	3.64E+03	3.64E+01	1	0.99		
5.63E-16	3.68E+03	3.71E+01	6.90E-01	1.55E+01	3.14E+00	8.37E+01	1.68E+02	2.49E-11	1.73E+08	3.71E+03	3.71E+01	1	0.99		
3.92E-16	3.75E+03	3.79E+01	7.03E-01	1.58E+01	3.20E+00	8.69E+01	1.75E+02	1.91E-11	1.80E+08	3.79E+03	3.79E+01	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.05E-199	9.84E+04	9.94E+02	1.85E+01	4.14E+02	1.50E+03	5.15E+02	1.21E+05	1.90E-188	1.24E+11	9.94E+04	9.94E+02	1	0.99		
3.49E-203	1.00E+05	1.01E+03	1.88E+01	4.22E+02	1.57E+03	5.15E+02	1.25E+05	3.54E-192	1.29E+11	1.01E+05	1.01E+03	1	0.99		
5.00E-207	1.02E+05	1.03E+03	1.92E+01	4.30E+02	1.65E+03	5.15E+02	1.30E+05	5.52E-196	1.34E+11	1.03E+05	1.03E+03	1	0.99		
							∑ F_{AM}-ref =	1.13E-04							

Table 2.97 Calculation of F_{AM} for Tc-99 in an Area Source of 4 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	1.77E-03	0.98	0.361	4.45E-03	4.35E-03	4.16E-01	4.26E-01	1.88E-04

ta (cm) =	99		tc (cm) =	1		Source area (m2) =	4		Source-ref area (m2) =	3.36E+06

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
5.10E-06	1.86E-02	4.26E-01	9.90E+01	1.00E+00	1.05E+00	1.76E+00	0.00E+00	0.00E+00	1.26E+05	1.00E+02	0.00E+00	1	0.99		
5.04E-06	1.87E-02	4.28E-01	9.95E+01	1.00E+00	1.05E+00	1.76E+00	3.14E-02	2.93E-07	1.27E+05	1.00E+02	1.00E-01	1	0.99		
5.03E-06	1.87E-02	4.28E-01	9.95E+01	1.01E+00	1.05E+00	1.76E+00	1.91E-03	1.78E-08	1.27E+05	1.01E+02	1.03E-01	1	0.99		
5.03E-06	1.87E-02	4.29E-01	9.96E+01	1.01E+00	1.05E+00	1.76E+00	2.03E-03	1.89E-08	1.27E+05	1.01E+02	1.06E-01	1	0.99		
5.02E-06	1.87E-02	4.29E-01	9.96E+01	1.01E+00	1.05E+00	1.76E+00	2.15E-03	2.00E-08	1.27E+05	1.01E+02	1.09E-01	1	0.99		
5.02E-06	1.87E-02	4.29E-01	9.96E+01	1.01E+00	1.05E+00	1.76E+00	2.29E-03	2.12E-08	1.27E+05	1.01E+02	1.13E-01	1	0.99		
5.02E-06	1.87E-02	4.29E-01	9.97E+01	1.01E+00	1.05E+00	1.76E+00	2.42E-03	2.25E-08	1.27E+05	1.01E+02	1.16E-01	1	0.99		
5.01E-06	1.87E-02	4.29E-01	9.97E+01	1.01E+00	1.05E+00	1.76E+00	2.57E-03	2.39E-08	1.28E+05	1.01E+02	1.19E-01	1	0.99		
5.01E-06	1.87E-02	4.29E-01	9.97E+01	1.01E+00	1.05E+00	1.76E+00	2.73E-03	2.53E-08	1.28E+05	1.01E+02	1.23E-01	1	0.99		
5.00E-06	1.87E-02	4.30E-01	9.98E+01	1.01E+00	1.05E+00	1.76E+00	2.90E-03	2.68E-08	1.28E+05	1.01E+02	1.27E-01	1	0.99		
4.99E-06	1.87E-02	4.30E-01	9.98E+01	1.01E+00	1.05E+00	1.76E+00	3.07E-03	2.84E-08	1.28E+05	1.01E+02	1.30E-01	1	0.99		
4.99E-06	1.87E-02	4.30E-01	9.99E+01	1.01E+00	1.05E+00	1.76E+00	3.26E-03	3.01E-08	1.28E+05	1.01E+02	1.34E-01	1	0.99		
4.98E-06	1.87E-02	4.30E-01	9.99E+01	1.01E+00	1.05E+00	1.77E+00	3.46E-03	3.19E-08	1.28E+05	1.01E+02	1.38E-01	1	0.99		
4.97E-06	1.88E-02	4.31E-01	1.00E+02	1.01E+00	1.05E+00	1.77E+00	3.67E-03	3.38E-08	1.28E+05	1.01E+02	1.43E-01	1	0.99	0	100
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.11E-06	2.63E-02	6.04E-01	1.40E+02	1.42E+00	1.07E+00	2.07E+00	1.81E-01	8.51E-07	2.52E+05	1.42E+02	1.00E+00	1	0.99		
2.03E-06	2.67E-02	6.13E-01	1.42E+02	1.44E+00	1.07E+00	2.09E+00	1.93E-01	8.76E-07	2.60E+05	1.44E+02	1.03E+00	1	0.99		
1.95E-06	2.71E-02	6.22E-01	1.45E+02	1.46E+00	1.07E+00	2.11E+00	2.04E-01	9.00E-07	2.68E+05	1.46E+02	1.06E+00	1	0.99		
1.87E-06	2.75E-02	6.32E-01	1.47E+02	1.48E+00	1.07E+00	2.13E+00	2.17E-01	9.24E-07	2.77E+05	1.48E+02	1.10E+00	1	0.99		
1.79E-06	2.80E-02	6.43E-01	1.49E+02	1.51E+00	1.08E+00	2.14E+00	2.30E-01	9.48E-07	2.86E+05	1.51E+02	1.13E+00	1	0.99		
							∑ F_{AM}-source =	2.41E-05							
							F_{AM} =	2.13E-01							

Table 2.98 Calculation of F_{AM} for Tc-99 in an Area Source of 10 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	1.77E-03	0.98	0.361	4.45E-03	4.35E-03	4.16E-01	4.26E-01	1.88E-04

ta (cm) = 99 tc (cm) = 1 Source area (m2) = 10 Source-ref area (m2) = 3.36E+06

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.71E-06	2.85E-02	6.54E-01	1.52E+02	1.53E+00	1.08E+00	2.16E+00	2.44E-01	9.71E-07	2.96E+05	1.53E+02	1.16E+00	1	0.99		
1.63E-06	2.90E-02	6.65E-01	1.54E+02	1.56E+00	1.08E+00	2.18E+00	2.59E-01	9.94E-07	3.06E+05	1.56E+02	1.20E+00	1	0.99		
1.56E-06	2.95E-02	6.77E-01	1.57E+02	1.59E+00	1.08E+00	2.20E+00	2.75E-01	1.02E-06	3.17E+05	1.59E+02	1.23E+00	1	0.99		
1.48E-06	3.00E-02	6.89E-01	1.60E+02	1.62E+00	1.08E+00	2.23E+00	2.91E-01	1.04E-06	3.29E+05	1.62E+02	1.27E+00	1	0.99		
1.41E-06	3.06E-02	7.02E-01	1.63E+02	1.65E+00	1.08E+00	2.25E+00	3.09E-01	1.06E-06	3.41E+05	1.65E+02	1.31E+00	1	0.99		
1.34E-06	3.12E-02	7.15E-01	1.66E+02	1.68E+00	1.08E+00	2.27E+00	3.28E-01	1.08E-06	3.54E+05	1.68E+02	1.35E+00	1	0.99		
1.27E-06	3.18E-02	7.29E-01	1.69E+02	1.71E+00	1.09E+00	2.30E+00	3.48E-01	1.10E-06	3.68E+05	1.71E+02	1.39E+00	1	0.99		
1.20E-06	3.24E-02	7.44E-01	1.73E+02	1.75E+00	1.09E+00	2.32E+00	3.69E-01	1.12E-06	3.83E+05	1.75E+02	1.43E+00	1	0.99		
1.14E-06	3.31E-02	7.59E-01	1.76E+02	1.78E+00	1.09E+00	2.35E+00	3.91E-01	1.14E-06	3.98E+05	1.78E+02	1.47E+00	1	0.99	0	100
1.07E-06	3.37E-02	7.75E-01	1.80E+02	1.82E+00	1.09E+00	2.38E+00	4.15E-01	1.16E-06	4.15E+05	1.82E+02	1.52E+00	1	0.99		
1.01E-06	3.44E-02	7.91E-01	1.84E+02	1.86E+00	1.09E+00	2.41E+00	4.41E-01	1.17E-06	4.33E+05	1.86E+02	1.56E+00	1	0.99		
9.54E-07	3.52E-02	8.08E-01	1.88E+02	1.89E+00	1.09E+00	2.44E+00	4.67E-01	1.19E-06	4.51E+05	1.89E+02	1.61E+00	1	0.99		
8.97E-07	3.59E-02	8.25E-01	1.92E+02	1.94E+00	1.10E+00	2.47E+00	4.96E-01	1.20E-06	4.71E+05	1.94E+02	1.66E+00	1	0.99		
8.42E-07	3.67E-02	8.43E-01	1.96E+02	1.98E+00	1.10E+00	2.50E+00	5.26E-01	1.22E-06	4.92E+05	1.98E+02	1.71E+00	1	0.99		
7.90E-07	3.76E-02	8.62E-01	2.00E+02	2.02E+00	1.10E+00	2.54E+00	5.58E-01	1.23E-06	5.15E+05	2.02E+02	1.76E+00	1	0.99		
7.56E-07	3.81E-02	8.75E-01	2.03E+02	2.05E+00	1.10E+00	2.56E+00	3.93E-01	8.38E-07	5.30E+05	2.05E+02	1.79E+00	1	0.99		
							∑ F_{AM}-source =	4.16E-05							
							F_{AM} =	3.68E-01							

Table 2.99 Calculation of F_{AM} for Tc-99 in an Area Source of 36 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)						
1	0.101	1.77E-03	0.98	0.361	4.45E-03	4.35E-03	4.16E-01	4.26E-01	1.88E-04						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =		36	Source-ref area (m2) =		3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
6.92E-07	3.93E-02	9.03E-01	2.10E+02	2.12E+00	1.11E+00	2.61E+00	4.25E-01	8.48E-07	5.64E+05	2.12E+02	1.87E+00	1	0.99		
6.61E-07	3.99E-02	9.17E-01	2.13E+02	2.15E+00	1.11E+00	2.63E+00	4.42E-01	8.52E-07	5.81E+05	2.15E+02	1.90E+00	1	0.99		
6.31E-07	4.06E-02	9.31E-01	2.16E+02	2.18E+00	1.11E+00	2.66E+00	4.60E-01	8.56E-07	6.00E+05	2.18E+02	1.94E+00	1	0.99		
6.02E-07	4.12E-02	9.46E-01	2.20E+02	2.22E+00	1.11E+00	2.68E+00	4.79E-01	8.60E-07	6.19E+05	2.22E+02	1.98E+00	1	0.99		
5.74E-07	4.19E-02	9.61E-01	2.23E+02	2.25E+00	1.11E+00	2.71E+00	4.98E-01	8.63E-07	6.39E+05	2.25E+02	2.02E+00	1	0.99		
5.47E-07	4.25E-02	9.76E-01	2.27E+02	2.29E+00	1.11E+00	2.74E+00	5.18E-01	8.66E-07	6.60E+05	2.29E+02	2.06E+00	1	0.99		
5.21E-07	4.32E-02	9.92E-01	2.30E+02	2.33E+00	1.12E+00	2.77E+00	5.39E-01	8.68E-07	6.81E+05	2.33E+02	2.10E+00	1	0.99		
4.96E-07	4.39E-02	1.01E+00	2.34E+02	2.37E+00	1.12E+00	2.80E+00	5.61E-01	8.70E-07	7.04E+05	2.37E+02	2.14E+00	1	0.99		
4.72E-07	4.46E-02	1.02E+00	2.38E+02	2.40E+00	1.12E+00	2.83E+00	5.84E-01	8.73E-07	7.27E+05	2.40E+02	2.19E+00	1	0.99		
4.49E-07	4.54E-02	1.04E+00	2.42E+02	2.44E+00	1.12E+00	2.86E+00	6.07E-01	8.74E-07	7.51E+05	2.44E+02	2.23E+00	1	0.99	0	100
4.26E-07	4.61E-02	1.06E+00	2.46E+02	2.49E+00	1.12E+00	2.89E+00	6.32E-01	8.75E-07	7.76E+05	2.49E+02	2.28E+00	1	0.99		
4.05E-07	4.69E-02	1.08E+00	2.50E+02	2.53E+00	1.13E+00	2.92E+00	6.57E-01	8.76E-07	8.03E+05	2.53E+02	2.32E+00	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.07E-07	5.77E-02	1.32E+00	3.08E+02	3.11E+00	1.16E+00	3.38E+00	1.06E+00	8.54E-07	1.21E+06	3.11E+02	2.94E+00	1	0.99		
1.94E-07	5.88E-02	1.35E+00	3.13E+02	3.16E+00	1.16E+00	3.43E+00	1.10E+00	8.49E-07	1.26E+06	3.16E+02	3.00E+00	1	0.99		
1.83E-07	5.98E-02	1.37E+00	3.19E+02	3.22E+00	1.16E+00	3.47E+00	1.14E+00	8.44E-07	1.30E+06	3.22E+02	3.06E+00	1	0.99		
1.72E-07	6.09E-02	1.40E+00	3.25E+02	3.28E+00	1.16E+00	3.52E+00	1.19E+00	8.39E-07	1.35E+06	3.28E+02	3.12E+00	1	0.99		
1.62E-07	6.20E-02	1.42E+00	3.31E+02	3.34E+00	1.17E+00	3.57E+00	1.24E+00	8.33E-07	1.40E+06	3.34E+02	3.19E+00	1	0.99		
1.52E-07	6.31E-02	1.45E+00	3.37E+02	3.40E+00	1.17E+00	3.62E+00	1.29E+00	8.27E-07	1.45E+06	3.40E+02	3.25E+00	1	0.99		
1.42E-07	6.43E-02	1.48E+00	3.43E+02	3.46E+00	1.17E+00	3.67E+00	1.34E+00	8.20E-07	1.51E+06	3.46E+02	3.31E+00	1	0.99		
							∑ F_{AM}-source =		6.91E-05						
							F_{AM} =		6.10E-01						

Table 2.100 Calculation of F_{AM} for Tc-99 in an Area Source of 100 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	0.101	1.77E-03	0.98	0.361	4.45E-03	4.35E-03	4.16E-01	4.26E-01	1.88E-04

ta (cm) = 99 tc (cm) = 1 Source area (m2) = 100 Source-ref area (m2) = 3.36E+06

exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	r - source (m)	ta + tc (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.25E-07	6.67E-02	1.53E+00	3.55E+02	3.59E+00	1.18E+00	3.77E+00	1.45E+00	8.06E-07	1.62E+06	3.59E+02	3.45E+00	1	0.99		
1.17E-07	6.79E-02	1.56E+00	3.62E+02	3.66E+00	1.18E+00	3.82E+00	1.51E+00	7.98E-07	1.68E+06	3.66E+02	3.52E+00	1	0.99		
1.09E-07	6.92E-02	1.59E+00	3.69E+02	3.72E+00	1.19E+00	3.87E+00	1.57E+00	7.90E-07	1.74E+06	3.72E+02	3.59E+00	1	0.99		
1.02E-07	7.04E-02	1.62E+00	3.76E+02	3.79E+00	1.19E+00	3.93E+00	1.63E+00	7.81E-07	1.81E+06	3.79E+02	3.66E+00	1	0.99		
9.55E-08	7.18E-02	1.65E+00	3.83E+02	3.86E+00	1.19E+00	3.98E+00	1.70E+00	7.72E-07	1.88E+06	3.86E+02	3.73E+00	1	0.99		
8.91E-08	7.31E-02	1.68E+00	3.90E+02	3.94E+00	1.20E+00	4.04E+00	1.77E+00	7.62E-07	1.95E+06	3.94E+02	3.81E+00	1	0.99		
8.31E-08	7.45E-02	1.71E+00	3.97E+02	4.01E+00	1.20E+00	4.10E+00	1.84E+00	7.53E-07	2.02E+06	4.01E+02	3.88E+00	1	0.99		
7.74E-08	7.59E-02	1.74E+00	4.04E+02	4.09E+00	1.20E+00	4.16E+00	1.91E+00	7.43E-07	2.10E+06	4.09E+02	3.96E+00	1	0.99		
7.21E-08	7.73E-02	1.77E+00	4.12E+02	4.16E+00	1.21E+00	4.22E+00	1.99E+00	7.32E-07	2.18E+06	4.16E+02	4.04E+00	1	0.99		
6.71E-08	7.87E-02	1.81E+00	4.20E+02	4.24E+00	1.21E+00	4.28E+00	2.07E+00	7.21E-07	2.26E+06	4.24E+02	4.12E+00	1	0.99		
6.23E-08	8.02E-02	1.84E+00	4.28E+02	4.32E+00	1.22E+00	4.35E+00	2.16E+00	7.10E-07	2.35E+06	4.32E+02	4.20E+00	1	0.99		
5.79E-08	8.17E-02	1.88E+00	4.36E+02	4.40E+00	1.22E+00	4.41E+00	2.24E+00	6.99E-07	2.44E+06	4.40E+02	4.29E+00	1	0.99		
5.37E-08	8.33E-02	1.91E+00	4.44E+02	4.49E+00	1.22E+00	4.48E+00	2.33E+00	6.87E-07	2.53E+06	4.49E+02	4.37E+00	1	0.99	0	100
4.98E-08	8.49E-02	1.95E+00	4.53E+02	4.57E+00	1.23E+00	4.54E+00	2.43E+00	6.75E-07	2.63E+06	4.57E+02	4.46E+00	1	0.99		
4.61E-08	8.65E-02	1.99E+00	4.61E+02	4.66E+00	1.23E+00	4.61E+00	2.53E+00	6.63E-07	2.73E+06	4.66E+02	4.55E+00	1	0.99		
4.27E-08	8.82E-02	2.02E+00	4.70E+02	4.75E+00	1.24E+00	4.69E+00	2.63E+00	6.51E-07	2.83E+06	4.75E+02	4.64E+00	1	0.99		
3.95E-08	8.98E-02	2.06E+00	4.79E+02	4.84E+00	1.24E+00	4.77E+00	2.73E+00	6.39E-07	2.94E+06	4.84E+02	4.73E+00	1	0.99		
3.65E-08	9.16E-02	2.10E+00	4.88E+02	4.93E+00	1.25E+00	4.85E+00	2.85E+00	6.27E-07	3.06E+06	4.93E+02	4.83E+00	1	0.99		
3.37E-08	9.33E-02	2.14E+00	4.98E+02	5.03E+00	1.25E+00	4.93E+00	2.96E+00	6.15E-07	3.18E+06	5.03E+02	4.93E+00	1	0.99		
3.11E-08	9.51E-02	2.18E+00	5.07E+02	5.12E+00	1.26E+00	5.01E+00	3.08E+00	6.02E-07	3.30E+06	5.12E+02	5.02E+00	1	0.99		
2.86E-08	9.69E-02	2.23E+00	5.17E+02	5.22E+00	1.26E+00	5.09E+00	3.20E+00	5.89E-07	3.43E+06	5.22E+02	5.12E+00	1	0.99		
2.63E-08	9.88E-02	2.27E+00	5.27E+02	5.32E+00	1.27E+00	5.18E+00	3.33E+00	5.76E-07	3.56E+06	5.32E+02	5.23E+00	1	0.99		
2.42E-08	1.01E-01	2.31E+00	5.37E+02	5.42E+00	1.27E+00	5.27E+00	3.47E+00	5.63E-07	3.70E+06	5.42E+02	5.33E+00	1	0.99		
2.22E-08	1.03E-01	2.36E+00	5.47E+02	5.53E+00	1.28E+00	5.36E+00	3.61E+00	5.49E-07	3.84E+06	5.53E+02	5.44E+00	1	0.99		
2.04E-08	1.05E-01	2.40E+00	5.58E+02	5.64E+00	1.28E+00	5.45E+00	3.75E+00	5.35E-07	3.99E+06	5.64E+02	5.55E+00	1	0.99		
1.87E-08	1.07E-01	2.45E+00	5.69E+02	5.75E+00	1.29E+00	5.54E+00	3.91E+00	5.22E-07	4.15E+06	5.75E+02	5.66E+00	1	0.99		
							∑ F_{AM}-source =	8.67E-05							
							F_{AM} =	7.65E-01							

Table 2.101 Calculation of F_{AM} for Tc-99 in an Area Source of 1,000 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.101	1.77E-03	0.98	0.361	4.45E-03	4.35E-03	4.16E-01	4.26E-01	1.88E-04						
ta (cm) =	99		tc (cm) =	1		Source area (m2) =	1000		Source-ref area (m2) =	3.36E+06					
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air	dist. in-source-cover	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2	distance-source	r - source, m	ta + tc, m	ta, m	Receptor location y, cm	Receptor location z, cm
1.71E-08	1.09E-01	2.50E+00	5.80E+02	5.86E+00	1.29E+00	5.64E+00	4.06E+00	5.08E-07	4.31E+06	5.86E+02	5.77E+00	1	0.99		
1.57E-08	1.11E-01	2.54E+00	5.91E+02	5.97E+00	1.30E+00	5.74E+00	4.23E+00	4.94E-07	4.48E+06	5.97E+02	5.89E+00	1	0.99		
1.43E-08	1.13E-01	2.59E+00	6.03E+02	6.09E+00	1.30E+00	5.84E+00	4.40E+00	4.80E-07	4.66E+06	6.09E+02	6.00E+00	1	0.99		
1.31E-08	1.15E-01	2.64E+00	6.14E+02	6.20E+00	1.31E+00	5.94E+00	4.58E+00	4.66E-07	4.84E+06	6.20E+02	6.12E+00	1	0.99		
1.19E-08	1.17E-01	2.70E+00	6.26E+02	6.33E+00	1.32E+00	6.04E+00	4.76E+00	4.52E-07	5.03E+06	6.33E+02	6.25E+00	1	0.99		
1.09E-08	1.20E-01	2.75E+00	6.38E+02	6.45E+00	1.32E+00	6.15E+00	4.95E+00	4.37E-07	5.23E+06	6.45E+02	6.37E+00	1	0.99		
9.88E-09	1.22E-01	2.80E+00	6.51E+02	6.58E+00	1.33E+00	6.26E+00	5.15E+00	4.23E-07	5.43E+06	6.58E+02	6.50E+00	1	0.99		
8.97E-09	1.24E-01	2.86E+00	6.64E+02	6.70E+00	1.34E+00	6.37E+00	5.36E+00	4.09E-07	5.65E+06	6.70E+02	6.63E+00	1	0.99		
8.14E-09	1.27E-01	2.91E+00	6.77E+02	6.83E+00	1.34E+00	6.48E+00	5.58E+00	3.95E-07	5.87E+06	6.83E+02	6.76E+00	1	0.99	0	100
7.38E-09	1.29E-01	2.97E+00	6.90E+02	6.97E+00	1.35E+00	6.60E+00	5.80E+00	3.81E-07	6.10E+06	6.97E+02	6.90E+00	1	0.99		
6.68E-09	1.32E-01	3.03E+00	7.03E+02	7.11E+00	1.36E+00	6.72E+00	6.04E+00	3.67E-07	6.35E+06	7.11E+02	7.03E+00	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.26E-11	3.01E-01	6.90E+00	1.60E+03	1.62E+01	1.81E+00	1.62E+01	3.19E+01	2.11E-08	3.30E+07	1.62E+03	1.62E+01	1	0.99		
1.88E-11	3.07E-01	7.04E+00	1.63E+03	1.65E+01	1.83E+00	1.66E+01	3.32E+01	1.89E-08	3.43E+07	1.65E+03	1.65E+01	1	0.99		
1.56E-11	3.13E-01	7.18E+00	1.67E+03	1.68E+01	1.84E+00	1.70E+01	3.45E+01	1.69E-08	3.57E+07	1.68E+03	1.68E+01	1	0.99		
1.30E-11	3.19E-01	7.32E+00	1.70E+03	1.72E+01	1.86E+00	1.74E+01	3.59E+01	1.50E-08	3.71E+07	1.72E+03	1.71E+01	1	0.99		
1.07E-11	3.25E-01	7.47E+00	1.73E+03	1.75E+01	1.88E+00	1.78E+01	3.73E+01	1.34E-08	3.86E+07	1.75E+03	1.75E+01	1	0.99		
8.80E-12	3.32E-01	7.62E+00	1.77E+03	1.79E+01	1.89E+00	1.83E+01	3.88E+01	1.18E-08	4.01E+07	1.79E+03	1.78E+01	1	0.99		
							∑ F_{AM}-source =	9.78E-05							
							F_{AM} =	8.63E-01							

Table 2.102 Calculation of F_{AM} for Tc-99 in an Area Source of 10,000 m^2 with a Cover of 1 cm at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	0.101	1.77E-03	0.98	0.361	4.45E-03	4.35E-03	4.16E-01	4.26E-01	1.88E-04						
ta (cm) =	99		tc (cm) =	1			Source area (m2) =	10000		Source-ref area (m2) =	3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	mfp-dist. in-source-cover	dist. in - source-air	dist. in-source-cover	BF-source-air	BF-source-cover	Vol-source	F_{AM}-source	4π x dist-source^2	distance-source	r - source, m	ta + tc, m	ta, m	Receptor location y, cm	Receptor location z, cm
7.22E-12	3.38E-01	7.77E+00	1.80E+03	1.82E+01	1.91E+00	1.87E+01	4.04E+01	1.04E-08	4.18E+07	1.82E+03	1.82E+01	1	0.99		
5.90E-12	3.45E-01	7.92E+00	1.84E+03	1.86E+01	1.93E+00	1.92E+01	4.21E+01	9.19E-09	4.34E+07	1.86E+03	1.86E+01	1	0.99		
4.81E-12	3.52E-01	8.08E+00	1.88E+03	1.90E+01	1.95E+00	1.97E+01	4.37E+01	8.07E-09	4.52E+07	1.90E+03	1.89E+01	1	0.99		
3.91E-12	3.59E-01	8.24E+00	1.91E+03	1.93E+01	1.97E+00	2.02E+01	4.55E+01	7.07E-09	4.70E+07	1.93E+03	1.93E+01	1	0.99		
3.17E-12	3.66E-01	8.41E+00	1.95E+03	1.97E+01	1.99E+00	2.07E+01	4.74E+01	6.17E-09	4.89E+07	1.97E+03	1.97E+01	1	0.99		
2.55E-12	3.74E-01	8.57E+00	1.99E+03	2.01E+01	2.01E+00	2.13E+01	4.93E+01	5.37E-09	5.09E+07	2.01E+03	2.01E+01	1	0.99		
2.05E-12	3.81E-01	8.75E+00	2.03E+03	2.05E+01	2.03E+00	2.18E+01	5.13E+01	4.66E-09	5.29E+07	2.05E+03	2.05E+01	1	0.99		
1.65E-12	3.89E-01	8.92E+00	2.07E+03	2.09E+01	2.05E+00	2.24E+01	5.33E+01	4.03E-09	5.51E+07	2.09E+03	2.09E+01	1	0.99		
1.31E-12	3.96E-01	9.10E+00	2.11E+03	2.13E+01	2.07E+00	2.30E+01	5.55E+01	3.46E-09	5.73E+07	2.13E+03	2.13E+01	1	0.99		
1.04E-12	4.04E-01	9.28E+00	2.16E+03	2.18E+01	2.09E+00	2.36E+01	5.77E+01	2.97E-09	5.96E+07	2.18E+03	2.17E+01	1	0.99		
8.28E-13	4.12E-01	9.47E+00	2.20E+03	2.22E+01	2.11E+00	2.42E+01	6.01E+01	2.54E-09	6.20E+07	2.22E+03	2.22E+01	1	0.99	0	100
6.53E-13	4.21E-01	9.65E+00	2.24E+03	2.26E+01	2.13E+00	2.48E+01	6.25E+01	2.16E-09	6.45E+07	2.26E+03	2.26E+01	1	0.99		
5.14E-13	4.29E-01	9.85E+00	2.29E+03	2.31E+01	2.15E+00	2.54E+01	6.50E+01	1.83E-09	6.71E+07	2.31E+03	2.31E+01	1	0.99		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
4.36E-19	9.46E-01	2.17E+01	5.05E+03	5.10E+01	4.22E+00	7.77E+01	3.17E+02	4.53E-14	3.27E+08	5.10E+03	5.10E+01	1	0.99		
2.66E-19	9.65E-01	2.22E+01	5.15E+03	5.20E+01	4.30E+00	7.95E+01	3.30E+02	3.00E-14	3.40E+08	5.20E+03	5.20E+01	1	0.99		
1.61E-19	9.85E-01	2.26E+01	5.25E+03	5.30E+01	4.38E+00	8.13E+01	3.43E+02	1.97E-14	3.54E+08	5.30E+03	5.30E+01	1	0.99		
9.67E-20	1.00E+00	2.31E+01	5.35E+03	5.41E+01	4.48E+00	8.31E+01	3.57E+02	1.28E-14	3.68E+08	5.41E+03	5.41E+01	1	0.99		
5.74E-20	1.02E+00	2.35E+01	5.46E+03	5.52E+01	4.62E+00	8.50E+01	3.71E+02	8.37E-15	3.83E+08	5.52E+03	5.52E+01	1	0.99		
3.38E-20	1.04E+00	2.40E+01	5.57E+03	5.63E+01	4.76E+00	8.69E+01	3.86E+02	5.40E-15	3.98E+08	5.63E+03	5.63E+01	1	0.99		
							∑ F_{AM}-source =	9.78E-05							
							F_{AM} =	8.63E-01							

Table 2.103 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Tc-99 in Six Area Sources with a Concrete Cover of 1 cm

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	1.01E-05	10,000	8.63E-01	1.10E-09
				1,000	8.63E-01	1.09E-09
				100	7.65E-01	9.70E-10
				36	6.10E-01	7.74E-10
				10	3.68E-01	4.66E-10
				4	2.13E-01	2.70E-10

Table 2.104 Calculation of F_{CD} for Tc-99 in an Area Source with a Cover of 5 cm

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.787	0.213	0.211	2.63				
Reference source –		Cover material =	none	Cover thickness, cm =			5	Density of cover, g/cm3 =			2.4
		Source density , g/cm3 =		1.6	Source thickness, cm =			0.001			
Surface activity conversion factor, (pCi/g)/(pCi/m2)				0.0625							
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho s t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho s t_S})$,											
FCD-surf=	0.00000132		(Note: FCD-surf = FCD × Surface activity conversion factor)								

Table 2.105 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Tc-99 in Six Area Sources with a Concrete Cover of 5 cm

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	1.32E-06	10,000	7.39E-01	1.22E-10
				1,000	7.39E-01	1.22E-10
				100	7.39E-01	1.22E-10
				36	7.35E-01	1.22E-10
				10	6.60E-01	1.09E-10
				4	4.92E-01	8.15E-11

Table 2.106 Comparison of External Radiation Doses (mrem/yr) at the Receptor Location (0, 0, 1) (m) Estimated by RESRAD-BUILD and Spreadsheets from Tc-99 in Six Area Sources with Concrete Covers

Area of Source (m^2)	With 1-cm Cover			With 5-cm Cover		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
10,000	1.10E-09	1.10E-09	1.00	1.23E-10	1.22E-10	1.01
1,000	1.10E-09	1.09E-09	1.01	1.23E-10	1.22E-10	1.01
100	9.97E-10	9.70E-10	1.03	1.23E-10	1.22E-10	1.01
36	8.08E-10	7.74E-10	1.04	1.23E-10	1.22E-10	1.01
10	4.91E-10	4.66E-10	1.05	1.10E-10	1.09E-10	1.01
4	2.87E-10	2.70E-10	1.06	8.25E-11	8.15E-11	1.01

2.3.2 Rectangular Area Sources

The external radiation dose modeling for rectangular area sources by RESRAD-BUILD was verified by comparing the external dose results with those of spreadsheets for a receptor at (0, 0, 1) (m) from six rectangular area sources, which was centered at (0, 0, 0) (m) with a z-direction. These six area sources contained C-14 of a concentration of 1 pCi/m^2 and had dimensions of 2 m × 2 m, 4 m × 2 m, 4 m × 3 m, 4 m × 4 m, 6 m × 6 m, and 10 m × 10 m. There was no shielding material, and the indoor time fraction for the receptor was assumed to be 1.

Unlike a circular area source, which was subdivided into multiple annuli to estimate the effective F_{AM} in the spreadsheet calculations, as described in Section 2.3.1, a rectangular area source was subdivided into multiple squares. The sum of the F_{AM} of each square was the effective F_{AM} of the rectangular source. Tables 2.107 to 2.112 show the estimation of F_{AM} for each rectangular source considered. The final values of F_{AM} for each rectangular source are listed in Table 2.113, which shows the calculation of radiation doses at the receptor location.

Comparisons of the dose results for C-14 between the spreadsheets and RESRAD-BUILD are presented in Table 2.114. In general, the differences are less than 3%. Based on the comparison, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Table 2.107 Calculation of F_{AM} for C-14 in a Rectangular Area Source of 2 m × 2 m without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$
1	0.049	8.65E-04	0.1	0.22	2.59E-04	2.59E-04	5.79E-01	9.99E-01	2.59E-04	

ta (cm) =	100		tc (cm) =	0		Source area (m2) =	2 x 2 = 4			Source-ref area (m2) =		3.36E+06				

exp(-ux)/x2 - source	mfp-dist. in - source-air	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	x-source (m)	y-source (m)	z-source (m)	ta + tc (m)	ta (m)	Receptor location x (m)	Receptor location y (m)	Receptor location z (m)
4.31E-06	3.45E-02	1.33E+02	0.00E+00	1.10E+00	2.50E-01	1.19E-06	2.24E+05	1.33E+02	0.125	0.125	0	1	1	0	0	1
5.49E-06	3.07E-02	1.19E+02	0.00E+00	1.09E+00	2.50E-01	1.49E-06	1.77E+05	1.19E+02	0.125	0.375	0	1	1	0	0	1
6.69E-06	2.78E-02	1.08E+02	0.00E+00	1.08E+00	2.50E-01	1.81E-06	1.45E+05	1.08E+02	0.125	0.625	0	1	1	0	0	1
7.51E-06	2.63E-02	1.02E+02	0.00E+00	1.08E+00	2.50E-01	2.02E-06	1.30E+05	1.02E+02	0.125	0.875	0	1	1	0	0	1
4.03E-06	3.57E-02	1.38E+02	0.00E+00	1.10E+00	2.50E-01	1.11E-06	2.40E+05	1.38E+02	0.375	0.125	0	1	1	0	0	1
5.03E-06	3.20E-02	1.24E+02	0.00E+00	1.09E+00	2.50E-01	1.37E-06	1.93E+05	1.24E+02	0.375	0.375	0	1	1	0	0	1
6.03E-06	2.93E-02	1.13E+02	0.00E+00	1.09E+00	2.50E-01	1.64E-06	1.61E+05	1.13E+02	0.375	0.625	0	1	1	0	0	1
6.69E-06	2.78E-02	1.08E+02	0.00E+00	1.08E+00	2.50E-01	1.81E-06	1.45E+05	1.08E+02	0.375	0.875	0	1	1	0	0	1
3.55E-06	3.80E-02	1.47E+02	0.00E+00	1.11E+00	2.50E-01	9.86E-07	2.71E+05	1.47E+02	0.625	0.125	0	1	1	0	0	1
4.31E-06	3.45E-02	1.33E+02	0.00E+00	1.10E+00	2.50E-01	1.19E-06	2.24E+05	1.33E+02	0.625	0.375	0	1	1	0	0	1
5.03E-06	3.20E-02	1.24E+02	0.00E+00	1.09E+00	2.50E-01	1.37E-06	1.93E+05	1.24E+02	0.625	0.625	0	1	1	0	0	1
5.49E-06	3.07E-02	1.19E+02	0.00E+00	1.09E+00	2.50E-01	1.49E-06	1.77E+05	1.19E+02	0.625	0.875	0	1	1	0	0	1
3.02E-06	4.12E-02	1.59E+02	0.00E+00	1.12E+00	2.50E-01	8.44E-07	3.18E+05	1.59E+02	0.875	0.125	0	1	1	0	0	1
3.55E-06	3.80E-02	1.47E+02	0.00E+00	1.11E+00	2.50E-01	9.86E-07	2.71E+05	1.47E+02	0.875	0.375	0	1	1	0	0	1
4.03E-06	3.57E-02	1.38E+02	0.00E+00	1.10E+00	2.50E-01	1.11E-06	2.40E+05	1.38E+02	0.875	0.625	0	1	1	0	0	1
4.31E-06	3.45E-02	1.33E+02	0.00E+00	1.10E+00	2.50E-01	1.19E-06	2.24E+05	1.33E+02	0.875	0.875	0	1	1	0	0	1
3.83E-06	3.66E-02	1.41E+02	0.00E+00	1.11E+00	0.00E+00	0.00E+00	2.51E+05	1.41E+02	1.000	1.000	0	1	1	0	0	1
					∑FAM-source =	2.16E-05										
					FAM=	7.02E-02										

Table 2.108 Calculation of F_{AM} for C-14 in a Rectangular Area Source of 4 m × 2 m without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$						
1	0.049	8.65E-04	0.1	0.22	2.59E-04	2.59E-04	5.79E-01	9.99E-01	2.59E-04							
ta (cm) =	100		tc (cm) =	0		Source area (m2) =	4 x 2 = 8			Source-ref area (m2) =		3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	x-source (m)	y-source (m)	z-source (m)	ta + tc (m)	ta (m)	Receptor location x (m)	Receptor location y (m)	Receptor location z (m)
3.35E-06	3.91E-02	1.55E+02	0.00E+00	1.11E+00	2.50E-01	9.33E-07	2.87E+05	1.51E+02	1.125	0.125	0	1	0	0	0	1
3.18E-06	4.01E-02	1.63E+02	0.00E+00	1.12E+00	2.50E-01	8.86E-07	3.03E+05	1.55E+02	1.125	0.375	0	1	0	0	0	1
2.87E-06	4.22E-02	1.74E+02	0.00E+00	1.12E+00	2.50E-01	8.06E-07	3.34E+05	1.63E+02	1.125	0.625	0	1	0	0	0	1
2.51E-06	4.50E-02	1.70E+02	0.00E+00	1.13E+00	2.50E-01	7.09E-07	3.81E+05	1.74E+02	1.125	0.875	0	1	0	0	0	1
2.62E-06	4.41E-02	1.74E+02	0.00E+00	1.13E+00	2.50E-01	7.39E-07	3.65E+05	1.70E+02	1.375	0.125	0	1	0	0	0	1
2.51E-06	4.50E-02	1.81E+02	0.00E+00	1.13E+00	2.50E-01	7.09E-07	3.81E+05	1.74E+02	1.375	0.375	0	1	0	0	0	1
2.31E-06	4.69E-02	1.91E+02	0.00E+00	1.14E+00	2.50E-01	6.57E-07	4.13E+05	1.81E+02	1.375	0.625	0	1	0	0	0	1
2.07E-06	4.95E-02	1.91E+02	0.00E+00	1.14E+00	2.50E-01	5.92E-07	4.60E+05	1.91E+02	1.375	0.875	0	1	1	0	0	1
2.07E-06	4.95E-02	1.94E+02	0.00E+00	1.14E+00	2.50E-01	5.92E-07	4.60E+05	1.91E+02	1.625	0.125	0	1	1	0	0	1
2.00E-06	5.03E-02	2.01E+02	0.00E+00	1.15E+00	2.50E-01	5.73E-07	4.75E+05	1.94E+02	1.625	0.375	0	1	1	0	0	1
1.87E-06	5.19E-02	2.10E+02	0.00E+00	1.15E+00	2.50E-01	5.39E-07	5.07E+05	2.01E+02	1.625	0.625	0	1	1	0	0	1
1.71E-06	5.43E-02	2.13E+02	0.00E+00	1.16E+00	2.50E-01	4.95E-07	5.54E+05	2.10E+02	1.625	0.875	0	1	1	0	0	1
1.66E-06	5.51E-02	2.16E+02	0.00E+00	1.16E+00	2.50E-01	4.82E-07	5.70E+05	2.13E+02	1.875	0.125	0	1	1	0	0	1
1.62E-06	5.58E-02	2.22E+02	0.00E+00	1.16E+00	2.50E-01	4.69E-07	5.85E+05	2.16E+02	1.875	0.375	0	1	1	0	0	1
1.53E-06	5.73E-02	2.07E+02	0.00E+00	1.17E+00	2.50E-01	4.46E-07	6.17E+05	2.22E+02	1.875	0.625	0	1	1	0	0	1
1.76E-06	5.35E-02	2.24E+02	0.00E+00	1.16E+00	2.50E-01	5.09E-07	5.38E+05	2.07E+02	1.875	0.875	0	1	1	0	0	0
1.50E-06	5.78E-02	0.00E+00	0.00E+00	1.17E+00	0.00E+00	0.00E+00	6.29E+05	2.24E+02	2.000	1.000	0	1	1	0	0	0
					∑FAM-source	1.01E-05										
					FAM=	1.03E-01										

Table 2.109 Calculation of F_{AM} for C-14 in a Rectangular Area Source of 4 m × 3 m without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$
1	0.049	8.65E-04	0.1	0.22	2.59E-04	2.59E-04	5.79E-01	9.99E-01	2.59E-04	

ta (cm) =	100		tc (cm) =	0		Source area (m2) =	4 x 3 = 12			Source-ref area (m2) =		3.36E+06				

exp(-ux)/x2 - source	mfp-dist. in - source-air	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	x-source (m)	y-source (m)	z-source (m)	ta + tc (m)	ta (m)	Receptor location x (m)	Receptor location y (m)	Receptor location z (m)
3.35E-06	3.91E-02	1.51E+02	0.00E+00	1.11E+00	2.50E-01	9.33E-07	2.87E+05	1.51E+02	0.125	1.125	0	1	0	0	0	1
3.18E-06	4.01E-02	1.55E+02	0.00E+00	1.12E+00	2.50E-01	8.86E-07	3.03E+05	1.55E+02	0.375	1.125	0	1	0	0	0	1
2.87E-06	4.22E-02	1.63E+02	0.00E+00	1.12E+00	2.50E-01	8.06E-07	3.34E+05	1.63E+02	0.625	1.125	0	1	0	0	0	1
2.51E-06	4.50E-02	1.74E+02	0.00E+00	1.13E+00	2.50E-01	7.09E-07	3.81E+05	1.74E+02	0.875	1.125	0	1	0	0	0	1
2.15E-06	4.86E-02	1.88E+02	0.00E+00	1.14E+00	2.50E-01	6.12E-07	4.44E+05	1.88E+02	1.125	1.125	0	1	0	0	0	1
1.82E-06	5.27E-02	2.04E+02	0.00E+00	1.15E+00	2.50E-01	5.23E-07	5.23E+05	2.04E+02	1.375	1.125	0	1	0	0	0	1
1.53E-06	5.73E-02	2.22E+02	0.00E+00	1.17E+00	2.50E-01	4.46E-07	6.17E+05	2.22E+02	1.625	1.125	0	1	0	0	0	1
1.29E-06	6.22E-02	2.40E+02	0.00E+00	1.18E+00	2.50E-01	3.82E-07	7.27E+05	2.40E+02	1.875	1.125	0	1	1	0	0	1
2.62E-06	4.41E-02	1.70E+02	0.00E+00	1.13E+00	2.50E-01	7.39E-07	3.65E+05	1.70E+02	0.125	1.375	0	1	1	0	0	1
2.51E-06	4.50E-02	1.74E+02	0.00E+00	1.13E+00	2.50E-01	7.09E-07	3.81E+05	1.74E+02	0.375	1.375	0	1	1	0	0	1
2.31E-06	4.69E-02	1.81E+02	0.00E+00	1.14E+00	2.50E-01	6.57E-07	4.13E+05	1.81E+02	0.625	1.375	0	1	1	0	0	1
2.07E-06	4.95E-02	1.91E+02	0.00E+00	1.14E+00	2.50E-01	5.92E-07	4.60E+05	1.91E+02	0.875	1.375	0	1	1	0	0	1
1.82E-06	5.27E-02	2.04E+02	0.00E+00	1.15E+00	2.50E-01	5.23E-07	5.23E+05	2.04E+02	1.125	1.375	0	1	1	0	0	1
1.57E-06	5.66E-02	2.19E+02	0.00E+00	1.16E+00	2.50E-01	4.58E-07	6.01E+05	2.19E+02	1.375	1.375	0	1	1	0	0	1
1.35E-06	6.08E-02	2.35E+02	0.00E+00	1.18E+00	2.50E-01	3.98E-07	6.95E+05	2.35E+02	1.625	1.375	0	1	1	0	0	1
1.16E-06	6.55E-02	2.53E+02	0.00E+00	1.19E+00	2.50E-01	3.46E-07	8.05E+05	2.53E+02	1.875	1.375	0	1	1	0	0	1
1.02E-06	6.97E-02	2.69E+02	0.00E+00	1.20E+00	0.00E+00	0.00E+00	9.11E+05	2.69E+02	2.000	1.500	0	1	1	0	0	1
					∑FAM-source	9.72E-06										
					FAM=	1.35E-01										

Table 2.110 Calculation of F_{AM} for C-14 in a Rectangular Area Source of 4 m × 4 m without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$
1	0.049	8.65E-04	0.1	0.22	2.59E-04	2.59E-04	5.79E-01	9.99E-01	2.59E-04	

ta (cm) =	100		tc (cm) =	0		Source area (m2) =	4 x 4 = 16			Source-ref area (m2) =	3.36E+06					

exp(-ux)/x2 - source	mfp-dist. in - source-air	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	x-source (m)	y-source (m)	z-source (m)	ta + tc (m)	ta (m)	Receptor location x (m)	Receptor location y (m)	Receptor location z (m)
2.07E-06	4.95E-02	1.91E+02	0.00E+00	1.14E+00	2.50E-01	5.92E-07	4.60E+05	1.91E+02	0.125	1.625	0	1	1	0	0	1
2.00E-06	5.03E-02	1.94E+02	0.00E+00	1.15E+00	2.50E-01	5.73E-07	4.75E+05	1.94E+02	0.375	1.625	0	1	1	0	0	1
1.87E-06	5.19E-02	2.01E+02	0.00E+00	1.15E+00	2.50E-01	5.39E-07	5.07E+05	2.01E+02	0.625	1.625	0	1	1	0	0	1
1.71E-06	5.43E-02	2.10E+02	0.00E+00	1.16E+00	2.50E-01	4.95E-07	5.54E+05	2.10E+02	0.875	1.625	0	1	1	0	0	1
1.53E-06	5.73E-02	2.22E+02	0.00E+00	1.17E+00	2.50E-01	4.46E-07	6.17E+05	2.22E+02	1.125	1.625	0	1	1	0	0	1
1.35E-06	6.08E-02	2.35E+02	0.00E+00	1.18E+00	2.50E-01	3.98E-07	6.95E+05	2.35E+02	1.375	1.625	0	1	1	0	0	1
1.19E-06	6.48E-02	2.51E+02	0.00E+00	1.19E+00	2.50E-01	3.53E-07	7.90E+05	2.51E+02	1.625	1.625	0	1	1	0	0	1
1.04E-06	6.92E-02	2.68E+02	0.00E+00	1.20E+00	2.50E-01	3.11E-07	9.00E+05	2.68E+02	1.875	1.625	0	1	1	0	0	1
1.66E-06	5.51E-02	2.13E+02	0.00E+00	1.16E+00	2.50E-01	4.82E-07	5.70E+05	2.13E+02	0.125	1.875	0	1	1	0	0	1
1.62E-06	5.58E-02	2.16E+02	0.00E+00	1.16E+00	2.50E-01	4.69E-07	5.85E+05	2.16E+02	0.375	1.875	0	1	1	0	0	1
1.53E-06	5.73E-02	2.22E+02	0.00E+00	1.17E+00	2.50E-01	4.46E-07	6.17E+05	2.22E+02	0.625	1.875	0	1	1	0	0	1
1.42E-06	5.95E-02	2.30E+02	0.00E+00	1.17E+00	2.50E-01	4.16E-07	6.64E+05	2.30E+02	0.875	1.875	0	1	1	0	0	1
1.29E-06	6.22E-02	2.40E+02	0.00E+00	1.18E+00	2.50E-01	3.82E-07	7.27E+05	2.40E+02	1.125	1.875	0	1	1	0	0	1
1.16E-06	6.55E-02	2.53E+02	0.00E+00	1.19E+00	2.50E-01	3.46E-07	8.05E+05	2.53E+02	1.375	1.875	0	1	1	0	0	1
1.04E-06	6.92E-02	2.68E+02	0.00E+00	1.20E+00	2.50E-01	3.11E-07	9.00E+05	2.68E+02	1.625	1.875	0	1	1	0	0	1
9.20E-07	7.33E-02	2.83E+02	0.00E+00	1.21E+00	2.50E-01	2.79E-07	1.01E+06	2.83E+02	1.875	1.875	0	1	1	0	0	1
8.18E-07	7.76E-02	3.00E+02	0.00E+00	1.23E+00	0.00E+00	0.00E+00	1.13E+06	3.00E+02	2.000	2.000	0	1	1	0	0	1
					∑FAM-source	6.84E-06										
					FAM =	1.57E-01										

Table 2.111 Calculation of F_{AM} for C-14 in a Rectangular Area Source of 6 m × 6 m without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$						
1	0.049	8.65E-04	0.1	0.22	2.59E-04	2.59E-04	5.79E-01	9.99E-01	2.59E-04							
ta (cm) =	100		tc (cm) =	0		Source area (m2) =		6 x 6 = 36		Source-ref area (m2) =		3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	x-source (m)	y-source (m)	z-source (m)	ta + tc (m)	ta (m)	Receptor location x (m)	Receptor location y (m)	Receptor location z (m)
1.22E-06	6.40E-02	2.47E+02	0.00E+00	1.19E+00	1.00E+00	1.44E-06	7.70E+05	2.47E+02	2.25	0.25	0	1	1	0	0	1
1.12E-06	6.66E-02	2.57E+02	0.00E+00	1.19E+00	1.00E+00	1.34E-06	8.33E+05	2.57E+02	2.25	0.75	0	1	1	0	0	1
9.71E-07	7.14E-02	2.76E+02	0.00E+00	1.21E+00	1.00E+00	1.17E-06	9.59E+05	2.76E+02	2.25	1.25	0	1	1	0	0	1
8.06E-07	7.81E-02	3.02E+02	0.00E+00	1.23E+00	1.00E+00	9.89E-07	1.15E+06	3.02E+02	2.25	1.75	0	1	1	0	0	1
6.56E-07	8.63E-02	3.34E+02	0.00E+00	1.25E+00	1.00E+00	8.20E-07	1.40E+06	3.34E+02	2.25	2.25	0	1	1	0	0	1
5.31E-07	9.55E-02	3.69E+02	0.00E+00	1.28E+00	1.00E+00	6.78E-07	1.71E+06	3.69E+02	2.25	2.75	0	1	1	0	0	1
8.55E-07	7.60E-02	2.94E+02	0.00E+00	1.22E+00	1.00E+00	1.04E-06	1.08E+06	2.94E+02	2.75	0.25	0	1	1	0	0	1
8.06E-07	7.81E-02	3.02E+02	0.00E+00	1.23E+00	1.00E+00	9.89E-07	1.15E+06	3.02E+02	2.75	0.75	0	1	1	0	0	1
7.24E-07	8.23E-02	3.18E+02	0.00E+00	1.24E+00	1.00E+00	8.97E-07	1.27E+06	3.18E+02	2.75	1.25	0	1	1	0	0	1
6.26E-07	8.82E-02	3.41E+02	0.00E+00	1.26E+00	1.00E+00	7.87E-07	1.46E+06	3.41E+02	2.75	1.75	0	1	1	0	0	1
5.31E-07	9.55E-02	3.69E+02	0.00E+00	1.28E+00	1.00E+00	6.78E-07	1.71E+06	3.69E+02	2.75	2.25	0	1	1	0	0	1
4.45E-07	1.04E-01	4.02E+02	0.00E+00	1.30E+00	1.00E+00	5.79E-07	2.03E+06	4.02E+02	2.75	2.75	0	1	1	0	0	1
1.22E-06	6.40E-02	2.47E+02	0.00E+00	1.19E+00	1.00E+00	1.44E-06	7.70E+05	2.47E+02	0.25	2.25	0	1	1	0	0	1
1.12E-06	6.66E-02	2.57E+02	0.00E+00	1.19E+00	1.00E+00	1.34E-06	8.33E+05	2.57E+02	0.75	2.25	0	1	1	0	0	1
9.71E-07	7.14E-02	2.76E+02	0.00E+00	1.21E+00	1.00E+00	1.17E-06	9.59E+05	2.76E+02	1.25	2.25	0	1	1	0	0	1
8.06E-07	7.81E-02	3.02E+02	0.00E+00	1.23E+00	1.00E+00	9.89E-07	1.15E+06	3.02E+02	1.75	2.25	0	1	1	0	0	1
8.55E-07	7.60E-02	2.94E+02	0.00E+00	1.22E+00	1.00E+00	1.04E-06	1.08E+06	2.94E+02	0.25	2.75	0	1	1	0	0	1
8.06E-07	7.81E-02	3.02E+02	0.00E+00	1.23E+00	1.00E+00	9.89E-07	1.15E+06	3.02E+02	0.75	2.75	0	1	1	0	0	1
7.24E-07	8.23E-02	3.18E+02	0.00E+00	1.24E+00	1.00E+00	8.97E-07	1.27E+06	3.18E+02	1.25	2.75	0	1	1	0	0	1
6.26E-07	8.82E-02	3.41E+02	0.00E+00	1.26E+00	1.00E+00	7.87E-07	1.46E+06	3.41E+02	1.75	2.75	0	1	1	0	0	1
					∑FAM-source	2.01E-05										
					FAM=	2.22E-01										

Table 2.112 Calculation of F_{AM} for C-14 in a Rectangular Area Source of 10 m × 10 m without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor (pSv-cm2)	Effective Mass Attenuation Coefficient (source) (/cm)	Effective mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$						
1	0.049	8.65E-04	0.1	0.22	2.59E-04	2.59E-04	5.79E-01	9.99E-01	2.59E-04							
ta (cm) =	100		tc (cm) =	0		Source area (m2) =		10 x 10 = 100		Source-ref area (m2) =		3.36E+06				
exp(-ux)/x2 - source	mfp-dist. in - source-air	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	Vol-source	F_{AM}-source	4π x dist-source^2 (cm2)	distance-source (cm)	x-source (m)	y-source (m)	z-source (m)	ta + tc (m)	ta (m)	Receptor location x (m)	Receptor location y (m)	Receptor location z (m)
5.36E-07	9.51E-02	3.67E+02	0.00E+00	1.28E+00	3.20E+00	2.19E-06	1.70E+06	3.67E+02	3.50	0.50	0	1	1	0	0	1
4.64E-07	1.02E-01	3.94E+02	0.00E+00	1.30E+00	3.20E+00	1.92E-06	1.95E+06	3.94E+02	3.50	1.50	0	1	1	0	0	1
3.64E-07	1.14E-01	4.42E+02	0.00E+00	1.33E+00	3.20E+00	1.55E-06	2.45E+06	4.42E+02	3.50	2.50	0	1	1	0	0	1
2.74E-07	1.31E-01	5.05E+02	0.00E+00	1.38E+00	3.20E+00	1.21E-06	3.21E+06	5.05E+02	3.50	3.50	0	1	1	0	0	1
2.04E-07	1.50E-01	5.79E+02	0.00E+00	1.43E+00	3.20E+00	9.39E-07	4.21E+06	5.79E+02	3.50	4.50	0	1	1	0	0	1
3.28E-07	1.20E-01	4.64E+02	0.00E+00	1.35E+00	3.20E+00	1.42E-06	2.70E+06	4.64E+02	4.50	0.50	0	1	1	0	0	1
2.99E-07	1.25E-01	4.85E+02	0.00E+00	1.36E+00	3.20E+00	1.30E-06	2.95E+06	4.85E+02	4.50	1.50	0	1	1	0	0	1
2.53E-07	1.36E-01	5.24E+02	0.00E+00	1.39E+00	3.20E+00	1.13E-06	3.46E+06	5.24E+02	4.50	2.50	0	1	1	0	0	1
2.04E-07	1.50E-01	5.79E+02	0.00E+00	1.43E+00	3.20E+00	9.39E-07	4.21E+06	5.79E+02	4.50	3.50	0	1	1	0	0	1
1.62E-07	1.67E-01	6.44E+02	0.00E+00	1.48E+00	3.20E+00	7.70E-07	5.22E+06	6.44E+02	4.50	4.50	0	1	1	0	0	1
5.36E-07	9.51E-02	3.67E+02	0.00E+00	1.28E+00	3.20E+00	2.19E-06	1.70E+06	3.67E+02	0.50	3.50	0	1	1	0	0	1
4.64E-07	1.02E-01	3.94E+02	0.00E+00	1.30E+00	3.20E+00	1.92E-06	1.95E+06	3.94E+02	1.50	3.50	0	1	1	0	0	1
3.64E-07	1.14E-01	4.42E+02	0.00E+00	1.33E+00	3.20E+00	1.55E-06	2.45E+06	4.42E+02	2.50	3.50	0	1	1	0	0	1
2.74E-07	1.31E-01	5.05E+02	0.00E+00	1.38E+00	3.20E+00	1.21E-06	3.21E+06	5.05E+02	3.50	3.50	0	1	1	0	0	1
2.04E-07	1.50E-01	5.79E+02	0.00E+00	1.43E+00	3.20E+00	9.39E-07	4.21E+06	5.79E+02	4.50	3.50	0	1	1	0	0	1
3.28E-07	1.20E-01	4.64E+02	0.00E+00	1.35E+00	3.20E+00	1.42E-06	2.70E+06	4.64E+02	0.50	4.50	0	1	1	0	0	1
2.99E-07	1.25E-01	4.85E+02	0.00E+00	1.36E+00	3.20E+00	1.30E-06	2.95E+06	4.85E+02	1.50	4.50	0	1	1	0	0	1
2.53E-07	1.36E-01	5.24E+02	0.00E+00	1.39E+00	3.20E+00	1.13E-06	3.46E+06	5.24E+02	2.50	4.50	0	1	1	0	0	1
2.04E-07	1.50E-01	5.79E+02	0.00E+00	1.43E+00	3.20E+00	9.39E-07	4.21E+06	5.79E+02	3.50	4.50	0	1	1	0	0	1
1.62E-07	1.67E-01	6.44E+02	0.00E+00	1.48E+00	3.20E+00	7.70E-07	5.22E+06	6.44E+02	4.50	4.50	0	1	1	0	0	1
					∑FAM-source	2.67E-05										
					FAM=	3.09E-01										

Table 2.113 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from C-14 in Six Rectangular Area Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}-surf	Area of Source (m2)	F_{AM}	Estimated Dose (mrem/yr)
1.35E-05	5.73E+03	1.00E+00	1.40E-04	100	3.09E-01	5.82E-10
				36	2.22E-01	4.19E-10
				16	1.57E-01	2.96E-10
				12	1.35E-01	2.54E-10
				8	1.03E-01	1.94E-10
				4	7.02E-02	1.32E-10

Table 2.114 Comparison of Radiation Doses (mrem/yr) at the Receptor Location (0, 0, 1) (m) Estimated by RESRAD-BUILD and Spreadsheets from C-14 in Six Rectangular Area Sources without Cover

Area of Source (m2)	Dimensions of Source (m x m)	Receptor Location (0, 0, 1) (m)		
		Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
100	10 x 10	5.79E-10	5.82E-10	0.99
36	6 x 6	4.09E-10	4.19E-10	0.98
16	4 x 4	2.88E-10	2.96E-10	0.97
12	4 x 3	2.46E-10	2.54E-10	0.97
8	4 x 2	1.89E-10	1.94E-10	0.97
4	2 x 2	1.29E-10	1.32E-10	0.98

2.4 EXTERNAL RADIATION OF VOLUME SOURCES

The external radiation dose modeling for volume sources by RESRAD-BUILD was verified by comparing the no-shielding external dose results for Co-60, Mn-54, and Tc-99 and then the with-shielding external dose results for Mn-54 with those from spreadsheets for a receptor at (0, 0, 1) (m). To compare the no-shielding external dose results, 24 cylindrical volume sources, which were different combinations of six circular areas (4, 10, 36, 100, 1,000, 100,000) (m^2) and four thicknesses, were assumed to contain Co-60, Mn-54, and then Tc-99. The volume sources containing Co-60 were assumed to have a thickness of 1, 5, 15, or 50 cm. Those containing Mn-54 or Tc-99 had a thickness of 1, 2, 5, or 10 cm. All the volume sources pointed to the z-direction. The receptor was placed at a distance of 1 m from the top surface of the source. Another six cylindrical volume sources, with a circular area of 4, 10, 36, 100, 1,000, and 100,000 m^2 and a thickness of 10 cm, that contained Mn-54 were assumed to have a concrete cover on the top. The thickness of the concrete cover was assumed to be 1 cm, 2 cm, and then 5 cm. These six volume sources also pointed in the z-direction.

The density of each volume source assumed in the verification was 1.6 g/cm^3. The receptor considered was assumed to spend all his time in a building that housed the volume source. There was no erosion of the source material; therefore, there was no release of source particles to the air.

To evaluate the external dose emitted from a volume source, the volume source was subdivided along the axial direction into 10 smaller cylindrical volumes that have the same circular cross section but a smaller thickness. The F_{AM} of each sub-source was calculated, and their weighted average with F_{CD} was used as the effective F_{AM} of the volume source. When calculating the F_{AM} of a sub-source, the buildup effect from sub-sources above it was factored into account. As discussed previously, an area source was treated as a volume source with a thickness of 0.001 cm by RESRAD-BUILD to model the external radiation. Therefore, the calculation design used in the spreadsheets to estimate the F_{AM} of an area source, as presented in Section 2.3, was applied to estimate the F_{AM} of each sub-source.

Table 2.115 lists the buildup factors in soil (the reference source) calculated for Co-60, Mn-54, and Tc-99, based on literature data of magnesium (Trubey 1991). The buildup factors in air and concrete were previously calculated and listed in Table 2.3 and 2.5, respectively. Table 2.30 lists the mass attenuation coefficients in air, concrete, and soil and the fluence to effective dose equivalent conversion factor.

2.4.1 Dose Results without Shielding

Results for Co-60. Table 2.116 shows the spreadsheet calculation of F_{CD} for a 1-cm-thick volume source containing Co-60 without a cover at the top. To estimate F_{AM} for the volume source, the volume source was divided into 10 sub-volumes each with a thickness of 0.1 cm. Table 2.117 shows the calculations of $F_{AM\text{-}ref}$, the F_{AM} of the reference source for the 10th sub-volume. Tables 2.118 and 2.119 show the calculation of F_{AM} for the 10th sub-volume that has a circular surface area of 4 m^2 and 100 m^2, respectively. (Note: The sub-volumes were numbered from the top to the bottom as 1st, 2nd, …, 10th sub-volume.) Table 2.120 shows the calculation of $F_{AM\text{-}ref}$ for the 6th sub-volume, and Tables 2.121 and 2.122 show the calculation of F_{AM} for the 6th sub-volume that has a circular surface area of 36 m^2 and 1,000 m^2, respectively. Calculation of $F_{AM\text{-}ref}$ for other sub-volumes and F_{AM} for sub-volumes of different surface areas were performed with the same calculation design in the spreadsheets. Table 2.123 summarizes the F_{AM}'s calculated for each sub-volume of six 1-cm thick volume sources. The external radiation dose estimated for these six volume sources are presented in Table 2.124.

Table 2.125 shows the spreadsheet calculation of F_{CD} for a 5-cm thick volume source containing Co-60 without a cover at the top. Table 2.126 summarizes the F_{AM}'s calculated for each sub-volume of six 5-cm-thick volume sources. The external radiation doses estimated for these six volume sources are presented in Table 2.127.

Table 2.115 Estimates of Buildup Factors in Soil Based on Data of Magnesium

Thickness in Mean Free Path	Buildup Factors for Magnesium from Trubey 1991									Tc-99	Mn-54	Co-60
	0.04 MeV	0.05 MeV	0.1 MeV	0.15 MeV	0.5 MeV	0.6 MeV	0.8 MeV	1 MeV	1.5 MeV	0.101 MeV	0.835 MeV	1.25 MeV
0.5	1.38	1.67	1.99	1.90	1.58	1.54	1.49	1.45	1.40	1.99	1.48	1.43
1	1.62	2.13	3.1	3.01	2.31	2.21	2.09	2.00	1.86	3.10	2.07	1.93
2	1.99	2.8	5.61	5.83	4.18	3.92	3.56	3.30	2.90	5.61	3.51	3.10
3	2.27	3.39	8.51	9.41	6.58	6.08	5.35	4.85	4.07	8.53	5.26	4.46
4	2.49	3.95	11.8	13.80	9.53	8.67	7.45	6.62	5.35	11.84	7.30	5.99
5	2.70	4.48	15.5	19.00	13.00	11.7	9.87	8.60	6.74	15.57	9.65	7.67
6	2.89	4.97	19.5	25.20	17.10	15.2	12.60	10.80	8.22	19.61	12.29	9.51
7	3.06	5.44	24.1	32.30	21.90	19.2	15.60	13.20	9.79	24.26	15.18	11.50
8	3.22	5.9	29	40.40	27.20	23.7	18.90	15.80	11.40	29.23	18.36	13.60
10	3.52	6.8	40.4	60.20	39.90	34.2	26.50	21.60	14.90	40.80	25.64	18.25
15	4.18	8.95	77.8	133.00	83.90	69	50.10	38.80	24.80	78.90	48.12	31.80
20	4.73	10.9	129	247.00	147.00	116	80.30	59.80	35.90	131.36	76.71	47.85
25	5.22	13	196	412.00	229.00	176	116.00	84.00	48.10	200.32	110.40	66.05
30	5.66	15.3	279	637.00	331.00	249	158.00	111.00	61.10	286.16	149.78	86.05
35	6.03	17.5	380	930.00	454.00	334	206.00	141.00	74.90	391.00	194.63	107.95
40	6.30	19.7	499	1300.00	598.00	430	258.00	173.00	89.30	515.02	243.13	131.15

Table 2.116 Calculation of F_{CD} for Co-60 in a 1-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.924	0.076	0.078	1.28			
Reference source –		Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =		1.6
		Source density , g/cm3 =	1.6		Source thickness, cm =		1			
$F_{CD} = \frac{D(T_c=t_c,T_S=t_S)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$										
FCD=	0.17460632									

Table 2.117 Calculation of F_{AM} for Co-60 in a Reference Source for the 10th Sub-volume of a 1-cm-Thick Volume Source without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor pSv cm2	Effective Mass Attenuation Coefficient (source) (/cm)	Effective Mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	1.25	2	0.5	4.495	9.87E-04	1.00E-03	9.41E-02	9.26E-02	7.04E-05						
ta (cm) =	100	tc (cm) =	0	Source-ref area (m2) =			3.36E+06		ts (cm) =	1					
exp(-ux)/x2 - ref	dist. in -ref-air (cm)	dist. in-ref-source-cover (cm)	mfp-dist. in - ref-air	mfp-dist. in-ref-source-cover	BF-ref-air	BF-ref-cover	Vol-sour-ref (m2)	FAM-ref	4pi x dist-ref^2 (cm2)	distance-ref (cm)	ta + tc + ts (m)	r - ref (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.05E-06	1.00E+02	1.00E+00	7.04E-03	9.41E-02	1.01E+00	1.08E+00	0.00E+00	0.00E+00	1.28E+05	1.01E+02	1.01E+00	0.00E+00	1.00E+00		
6.98E-06	1.00E+02	1.00E+00	7.07E-03	9.45E-02	1.01E+00	1.08E+00	3.14E-02	2.38E-07	1.29E+05	1.01E+02	1.01E+00	1.00E-01	1.00E+00		
6.97E-06	1.01E+02	1.01E+00	7.07E-03	9.46E-02	1.01E+00	1.08E+00	1.91E-03	1.45E-08	1.30E+05	1.02E+02	1.01E+00	1.03E-01	1.00E+00		
6.97E-06	1.01E+02	1.01E+00	7.07E-03	9.46E-02	1.01E+00	1.08E+00	2.03E-03	1.54E-08	1.30E+05	1.02E+02	1.01E+00	1.06E-01	1.00E+00		
6.96E-06	1.01E+02	1.01E+00	7.08E-03	9.46E-02	1.01E+00	1.08E+00	2.15E-03	1.63E-08	1.30E+05	1.02E+02	1.01E+00	1.09E-01	1.00E+00		
6.96E-06	1.01E+02	1.01E+00	7.08E-03	9.47E-02	1.01E+00	1.08E+00	2.29E-03	1.73E-08	1.30E+05	1.02E+02	1.01E+00	1.13E-01	1.00E+00		
6.95E-06	1.01E+02	1.01E+00	7.08E-03	9.47E-02	1.01E+00	1.08E+00	2.42E-03	1.83E-08	1.30E+05	1.02E+02	1.01E+00	1.16E-01	1.00E+00		
6.95E-06	1.01E+02	1.01E+00	7.08E-03	9.47E-02	1.01E+00	1.08E+00	2.57E-03	1.94E-08	1.30E+05	1.02E+02	1.01E+00	1.19E-01	1.00E+00	0	100
6.94E-06	1.01E+02	1.01E+00	7.09E-03	9.48E-02	1.01E+00	1.08E+00	2.73E-03	2.06E-08	1.30E+05	1.02E+02	1.01E+00	1.23E-01	1.00E+00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
2.18E-10	3.40E+03	3.40E+01	2.39E-01	3.20E+00	1.21E+00	4.76E+00	1.44E+02	1.80E-07	1.48E+08	3.43E+03	1.01E+00	3.43E+01	1.00E+00		
1.95E-10	3.46E+03	3.46E+01	2.44E-01	3.26E+00	1.22E+00	4.86E+00	1.49E+02	1.72E-07	1.54E+08	3.50E+03	1.01E+00	3.50E+01	1.00E+00		
1.75E-10	3.53E+03	3.53E+01	2.49E-01	3.32E+00	1.22E+00	4.96E+00	1.55E+02	1.65E-07	1.60E+08	3.57E+03	1.01E+00	3.57E+01	1.00E+00		
1.57E-10	3.60E+03	3.60E+01	2.54E-01	3.39E+00	1.23E+00	5.06E+00	1.62E+02	1.57E-07	1.67E+08	3.64E+03	1.01E+00	3.64E+01	1.00E+00		
1.40E-10	3.68E+03	3.68E+01	2.59E-01	3.46E+00	1.23E+00	5.16E+00	1.68E+02	1.50E-07	1.73E+08	3.71E+03	1.01E+00	3.71E+01	1.00E+00		
1.25E-10	3.75E+03	3.75E+01	2.64E-01	3.53E+00	1.23E+00	5.27E+00	1.75E+02	1.42E-07	1.80E+08	3.79E+03	1.01E+00	3.79E+01	1.00E+00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
5.01E-55	9.84E+04	9.84E+02	6.92E+00	9.26E+01	1.30E+01	1.31E+02	1.21E+05	1.03E-46	1.24E+11	9.94E+04	1.01E+00	9.94E+02	1.00E+00		
6.59E-56	1.00E+05	1.00E+03	7.06E+00	9.44E+01	1.34E+01	1.31E+02	1.25E+05	1.45E-47	1.29E+11	1.01E+05	1.01E+00	1.01E+03	1.00E+00		
8.32E-57	1.02E+05	1.02E+03	7.20E+00	9.63E+01	1.37E+01	1.31E+02	1.30E+05	1.95E-48	1.34E+11	1.03E+05	1.01E+00	1.03E+03	1.00E+00		
							∑FAM-ref=	1.33E-04							

Table 2.118 Calculation of F_{AM} for Co-60 in the 10th Sub-volume of a 1-cm-Thick Volume Source with an Area of 4 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

$$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$$

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor pSv cm2	Effective Mass Attenuation Coefficient (source) (/cm)	Effective Mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)
1	1.25	2	0.5	4.495	9.87E-04	1.00E-03	9.41E-02	9.26E-02	7.04E-05

0										
ta (cm) =	100	tc (cm) =	0	0	Source area (m2) =	4	0	ts (cm) =	1	

exp(-ux)/x2 source	mfp-dist. in -sour-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source (m2)	FAM-source	4pi x dist-source^2 (cm2)	distance-source-air (cm)	dist-cover (cm)	dist-source (cm)	r - source (m)	ta + tc + ts (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.06E-06	7.11E-03	9.26E-02	1.00E+02	1.00E+00	1.01E+00	1.08E+00	0.00E+00	0.00E+00	1.28E+05	1.01E+02	0.00E+00	3.00E-01	0.00E+00	1.01E+00	1.00E+00		
6.98E-06	7.14E-03	9.31E-02	1.01E+02	1.00E+00	1.01E+00	1.08E+00	3.14E-02	2.38E-07	1.29E+05	1.01E+02	0.00E+00	1.00E+00	1.00E-01	1.01E+00	1.00E+00		
6.97E-06	7.14E-03	9.31E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	1.91E-03	1.45E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.03E-01	1.01E+00	1.00E+00		
6.97E-06	7.14E-03	9.31E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	2.03E-03	1.54E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.06E-01	1.01E+00	1.00E+00		
6.97E-06	7.15E-03	9.32E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	2.15E-03	1.63E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.09E-01	1.01E+00	1.00E+00		
6.96E-06	7.15E-03	9.32E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	2.29E-03	1.73E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.13E-01	1.01E+00	1.00E+00		
6.95E-06	7.15E-03	9.32E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	2.42E-03	1.83E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.16E-01	1.01E+00	1.00E+00		
6.95E-06	7.15E-03	9.33E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	2.57E-03	1.94E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.19E-01	1.01E+00	1.00E+00		
6.94E-06	7.16E-03	9.33E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	2.73E-03	2.06E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.23E-01	1.01E+00	1.00E+00		
6.94E-06	7.16E-03	9.34E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	2.90E-03	2.18E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.27E-01	1.01E+00	1.00E+00		
6.93E-06	7.16E-03	9.34E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	3.07E-03	2.31E-08	1.30E+05	1.02E+02	0.00E+00	1.00E+00	1.30E-01	1.01E+00	1.00E+00		
6.92E-06	7.17E-03	9.34E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	3.26E-03	2.45E-08	1.31E+05	1.02E+02	0.00E+00	1.00E+00	1.34E-01	1.01E+00	1.00E+00		
6.91E-06	7.17E-03	9.35E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	3.46E-03	2.59E-08	1.31E+05	1.02E+02	0.00E+00	1.00E+00	1.38E-01	1.01E+00	1.00E+00		
6.91E-06	7.18E-03	9.36E-02	1.02E+02	1.01E+00	1.01E+00	1.08E+00	3.67E-03	2.75E-08	1.31E+05	1.02E+02	0.00E+00	1.00E+00	1.43E-01	1.01E+00	1.00E+00	0	100
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..		
3.41E-06	1.00E-02	1.31E-01	1.42E+02	1.41E+00	1.01E+00	1.11E+00	1.81E-01	6.92E-07	2.55E+05	1.42E+02	0.00E+00	1.12E+00	1.00E+00	1.01E+00	1.00E+00		
3.30E-06	1.02E-02	1.33E-01	1.44E+02	1.43E+00	1.01E+00	1.11E+00	1.93E-01	7.12E-07	2.62E+05	1.44E+02	0.00E+00	1.12E+00	1.03E+00	1.01E+00	1.00E+00		
3.19E-06	1.03E-02	1.35E-01	1.47E+02	1.45E+00	1.01E+00	1.11E+00	2.04E-01	7.33E-07	2.71E+05	1.47E+02	0.00E+00	1.13E+00	1.06E+00	1.01E+00	1.00E+00		
3.09E-06	1.05E-02	1.37E-01	1.49E+02	1.48E+00	1.01E+00	1.11E+00	2.17E-01	7.53E-07	2.79E+05	1.49E+02	0.00E+00	1.14E+00	1.10E+00	1.01E+00	1.00E+00		
2.98E-06	1.07E-02	1.39E-01	1.51E+02	1.50E+00	1.01E+00	1.12E+00	2.30E-01	7.73E-07	2.88E+05	1.51E+02	0.00E+00	1.15E+00	1.13E+00	1.01E+00	1.00E+00		
						∑FAM-source=		1.96E-05									
							FAM=	1.47E-01									

Table 2.119 Calculation of F_{AM} for Co-60 in the 10th Sub-volume of a 1-cm-Thick Volume Source with an Area of 100 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor pSv cm2	Effective Mass Attenuation Coefficient (source) (/cm)	Effective Mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$							
1	1.25	2	0.5	4.495	9.87E-04	1.00E-03	9.41E-02	9.26E-02	7.04E-05								
ta (cm) =	100	tc (cm) =	0	0	Source area (m2) =		100		ts (cm) =	1							
exp(-ux)/x2 - source	mfp-dist. in -sour-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source (m2)	FAM-source	4pi x dist-source^2 (cm2)	distance-source-air (cm)	dist-cover (cm)	0	r - source (m)	ta + tc + ts (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
4.31E-07	2.53E-02	3.30E-01	3.59E+02	3.56E+00	1.02E+00	1.28E+00	1.45E+00	8.16E-07	1.62E+06	3.59E+02	0.00E+00	1.98E+00	3.45E+00	1.01E+00	1.00E+00		
4.12E-07	2.57E-02	3.36E-01	3.66E+02	3.62E+00	1.02E+00	1.28E+00	1.51E+00	8.17E-07	1.68E+06	3.66E+02	0.00E+00	2.01E+00	3.52E+00	1.01E+00	1.00E+00		
3.95E-07	2.62E-02	3.42E-01	3.73E+02	3.69E+00	1.02E+00	1.29E+00	1.57E+00	8.17E-07	1.75E+06	3.73E+02	0.00E+00	2.04E+00	3.59E+00	1.01E+00	1.00E+00		
3.78E-07	2.67E-02	3.48E-01	3.80E+02	3.76E+00	1.02E+00	1.29E+00	1.63E+00	8.18E-07	1.81E+06	3.80E+02	0.00E+00	2.07E+00	3.66E+00	1.01E+00	1.00E+00		
3.62E-07	2.72E-02	3.55E-01	3.87E+02	3.83E+00	1.02E+00	1.30E+00	1.70E+00	8.18E-07	1.88E+06	3.87E+02	0.00E+00	2.10E+00	3.73E+00	1.01E+00	1.00E+00		
3.46E-07	2.77E-02	3.61E-01	3.94E+02	3.90E+00	1.02E+00	1.30E+00	1.77E+00	8.18E-07	1.95E+06	3.94E+02	0.00E+00	2.13E+00	3.81E+00	1.01E+00	1.00E+00		
3.31E-07	2.82E-02	3.68E-01	4.01E+02	3.97E+00	1.03E+00	1.31E+00	1.84E+00	8.18E-07	2.02E+06	4.01E+02	0.00E+00	2.17E+00	3.88E+00	1.01E+00	1.00E+00		
3.17E-07	2.88E-02	3.75E-01	4.09E+02	4.05E+00	1.03E+00	1.31E+00	1.91E+00	8.18E-07	2.10E+06	4.09E+02	0.00E+00	2.20E+00	3.96E+00	1.01E+00	1.00E+00		
3.03E-07	2.93E-02	3.82E-01	4.16E+02	4.12E+00	1.03E+00	1.32E+00	1.99E+00	8.18E-07	2.18E+06	4.16E+02	0.00E+00	2.24E+00	4.04E+00	1.01E+00	1.00E+00		
2.89E-07	2.99E-02	3.89E-01	4.24E+02	4.20E+00	1.03E+00	1.33E+00	2.07E+00	8.17E-07	2.26E+06	4.24E+02	0.00E+00	2.27E+00	4.12E+00	1.01E+00	1.00E+00		
2.77E-07	3.04E-02	3.97E-01	4.32E+02	4.28E+00	1.03E+00	1.33E+00	2.16E+00	8.17E-07	2.35E+06	4.32E+02	0.00E+00	2.31E+00	4.20E+00	1.01E+00	1.00E+00		
2.64E-07	3.10E-02	4.04E-01	4.40E+02	4.36E+00	1.03E+00	1.34E+00	2.24E+00	8.16E-07	2.44E+06	4.40E+02	0.00E+00	2.35E+00	4.29E+00	1.01E+00	1.00E+00		
2.52E-07	3.16E-02	4.12E-01	4.49E+02	4.44E+00	1.03E+00	1.35E+00	2.33E+00	8.15E-07	2.53E+06	4.49E+02	0.00E+00	2.38E+00	4.37E+00	1.01E+00	1.00E+00	0	100
2.41E-07	3.22E-02	4.19E-01	4.57E+02	4.53E+00	1.03E+00	1.35E+00	2.43E+00	8.14E-07	2.63E+06	4.57E+02	0.00E+00	2.42E+00	4.46E+00	1.01E+00	1.00E+00		
2.30E-07	3.28E-02	4.27E-01	4.66E+02	4.61E+00	1.03E+00	1.36E+00	2.53E+00	8.13E-07	2.73E+06	4.66E+02	0.00E+00	2.46E+00	4.55E+00	1.01E+00	1.00E+00		
2.20E-07	3.34E-02	4.36E-01	4.75E+02	4.70E+00	1.03E+00	1.37E+00	2.63E+00	8.12E-07	2.84E+06	4.75E+02	0.00E+00	2.51E+00	4.64E+00	1.01E+00	1.00E+00		
2.10E-07	3.41E-02	4.44E-01	4.84E+02	4.79E+00	1.03E+00	1.37E+00	2.73E+00	8.11E-07	2.95E+06	4.84E+02	0.00E+00	2.55E+00	4.73E+00	1.01E+00	1.00E+00		
2.00E-07	3.47E-02	4.52E-01	4.93E+02	4.88E+00	1.03E+00	1.38E+00	2.85E+00	8.09E-07	3.06E+06	4.93E+02	0.00E+00	2.59E+00	4.83E+00	1.01E+00	1.00E+00		
1.91E-07	3.54E-02	4.61E-01	5.03E+02	4.98E+00	1.03E+00	1.39E+00	2.96E+00	8.08E-07	3.18E+06	5.03E+02	0.00E+00	2.64E+00	4.93E+00	1.01E+00	1.00E+00		
1.82E-07	3.60E-02	4.70E-01	5.12E+02	5.07E+00	1.03E+00	1.39E+00	3.08E+00	8.06E-07	3.30E+06	5.12E+02	0.00E+00	2.68E+00	5.02E+00	1.01E+00	1.00E+00		
1.73E-07	3.67E-02	4.79E-01	5.22E+02	5.17E+00	1.03E+00	1.40E+00	3.20E+00	8.04E-07	3.43E+06	5.22E+02	0.00E+00	2.73E+00	5.12E+00	1.01E+00	1.00E+00		
1.65E-07	3.75E-02	4.88E-01	5.32E+02	5.27E+00	1.03E+00	1.41E+00	3.33E+00	8.02E-07	3.56E+06	5.32E+02	0.00E+00	2.77E+00	5.23E+00	1.01E+00	1.00E+00		
1.57E-07	3.82E-02	4.98E-01	5.43E+02	5.37E+00	1.03E+00	1.42E+00	3.47E+00	8.00E-07	3.70E+06	5.43E+02	0.00E+00	2.82E+00	5.33E+00	1.01E+00	1.00E+00		
1.50E-07	3.89E-02	5.07E-01	5.53E+02	5.48E+00	1.03E+00	1.43E+00	3.61E+00	7.99E-07	3.85E+06	5.53E+02	0.00E+00	2.87E+00	5.44E+00	1.01E+00	1.00E+00		
1.43E-07	3.97E-02	5.17E-01	5.64E+02	5.58E+00	1.04E+00	1.44E+00	3.75E+00	7.97E-07	4.00E+06	5.64E+02	0.00E+00	2.92E+00	5.55E+00	1.01E+00	1.00E+00		
1.36E-07	4.04E-02	5.27E-01	5.75E+02	5.69E+00	1.04E+00	1.45E+00	3.91E+00	7.95E-07	4.15E+06	5.75E+02	0.00E+00	2.97E+00	5.66E+00	1.01E+00	1.00E+00		
						∑FAM-source=		8.00E-05									
							FAM=	6.02E-01									

Table 2.120 Calculation of F_{AM} for Co-60 in a Reference Source for the 6th Sub-volume of a 1-cm-Thick Volume Source without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor pSv cm2	Effective Mass Attenuation Coefficient (source) (/cm)	Effective Mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$					
1	1.25	2	0.5	4.495	6.22E-04	6.31E-04	9.41E-02	9.26E-02	7.04E-05						
ta (cm) =	100	tc (cm) =	0	Source-ref area (m2) =			3.36E+06	0	ts (cm) =	0.6					
exp(-ux)/x2 - ref	dist. in -ref-air (cm)	dist. in-ref-source-cover (cm)	mfp-dist. in -ref-air	mfp-dist. in-ref-source-cover	BF-ref-air	BF-ref-cover	Vol-sour-ref (m2)	FAM-ref	4pi x dist-ref^2 (cm2)	distance-ref (cm)	ta + tc + ts (m)	r - ref (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
7.38E-06	1.00E+02	6.00E-01	7.04E-03	5.64E-02	1.01E+00	1.05E+00	0.00E+00	0.00E+00	1.27E+05	1.01E+02	1.01E+00	0.00E+00	1.00E+00		
7.30E-06	1.00E+02	6.03E-01	7.07E-03	5.67E-02	1.01E+00	1.05E+00	3.14E-02	2.42E-07	1.28E+05	1.01E+02	1.01E+00	1.00E-01	1.00E+00		
7.30E-06	1.01E+02	6.03E-01	7.07E-03	5.67E-02	1.01E+00	1.05E+00	1.91E-03	1.47E-08	1.29E+05	1.01E+02	1.01E+00	1.03E-01	1.00E+00		
7.29E-06	1.01E+02	6.03E-01	7.07E-03	5.68E-02	1.01E+00	1.05E+00	2.03E-03	1.56E-08	1.29E+05	1.01E+02	1.01E+00	1.06E-01	1.00E+00		
7.29E-06	1.01E+02	6.04E-01	7.08E-03	5.68E-02	1.01E+00	1.05E+00	2.15E-03	1.66E-08	1.29E+05	1.01E+02	1.01E+00	1.09E-01	1.00E+00		
7.28E-06	1.01E+02	6.04E-01	7.08E-03	5.68E-02	1.01E+00	1.05E+00	2.29E-03	1.76E-08	1.29E+05	1.01E+02	1.01E+00	1.13E-01	1.00E+00		
7.28E-06	1.01E+02	6.04E-01	7.08E-03	5.68E-02	1.01E+00	1.05E+00	2.42E-03	1.86E-08	1.29E+05	1.01E+02	1.01E+00	1.16E-01	1.00E+00		
7.27E-06	1.01E+02	6.04E-01	7.08E-03	5.68E-02	1.01E+00	1.05E+00	2.57E-03	1.97E-08	1.29E+05	1.01E+02	1.01E+00	1.19E-01	1.00E+00	0	100
7.26E-06	1.01E+02	6.04E-01	7.09E-03	5.69E-02	1.01E+00	1.05E+00	2.73E-03	2.09E-08	1.29E+05	1.01E+02	1.01E+00	1.23E-01	1.00E+00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
7.75E-10	3.41E+03	2.05E+01	2.40E-01	1.93E+00	1.21E+00	3.01E+00	1.44E+02	4.07E-07	1.48E+08	3.43E+03	1.01E+00	3.43E+01	1.00E+00		
7.14E-10	3.48E+03	2.09E+01	2.45E-01	1.96E+00	1.22E+00	3.06E+00	1.49E+02	3.97E-07	1.54E+08	3.50E+03	1.01E+00	3.50E+01	1.00E+00		
6.56E-10	3.55E+03	2.13E+01	2.50E-01	2.00E+00	1.22E+00	3.10E+00	1.55E+02	3.87E-07	1.60E+08	3.57E+03	1.01E+00	3.57E+01	1.00E+00		
6.03E-10	3.62E+03	2.17E+01	2.55E-01	2.04E+00	1.23E+00	3.16E+00	1.62E+02	3.78E-07	1.67E+08	3.64E+03	1.01E+00	3.64E+01	1.00E+00		
5.54E-10	3.69E+03	2.21E+01	2.60E-01	2.08E+00	1.23E+00	3.21E+00	1.68E+02	3.68E-07	1.73E+08	3.71E+03	1.01E+00	3.71E+01	1.00E+00		
5.08E-10	3.77E+03	2.26E+01	2.65E-01	2.13E+00	1.24E+00	3.27E+00	1.75E+02	3.59E-07	1.80E+08	3.79E+03	1.01E+00	3.79E+01	1.00E+00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
4.70E-39	9.88E+04	5.93E+02	6.95E+00	5.58E+01	1.31E+01	1.31E+02	1.21E+05	9.72E-31	1.24E+11	9.94E+04	1.01E+00	9.94E+02	1.00E+00		
1.29E-39	1.01E+05	6.05E+02	7.09E+00	5.69E+01	1.34E+01	1.31E+02	1.25E+05	2.85E-31	1.29E+11	1.01E+05	1.01E+00	1.01E+03	1.00E+00		
3.45E-40	1.03E+05	6.17E+02	7.23E+00	5.80E+01	1.38E+01	1.31E+02	1.30E+05	8.13E-32	1.34E+11	1.03E+05	1.01E+00	1.03E+03	1.00E+00		
							∑FAM-ref=	1.57E-04							

Table 2.121 Calculation of F_{AM} for Co-60 in the 6th Sub-volume of 1-cm-Thick Volume Source with an Area of 36 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor pSv cm2	Effective Mass Attenuation Coefficient (source) (/cm)	Effective Mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$							
1	1.25	2	0.5	4.495	6.22E-04	6.31E-04	9.41E-02	9.26E-02	7.04E-05								
ta (cm) =	100	tc (cm) =	0		Source area (m2) =		36		Source-ref area (m2) =		3.36E+06		ts (cm) =	0.6			
exp(-ux)/x2 - source	mfp-dist. in -sour-air	mfp-dist. in-source-cover	dist. in -source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source (m2)	FAM-source	4pi x dist-source^2 (cm2)	distance-source-air (cm)	dist-cover (cm)	dist-source (cm)	r - source (m)	ta + tc + ts (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.55E-06	1.49E-02	1.17E-01	2.12E+02	1.26E+00	1.01E+00	1.10E+00	4.25E-01	7.33E-07	5.65E+05	2.12E+02	0.00E+00	8.18E-01	1.87E+00	1.01E+00	1.00E+00		
1.50E-06	1.51E-02	1.19E-01	2.15E+02	1.28E+00	1.01E+00	1.10E+00	4.42E-01	7.39E-07	5.83E+05	2.15E+02	0.00E+00	8.26E-01	1.90E+00	1.01E+00	1.00E+00		
1.45E-06	1.54E-02	1.21E-01	2.19E+02	1.30E+00	1.01E+00	1.10E+00	4.60E-01	7.45E-07	6.01E+05	2.19E+02	0.00E+00	8.34E-01	1.94E+00	1.01E+00	1.00E+00		
1.40E-06	1.56E-02	1.23E-01	2.22E+02	1.32E+00	1.01E+00	1.10E+00	4.79E-01	7.51E-07	6.20E+05	2.22E+02	0.00E+00	8.42E-01	1.98E+00	1.01E+00	1.00E+00		
1.36E-06	1.59E-02	1.25E-01	2.26E+02	1.35E+00	1.01E+00	1.10E+00	4.98E-01	7.57E-07	6.40E+05	2.26E+02	0.00E+00	8.50E-01	2.02E+00	1.01E+00	1.00E+00		
1.31E-06	1.61E-02	1.27E-01	2.29E+02	1.37E+00	1.01E+00	1.11E+00	5.18E-01	7.62E-07	6.61E+05	2.29E+02	0.00E+00	8.59E-01	2.06E+00	1.01E+00	1.00E+00		
1.27E-06	1.64E-02	1.29E-01	2.33E+02	1.39E+00	1.01E+00	1.11E+00	5.39E-01	7.67E-07	6.83E+05	2.33E+02	0.00E+00	8.68E-01	2.10E+00	1.01E+00	1.00E+00		
1.22E-06	1.67E-02	1.31E-01	2.37E+02	1.41E+00	1.01E+00	1.11E+00	5.61E-01	7.73E-07	7.05E+05	2.37E+02	0.00E+00	8.77E-01	2.14E+00	1.01E+00	1.00E+00		
1.18E-06	1.69E-02	1.33E-01	2.41E+02	1.44E+00	1.02E+00	1.11E+00	5.84E-01	7.78E-07	7.28E+05	2.41E+02	0.00E+00	8.86E-01	2.19E+00	1.01E+00	1.00E+00		
1.14E-06	1.72E-02	1.35E-01	2.45E+02	1.46E+00	1.02E+00	1.11E+00	6.07E-01	7.83E-07	7.53E+05	2.45E+02	0.00E+00	8.96E-01	2.23E+00	1.01E+00	1.00E+00	0	100
1.10E-06	1.75E-02	1.37E-01	2.49E+02	1.48E+00	1.02E+00	1.12E+00	6.32E-01	7.87E-07	7.78E+05	2.49E+02	0.00E+00	9.06E-01	2.28E+00	1.01E+00	1.00E+00		
1.06E-06	1.78E-02	1.40E-01	2.53E+02	1.51E+00	1.02E+00	1.12E+00	6.57E-01	7.92E-07	8.04E+05	2.53E+02	0.00E+00	9.16E-01	2.32E+00	1.01E+00	1.00E+00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..		
6.77E-07	2.19E-02	1.72E-01	3.11E+02	1.86E+00	1.02E+00	1.14E+00	1.06E+00	8.35E-07	1.22E+06	3.11E+02	0.00E+00	1.06E+00	2.94E+00	1.01E+00	1.00E+00		
6.51E-07	2.23E-02	1.75E-01	3.17E+02	1.89E+00	1.02E+00	1.15E+00	1.10E+00	8.37E-07	1.26E+06	3.17E+02	0.00E+00	1.08E+00	3.00E+00	1.01E+00	1.00E+00		
6.26E-07	2.27E-02	1.78E-01	3.22E+02	1.92E+00	1.02E+00	1.15E+00	1.14E+00	8.40E-07	1.31E+06	3.22E+02	0.00E+00	1.09E+00	3.06E+00	1.01E+00	1.00E+00		
6.02E-07	2.31E-02	1.81E-01	3.28E+02	1.96E+00	1.02E+00	1.15E+00	1.19E+00	8.42E-07	1.35E+06	3.28E+02	0.00E+00	1.11E+00	3.12E+00	1.01E+00	1.00E+00		
5.78E-07	2.35E-02	1.85E-01	3.34E+02	1.99E+00	1.02E+00	1.16E+00	1.24E+00	8.44E-07	1.40E+06	3.34E+02	0.00E+00	1.12E+00	3.19E+00	1.01E+00	1.00E+00		
5.56E-07	2.39E-02	1.88E-01	3.40E+02	2.03E+00	1.02E+00	1.16E+00	1.29E+00	8.47E-07	1.45E+06	3.40E+02	0.00E+00	1.14E+00	3.25E+00	1.01E+00	1.00E+00		
5.34E-07	2.44E-02	1.91E-01	3.46E+02	2.07E+00	1.02E+00	1.16E+00	1.34E+00	8.49E-07	1.51E+06	3.46E+02	0.00E+00	1.16E+00	3.31E+00	1.01E+00	1.00E+00		
						∑FAM-source=		6.03E-05									
							FAM=	3.85E-01									

Table 2.122 Calculation of F_{AM} for Co-60 in the 6th Sub-volume of a 1-cm-Thick Volume Source with an Area of 1,000 m^2 without Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor pSv cm2	Effective Mass Attenuation Coefficient (source) (/cm)	Effective Mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)	$\mu = \frac{(t_a\mu_a + t_c\mu_c + t\mu_s)}{(t_a + t_c + t)}$							
1	1.25	2	0.5	4.495	6.22E-04	6.31E-04	9.41E-02	9.26E-02	7.04E-05								
ta (cm) =	100	tc (cm) =	0		Source area (m2) =		1,000		Source-ref area (m2) =		3.36E+06		ts (cm) =	0.6			
exp(-ux)/x2 - source	mfp-dist. in -sour-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source (m2)	FAM-source	4pi x dist-source^2 (cm2)	distance-source-air (cm)	dist-cover (cm)	dist-source (cm)	r - source (m)	ta + tc + ts (n	ta (m)	Receptor location y (cm)	Receptor location z (cm)
1.61E-07	4.12E-02	3.24E-01	5.86E+02	3.49E+00	1.04E+00	1.27E+00	4.06E+00	8.61E-07	4.31E+06	5.86E+02	0.00E+00	1.82E+00	5.77E+00	1.01E+00	1.00E+00		
1.53E-07	4.20E-02	3.30E-01	5.97E+02	3.56E+00	1.04E+00	1.28E+00	4.23E+00	8.60E-07	4.48E+06	5.97E+02	0.00E+00	1.85E+00	5.89E+00	1.01E+00	1.00E+00		
1.47E-07	4.28E-02	3.36E-01	6.09E+02	3.63E+00	1.04E+00	1.28E+00	4.40E+00	8.59E-07	4.66E+06	6.09E+02	0.00E+00	1.89E+00	6.00E+00	1.01E+00	1.00E+00		
1.40E-07	4.37E-02	3.43E-01	6.21E+02	3.70E+00	1.04E+00	1.29E+00	4.58E+00	8.58E-07	4.84E+06	6.21E+02	0.00E+00	1.92E+00	6.12E+00	1.01E+00	1.00E+00		
1.34E-07	4.45E-02	3.50E-01	6.33E+02	3.77E+00	1.04E+00	1.29E+00	4.76E+00	8.56E-07	5.03E+06	6.33E+02	0.00E+00	1.96E+00	6.25E+00	1.01E+00	1.00E+00		
1.28E-07	4.54E-02	3.56E-01	6.45E+02	3.85E+00	1.04E+00	1.30E+00	4.95E+00	8.55E-07	5.23E+06	6.45E+02	0.00E+00	1.99E+00	6.37E+00	1.01E+00	1.00E+00		
1.22E-07	4.63E-02	3.63E-01	6.58E+02	3.92E+00	1.04E+00	1.31E+00	5.15E+00	8.54E-07	5.44E+06	6.58E+02	0.00E+00	2.03E+00	6.50E+00	1.01E+00	1.00E+00		
1.16E-07	4.72E-02	3.70E-01	6.70E+02	4.00E+00	1.04E+00	1.31E+00	5.36E+00	8.52E-07	5.65E+06	6.70E+02	0.00E+00	2.07E+00	6.63E+00	1.01E+00	1.00E+00		
1.11E-07	4.81E-02	3.78E-01	6.84E+02	4.08E+00	1.04E+00	1.32E+00	5.58E+00	8.50E-07	5.87E+06	6.84E+02	0.00E+00	2.10E+00	6.76E+00	1.01E+00	1.00E+00	0	100
1.06E-07	4.90E-02	3.85E-01	6.97E+02	4.16E+00	1.04E+00	1.32E+00	5.80E+00	8.49E-07	6.11E+06	6.97E+02	0.00E+00	2.14E+00	6.90E+00	1.01E+00	1.00E+00		
1.01E-07	5.00E-02	3.93E-01	7.11E+02	4.24E+00	1.04E+00	1.33E+00	6.04E+00	8.47E-07	6.35E+06	7.11E+02	0.00E+00	2.18E+00	7.03E+00	1.01E+00	1.00E+00		
..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..		
1.10E-08	1.14E-01	8.95E-01	1.62E+03	9.66E+00	1.10E+00	1.81E+00	3.19E+01	7.00E-07	3.30E+07	1.62E+03	0.00E+00	4.86E+00	1.62E+01	1.01E+00	1.00E+00		
1.04E-08	1.16E-01	9.12E-01	1.65E+03	9.85E+00	1.10E+00	1.83E+00	3.32E+01	6.94E-07	3.43E+07	1.65E+03	0.00E+00	4.95E+00	1.65E+01	1.01E+00	1.00E+00		
9.77E-09	1.18E-01	9.31E-01	1.68E+03	1.00E+01	1.11E+00	1.85E+00	3.45E+01	6.88E-07	3.57E+07	1.68E+03	0.00E+00	5.05E+00	1.68E+01	1.01E+00	1.00E+00		
9.20E-09	1.21E-01	9.49E-01	1.72E+03	1.02E+01	1.11E+00	1.86E+00	3.59E+01	6.81E-07	3.71E+07	1.72E+03	0.00E+00	5.15E+00	1.71E+01	1.01E+00	1.00E+00		
8.65E-09	1.23E-01	9.68E-01	1.75E+03	1.04E+01	1.11E+00	1.88E+00	3.73E+01	6.75E-07	3.86E+07	1.75E+03	0.00E+00	5.25E+00	1.75E+01	1.01E+00	1.00E+00		
8.14E-09	1.26E-01	9.87E-01	1.79E+03	1.07E+01	1.11E+00	1.90E+00	3.88E+01	6.69E-07	4.01E+07	1.79E+03	0.00E+00	5.35E+00	1.78E+01	1.01E+00	1.00E+00		
						∑FAM-source=		1.28E-04									
							FAM=	8.20E-01									

Table 2.123 Summary of F_{AM}'s for Co-60 in Six 1-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.71E-01	2.55E-02	9.92E-01	4.83E-02	9.97E-01	6.88E-02	9.97E-01	8.75E-02	9.97E-01	1.05E-01
1,000	6.10E-01		6.73E-01		7.22E-01		7.61E-01		7.93E-01	
100	3.73E-01		4.15E-01		4.50E-01		4.79E-01		5.05E-01	
36	2.69E-01		3.00E-01		3.26E-01		3.47E-01		3.67E-01	
10	1.54E-01		1.72E-01		1.86E-01		1.99E-01		2.11E-01	
4	8.79E-02		9.82E-02		1.07E-01		1.14E-01		1.21E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	9.96E-01	1.20E-01	9.96E-01	1.35E-01	9.95E-01	1.49E-01	9.94E-01	1.62E-01	9.93E-01	1.75E-01
1,000	8.20E-01		8.43E-01		8.62E-01		8.79E-01		8.93E-01	
100	5.28E-01		5.49E-01		5.68E-01		5.85E-01		6.02E-01	
36	3.85E-01		4.01E-01		4.16E-01		4.30E-01		4.43E-01	
10	2.21E-01		2.31E-01		2.40E-01		2.48E-01		2.56E-01	
4	1.27E-01		1.33E-01		1.38E-01		1.43E-01		1.47E-01	

Table 2.124 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Co-60 in Six 1-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 1 cm (weighted - average)	Estimated Dose (mrem/yr)
1.62E+01	5.27E+00	9.37E-01	1.75E-01	100,000	9.92E-01	2.63E+00
				1,000	7.65E-01	2.03E+00
				100	4.88E-01	1.30E+00
				36	3.55E-01	9.43E-01
				10	2.04E-01	5.42E-01
				4	1.17E-01	3.11E-01

Table 2.125 Calculation of F_{CD} for Co-60 in a 5-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)			0.924	0.076	0.078	1.28		
Reference source –	Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =	1.6
	Source density , g/cm3 =	1.6		Source thickness, cm =		5		
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$								
FCD=	0.5049							

Table 2.126 Summary of F_{AM}'s for Co-60 in Six 5-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.97E-01	1.05E-01	9.93E-01	1.75E-01	9.88E-01	2.30E-01	9.83E-01	2.79E-01	9.77E-01	3.23E-01
1,000	7.93E-01		8.93E-01		9.39E-01		9.58E-01		9.65E-01	
100	5.05E-01		6.02E-01		6.70E-01		7.23E-01		7.64E-01	
36	3.67E-01		4.43E-01		5.00E-01		5.46E-01		5.85E-01	
10	2.10E-01		2.56E-01		2.92E-01		3.23E-01		3.48E-01	
4	1.21E-01		1.47E-01		1.69E-01		1.87E-01		2.02E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	9.71E-01	3.64E-01	9.64E-01	4.03E-01	9.57E-01	4.39E-01	9.49E-01	4.73E-01	9.42E-01	5.05E-01
1,000	9.65E-01		9.61E-01		9.56E-01		9.49E-01		9.41E-01	
100	7.96E-01		8.21E-01		8.40E-01		8.53E-01		8.63E-01	
36	6.19E-01		6.48E-01		6.73E-01		6.94E-01		7.13E-01	
10	3.71E-01		3.92E-01		4.12E-01		4.30E-01		4.47E-01	
4	2.16E-01		2.29E-01		2.41E-01		2.52E-01		2.63E-01	

Table 2.127 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Co-60 in Six 5-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 5 cm (weighted - average)	Estimated Dose (mrem/yr)
1.62E+01	5.27E+00	9.37E-01	5.05E-01	100,000	9.78E-01	7.51E+00
				1,000	9.12E-01	7.00E+00
				100	6.98E-01	5.36E+00
				36	5.36E-01	4.12E+00
				10	3.20E-01	2.45E+00
				4	1.86E-01	1.42E+00

Tables 2.128-2.130 present the calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 15-cm-thick volume sources containing Co-60. Tables 2.131-2.133 present the calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 50-cm-thick volume sources containing Co-60.

Comparisons of the dose estimates for 24 volume sources containing Co-60 between the verification spreadsheets and RESRAD-BUILD are presented in Table 2.134. For 19 volume sources, the difference is less than 5%. For only five volume sources, the difference is greater than 5% but less than 22%. Considering the approximate nature of the spreadsheet calculations, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Results for Mn-54. Tables 2.135-2.137 present the calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 1-cm-thick volume sources containing Mn-54. Tables 2.138-2.140 present the calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 2-cm thick volume sources containing Mn-54. Tables 2.141-2.143 present calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 5-cm-thick volume sources, and Table 2.144-2.146 present calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 10-cm-thick volume sources.

Comparisons of the dose estimates for 24 volume sources containing Mn-54 between the verification spreadsheets and RESRAD-BUILD are presented in Table 2.147. For 23 volume sources, the difference is less than 5%. Only for one volume source is the difference greater than 5% but less than 6%. Considering the approximate nature of the spreadsheet calculations, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Table 2.128 Calculation of F_{CD} for Co-60 in a 15-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.924	0.076	0.078	1.28			
Reference source –	Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =			1.6
	Source density , g/cm3 =	1.6		Source thickness, cm =		15				
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$										
FCD=	0.8579									

Table 2.129 Summary of F_{AM}'s for Co-60 in Six 15-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.88E-01	2.30E-01	9.70E-01	3.64E-01	9.48E-01	4.73E-01	9.22E-01	5.63E-01	8.98E-01	6.38E-01
1,000	9.39E-01		9.64E-01		9.47E-01		9.22E-01		8.98E-01	
100	6.70E-01		7.96E-01		8.53E-01		8.71E-01		8.70E-01	
36	5.00E-01		6.20E-01		6.96E-01		7.42E-01		7.66E-01	
10	2.92E-01		3.73E-01		4.35E-01		4.82E-01		5.11E-01	
4	1.69E-01		2.19E-01		2.57E-01		2.91E-01		3.08E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	8.70E-01	6.99E-01	8.40E-01	7.51E-01	8.09E-01	7.93E-01	7.77E-01	8.29E-01	7.45E-01	8.58E-01
1,000	8.70E-01		8.40E-01		8.09E-01		7.77E-01		7.45E-01	
100	8.54E-01		8.32E-01		8.04E-01		7.75E-01		7.43E-01	
36	7.74E-01		7.71E-01		7.60E-01		7.42E-01		7.19E-01	
10	5.36E-01		5.53E-01		5.62E-01		5.65E-01		5.63E-01	
4	3.28E-01		3.45E-01		3.57E-01		3.64E-01		3.68E-01	

Table 2.130 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Co-60 in Six 15-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 15 cm (weighted - average)	Estimated Dose (mrem/yr)
1.62E+01	5.27E+00	9.37E-01	8.58E-01	100,000	9.22E-01	1.20E+01
				1,000	9.08E-01	1.18E+01
				100	7.88E-01	1.03E+01
				36	6.58E-01	8.58E+00
				10	4.29E-01	5.59E+00
				4	2.59E-01	3.38E+00

Table 2.131 Calculation of F_{CD} for Co-60 in a 50-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.924	0.076	0.078	1.28			
Reference source –		Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =		1.6
		Source density , g/cm3 =	1.6		Source thickness, cm =		50			
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,										
FCD=	0.9982									

Table 2.132 Summary of F_{AM}'s for Co-60 in Six 50-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.40E-01	5.05E-01	8.43E-01	7.35E-01	7.30E-01	8.58E-01	6.15E-01	9.24E-01	5.31E-01	9.59E-01
1,000	9.39E-01		8.43E-01		7.30E-01		6.15E-01		5.31E-01	
100	8.62E-01		8.33E-01		7.29E-01		6.15E-01		5.31E-01	
36	7.14E-01		7.71E-01		7.09E-01		6.09E-01		5.28E-01	
10	4.52E-01		5.58E-01		5.71E-01		5.29E-01		4.65E-01	
4	2.69E-01		3.53E-01		3.87E-01		3.81E-01		3.33E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	4.34E-01	9.78E-01	3.49E-01	9.88E-01	2.76E-01	9.94E-01	2.15E-01	9.97E-01	1.66E-01	9.98E-01
1,000	4.34E-01		3.49E-01		2.76E-01		2.15E-01		1.66E-01	
100	4.34E-01		3.49E-01		2.76E-01		2.15E-01		1.66E-01	
36	4.33E-01		3.49E-01		2.76E-01		2.15E-01		1.66E-01	
10	3.95E-01		3.25E-01		2.62E-01		2.06E-01		1.60E-01	
4	2.93E-01		2.49E-01		2.05E-01		1.65E-01		1.31E-01	

Table 2.133 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Co-60 in Six 50-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 50 cm (weighted - average)	Estimated Dose (mrem/yr)
16.22	5.27E+00	9.37E-01	9.98E-01	100,000	8.33E-01	1.26E+01
				1,000	8.33E-01	1.26E+01
				100	7.91E-01	1.20E+01
				36	7.00E-01	1.06E+01
				10	4.92E-01	7.46E+00
				4	3.12E-01	4.73E+00

Table 2.134 Comparison of Radiation Doses (mrem/yr) at (0, 0, 1) (m) Estimated by RESRAD-BUILD and Spreadsheets from Co-60 in Volume Sources of Different Thicknesses and Areas without Cover

Area of Volume source (m2)	1 cm - Thick Volume Source			5 cm - Thick Volume Source			15 cm - Thick Volume Source			50 cm - Thick Volume Source		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
100,000	2.64E+00	2.63E+00	1.00E+00	7.66E+00	7.51E+00	1.02E+00	1.30E+01	1.20E+01	1.08E+00	1.51E+01	1.26E+01	1.19E+00
1,000	2.04E+00	2.03E+00	1.01E+00	7.00E+00	7.00E+00	1.00E+00	1.23E+01	1.18E+01	1.04E+00	1.38E+01	1.26E+01	1.09E+00
100	1.30E+00	1.30E+00	1.00E+00	5.29E+00	5.36E+00	9.87E-01	1.05E+01	1.03E+01	1.02E+00	1.26E+01	1.20E+01	1.05E+00
36	9.48E-01	9.43E-01	1.00E+00	4.06E+00	4.12E+00	9.87E-01	8.79E+00	8.58E+00	1.02E+00	1.13E+01	1.06E+01	1.06E+00
10	5.42E-01	5.42E-01	1.00E+00	2.41E+00	2.45E+00	9.82E-01	5.74E+00	5.59E+00	1.03E+00	8.46E+00	7.46E+00	1.13E+00
4	3.12E-01	3.11E-01	1.00E+00	1.40E+00	1.42E+00	9.83E-01	3.51E+00	3.38E+00	1.04E+00	5.77E+00	4.73E+00	1.22E+00

Table 2.135 Calculation of F_{CD} for Mn-54 in a 1-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.085	0.915	1.22	0.088			
Reference source –	Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =			1.6
	Source density , g/cm3 =	1.6		Source thickness, cm =		1				
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$										
FCD=	0.1931									

Table 2.136 Summary of F_{AM}'s for Mn-54 in Six 1-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.75E-01	2.79E-02	9.92E-01	5.29E-02	9.95E-01	7.55E-02	9.94E-01	9.62E-02	9.93E-01	1.15E-01
1,000	6.11E-01		6.79E-01		7.30E-01		7.71E-01		8.04E-01	
100	3.73E-01		4.17E-01		4.54E-01		4.85E-01		5.12E-01	
36	2.69E-01		3.01E-01		3.28E-01		3.51E-01		3.72E-01	
10	1.53E-01		1.72E-01		1.87E-01		2.01E-01		2.13E-01	
4	8.77E-02		9.84E-02		1.07E-01		1.15E-01		1.22E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	9.92E-01	1.33E-01	9.91E-01	1.49E-01	9.90E-01	1.65E-01	9.89E-01	1.79E-01	9.88E-01	1.93E-01
1,000	8.32E-01		8.55E-01		8.75E-01		8.92E-01		9.05E-01	
100	5.36E-01		5.58E-01		5.78E-01		5.96E-01		6.14E-01	
36	3.90E-01		4.07E-01		4.23E-01		4.38E-01		4.52E-01	
10	2.24E-01		2.34E-01		2.44E-01		2.53E-01		2.61E-01	
4	1.29E-01		1.34E-01		1.40E-01		1.45E-01		1.50E-01	

Table 2.137 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six 1-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 1 cm (weighted - average)	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	1.93E-01	100000	9.90E-01	6.75E-01
				1000	7.74E-01	5.28E-01
				100	4.95E-01	3.38E-01
				36	3.60E-01	2.46E-01
				10	2.07E-01	1.41E-01
				4	1.18E-01	8.08E-02

Table 2.138 Calculation of F_{CD} for Mn-54 in a 2-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.085	0.915	1.22	0.088				
Reference source –		Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =			1.6
		Source density , g/cm3 =	1.6		Source thickness, cm =		2				
		$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,									
FCD=	0.3078										

Table 2.139 Summary of F_{AM}'s for Mn-54 in Six 2-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.92E-01	5.29E-02	9.94E-01	9.62E-02	9.92E-01	1.33E-01	9.90E-01	1.65E-01	9.88E-01	1.93E-01
1,000	6.79E-01		7.71E-01		8.32E-01		8.75E-01		9.05E-01	
100	4.17E-01		4.85E-01		5.36E-01		5.78E-01		6.14E-01	
36	3.01E-01		3.51E-01		3.90E-01		4.23E-01		4.52E-01	
10	1.72E-01		2.01E-01		2.24E-01		2.44E-01		2.61E-01	
4	9.84E-02		1.15E-01		1.28E-01		1.40E-01		1.50E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	9.86E-01	2.19E-01	9.84E-01	2.43E-01	9.81E-01	2.66E-01	9.79E-01	2.87E-01	9.76E-01	3.08E-01
1,000	9.26E-01		9.41E-01		9.50E-01		9.57E-01		9.60E-01	
100	6.45E-01		6.73E-01		6.98E-01		7.20E-01		7.41E-01	
36	4.78E-01		5.01E-01		5.22E-01		5.42E-01		5.61E-01	
10	2.77E-01		2.92E-01		3.06E-01		3.19E-01		3.31E-01	
4	1.59E-01		1.68E-01		1.76E-01		1.84E-01		1.91E-01	

Table 2.140 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six 2-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 2 cm (weighted average)	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	3.08E-01	100000	9.88E-01	1.07E+00
				1000	8.51E-01	9.26E-01
				100	5.78E-01	6.29E-01
				36	4.26E-01	4.64E-01
				10	2.47E-01	2.69E-01
				4	1.42E-01	1.54E-01

Table 2.141 Calculation of F_{CD} for Mn-54 in a 5-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.085	0.915	1.22	0.088				
Reference source –		Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =			1.6
		Source density , g/cm3 =	1.6		Source thickness, cm =		5				
$F_{CD} = \frac{D(T_c=t_c, T_S=t_s)}{D(T_c=0, T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,											
FCD=	0.5474										

Table 2.142 Summary of F_{AM}'s for Mn-54 in Six 5-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.93E-01	1.15E-01	9.88E-01	1.93E-01	9.82E-01	2.55E-01	9.76E-01	3.08E-01	9.69E-01	3.56E-01
1,000	8.05E-01		9.05E-01		9.46E-01		9.60E-01		9.62E-01	
100	5.12E-01		6.14E-01		6.86E-01		7.41E-01		7.82E-01	
36	3.71E-01		4.52E-01		5.12E-01		5.62E-01		6.03E-01	
10	2.13E-01		2.61E-01		3.00E-01		3.32E-01		3.59E-01	
4	1.22E-01		1.50E-01		1.73E-01		1.93E-01		2.08E-01	
Area of source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	9.62E-01	4.00E-01	9.54E-01	4.41E-01	9.45E-01	4.79E-01	9.37E-01	5.14E-01	9.28E-01	5.47E-01
1,000	9.59E-01		9.53E-01		9.45E-01		9.36E-01		9.28E-01	
100	8.14E-01		8.36E-01		8.53E-01		8.64E-01		8.70E-01	
36	6.38E-01		6.68E-01		6.94E-01		7.15E-01		7.33E-01	
10	3.84E-01		4.07E-01		4.29E-01		4.48E-01		4.66E-01	
4	2.24E-01		2.38E-01		2.51E-01		2.64E-01		2.76E-01	

Table 2.143 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six 5-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 5 cm (weighted - average)	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	5.47E-01	100,000	9.71E-01	1.88E+00
				1,000	9.13E-01	1.77E+00
				100	7.09E-01	1.37E+00
				36	5.48E-01	1.06E+00
				10	3.28E-01	6.34E-01
				4	1.90E-01	3.68E-01

Table 2.144 Calculation of F_{CD} for Mn-54 in a 10-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)			0.085	0.915	1.22	0.088				
Reference source –	Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =			1.6
	Source density , g/cm3 =	1.6		Source thickness, cm =		10				
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,										
FCD=	0.7762									

Table 2.145 Summary of F_{AM}'s for Mn-54 in Six 10-cm-Thick Volume Sources without a Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.88E-01	1.93E-01	9.76E-01	3.08E-01	9.61E-01	4.00E-01	9.44E-01	4.79E-01	9.28E-01	5.47E-01
1,000	9.05E-01		9.60E-01		9.58E-01		9.43E-01		9.28E-01	
100	6.14E-01		7.41E-01		8.13E-01		8.52E-01		8.70E-01	
36	4.52E-01		5.62E-01		6.38E-01		6.95E-01		7.33E-01	
10	2.61E-01		3.32E-01		3.86E-01		4.32E-01		4.66E-01	
4	1.50E-01		1.93E-01		2.26E-01		2.55E-01		2.76E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	9.09E-01	6.07E-01	8.89E-01	6.59E-01	8.68E-01	7.03E-01	8.46E-01	7.42E-01	8.24E-01	7.76E-01
1,000	9.09E-01		8.89E-01		8.68E-01		8.46E-01		8.24E-01	
100	8.73E-01		8.67E-01		8.55E-01		8.38E-01		8.19E-01	
36	7.58E-01		7.72E-01		7.78E-01		7.77E-01		7.71E-01	
10	4.97E-01		5.22E-01		5.42E-01		5.57E-01		5.67E-01	
4	2.97E-01		3.16E-01		3.32E-01		3.47E-01		3.58E-01	

Table 2.146 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six 10-cm-Thick Volume Sources without a Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 10 cm (weighted - average)	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	7.76E-01	100,000	9.39E-01	2.58E+00
				1,000	9.16E-01	2.51E+00
				100	7.74E-01	2.12E+00
				36	6.34E-01	1.74E+00
				10	4.02E-01	1.10E+00
				4	2.39E-01	6.55E-01

Table 2.147 Comparison of Radiation Doses (mrem/yr) at (0, 0, 1) (m) Estimated by RESRAD-BUILD and Spreadsheets for Mn-54 in Volume Sources of Different Thicknesses and Areas without a Cover

Area of Volume source (m2)	1 cm - Thick Volume Source			2 cm - Thick Volume Source			5 cm - Thick Volume Source			10 cm - Thick Volume Source		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
100,000	6.77E-01	6.75E-01	1.00	1.08E+00	1.07E+00	1.00	1.92E+00	1.88E+00	1.02	2.72E+00	2.58E+00	1.06
1,000	5.32E-01	5.28E-01	1.01	9.26E-01	9.26E-01	1.00	1.77E+00	1.77E+00	1.00	2.56E+00	2.51E+00	1.02
100	3.39E-01	3.38E-01	1.00	6.26E-01	6.29E-01	0.99	1.35E+00	1.37E+00	0.98	2.12E+00	2.12E+00	1.00
36	2.47E-01	2.46E-01	1.01	4.61E-01	4.64E-01	0.99	1.04E+00	1.06E+00	0.98	1.71E+00	1.74E+00	0.98
10	1.41E-01	1.41E-01	1.00	2.65E-01	2.69E-01	0.99	6.10E-01	6.34E-01	0.96	1.06E+00	1.10E+00	0.96
4	8.10E-02	8.08E-02	1.00	1.52E-01	1.54E-01	0.99	3.54E-01	3.68E-01	0.96	6.24E-01	6.55E-01	0.95

Results for Tc-99. Tables 2.148-2.150 present the calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 1-cm-thick volume sources containing Tc-99. Tables 2.151-2.153 present the calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 2-cm-thick volume sources containing Tc-99. Tables 2.154-2.156 present calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 5-cm-thick volume sources, and Table 2.157-2.159 present calculations of $F_{CD,}$ F_{AM}, and radiation doses for six 10-cm-thick volume sources.

Comparisons of the dose estimates for 24 volume sources containing Tc-99 between the verification spreadsheets and RESRAD-BUILD are presented in Table 2.160. For 17 volume sources, the difference is less than 5%. For the remaining 7 volume sources, the difference is greater than 5% but less than 10%. Considering the approximate nature of the spreadsheet calculations, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

2.4.2 Dose Results with Shielding

To verify the RESRAD-BUILD external radiation dose modeling for volume sources with shielding, the external radiation doses incurred by a receptor at (0, 0, 1) (m) from six10-cm-thick volume sources containing Mn-54 that was covered by concrete material were estimated with spreadsheets. The thickness of the concrete cover was initially assumed to be 1 cm, which was then increased to 2 cm, and then to 5 cm.

Table 2.161 presents the calculations of F_{CD} for the 10-cm-thick Mn-54 volume sources covered by1-cm of concrete material. To estimate F_{AM} for the volume sources, each volume source was divided into 10 sub-volumes. Table 2.162 presents the calculations of $F_{AM\text{-}ref}$ for the reference source of the 7th sub-volume. Calculations of F_{AM} for the 7th sub-volume that has a circular area of 100 m^2 were presented in Table 2.163. Table 2.164 summarizes the F_{AM}'s calculated for each sub-volume of the six 10-cm-thick volume sources. The external doses estimated for these six sources are presented in Table 2.165.

Table 2.166 presents the calculations of F_{CD} for the 10-cm thick volume sources covered by 2-cm of concrete material. Table 2.167 summarizes the F_{AM}'s for the six volume sources. The external doses estimated for these six sources with a 2-cm concrete cover are presented in Table 2.168.

Table 2.169 presents the calculations of F_{CD} for the 10-cm thick volume sources covered by 5-cm of concrete material. Table 2.170 summarizes the F_{AM}'s for the six volume sources. The external doses estimated for these six sources with a 5-cm concrete cover are presented in Table 2.171.

Comparisons of the dose estimates for the six 10-cm volume sources containing Mn-54 are presented in Table 2.172. For all cases, the difference between the RESRAD-BUILD result and the spreadsheet result is less than 10%. Considering the approximate nature of the spreadsheet calculations, it is judged that the external radiation dose modeling was correctly implemented in the RESRAD-BUILD code.

Table 2.148 Calculation of F_{CD} for Tc-99 in a 1-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)			0.7871	0.2129	0.2106	2.63				
Reference source –	Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =			1.6
	Source density , g/cm3 =	1.6		Source thickness, cm =		1				
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$										
FCD= 0.4349										

Table 2.149 Summary of F_{AM}'s for Tc-99 in Six 1-cm-Thick Volume Sources without a Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.22E-01	9.92E-02	9.12E-01	1.72E-01	9.05E-01	2.28E-01	8.99E-01	2.73E-01	8.94E-01	3.09E-01
1,000	5.45E-01		6.71E-01		7.52E-01		8.02E-01		8.31E-01	
100	3.01E-01		3.79E-01		4.42E-01		4.95E-01		5.40E-01	
36	2.11E-01		2.64E-01		3.09E-01		3.48E-01		3.83E-01	
10	1.17E-01		1.46E-01		1.71E-01		1.92E-01		2.13E-01	
4	6.63E-02		8.25E-02		9.61E-02		1.08E-01		1.20E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	8.89E-01	1.88E-01	8.84E-01	3.67E-01	8.79E-01	3.92E-01	8.75E-01	4.14E-01	8.70E-01	4.35E-01
1,000	8.49E-01		8.59E-01		8.63E-01		8.64E-01		8.64E-01	
100	5.78E-01		6.11E-01		6.39E-01		6.64E-01		6.85E-01	
36	4.14E-01		4.42E-01		4.68E-01		4.92E-01		5.13E-01	
10	2.31E-01		2.48E-01		2.64E-01		2.80E-01		2.95E-01	
4	1.30E-01		1.40E-01		1.49E-01		1.58E-01		1.67E-01	

Table 2.150 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Tc-99 in Six 1-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 1 cm (Average)	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	4.35E-01	100,000	8.93E-01	4.89E-05
				1,000	7.90E-01	4.33E-05
				100	5.33E-01	2.92E-05
				36	3.84E-01	2.11E-05
				10	2.16E-01	1.18E-05
				4	1.22E-01	6.68E-06

Table 2.151 Calculation of F_{CD} for Tc-99 in a 2-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)				0.7871	0.2129	0.2106	2.63			
Reference source –		Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =		1.6
		Source density , g/cm3 =	1.6		Source thickness, cm =		2			
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,										
FCD=	0.5988									

Table 2.152 Summary of F_{AM}'s for Tc-99 in Six 2-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.12E-01	1.72E-01	8.99E-01	2.73E-01	8.89E-01	3.40E-01	8.79E-01	3.92E-01	8.70E-01	4.35E-01
1,000	6.71E-01		8.02E-01		8.49E-01		8.63E-01		8.64E-01	
100	3.79E-01		4.95E-01		5.78E-01		6.39E-01		6.85E-01	
36	2.64E-01		3.48E-01		4.14E-01		4.68E-01		5.13E-01	
10	1.46E-01		1.92E-01		2.31E-01		2.64E-01		2.95E-01	
4	8.25E-02		1.08E-01		1.30E-01		1.49E-01		1.67E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	8.61E-01	4.73E-01	8.52E-01	5.08E-01	8.43E-01	5.41E-01	8.34E-01	5.71E-01	8.25E-01	5.99E-01
1,000	8.58E-01		8.51E-01		8.43E-01		8.34E-01		8.25E-01	
100	7.18E-01		7.42E-01		7.58E-01		7.68E-01		7.74E-01	
36	5.52E-01		5.84E-01		6.10E-01		6.32E-01		6.50E-01	
10	3.22E-01		3.47E-01		3.70E-01		3.90E-01		4.09E-01	
4	1.84E-01		1.99E-01		2.14E-01		2.28E-01		2.41E-01	

Table 2.153 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Tc-99 in Six 2-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 2 cm (Average)	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	5.99E-01	100,000	8.66E-01	6.54E-05
				1,000	8.26E-01	6.23E-05
				100	6.54E-01	4.93E-05
				36	5.03E-01	3.80E-05
				10	2.97E-01	2.24E-05
				4	1.70E-01	1.28E-05

Table 2.154 Calculation of F_{CD} for Tc-99 in a 5-cm-Thick Volume Source without Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)			0.7871	0.2129	0.2106	2.63				
Reference source –	Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =			1.6
	Source density , g/cm3 =	1.6		Source thickness, cm =		5				
$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$										
FCD= 0.8540										

Table 2.155 Summary of F_{AM}'s for Tc-99 in Six 5-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	8.94E-01	3.09E-01	8.70E-01	4.35E-01	8.47E-01	5.25E-01	8.24E-01	5.99E-01	8.03E-01	6.61E-01
1,000	8.32E-01		8.64E-01		8.47E-01		8.24E-01		8.03E-01	
100	5.40E-01		6.85E-01		7.50E-01		7.74E-01		7.77E-01	
36	3.82E-01		5.13E-01		5.98E-01		6.50E-01		6.80E-01	
10	2.12E-01		2.95E-01		3.59E-01		4.10E-01		4.50E-01	
4	1.19E-01		1.67E-01		2.07E-01		2.42E-01		2.70E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	7.82E-01	7.14E-01	7.60E-01	7.58E-01	7.39E-01	7.96E-01	7.18E-01	8.27E-01	6.98E-01	8.54E-01
1,000	7.82E-01		7.60E-01		7.39E-01		7.18E-01		6.98E-01	
100	7.68E-01		7.53E-01		7.35E-01		7.16E-01		6.97E-01	
36	6.95E-01		7.00E-01		6.97E-01		6.89E-01		6.77E-01	
10	4.81E-01		5.04E-01		5.21E-01		5.33E-01		5.40E-01	
4	2.95E-01		3.16E-01		3.34E-01		3.49E-01		3.61E-01	

Table 2.156 Estimation of External Radiation Dose at the Receptor Location (0, 0,1) (m) from Tc-99 in Six 5-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 5 cm Weighted Average	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	8.54E-01	100,000	8.40E-01	9.03E-05
				1,000	8.16E-01	8.78E-05
				100	6.66E-01	7.17E-05
				36	5.39E-01	5.80E-05
				10	3.42E-01	3.68E-05
				4	2.04E-01	2.19E-05

Table 2.157 Calculation of F_{CD} for Tc-99 in a 10-cm-Thick Volume Source without a Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi (cm2/g)			0.7871	0.2129	0.2106	2.63				
Reference source –	Cover material =	none	Cover thickness, cm =		0		Density of cover, g/cm3 =			1.6
	Source density , g/cm3 =	1.6		Source thickness, cm =		10				
$F_{CD} = \frac{D(T_c=t_c, T_S=t_s)}{D(T_c=0, T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,										
FCD= 0.9729										

Table 2.158 Summary of F_{AM}'s for Tc-99 in Six 10-cm-Thick Volume Sources without Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	8.70E-01	4.35E-01	8.24E-01	5.99E-01	7.81E-01	7.14E-01	7.38E-01	7.96E-01	6.98E-01	8.54E-01
1,000	8.64E-01		8.24E-01		7.81E-01		7.38E-01		6.98E-01	
100	6.85E-01		7.74E-01		7.67E-01		7.34E-01		6.97E-01	
36	5.13E-01		6.50E-01		6.96E-01		6.96E-01		6.77E-01	
10	2.95E-01		4.10E-01		4.83E-01		5.24E-01		5.40E-01	
4	1.67E-01		2.42E-01		2.98E-01		3.39E-01		3.61E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	6.57E-01	8.96E-01	6.17E-01	9.26E-01	5.77E-01	9.47E-01	5.38E-01	9.62E-01	5.00E-01	9.73E-01
1,000	6.57E-01		6.17E-01		5.77E-01		5.38E-01		5.00E-01	
100	6.57E-01		6.17E-01		5.77E-01		5.38E-01		5.00E-01	
36	6.47E-01		6.12E-01		5.74E-01		5.37E-01		4.99E-01	
10	5.43E-01		5.35E-01		5.18E-01		4.95E-01		4.69E-01	
4	3.77E-01		3.85E-01		3.85E-01		3.80E-01		3.70E-01	

Table 2.159 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Tc-99 in Six 10-cm-Thick Volume Sources without Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} - 10 cm (Weighted Average)	Estimated Dose (mrem/yr)
1.26E-04	2.13E+05	1.00E+00	9.73E-01	100,000	7.98E-01	9.78E-05
				1,000	7.95E-01	9.74E-05
				100	7.04E-01	8.63E-05
				36	5.93E-01	7.27E-05
				10	3.98E-01	4.88E-05
				4	2.47E-01	3.03E-05

Table 2.160 Comparison of Radiation Doses (mrem/yr) at (0, 0, 1) (m) Estimated by RESRAD-BUILD and Spreadsheets from Tc-99 in Volume Sources of Different Thicknesses and Areas without Cover

Area of Volume source (m2)	1 cm - Thick Volume Source			2 cm - Thick Volume Source			5 cm - Thick Volume Source			10 cm - Thick Volume Source		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
100,000	4.97E-05	4.89E-05	1.02	6.72E-05	6.54E-05	1.03	9.28E-05	9.03E-05	1.03	1.03E-04	9.78E-05	1.05
1,000	4.44E-05	4.33E-05	1.03	6.26E-05	6.23E-05	1.00	8.86E-05	8.78E-05	1.01	9.83E-05	9.74E-05	1.01
100	3.05E-05	2.92E-05	1.04	4.81E-05	4.93E-05	0.98	7.53E-05	7.17E-05	1.05	8.63E-05	8.63E-05	1.00
36	2.23E-05	2.11E-05	1.06	3.68E-05	3.80E-05	0.97	6.25E-05	5.80E-05	1.08	7.42E-05	7.27E-05	1.02
10	1.26E-05	1.18E-05	1.07	2.14E-05	2.24E-05	0.96	4.01E-05	3.68E-05	1.09	5.10E-05	4.88E-05	1.04
4	7.15E-06	6.68E-06	1.07	1.23E-05	1.28E-05	0.96	2.41E-05	2.19E-05	1.10	3.20E-05	3.03E-05	1.06

Table 2.161 Calculation of F_{CD} for Mn-54 in a 10-cm-Thick Volume Source with 1-cm Concrete Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi(cm2/g)				0.085	0.915	1.22	0.088		
Source material =	concrete	thickness, cm =	10	Cover material =	concrete	Cover thickness, cm =	1	density, g/cm3	1.6
Reference material =	soil								
	$F_{CD} = \frac{D(T_c=t_c, T_S=t_s)}{D(T_c=0, T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$								
FCD =	0.612								

Table 2.162 Calculation of F_{AM} for Mn-54 in a Reference Source for the 7th Sub-volume of a 10-cm-Thick Volume Source with 1-cm Concrete Cover at the Receptor Location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor pSv cm2	Effective Mass Attenuation Coefficient (source) (/cm)	Effective Mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)						
1	0.835	1	0.825	3.189	8.42E-03	8.55E-03	1.13E-01	1.12E-01	8.48E-05						
ta (cm) =	99	tc (cm) =	1	Source-ref area (m2) =			3.36E+06	ts (cm) =	7						
exp(-ux)/x2 - ref	dist. in - ref- air (cm)	dist. in-ref-source-cover (cm)	mfp-dist. in - ref-air	mfp-dist. in-ref-source-cover	BF-ref-air	BF-ref-source-cover	Vol-sour-ref (m2)	FAM-ref	4pi x dist-ref^2 (cm2)	distance-ref (cm)	ta + tc + ts (m)	r - ref (m)	ta (m)	Receptor location y (cm)	Receptor location z (cm)
2.78E-06	9.90E+01	8.00E+00	8.39E-03	9.07E-01	1.01E+00	1.96E+00	0.00E+00	0.00E+00	1.44E+05	1.07E+02	1.07E+00	0.00E+00	9.90E-01		
2.75E-06	9.94E+01	8.03E+00	8.43E-03	9.10E-01	1.01E+00	1.97E+00	3.14E-02	1.71E-07	1.45E+05	1.07E+02	1.07E+00	1.00E-01	9.90E-01		
2.75E-06	9.95E+01	8.04E+00	8.43E-03	9.11E-01	1.01E+00	1.97E+00	1.91E-03	1.04E-08	1.45E+05	1.07E+02	1.07E+00	1.03E-01	9.90E-01		
2.74E-06	9.95E+01	8.04E+00	8.43E-03	9.11E-01	1.01E+00	1.97E+00	2.03E-03	1.11E-08	1.45E+05	1.08E+02	1.07E+00	1.06E-01	9.90E-01		
2.74E-06	9.95E+01	8.04E+00	8.44E-03	9.11E-01	1.01E+00	1.97E+00	2.15E-03	1.17E-08	1.45E+05	1.08E+02	1.07E+00	1.09E-01	9.90E-01		
2.74E-06	9.95E+01	8.04E+00	8.44E-03	9.12E-01	1.01E+00	1.97E+00	2.29E-03	1.24E-08	1.46E+05	1.08E+02	1.07E+00	1.13E-01	9.90E-01		
2.74E-06	9.96E+01	8.05E+00	8.44E-03	9.12E-01	1.01E+00	1.97E+00	2.42E-03	1.32E-08	1.46E+05	1.08E+02	1.07E+00	1.16E-01	9.90E-01		
2.73E-06	9.96E+01	8.05E+00	8.44E-03	9.12E-01	1.01E+00	1.97E+00	2.57E-03	1.40E-08	1.46E+05	1.08E+02	1.07E+00	1.19E-01	9.90E-01	0	100
2.73E-06	9.97E+01	8.05E+00	8.45E-03	9.12E-01	1.01E+00	1.97E+00	2.73E-03	1.48E-08	1.46E+05	1.08E+02	1.07E+00	1.23E-01	9.90E-01		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
1.22E-21	3.17E+03	2.57E+02	2.69E-01	2.91E+01	1.27E+00	1.42E+02	1.44E+02	3.17E-17	1.48E+08	3.43E+03	1.07E+00	3.43E+01	9.90E-01		
6.55E-22	3.24E+03	2.62E+02	2.75E-01	2.97E+01	1.27E+00	1.47E+02	1.49E+02	1.83E-17	1.54E+08	3.50E+03	1.07E+00	3.50E+01	9.90E-01		
3.46E-22	3.30E+03	2.67E+02	2.80E-01	3.02E+01	1.28E+00	1.52E+02	1.55E+02	1.04E-17	1.60E+08	3.57E+03	1.07E+00	3.57E+01	9.90E-01		
1.81E-22	3.37E+03	2.72E+02	2.86E-01	3.08E+01	1.28E+00	1.57E+02	1.62E+02	5.90E-18	1.67E+08	3.64E+03	1.07E+00	3.64E+01	9.90E-01		
9.33E-23	3.44E+03	2.78E+02	2.91E-01	3.15E+01	1.29E+00	1.63E+02	1.68E+02	3.29E-18	1.73E+08	3.71E+03	1.07E+00	3.71E+01	9.90E-01		
4.75E-23	3.50E+03	2.83E+02	2.97E-01	3.21E+01	1.29E+00	1.69E+02	1.75E+02	1.81E-18	1.80E+08	3.79E+03	1.07E+00	3.79E+01	9.90E-01		
..	..	..	..	..	..	..	..	..	..	..	..	..	..		
0.00E+00	9.19E+04	7.43E+03	7.79E+00	8.42E+02	2.20E+01	2.43E+02	1.21E+05	0.00E+00	1.24E+11	9.94E+04	1.07E+00	9.94E+02	9.90E-01		
0.00E+00	9.38E+04	7.58E+03	7.95E+00	8.59E+02	2.26E+01	2.43E+02	1.25E+05	0.00E+00	1.29E+11	1.01E+05	1.07E+00	1.01E+03	9.90E-01		
0.00E+00	9.57E+04	7.73E+03	8.11E+00	8.76E+02	2.34E+01	2.43E+02	1.30E+05	0.00E+00	1.34E+11	1.03E+05	1.07E+00	1.03E+03	9.90E-01		
							∑FAM-ref=	3.72E-05							

Table 2.163 Calculation of F_{AM} for Mn-54 in the 7th Sub-volume of a 10-cm-Thick Volume Source with an Area of 100 m^2 and 1-cm Concrete Cover at the Receptor location (0, 0, 1) (m)

# photons	Energy 1	Yield 1	FE	Fluence to Effective Dose Conversion Factor pSv cm2	Effective Mass Attenuation Coefficient (source) (/cm)	Effective Mass Attenuation Coefficient (ref) (/cm)	Mass Attenuation Coefficient (soil) (/cm)	Mass Attenuation Coefficient (concrete) (/cm)	Mass Attenuation Coefficient (air) (/cm)							
1	0.835	1	0.825	3.189	8.42E-03	8.55E-03	1.13E-01	1.12E-01	8.48E-05							
ta (cm) =	99	tc (cm) =	1		Source area (m2) =		100		Source-ref area (m2) =		3.36E+06	ts (cm) =	7			
exp(-ux)/x2 - source	mfp-dist. in -sour-air	mfp-dist. in-source-cover	dist. in - source-air (cm)	dist. in-source-cover (cm)	BF-source-air	BF-source-cover	Vol-source (m2)	FAM-source	4pi x dist-source^2 (cm2)	distance-source-air (cm)	dist-cover (cm)	r - source (m)	ta + tc + ts (	ta (m)	Receptor location y (cm)	Receptor location z (cm)
2.39E-08	3.03E-02	3.01E+00	3.57E+02	2.70E+01	1.03E+00	5.13E+00	1.45E+00	1.83E-07	1.64E+06	3.61E+02	1.00E+00	3.45E+00	1.07E+00	9.90E-01		
2.18E-08	3.09E-02	3.07E+00	3.64E+02	2.75E+01	1.03E+00	5.23E+00	1.51E+00	1.77E-07	1.70E+06	3.68E+02	1.00E+00	3.52E+00	1.07E+00	9.90E-01		
1.97E-08	3.14E-02	3.12E+00	3.71E+02	2.80E+01	1.03E+00	5.34E+00	1.57E+00	1.71E-07	1.76E+06	3.74E+02	1.00E+00	3.59E+00	1.07E+00	9.90E-01		
1.79E-08	3.20E-02	3.18E+00	3.77E+02	2.85E+01	1.03E+00	5.45E+00	1.63E+00	1.65E-07	1.83E+06	3.81E+02	1.00E+00	3.66E+00	1.07E+00	9.90E-01		
1.62E-08	3.26E-02	3.24E+00	3.84E+02	2.90E+01	1.03E+00	5.57E+00	1.70E+00	1.58E-07	1.90E+06	3.88E+02	1.00E+00	3.73E+00	1.07E+00	9.90E-01		
1.46E-08	3.32E-02	3.30E+00	3.92E+02	2.96E+01	1.03E+00	5.69E+00	1.77E+00	1.52E-07	1.97E+06	3.95E+02	1.00E+00	3.81E+00	1.07E+00	9.90E-01		
1.32E-08	3.38E-02	3.36E+00	3.99E+02	3.01E+01	1.03E+00	5.80E+00	1.84E+00	1.46E-07	2.04E+06	4.03E+02	1.00E+00	3.88E+00	1.07E+00	9.90E-01		
1.19E-08	3.44E-02	3.42E+00	4.06E+02	3.07E+01	1.03E+00	5.93E+00	1.91E+00	1.40E-07	2.12E+06	4.10E+02	1.00E+00	3.96E+00	1.07E+00	9.90E-01		
1.07E-08	3.51E-02	3.49E+00	4.14E+02	3.12E+01	1.03E+00	6.05E+00	1.99E+00	1.34E-07	2.20E+06	4.18E+02	1.00E+00	4.04E+00	1.07E+00	9.90E-01		
9.63E-09	3.57E-02	3.55E+00	4.22E+02	3.18E+01	1.04E+00	6.18E+00	2.07E+00	1.28E-07	2.28E+06	4.26E+02	1.00E+00	4.12E+00	1.07E+00	9.90E-01		
8.64E-09	3.64E-02	3.62E+00	4.29E+02	3.24E+01	1.04E+00	6.31E+00	2.16E+00	1.22E-07	2.37E+06	4.34E+02	1.00E+00	4.20E+00	1.07E+00	9.90E-01		
7.73E-09	3.71E-02	3.69E+00	4.37E+02	3.30E+01	1.04E+00	6.44E+00	2.24E+00	1.16E-07	2.46E+06	4.42E+02	1.00E+00	4.29E+00	1.07E+00	9.90E-01		
6.91E-09	3.78E-02	3.76E+00	4.46E+02	3.37E+01	1.04E+00	6.58E+00	2.33E+00	1.10E-07	2.55E+06	4.50E+02	1.00E+00	4.37E+00	1.07E+00	9.90E-01	0	100
6.17E-09	3.85E-02	3.83E+00	4.54E+02	3.43E+01	1.04E+00	6.71E+00	2.43E+00	1.04E-07	2.65E+06	4.59E+02	1.00E+00	4.46E+00	1.07E+00	9.90E-01		
5.50E-09	3.92E-02	3.90E+00	4.63E+02	3.49E+01	1.04E+00	6.85E+00	2.53E+00	9.89E-08	2.75E+06	4.67E+02	1.00E+00	4.55E+00	1.07E+00	9.90E-01		
4.89E-09	4.00E-02	3.98E+00	4.72E+02	3.56E+01	1.04E+00	7.00E+00	2.63E+00	9.35E-08	2.85E+06	4.76E+02	1.00E+00	4.64E+00	1.07E+00	9.90E-01		
4.34E-09	4.07E-02	4.05E+00	4.80E+02	3.63E+01	1.04E+00	7.16E+00	2.73E+00	8.85E-08	2.96E+06	4.85E+02	1.00E+00	4.73E+00	1.07E+00	9.90E-01		
3.85E-09	4.15E-02	4.13E+00	4.90E+02	3.70E+01	1.04E+00	7.33E+00	2.85E+00	8.36E-08	3.07E+06	4.95E+02	1.00E+00	4.83E+00	1.07E+00	9.90E-01		
3.41E-09	4.23E-02	4.21E+00	4.99E+02	3.77E+01	1.04E+00	7.51E+00	2.96E+00	7.89E-08	3.19E+06	5.04E+02	1.00E+00	4.93E+00	1.07E+00	9.90E-01		
3.01E-09	4.31E-02	4.29E+00	5.08E+02	3.84E+01	1.04E+00	7.68E+00	3.08E+00	7.42E-08	3.32E+06	5.14E+02	1.00E+00	5.02E+00	1.07E+00	9.90E-01		
2.65E-09	4.39E-02	4.37E+00	5.18E+02	3.91E+01	1.04E+00	7.87E+00	3.20E+00	6.98E-08	3.44E+06	5.23E+02	1.00E+00	5.12E+00	1.07E+00	9.90E-01		
2.33E-09	4.48E-02	4.45E+00	5.28E+02	3.99E+01	1.04E+00	8.05E+00	3.33E+00	6.54E-08	3.58E+06	5.34E+02	1.00E+00	5.23E+00	1.07E+00	9.90E-01		
2.05E-09	4.56E-02	4.54E+00	5.38E+02	4.07E+01	1.05E+00	8.24E+00	3.47E+00	6.12E-08	3.72E+06	5.44E+02	1.00E+00	5.33E+00	1.07E+00	9.90E-01		
1.80E-09	4.65E-02	4.63E+00	5.49E+02	4.14E+01	1.05E+00	8.44E+00	3.61E+00	5.72E-08	3.86E+06	5.54E+02	1.00E+00	5.44E+00	1.07E+00	9.90E-01		
1.57E-09	4.74E-02	4.71E+00	5.59E+02	4.22E+01	1.05E+00	8.64E+00	3.75E+00	5.33E-08	4.01E+06	5.65E+02	1.00E+00	5.55E+00	1.07E+00	9.90E-01		
1.37E-09	4.83E-02	4.81E+00	5.70E+02	4.30E+01	1.05E+00	8.84E+00	3.91E+00	4.96E-08	4.17E+06	5.76E+02	1.00E+00	5.66E+00	1.07E+00	9.90E-01		
						∑FAM-source=		3.23E-05								
							FAM=	8.69E-01								

Table 2.164 Summary of F_{AM}'s for Mn-54 in Six 10-cm-Thick Volume Sources with 1-cm Concrete Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.85E-01	1.15E-01	9.72E-01	2.07E-01	9.57E-01	2.86E-01	9.40E-01	3.54E-01	9.22E-01	4.14E-01
1,000	9.69E-01		9.69E-01		9.57E-01		9.40E-01		9.22E-01	
100	7.48E-01		8.23E-01		8.64E-01		8.82E-01		8.86E-01	
36	5.67E-01		6.45E-01		7.03E-01		7.43E-01		7.69E-01	
10	3.35E-01		3.90E-01		4.35E-01		4.73E-01		5.05E-01	
4	1.94E-01		2.27E-01		2.56E-01		2.82E-01		3.03E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	9.03E-01	4.65E-01	8.83E-01	5.10E-01	8.61E-01	5.49E-01	8.40E-01	5.83E-01	8.17E-01	6.12E-01
1,000	9.03E-01		8.83E-01		8.61E-01		8.40E-01		8.17E-01	
100	8.81E-01		8.69E-01		8.53E-01		8.35E-01		8.14E-01	
36	7.85E-01		7.92E-01		7.91E-01		7.86E-01		7.76E-01	
10	5.32E-01		5.52E-01		5.68E-01		5.79E-01		5.85E-01	
4	3.22E-01		3.40E-01		3.54E-01		3.67E-01		3.76E-01	

Table 2.165 Estimation External Radiation Dose at the Receptor Location (0, 10, 1) (m) from Mn-54 in Six 10-cm-Thick Volume Sources with 1-cm Concrete Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM}	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	6.12E-01	100,000	9.30E-01	2.01E+00
				1,000	9.27E-01	2.01E+00
				100	8.37E-01	1.81E+00
				36	7.07E-01	1.53E+00
				10	4.61E-01	9.98E-01
				4	2.77E-01	6.01E-01

Table 2.166 Calculation of F_{CD} for Mn-54 in a 10-cm-Thick Volume Source with 2-cm Concrete Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi(cm2/g)			0.085	0.915	1.22	0.088			
Source material =	concrete	thickness, cm =	10	Cover material =	concrete	Cover thickness, cm =	2	density, g/cm3	1.6
Reference material =	soil								
	$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,								
FCD =	0.523								

Table 2.167 Summary of F_{AM}'s for Mn-54 in Six 10-cm-Thick Volume Sources with 2-cm Concrete Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.83E-01	9.22E-02	9.69E-01	1.71E-01	9.53E-01	2.40E-01	9.36E-01	2.99E-01	9.17E-01	3.51E-01
1,000	9.80E-01		9.69E-01		9.53E-01		9.36E-01		9.17E-01	
100	8.32E-01		8.75E-01		8.94E-01		9.00E-01		8.95E-01	
36	6.53E-01		7.13E-01		7.54E-01		7.81E-01		7.98E-01	
10	3.95E-01		4.42E-01		4.81E-01		5.15E-01		5.42E-01	
4	2.31E-01		2.61E-01		2.87E-01		3.10E-01		3.29E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	8.98E-01	3.96E-01	8.77E-01	4.34E-01	8.55E-01	4.68E-01	8.33E-01	4.98E-01	8.11E-01	5.23E-01
1,000	8.98E-01		8.77E-01		8.55E-01		8.33E-01		8.11E-01	
100	8.84E-01		8.68E-01		8.50E-01		8.30E-01		8.09E-01	
36	8.05E-01		8.06E-01		8.01E-01		7.91E-01		7.78E-01	
10	5.63E-01		5.79E-01		5.91E-01		5.98E-01		6.02E-01	
4	3.47E-01		3.63E-01		3.76E-01		3.86E-01		3.93E-01	

Table 2.168 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six 10-cm-Thick Volume Sources with 2-cm Concrete Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM}	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	5.23E-01	100,000	9.25E-01	1.71E+00
				1,000	9.24E-01	1.71E+00
				100	8.68E-01	1.60E+00
				36	7.52E-01	1.39E+00
				10	5.04E-01	9.32E-01
				4	3.07E-01	5.68E-01

Table 2.169 Calculation of F_{CD} for Mn-54 in a 10-cm-Thick Volume Source with 5-cm Concrete Cover

Fitting parameters Ai, Bi, Kai (cm2/g), Kbi(cm2/g)			0.085	0.915	1.22	0.088			
Source material =	concrete	thickness, cm =	10	Cover material =	concrete	Cover thickness, cm =	5	density, g/cm3	1.6
Reference material =	soil								
	$F_{CD} = \frac{D(T_c=t_c,T_S=t_s)}{D(T_c=0,T_S=\infty)} = Ae^{-K_A\rho_c t_c}(1-e^{-K_A\rho_S t_S}) + Be^{-K_B\rho_c t_c}(1-e^{-K_B\rho_S t_S})$,								
FCD =	0.342								

Table 2.170 Summary of F_{AM}'s for Mn-54 in Six 10-cm-Thick Volume Sources with 5-cm Concrete Cover at the Receptor Location (0, 0, 1) (m)

Area of Volume source (m2)	1st Sub-source	F_{CD} for 1st Sub-source	2nd Sub-source	F_{CD} for 2nd Sub-source	3rd Sub-source	F_{CD} for 3rd Sub-source	4th Sub-source	F_{CD} for 4th Sub-source	5th Sub-source	F_{CD} for 5th Sub-source
100,000	9.79E-01	5.94E-02	9.62E-01	1.11E-01	9.44E-01	1.56E-01	9.25E-01	1.95E-01	9.05E-01	2.29E-01
1,000	9.79E-01		9.62E-01		9.44E-01		9.25E-01		9.05E-01	
100	9.41E-01		9.39E-01		9.30E-01		9.16E-01		8.99E-01	
36	8.19E-01		8.39E-01		8.49E-01		8.52E-01		8.48E-01	
10	5.43E-01		5.73E-01		5.97E-01		6.16E-01		6.30E-01	
4	3.29E-01		3.51E-01		3.71E-01		3.88E-01		4.03E-01	
Area of Volume source (m2)	6th Sub-source	F_{CD} for 6th Sub-source	7th Sub-source	F_{CD} for 7th Sub-source	8th Sub-source	F_{CD} for 8th Sub-source	9th Sub-source	F_{CD} for 9th Sub-source	10th Sub-source	F_{CD} for 10th Sub-source
100,000	8.84E-01	2.58E-01	8.62E-01	2.84E-01	8.39E-01	3.06E-01	8.16E-01	3.25E-01	7.93E-01	3.42E-01
1,000	8.84E-01		8.62E-01		8.39E-01		8.16E-01		7.93E-01	
100	8.80E-01		8.60E-01		8.38E-01		8.15E-01		7.92E-01	
36	8.40E-01		8.29E-01		8.14E-01		7.97E-01		7.78E-01	
10	6.39E-01		6.45E-01		6.46E-01		6.45E-01		6.40E-01	
4	4.15E-01		4.23E-01		4.30E-01		4.34E-01		4.36E-01	

Table 2.171 Estimation of External Radiation Dose at the Receptor Location (0, 0, 1) (m) from Mn-54 in Six 10-cm-Thick Volume Sources with 5-cm Concrete Cover

DCF-inf (mrem/yr per pCi/g)	Half-life, yr	Average Decay Factor in 1st year	F_{CD}	Area of Volume source (m2)	F_{AM} (weighted - average)	Estimated Dose (mrem/yr)
5.16E+00	8.56E-01	6.85E-01	3.42E-01	100,000	9.14E-01	1.10E+00
				1,000	9.14E-01	1.10E+00
				100	9.00E-01	1.09E+00
				36	8.31E-01	1.00E+00
				10	6.05E-01	7.30E-01
				4	3.84E-01	4.64E-01

Table 2.172 Comparison of Radiation Doses (mrem/yr) at (0, 0, 1) (m) Estimated by RESRAD-BUILD and Spreadsheets from Mn-54 in 10-cm-Thick Volume Sources with Different Concrete Covers

Area of Volume source (m2)	1 cm - Thick Concrete Cover			5 cm - Thick Concrete Cover			5 cm - Thick Concrete Cover		
	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets	Dose Results from RESRAD-BUILD	Dose Results from Spreadsheets	Ratio - RESRAD-BUILD/ Spreadsheets
100,000	2.16E+00	2.01E+00	1.07	1.85E+00	1.71E+00	1.08	1.21E+00	1.10E+00	1.10
1,000	2.14E+00	2.01E+00	1.07	1.85E+00	1.71E+00	1.08	1.21E+00	1.10E+00	1.10
100	1.89E+00	1.81E+00	1.04	1.71E+00	1.60E+00	1.07	1.19E+00	1.09E+00	1.09
36	1.57E+00	1.53E+00	1.03	1.46E+00	1.39E+00	1.05	1.09E+00	1.00E+00	1.09
10	9.96E-01	9.98E-01	1.00	9.50E-01	9.32E-01	1.02	7.72E-01	7.30E-01	1.06
4	5.94E-01	6.01E-01	0.99	5.73E-01	5.68E-01	1.01	4.85E-01	4.64E-01	1.05

2.5 EXTERNAL RADIATION OF FLOOR DEPOSITION

In RESRAD-BUILD, a floor with deposited radionuclides is treated as an area source; therefore, the modeling of external radiation dose for area sources is applied to estimate the external radiation dose from deposited radionuclides. In the modeling, the receptor is assumed to stay at 1 m above the center of the floor and there is no shielding between the floor and the receptor.

To verify the RESRAD-BUILD modeling results for floor deposition, the previous radiation dose estimates from verification spreadsheets for area sources (presented in Section 2.3.1.1) were utilized. These dose estimates concerned a receptor located at (0, 0, 1) (m) and four area sources of 10 m^2, 36 m^2, 100 m^2, and 1,000 m^2, each containing C-14, Mn-54, and Tc-99 with an initial concentration of 1 pCi/m^2. These dose estimates were normalized by the average decay factor in the 1st year to get the dose estimates for an average concentration of 1 pCi/m^2. Table 2.173 lists the normalized dose estimates. To obtain dose estimates for floor deposition, these normalized dose estimates need to be multiplied by the deposition concentrations of radionuclides. A RESRAD-BUILD analysis was conducted to provide the deposition concentrations needed. After dose estimates for the floor deposition were obtained, they were used to verify the dose results from the RESRAD-BUILD analysis.

In the RESRAD-BUILD analysis, a building containing four rooms of different floor areas (Room 1 – 10 m^2, Room 2 – 36 m^2, Room 3 – 100 m^2, and Room 4 – 1,000 m^2) was assumed contaminated. There were four radiation sources in the building, one in each room contaminated with different radionuclides (Source 1 with C-14, Source 2 with Mn-54, Source 3 with Mn-54, and Source 4 with Tc-99). Source 1 was a volume source located at (0, 0, 0) (m) with z-direction; it had an area of 10 m^2, a thickness of 15 cm, and a density of 2.4 g/cm^3. Source 1 had an erosion rate of 2.4E-8 cm/d, and 10% of the eroded materials were assumed to get into the indoor air. Source 1 was in Room 1. Source 2 was an area source with z-direction and located at (6, 6, 0) (m). It had an area of 10 m^2 and a removable fraction of 0.5; 10% of the source removed would be released into the indoor air. Source 2 was in Room 2. Source 3 was a line source with x-direction and was located at (10, 10, 0) (m). It had a length of 10 m and a removable fraction of 0.5; 10% of the source removed would be released into the indoor air. Source 3 was in Room 3. Source 4 was a point source located at (25, 40, 0) (m). It also had a removable fraction of 0.5, and 10% of the source removed would be released into the indoor air. Source 4 was in Room 4. There were four receptors considered in the analysis, Receptor 1 in Room 1 at (0, 0, 1) m, Receptor 2 in Room 2 at (6, 6, 1) (m), Receptor 3 in Room 3 at (10, 10, 1) (m), and Receptor 4 in Room 4 at (25, 40, 1) (m). Each receptor was located at the center of the room, 1 m above the floor. Table 2.174 lists the average floor concentrations of each radionuclide for the 1st year, projected by the RESRAD-BUILD code.

Table 2.175 compares the external radiation dose estimates for the floor deposition from the spreadsheets and the RESRAD-BUILD analysis. The differences are the same as those seen with the dose estimates for the area sources. This confirms that the external radiation dose modeling for floor deposition is accurately implemented in RESRAD-BUILD.

Table 2.173 Estimated External Radiation Doses to a Receptor at (0, 0, 1) (m) from Different Radionuclides in Four Area Sources without Cover

Area of Source (m^2)	C-14	Mn-54	Tc-99
1,000	1.05E-09	5.09E-05	4.20E-09
100	5.90E-10	3.09E-05	2.40E-09
36	4.15E-10	2.23E-05	1.70E-09
10	2.32E-10	1.28E-05	9.58E-10

Note: The listed values are from Tables 2.43 and 2.67 for C-14 and Tc-99, respectively. The listed values for Mn-54 are those in Table 55 divided by 0.685, the average decay factor in 1st year.

Table 2.174 Average Floor Deposition Concentrations (pCi/m^2) for the 1st Year Projected by the RESRAD-BUILD Code

	Contribution from Each Source			
Room – Floor Area	Source 1 – C-14	Source 2 – Mn-54	Source 3 – Mn-54	Source 4 – Tc-99
Room 4 – 1,000 m^2	3.47E-05	4.77E-05	4.77E-05	8.26E-06
Room 3 – 100 m^2	2.27E-04	3.19E-04	3.19E-04	5.41E-05
Room 2 – 36 m^2	3.61E-04	5.19E-04	5.19E-04	8.60E-05
Room 1 – 10 m^2	1.87E-03	2.85E-03	2.85E-03	4.45E-04

Table 2.175 Comparison of Estimated External Radiation Doses (mrem/yr) for Floor Depositions by RESRAD-BUILD and Spreadsheets

	Source 1 – C-14			Source 2 – Mn-54		
Room – Floor Area	RESRAD-BUILD	Spread-sheet	Ratio RESRAD-BUILD/Spread-sheet	RESRAD-BUILD	Spread-sheet	Ratio RESRAD-BUILD/Spread-sheet
Room 4 – 1,000 m^2	3.63E-14	3.64E-14	1.00	2.41E-09	2.43E-09	0.99
Room 3 – 100 m^2	1.33E-13	1.34E-13	0.99	9.80E-09	9.87E-09	0.99
Room 2 – 36 m^2	1.485E-13	1.50E-13	0.99	1.15E-08	1.16E-08	0.99
Room 1 – 10 m^2	4.28E-13	4.34E-13	0.99	3.60E-08	3.65E-08	0.99
	Source 3 – Mn-54			Source 4 – Tc-99		
Room – Floor Area	RESRAD-BUILD	Spread-sheet	Ratio RESRAD-BUILD/Spread-sheet	RESRAD-BUILD	Spread-sheet	Ratio RESRAD-BUILD/Spread-sheet
Room 4 – 1,000 m2	2.41E-09	2.43E-09	0.99	3.46E-14	3.47E-14	1.00
Room 3 – 100 m2	9.80E-09	9.87E-09	0.99	1.3E-13	1.30E-13	1.00
Room 2 – 36 m2	1.15E-08	1.16E-08	0.99	1.48E-13	1.46E-13	1.01
Room 1 – 10 m2	3.60E-08	3.65E-08	0.99	4.29E-13	4.26E-13	1.01

3 VERIFICATION OF THE VENTILATION MODELING

To verify the ventilation modeling results of the RESRAD-BUILD code, seven cases involving a building with nine rooms, different types of radiation sources in different rooms, different air exchange rates between the rooms and with the outside environment, as well as different vacuuming schedules and vacuuming efficiencies were developed. Both the RESRAD-BUILD code and the verification spreadsheets were applied to calculate release rates of radionuclides to the indoor air; concentrations of radionuclides remaining in the source, in the air, and on the floor of each room over time; the average radionuclide concentrations and integrated ingestion over the exposure duration; and the potential radiation doses and risks to four receptors in different rooms of the building.

Each source considered in the verification cases was assumed to initially contain Co-60, Cs-137, and Ra-226 with a concentration of 1 pCi/g in a volume source or 1 pCi/m^2 in an area source. A cut-off half-life of 30 days was used to assemble the radiological decay chains. ICRP 72 adult internal dose coefficients and ICRP 60 external dose coefficients were used to calculate radiation doses, while FGR 13 morbidity slope factors were used to calculate cancer risks.

Appendix B of the RESRAD-BUILD User's Manual, Volume I (Yu et al. 2022) describes the modeling of the fate of radionuclides implemented in Version 4.0. Equations B.10 and B.11 are solved to track the changes in the concentrations of source particles in the air and on the floor of each room in the building as time progresses. After the concentration of source particles in the air and on the floor are determined, they are multiplied by the initial concentration of a parent nuclide in the source and an ingrowth and decay factor relating the concentration of a progeny in the decay chain to the initial concentration of parent nuclide in the source to obtain the concentration of that progeny in the air and on the floor over time. In the verification spreadsheets, a numerical analysis method was implemented to solve Equations B.10 and B.11. The ingrowth and decay factors obtained from an execution of RESRAD-OFFSITE were imported to the spreadsheets to calculate radionuclide concentrations in the air and on the floor.

The numerical analysis method implemented in the spreadsheets involved calculating the concentration of source particles in the air and on the floor at numerous time steps that began at 0 and increased steadily. To obtain more precise estimates of concentrations, a small increment between successive time steps (2 hours) was selected to build the concentration profiles up to 1.5 years. The exposure duration and indoor time fraction for each receptor were set to 91.25 days (25% of a year) and 0.5, respectively.

The following sections discuss in more detail the calculations performed and the comparison of the calculation results from RESRAD-BUILD and spreadsheets for each case.

3.1 CASE I – A VOLUME SOURCE IN ROOM 1 WITH NO SCHEDULED VACUUMING

Case I considers a cylindrical volume source, with a circular area of 36 m^2 and a length of 15 cm, located in Room 1. No vacuuming to remove dust deposition on the floor was assumed.

Potential radiation dose and cancer risk to four receptors, located in Rooms 1, 3, 6, and 9, respectively, via the inhalation of airborne particulates, ingestion of source particles, and external radiation emitted by airborne particulates were evaluated.

Table 3.1 shows the room dimensions, ventilation rates between rooms and the outside environment, deposition velocity, and resuspension rate assumed for the case. Vacuuming to reduce floor deposition periodically was not considered in the analysis. Table 3.2 lists the properties assumed for the radiation source as well as its releases over time.

3.1.1 Calculation and Comparison of Release Rates and Source Concentrations

Table 3.3 shows the air release rate calculated by RESRAD-BUILD, obtained from the intermediate output file "AirRelRate1.out," and part of the estimated air release rates in the spreadsheet. The air release rate calculated by RESRAD-BUILD in terms of the fraction of the initial source per second was converted to mass of source materials per hour. The converted air release rate matches those estimated in the spreadsheet.

Table 3.4 lists part of the ingrowth and decay factors obtained with an execution of RESRAD-OFFSITE, which were used with the remaining mass of source materials to estimate the remaining radioactivity in the source and the integrated radioactivity directly ingested over the exposure duration by a receptor located in the same room as the source. Table 3.5 shows part of calculations in the spreadsheet.

Table 3.6 compares the average radioactivity remaining in the source over the exposure duration from RESRAD-BUILD and spreadsheets. Table 3.7 compares the integrated radioactivity directly ingested over the exposure duration, based on full occupancy. The results from RESRAD-BUILD were listed in the intermediate output file "AirRelTimeIntegratedConcSource1.out." The comparisons show the RESRAD-BUILD results agree with the spreadsheet results.

3.1.2 Calculation and Comparison of Air and Floor Concentrations

Equations B.10 and B.11 in the User's Manual of RESRAD-BUILD, Vol. 1 (Yu et al. 2022) describe the change in the fraction of source materials suspended in the air and deposited on the floor, respectively, in each room of the building as a function of time. They were solved numerically in the spreadsheets to obtain source particulate concentrations in each room. Table 3.8 presents part of the calculations and results at different time steps in the spreadsheets.

Table 3.1 Air Flows, Vacuuming, and Resuspension and Deposition of Particulates Assumed for Case I

Deposition Velocity		0.00039	(m/s) =	1.404	(m/hr)					
	Outdoors	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9
Area (m2)		36	36	36	36	36	36	36	36	36
Volume (m3)		90	90	90	90	90	90	90	90	90
Resuspension rate (1/s)		5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07
Resuspension rate (1/h)		1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03
Air flow (m3/hr) from										
Outdoors	0	72	72	72	72	72	72	72	72	72
Room 1	72	0	72	72	72	72	72	72	72	72
Room 2	72	72	0	72	72	72	72	72	72	72
Room 3	72	72	72	0	72	72	72	72	72	72
Room 4	72	72	72	72	0	72	72	72	72	72
Room 5	72	72	72	72	72	0	72	72	72	72
Room 6	72	72	72	72	72	72	0	72	72	72
Room 7	72	72	72	72	72	72	72	0	72	72
Room 8	72	72	72	72	72	72	72	72	0	72
Room 9	72	72	72	72	72	72	72	72	72	0
Vacuum frequency (once in)		366	day(s) =	8784	hr(s)					
Vacuum efficiency		0								

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

Table 3.2 Source Releases Assumed for Case I

Location (Room No.)	1	Air Fraction	0.1	Area of source		36	m2
	Region 1	Region 2	Region 3	Region 4	Region 5		
Contamination? 1-Yes, 2-No	1	2	2	2	2		
thickness (cm)	15	0	0	0	0		
density (g/cm3)	2.4	2.4	2.4	2.4	2.4		
erosion rate (cm/d)	2.40E-03	2.40E-08	2.40E-08	2.40E-08	2.40E-08		
Start time (d)	0.00E+00	6.25E+03	6.25E+03	6.25E+03	6.25E+03		
Start time (hr)	0	150000	150000	150000	150000		
End time (d)	6.25E+03	6.25E+03	6.25E+03	6.25E+03	6.25E+03		
End time (hr)	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05		
Release rate (g/hr)	86.4	0	0	0	0		

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

Table 3.3 Comparison of Calculated Air Release Rate from RESRAD-BUILD and Spreadsheets for Case I

From "AirRelRate1.out"							
Rate of release of source material to air							
fraction of source per second per volume (m3) of the room of release							
2.06E-12	from	time	0.00E+00	to	time	5.4E+08	seconds
8.64E+00	(g/hr) from	time	0.00E+00	to	time	150000	hrs
Initial source mass		1.30E+07	g				
Volume of source room		90	m3				
time (hr)	Estimated Air release rate (g/hr)						
0	0						
2	8.64						
4	8.64						
6	8.64						
8	8.64						
10	8.64						
12	8.64						
14	8.64						
16	8.64						
18	8.64						
20	8.64						

Table 3.4 Radiological Ingrowth and Decay Factors Obtained from RESRAD-OFFSITE

Year	Hour	Co-60	Cs-137	Ra-226	Pb-210	Po-210
0	0.00	1	1	1	0	0
0.000228	2.00	0.99997	0.999995	1	7.1E-06	1.48E-09
0.000457	4.00	0.99994	0.99999	1	1.42E-05	5.93E-09
0.000685	6.00	0.99991	0.999984	1	2.13E-05	1.33E-08
0.000913	8.00	0.99988	0.999979	1	2.84E-05	2.37E-08
0.001141	10.00	0.99985	0.999974	0.999999	3.55E-05	3.7E-08
0.00137	12.00	0.99982	0.999969	0.999999	4.26E-05	5.33E-08
0.001598	14.00	0.99979	0.999963	0.999999	4.97E-05	7.25E-08
0.001826	16.00	0.99976	0.999958	0.999999	5.68E-05	9.47E-08
0.002055	18.00	0.99973	0.999953	0.999999	6.39E-05	1.2E-07
0.002283	20.00	0.9997	0.999948	0.999999	7.1E-05	1.48E-07
0.002511	22.00	0.99967	0.999942	0.999999	7.8E-05	1.79E-07
0.002739	24.00	0.99964	0.999937	0.999999	8.51E-05	2.13E-07
0.002968	26.00	0.99961	0.999932	0.999999	9.22E-05	2.5E-07
0.003196	28.00	0.99958	0.999927	0.999998	9.93E-05	2.9E-07
0.003424	30.00	0.99955	0.999921	0.999998	0.000106	3.33E-07
0.003653	32.00	0.99952	0.999916	0.999998	0.000114	3.78E-07
0.003881	34.00	0.99949	0.999911	0.999998	0.000121	4.27E-07
0.004109	36.00	0.99946	0.999906	0.999998	0.000128	4.79E-07
0.004337	38.00	0.99943	0.9999	0.999998	0.000135	5.33E-07
0.004566	40.00	0.9994	0.999895	0.999998	0.000142	5.91E-07

Table 3.5 Calculation of Remaining Mass and Radioactivity in the Source and Direct Ingestion Rate of Radioactivity for Case I

Initial mass of contamination			1.30E+07	g	Direct ingestion rate		0.01	g/hr	(reflect input value in the input file)				
					Occupancy factor (summing all occupants in the source room)						0.5		
			Based on an initial conc. of 1 pCi/g for the parent nuclide					Direct ingestion rate of nuclide, base on full occupancy					
Time (hr)	Remaining mass of contamination (g)	Remaining fraction of contamination	Remaining activity of Co-60 (pCi)	Remaining activity of Cs-137 (pCi)	Remaining activity of Ra-226 (pCi)	Remaining activity of Pb-210 (pCi)	Remaining activity of Po-210 (pCi)	Co-60 (pCi/hr)	Cs-137 (pCi/hr)	Ra-226 (pCi/hr)	Pb-210 (pCi/hr)	Po-210 (pCi/hr)	
0	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
2	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	9.20E+01	1.92E-02	1.00E-02	1.00E-02	1.00E-02	7.10E-08	1.48E-11	
4	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	1.84E+02	7.68E-02	1.00E-02	1.00E-02	1.00E-02	1.42E-07	5.93E-11	
6	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	2.76E+02	1.73E-01	1.00E-02	1.00E-02	1.00E-02	2.13E-07	1.33E-10	
8	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	3.68E+02	3.07E-01	1.00E-02	1.00E-02	1.00E-02	2.84E-07	2.37E-10	
10	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	4.60E+02	4.80E-01	1.00E-02	1.00E-02	1.00E-02	3.55E-07	3.70E-10	
12	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	5.52E+02	6.91E-01	1.00E-02	1.00E-02	1.00E-02	4.26E-07	5.33E-10	
14	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	6.44E+02	9.40E-01	1.00E-02	1.00E-02	1.00E-02	4.97E-07	7.25E-10	
16	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	7.36E+02	1.23E+00	1.00E-02	1.00E-02	1.00E-02	5.68E-07	9.47E-10	
18	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	8.28E+02	1.55E+00	1.00E-02	1.00E-02	1.00E-02	6.39E-07	1.20E-09	
20	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	9.19E+02	1.92E+00	1.00E-02	1.00E-02	1.00E-02	7.10E-07	1.48E-09	
22	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	1.01E+03	2.32E+00	1.00E-02	1.00E-02	1.00E-02	7.80E-07	1.79E-09	
24	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	1.10E+03	2.76E+00	1.00E-02	1.00E-02	1.00E-02	8.51E-07	2.13E-09	
26	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	1.20E+03	3.24E+00	1.00E-02	1.00E-02	1.00E-02	9.22E-07	2.50E-09	
28	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	1.29E+03	3.76E+00	1.00E-02	1.00E-02	1.00E-02	9.93E-07	2.90E-09	
30	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	1.38E+03	4.31E+00	1.00E-02	1.00E-02	1.00E-02	1.06E-06	3.33E-09	
32	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	1.47E+03	4.90E+00	1.00E-02	1.00E-02	1.00E-02	1.14E-06	3.78E-09	
34	1.30E+07	1.00E+00	1.30E+07	1.30E+07	1.30E+07	1.56E+03	5.54E+00	9.99E-03	1.00E-02	1.00E-02	1.21E-06	4.27E-09	
36	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	1.65E+03	6.20E+00	9.99E-03	1.00E-02	1.00E-02	1.28E-06	4.79E-09	
38	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	1.75E+03	6.91E+00	9.99E-03	1.00E-02	1.00E-02	1.35E-06	5.33E-09	
40	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	1.84E+03	7.66E+00	9.99E-03	1.00E-02	1.00E-02	1.42E-06	5.91E-09	
42	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	1.93E+03	8.44E+00	9.99E-03	1.00E-02	1.00E-02	1.49E-06	6.52E-09	
44	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.02E+03	9.26E+00	9.99E-03	1.00E-02	1.00E-02	1.56E-06	7.15E-09	
46	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.11E+03	1.01E+01	9.99E-03	1.00E-02	1.00E-02	1.63E-06	7.81E-09	
48	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.21E+03	1.10E+01	9.99E-03	1.00E-02	1.00E-02	1.70E-06	8.51E-09	
50	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.30E+03	1.20E+01	9.99E-03	1.00E-02	1.00E-02	1.77E-06	9.23E-09	
52	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.39E+03	1.29E+01	9.99E-03	1.00E-02	1.00E-02	1.84E-06	9.98E-09	
54	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.48E+03	1.39E+01	9.99E-03	1.00E-02	1.00E-02	1.92E-06	1.08E-08	
56	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.57E+03	1.50E+01	9.99E-03	1.00E-02	1.00E-02	1.99E-06	1.16E-08	
58	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.67E+03	1.61E+01	9.99E-03	1.00E-02	1.00E-02	2.06E-06	1.24E-08	
60	1.30E+07	1.00E+00	1.29E+07	1.30E+07	1.30E+07	2.76E+03	1.72E+01	9.99E-03	1.00E-02	1.00E-02	2.13E-06	1.33E-08	

Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It reflected the input to the RESRAD-BUILD code.

Table 3.6 Comparison of Time-Averaged Radioactivity Remaining in the Source over the Exposure Duration for Case I

iSrc	iTime	Begin Time (yr)	Parent	Porgeny	Time Averaged Activity (pCi)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
1	1	0	RA-226	RA-226	1.29E+07	1.29E+07	0.00
1	1	0	RA-226	PB-210	4.97E+04	4.97E+04	0.06
1	1	0	RA-226	PO-210	6.77E+03	6.79E+03	0.18
1	2	0.25	RA-226	RA-226	1.27E+07	1.27E+07	0.00
1	2	0.25	RA-226	PB-210	1.47E+05	1.47E+05	0.01
1	2	0.25	RA-226	PO-210	4.15E+04	4.15E+04	0.05
1	3	0.5	RA-226	RA-226	1.25E+07	1.25E+07	0.00
1	3	0.5	RA-226	PB-210	2.40E+05	2.40E+05	0.00
1	3	0.5	RA-226	PO-210	9.78E+04	9.78E+04	0.03
1	4	0.75	RA-226	RA-226	1.23E+07	1.23E+07	0.00
1	4	0.75	RA-226	PB-210	3.30E+05	3.30E+05	0.00
1	4	0.75	RA-226	PO-210	1.66E+05	1.66E+05	0.02
1	5	1	RA-226	RA-226	1.21E+07	1.21E+07	0.01
1	5	1	RA-226	PB-210	4.16E+05	4.16E+05	0.00
1	5	1	RA-226	PO-210	2.41E+05	2.41E+05	0.01
1	6	1.25	RA-226	RA-226	1.19E+07	1.19E+07	0.01
1	6	1.25	RA-226	PB-210	4.98E+05	4.98E+05	0.01
1	6	1.25	RA-226	PO-210	3.18E+05	3.18E+05	0.01
1	7	1.5	RA-226	RA-226	1.17E+07	1.17E+07	0.01
1	7	1.5	RA-226	PB-210	5.77E+05	5.77E+05	0.01
1	7	1.5	RA-226	PO-210	3.95E+05	3.95E+05	0.01
1	1	0	CS-137	CS-137	1.28E+07	1.28E+07	0.00
1	2	0.25	CS-137	CS-137	1.26E+07	1.26E+07	0.00
1	3	0.5	CS-137	CS-137	1.23E+07	1.23E+07	0.00
1	4	0.75	CS-137	CS-137	1.21E+07	1.21E+07	0.00
1	5	1	CS-137	CS-137	1.18E+07	1.18E+07	0.01
1	6	1.25	CS-137	CS-137	1.15E+07	1.15E+07	0.01
1	7	1.5	CS-137	CS-137	1.13E+07	1.13E+07	0.01
1	1	0	CO-60	CO-60	1.27E+07	1.27E+07	0.00
1	2	0.25	CO-60	CO-60	1.21E+07	1.21E+07	0.00
1	3	0.5	CO-60	CO-60	1.15E+07	1.15E+07	0.00
1	4	0.75	CO-60	CO-60	1.10E+07	1.10E+07	0.01
1	5	1	CO-60	CO-60	1.04E+07	1.04E+07	0.01
1	6	1.25	CO-60	CO-60	9.95E+06	9.95E+06	0.01
1	7	1.5	CO-60	CO-60	9.47E+06	9.47E+06	0.01

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

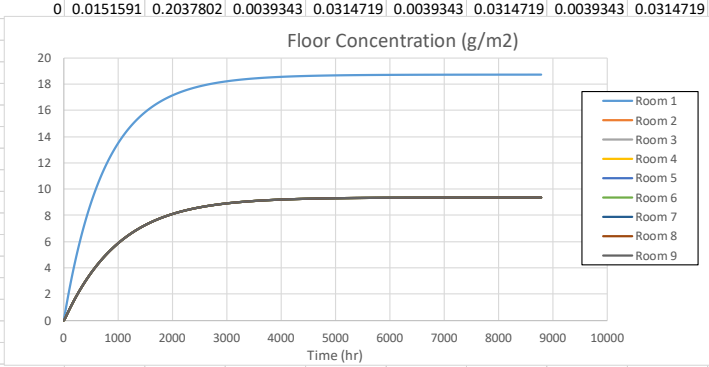
Table 3.7 Comparison of Time-Integrated Radioactivity Directly Ingested over the Exposure Duration for Case I

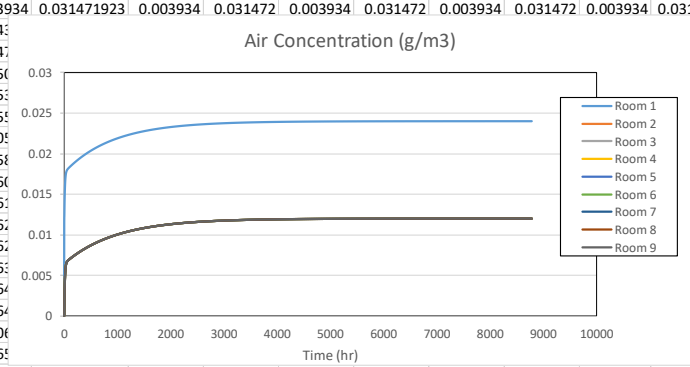
iSrc	iTime	Begin Time (yr)	Parent	Porgeny	Time-integrated Ingestion (pCi)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
1	1	0	RA-226	RA-226	2.19E+01	2.19E+01	0.09
1	1	0	RA-226	PB-210	8.48E-02	8.49E-02	0.06
1	1	0	RA-226	PO-210	1.16E-02	1.16E-02	0.18
1	2	0.25	RA-226	RA-226	2.19E+01	2.19E+01	0.00
1	2	0.25	RA-226	PB-210	2.54E-01	2.54E-01	0.01
1	2	0.25	RA-226	PO-210	7.18E-02	7.19E-02	0.05
1	3	0.5	RA-226	RA-226	2.19E+01	2.19E+01	0.01
1	3	0.5	RA-226	PB-210	4.21E-01	4.21E-01	0.00
1	3	0.5	RA-226	PO-210	1.72E-01	1.72E-01	0.03
1	4	0.75	RA-226	RA-226	2.19E+01	2.19E+01	0.01
1	4	0.75	RA-226	PB-210	5.87E-01	5.87E-01	0.01
1	4	0.75	RA-226	PO-210	2.96E-01	2.96E-01	0.01
1	5	1	RA-226	RA-226	2.19E+01	2.19E+01	0.01
1	5	1	RA-226	PB-210	7.52E-01	7.52E-01	0.01
1	5	1	RA-226	PO-210	4.36E-01	4.36E-01	0.01
1	6	1.25	RA-226	RA-226	2.19E+01	2.19E+01	0.01
1	6	1.25	RA-226	PB-210	9.16E-01	9.16E-01	0.01
1	6	1.25	RA-226	PO-210	5.84E-01	5.84E-01	0.00
1	7	1.5	RA-226	RA-226	2.19E+01	2.19E+01	0.01
1	7	1.5	RA-226	PB-210	1.08E+00	1.08E+00	0.01
1	7	1.5	RA-226	PO-210	7.38E-01	7.38E-01	0.00
1	1	0	CS-137	CS-137	2.18E+01	2.18E+01	0.09
1	2	0.25	CS-137	CS-137	2.17E+01	2.17E+01	0.00
1	3	0.5	CS-137	CS-137	2.16E+01	2.16E+01	0.00
1	4	0.75	CS-137	CS-137	2.15E+01	2.15E+01	0.00
1	5	1	CS-137	CS-137	2.13E+01	2.13E+01	0.00
1	6	1.25	CS-137	CS-137	2.12E+01	2.12E+01	0.00
1	7	1.5	CS-137	CS-137	2.11E+01	2.11E+01	0.00
1	1	0	CO-60	CO-60	2.15E+01	2.15E+01	0.09
1	2	0.25	CO-60	CO-60	2.08E+01	2.08E+01	0.00
1	3	0.5	CO-60	CO-60	2.02E+01	2.02E+01	0.00
1	4	0.75	CO-60	CO-60	1.95E+01	1.95E+01	0.00
1	5	1	CO-60	CO-60	1.89E+01	1.89E+01	0.00
1	6	1.25	CO-60	CO-60	1.83E+01	1.83E+01	0.00
1	7	1.5	CO-60	CO-60	1.77E+01	1.77E+01	0.01

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.8 Calculations of Source Particulate Concentrations in the Air and on the Floor of Each Room for Case I

	time interval	2 hr																		
			Room 1		Room 2		Room 3		Room 4		Room 5		Room 6		Room 7		Room 8		Room 9	
	Source_Rm (1-Yes, 0-No)		1		0		0		0		0		0		0		0		0	
time (hr)	Air release rate (g/hr)	Vacuum Removal (1-Yes, 0-No)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	8.64	0	0.01162	0.016256	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	8.64	0	0.0123247	0.0496955	0.0011252	0.0015741	0.0011252	0.0015741	0.0011252	0.0015741	0.001125	0.001574125	0.001125	0.001574	0.001125	0.001574	0.001125	0.001574	0.001125	0.001574
6	8.64	0	0.0132419	0.085284	0.0020244	0.0059746	0.0020244	0.0059746	0.0020244	0.0059746	0.002024	0.005974646	0.002024	0.005975	0.002024	0.005975	0.002024	0.005975	0.002024	0.005975
8	8.64	0	0.0139971	0.1230845	0.0027775	0.0126709	0.0027775	0.0126709	0.0027775	0.0126709	0.002777	0.012670877	0.002777	0.012671	0.002777	0.012671	0.002777	0.012671	0.002777	0.012671
10	8.64	0	0.0146295	0.1626905	0.0034073	0.0212777	0.0034073	0.0212777	0.0034073	0.0212777	0.003407	0.021277701	0.003407	0.021278	0.003407	0.021278	0.003407	0.021278	0.003407	0.021278
12	8.64	0	0.0151591	0.2037802	0.0039343	0.0314719	0.0039343	0.0314719	0.0039343	0.0314719	0.003934	0.031471923	0.003934	0.031472	0.003934	0.031472	0.003934	0.031472	0.003934	0.031472
14	8.64										0.004									2984
16	8.64										0.004									5559
18	8.64										0.005									9101
20	8.64										0.005									3363
22	8.64										0.005									3244
24	8.64										0.005									3637
26	8.64										0.005									2945
28	8.64										0.006									5609
30	8.64										0.006									5205
32	8.64										0.006									7872
34	8.64										0.006									5577
36	8.64										0.006									2584
38	8.64										0.006									2971
40	8.64										0.006									4693
42	8.64										0.006									4224
44	8.64										0.006									1572
46	8.64	0	0.0178611	0.9809285	0.0065932	0.2989613	0.0065932	0.2989613	0.0065932	0.2989613	0.006593	0.298961272	0.006593	0.298961	0.006593	0.298961	0.006593	0.298961	0.006593	0.298961
48	8.64	0	0.0178941	1.02743	0.0066238	0.316379	0.0066238	0.316379	0.0066238	0.316379	0.006624	0.316379003	0.006624	0.316379	0.006624	0.316379	0.006624	0.316379	0.006624	0.316379
50	8.64	0	0.0179238	1.0738524	0.006651	0.3338151	0.006651	0.3338151	0.006651	0.3338151	0.006651	0.333815071	0.006651	0.333815	0.006651	0.333815	0.006651	0.333815	0.006651	0.333815
52	8.64	0	0.0179507	1.1201874	0.0066755	0.351261	0.0066755	0.351261	0.0066755	0.351261	0.006676	0.351261003	0.006676	0.351261	0.006676	0.351261	0.006676	0.351261	0.006676	0.351261





Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It was chosen to generate results for comparison.

During the analysis of Case I, the RESRAD-BUILD code generated an intermediate output file "AirRelConcSource1.out" that listed the concentrations in the air and on the floor of each room at various time points. The concentrations were expressed as the fraction of the initial source per m^3 of air and the fraction of the initial source per m^2 on the floor. They were multiplied by the total mass of source (materials) to convert the concentration to mass of source (particulate) per unit volume in the air (g/m^3) and mass of source (particulate) per unit area on the floor (g/m^2) for comparison with spreadsheet calculations.

Figure 3.1 compares the air concentrations of source particles (g/m^3) in Room 1, where the volume source was assumed to be located. Figure 3.2 compares the floor deposition concentrations of source particles (g/m^2) in the same room. Figures 3.3 and 3.4 compare the air concentrations and floor deposition concentrations, respectively, in Room 2. In the figures, the blue solid curve displays the results from the spreadsheets while the red dashed curve displays the results from RESRAD-BUILD. The comparisons of concentrations in the air and on the floor for Rooms 3-9 were like those for Room 2. As shown in the figures, the concentration results from RESRAD-BUILD and from the spreadsheets are in good agreement.

Table 3.9 compares calculated average concentrations of radionuclides in the air and on the floor over the exposure duration in Room 1. Table 3.10 compares the same calculated results in Room 3. The comparisons show good agreement between the calculated results from RESRAD-BUILD and the spreadsheets. All but six results differ by less than 1%. The six exceptions are the calculated concentrations of Ra-226, Cs-137, and Co-60 at time 0 in Room 3; for them, the difference is more than 1% but less than 1.5%. The same calculated results in the other rooms from RESRAD-BUILD and the spreadsheets also show good agreement.

3.1.3 Calculation and Comparison of Radiation Doses and Cancer Risks

Table 3.11 lists the dose coefficients and slope factors used to calculate radiation doses and cancer risks incurred by the four receptors considered in the seven verification cases.

Table 3.12 compares the radiation doses at t = 0 and 0.75 year and the cancer risks at t = 1 year that RESRAD-BUILD and the spreadsheets estimated to Receptor 1. Receptor 1 was assumed to spend 100% of the time in Room 1, same as the source, while he was in the building. He was also assumed to inhale 18 m^3 of air per day, would not ingest dust particles deposited on floor, but would ingest 0.01 g of source particles per hour. The comparison shows the RESRAD-BUILD results agree well with the spreadsheet results, with a difference of less than 1 %.

Table 3.13 compares the radiation doses at t = 0 and 1.5 years and the cancer risks at t = 1 year that RESRAD-BUILD and the spreadsheets estimated to Receptor 3 in Room 6. Receptor 3 would spend 30% of the time in Room 6 while he was in the building. He was assumed to inhale 25 m^3 of air per day, would ingest dust particles deposited on floor, 0.0002 m^2 per hour, and would ingest 0.01 g of source particles per hour. The comparison shows the RESRAD-BUILD results agree well with the spreadsheet results, with a difference of less than 1.5%.

The radiation doses and cancer risks calculated by RESRAD-BUILD and the spreadsheets at other times or to other receptors all agree well with each other.

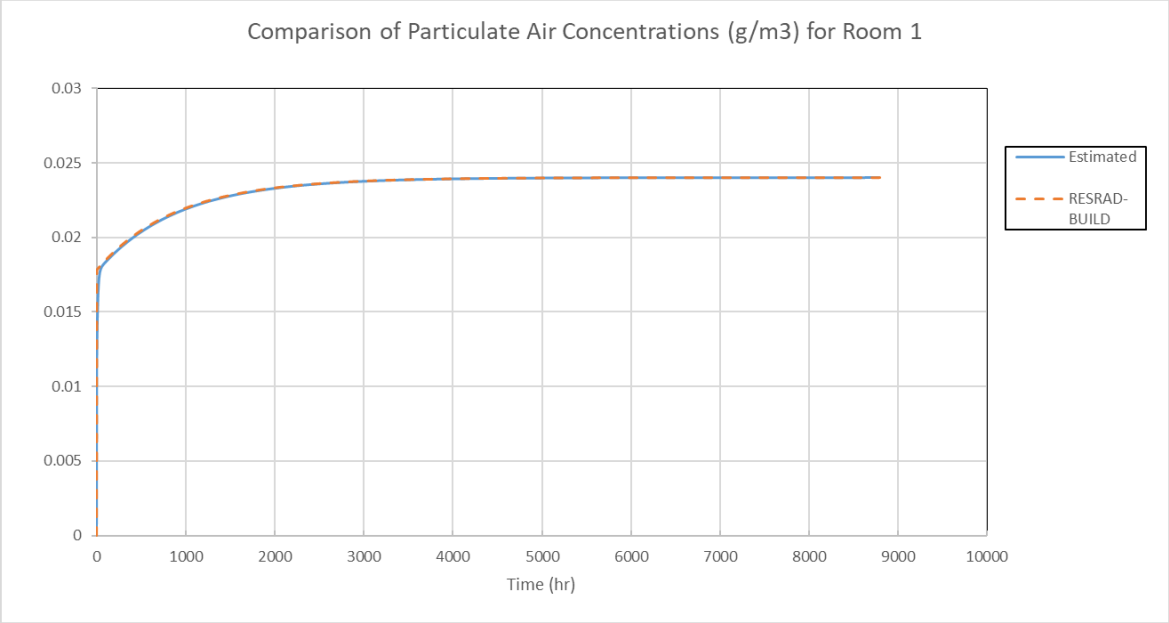


Figure 3.1 Comparison of Calculated Source Particulate Concentrations in the Air of Room 1 for Case I

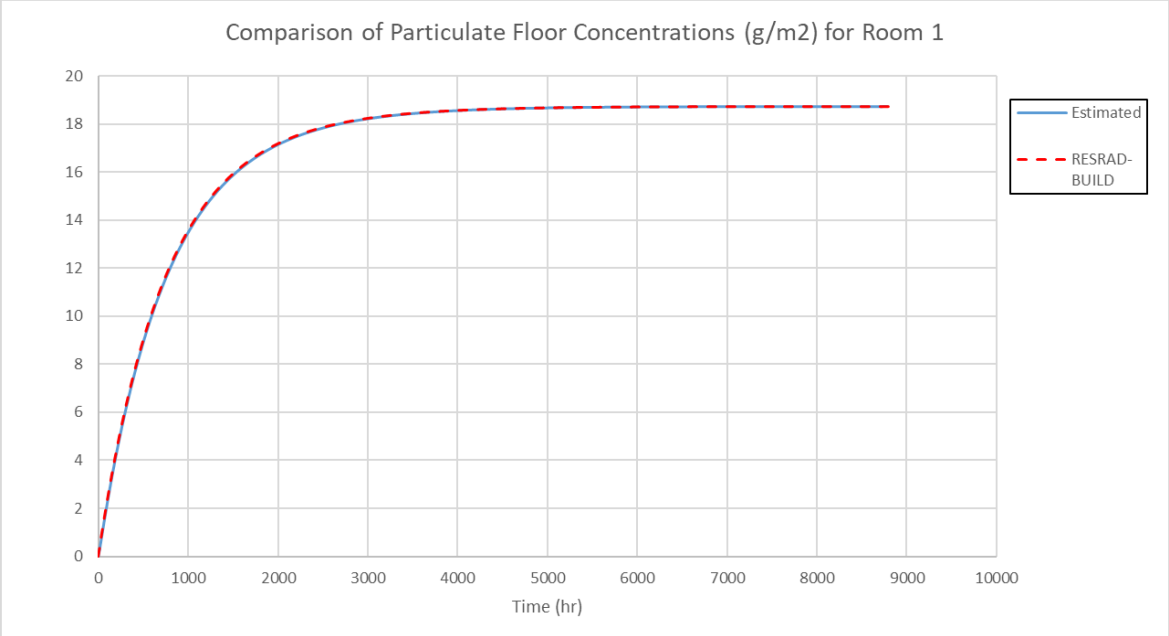


Figure 3.2 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 1 for Case I

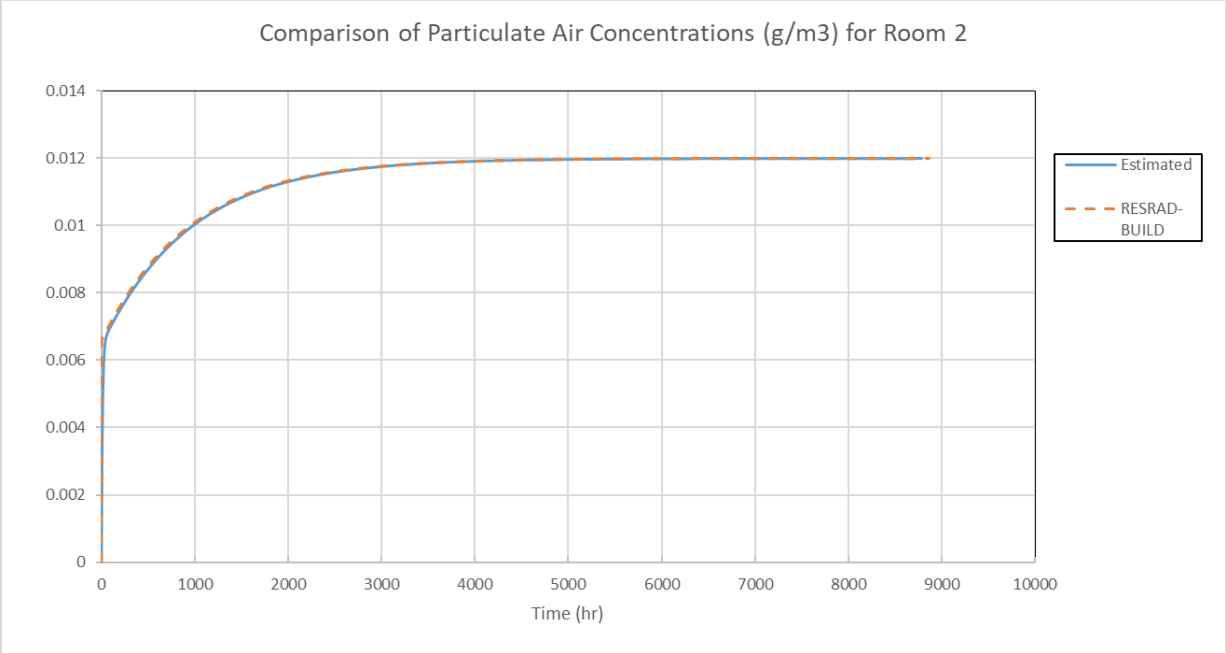


Figure 3.3 Comparison of Calculated Source Particulate Concentrations in the Air of Room 2 for Case I

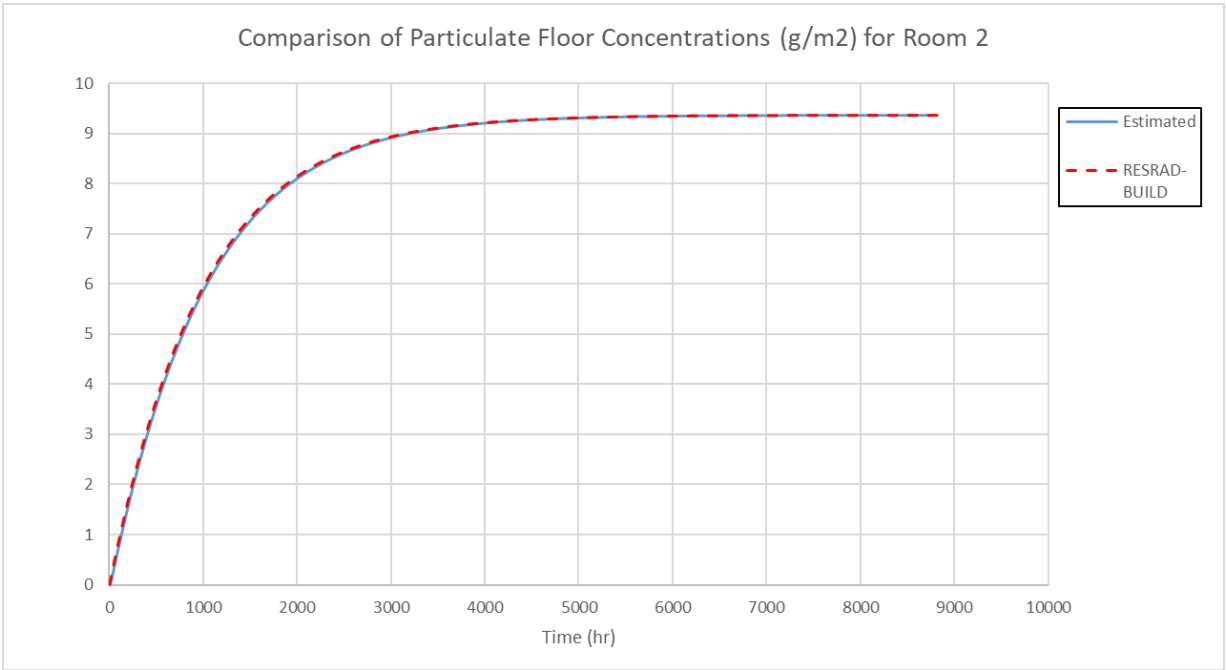


Figure 3.4 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 2 for Case I

Table 3.9 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 1 for Case I

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m^3) or (pCi/m^2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
1	0	RA-226	RA-226	Air	2.17E-02	2.15E-02	0.50
1	0	RA-226	RA-226	Floor	1.25E+01	1.24E+01	0.69
1	0	RA-226	PB-210	Air	8.72E-05	8.71E-05	0.17
1	0	RA-226	PB-210	Floor	5.82E-02	5.80E-02	0.37
1	0	RA-226	PO-210	Air	1.21E-05	1.21E-05	0.01
1	0	RA-226	PO-210	Floor	8.41E-03	8.39E-03	0.18
1	0.25	RA-226	RA-226	Air	2.38E-02	2.38E-02	0.06
1	0.25	RA-226	RA-226	Floor	1.83E+01	1.82E+01	0.11
1	0.25	RA-226	PB-210	Air	2.76E-04	2.76E-04	0.04
1	0.25	RA-226	PB-210	Floor	2.12E-01	2.12E-01	0.08
1	0.25	RA-226	PO-210	Air	7.81E-05	7.82E-05	0.01
1	0.25	RA-226	PO-210	Floor	6.02E-02	6.02E-02	0.03
1	0.5	RA-226	RA-226	Air	2.40E-02	2.40E-02	0.01
1	0.5	RA-226	RA-226	Floor	1.87E+01	1.87E+01	0.02
1	0.5	RA-226	PB-210	Air	4.61E-04	4.61E-04	0.01
1	0.5	RA-226	PB-210	Floor	3.59E-01	3.59E-01	0.02
1	0.5	RA-226	PO-210	Air	1.88E-04	1.88E-04	0.02
1	0.5	RA-226	PO-210	Floor	1.46E-01	1.46E-01	0.01
1	0.75	RA-226	RA-226	Air	2.40E-02	2.40E-02	0.01
1	0.75	RA-226	RA-226	Floor	1.87E+01	1.87E+01	0.01
1	0.75	RA-226	PB-210	Air	6.44E-04	6.44E-04	0.01
1	0.75	RA-226	PB-210	Floor	5.02E-01	5.02E-01	0.01
1	0.75	RA-226	PO-210	Air	3.24E-04	3.24E-04	0.01
1	0.75	RA-226	PO-210	Floor	2.53E-01	2.53E-01	0.01
1	1	RA-226	RA-226	Air	2.40E-02	2.40E-02	0.01
1	1	RA-226	RA-226	Floor	1.87E+01	1.87E+01	0.01
1	1	RA-226	PB-210	Air	8.24E-04	8.24E-04	0.01
1	1	RA-226	PB-210	Floor	6.43E-01	6.43E-01	0.01
1	1	RA-226	PO-210	Air	4.77E-04	4.77E-04	0.01
1	1	RA-226	PO-210	Floor	3.72E-01	3.72E-01	0.01
1	1.25	RA-226	RA-226	Air	2.40E-02	2.40E-02	0.01
1	1.25	RA-226	RA-226	Floor	1.87E+01	1.87E+01	0.01
1	1.25	RA-226	PB-210	Air	1.00E-03	1.00E-03	0.01
1	1.25	RA-226	PB-210	Floor	7.83E-01	7.83E-01	0.01
1	1.25	RA-226	PO-210	Air	6.40E-04	6.40E-04	0.00
1	1.25	RA-226	PO-210	Floor	4.99E-01	4.99E-01	0.00
1	1.5	RA-226	RA-226	Air	2.40E-02	2.40E-02	0.01
1	1.5	RA-226	RA-226	Floor	1.87E+01	1.87E+01	0.01
1	1.5	RA-226	PB-210	Air	1.18E-03	1.18E-03	0.01
1	1.5	RA-226	PB-210	Floor	9.22E-01	9.22E-01	0.01
1	1.5	RA-226	PO-210	Air	8.09E-04	8.09E-04	0.00
1	1.5	RA-226	PO-210	Floor	6.31E-01	6.31E-01	0.00

Table 3.9 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m^3) or (pCi/m^2)]		Difference (%) $\left\lvert\frac{RESRAD - Spreadsheet}{RESRAD}\right\rvert$
					RESRAD-BUILD	Spreadsheet	
1	0	CS-137	CS-137	Air	2.16E-02	2.15E-02	0.50
1	0	CS-137	CS-137	Floor	1.24E+01	1.23E+01	0.69
1	0.25	CS-137	CS-137	Air	2.36E-02	2.36E-02	0.05
1	0.25	CS-137	CS-137	Floor	1.81E+01	1.81E+01	0.10
1	0.5	CS-137	CS-137	Air	2.36E-02	2.36E-02	0.01
1	0.5	CS-137	CS-137	Floor	1.84E+01	1.84E+01	0.01
1	0.75	CS-137	CS-137	Air	2.35E-02	2.35E-02	0.00
1	0.75	CS-137	CS-137	Floor	1.83E+01	1.83E+01	0.00
1	1	CS-137	CS-137	Air	2.34E-02	2.34E-02	0.00
1	1	CS-137	CS-137	Floor	1.82E+01	1.82E+01	0.00
1	1.25	CS-137	CS-137	Air	2.32E-02	2.32E-02	0.00
1	1.25	CS-137	CS-137	Floor	1.81E+01	1.81E+01	0.00
1	1.5	CS-137	CS-137	Air	2.31E-02	2.31E-02	0.00
1	1.5	CS-137	CS-137	Floor	1.80E+01	1.80E+01	0.00
1	0	CO-60	CO-60	Air	2.13E-02	2.12E-02	0.50
1	0	CO-60	CO-60	Floor	1.22E+01	1.21E+01	0.69
1	0.25	CO-60	CO-60	Air	2.26E-02	2.26E-02	0.05
1	0.25	CO-60	CO-60	Floor	1.74E+01	1.74E+01	0.10
1	0.5	CO-60	CO-60	Air	2.21E-02	2.21E-02	0.01
1	0.5	CO-60	CO-60	Floor	1.72E+01	1.72E+01	0.01
1	0.75	CO-60	CO-60	Air	2.14E-02	2.14E-02	0.00
1	0.75	CO-60	CO-60	Floor	1.67E+01	1.67E+01	0.00
1	1	CO-60	CO-60	Air	2.07E-02	2.07E-02	0.00
1	1	CO-60	CO-60	Floor	1.61E+01	1.61E+01	0.00
1	1.25	CO-60	CO-60	Air	2.00E-02	2.00E-02	0.00
1	1.25	CO-60	CO-60	Floor	1.56E+01	1.56E+01	0.00
1	1.5	CO-60	CO-60	Air	1.94E-02	1.94E-02	0.01
1	1.5	CO-60	CO-60	Floor	1.51E+01	1.51E+01	0.01

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.10 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 3 for Case I

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m^3) or (pCi/m^2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
3	0	RA-226	RA-226	Air	9.87E-03	9.77E-03	1.05
3	0	RA-226	RA-226	Floor	5.58E+00	5.51E+00	1.35
3	0	RA-226	PB-210	Air	4.12E-05	4.10E-05	0.41
3	0	RA-226	PB-210	Floor	2.66E-02	2.64E-02	0.81
3	0	RA-226	PO-210	Air	5.76E-06	5.75E-06	0.21
3	0	RA-226	PO-210	Floor	3.89E-03	3.87E-03	0.54
3	0.25	RA-226	RA-226	Air	1.18E-02	1.18E-02	0.11
3	0.25	RA-226	RA-226	Floor	8.97E+00	8.95E+00	0.20
3	0.25	RA-226	PB-210	Air	1.37E-04	1.37E-04	0.08
3	0.25	RA-226	PB-210	Floor	1.04E-01	1.04E-01	0.17
3	0.25	RA-226	PO-210	Air	3.88E-05	3.88E-05	0.03
3	0.25	RA-226	PO-210	Floor	2.97E-02	2.96E-02	0.11
3	0.5	RA-226	RA-226	Air	1.20E-02	1.20E-02	0.02
3	0.5	RA-226	RA-226	Floor	9.32E+00	9.31E+00	0.04
3	0.5	RA-226	PB-210	Air	2.30E-04	2.30E-04	0.02
3	0.5	RA-226	PB-210	Floor	1.79E-01	1.79E-01	0.03
3	0.5	RA-226	PO-210	Air	9.39E-05	9.39E-05	0.01
3	0.5	RA-226	PO-210	Floor	7.31E-02	7.31E-02	0.00
3	0.75	RA-226	RA-226	Air	1.20E-02	1.20E-02	0.01
3	0.75	RA-226	RA-226	Floor	9.35E+00	9.35E+00	0.01
3	0.75	RA-226	PB-210	Air	3.22E-04	3.22E-04	0.01
3	0.75	RA-226	PB-210	Floor	2.51E-01	2.51E-01	0.01
3	0.75	RA-226	PO-210	Air	1.62E-04	1.62E-04	0.01
3	0.75	RA-226	PO-210	Floor	1.26E-01	1.27E-01	0.01
3	1	RA-226	RA-226	Air	1.20E-02	1.20E-02	0.01
3	1	RA-226	RA-226	Floor	9.36E+00	9.35E+00	0.01
3	1	RA-226	PB-210	Air	4.12E-04	4.12E-04	0.01
3	1	RA-226	PB-210	Floor	3.22E-01	3.21E-01	0.01
3	1	RA-226	PO-210	Air	2.39E-04	2.39E-04	0.01
3	1	RA-226	PO-210	Floor	1.86E-01	1.86E-01	0.01
3	1.25	RA-226	RA-226	Air	1.20E-02	1.20E-02	0.01
3	1.25	RA-226	RA-226	Floor	9.35E+00	9.35E+00	0.01
3	1.25	RA-226	PB-210	Air	5.02E-04	5.02E-04	0.01
3	1.25	RA-226	PB-210	Floor	3.91E-01	3.91E-01	0.01
3	1.25	RA-226	PO-210	Air	3.20E-04	3.20E-04	0.00
3	1.25	RA-226	PO-210	Floor	2.50E-01	2.50E-01	0.00
3	1.5	RA-226	RA-226	Air	1.20E-02	1.20E-02	0.01
3	1.5	RA-226	RA-226	Floor	9.35E+00	9.35E+00	0.01
3	1.5	RA-226	PB-210	Air	5.91E-04	5.91E-04	0.01
3	1.5	RA-226	PB-210	Floor	4.61E-01	4.61E-01	0.01
3	1.5	RA-226	PO-210	Air	4.04E-04	4.04E-04	0.00
3	1.5	RA-226	PO-210	Floor	3.15E-01	3.15E-01	0.00

Table 3.10 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m^3) or (pCi/m^2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
3	0	CS-137	CS-137	Air	9.84E-03	9.74E-03	1.05
3	0	CS-137	CS-137	Floor	5.56E+00	5.49E+00	1.35
3	0.25	CS-137	CS-137	Air	1.17E-02	1.17E-02	0.10
3	0.25	CS-137	CS-137	Floor	8.89E+00	8.87E+00	0.20
3	0.5	CS-137	CS-137	Air	1.18E-02	1.18E-02	0.01
3	0.5	CS-137	CS-137	Floor	9.19E+00	9.18E+00	0.03
3	0.75	CS-137	CS-137	Air	1.18E-02	1.18E-02	0.00
3	0.75	CS-137	CS-137	Floor	9.17E+00	9.17E+00	0.00
3	1	CS-137	CS-137	Air	1.17E-02	1.17E-02	0.00
3	1	CS-137	CS-137	Floor	9.12E+00	9.12E+00	0.00
3	1.25	CS-137	CS-137	Air	1.16E-02	1.16E-02	0.00
3	1.25	CS-137	CS-137	Floor	9.07E+00	9.07E+00	0.00
3	1.5	CS-137	CS-137	Air	1.16E-02	1.16E-02	0.00
3	1.5	CS-137	CS-137	Floor	9.02E+00	9.02E+00	0.00
3	0	CO-60	CO-60	Air	9.70E-03	9.60E-03	1.06
3	0	CO-60	CO-60	Floor	5.47E+00	5.40E+00	1.36
3	0.25	CO-60	CO-60	Air	1.12E-02	1.12E-02	0.10
3	0.25	CO-60	CO-60	Floor	8.53E+00	8.52E+00	0.20
3	0.5	CO-60	CO-60	Air	1.10E-02	1.10E-02	0.01
3	0.5	CO-60	CO-60	Floor	8.59E+00	8.58E+00	0.03
3	0.75	CO-60	CO-60	Air	1.07E-02	1.07E-02	0.00
3	0.75	CO-60	CO-60	Floor	8.34E+00	8.34E+00	0.00
3	1	CO-60	CO-60	Air	1.03E-02	1.04E-02	0.00
3	1	CO-60	CO-60	Floor	8.07E+00	8.07E+00	0.00
3	1.25	CO-60	CO-60	Air	1.00E-02	1.00E-02	0.00
3	1.25	CO-60	CO-60	Floor	7.81E+00	7.81E+00	0.00
3	1.5	CO-60	CO-60	Air	9.69E-03	9.69E-03	0.01
3	1.5	CO-60	CO-60	Floor	7.56E+00	7.56E+00	0.01

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.11 Dose Conversion Factors and Slope Factors Used for Radiation Dose and Cancer Risk Estimates

	Dose conversion factors - ICRP-72 Adults			Slope factors - FGR13 Morbidity		
Radionuclide	Ingestion (mrem/pCi)	Inhalation (mrem/pCi)	Air submersion (mrem/yr)/ (pCi/m^3)	Ingestion (1/pCi)	Inhalation (1/pCi)	Air submersion (1/yr)/ (pCi/m^3)
Ra-226	1.04E-03	3.53E-02	9.77E-03	5.15E-10	2.83E-08	7.87E-09
Pb-210	2.56E-03	2.11E-02	3.53E-05	1.19E-09	1.63E-08	9.04E-12
Po-210	4.44E-03	1.59E-02	4.54E-08	2.25E-09	1.45E-08	3.66E-14
Cs-137	4.81E-05	1.44E-04	2.98E-03	3.74E-11	1.12E-10	2.39E-09
Co-60	1.26E-05	1.15E-04	1.39E-02	2.23E-11	1.01E-10	1.12E-08

Table 3.12 Comparison of Radiation Doses and Cancer Risks to Receptor 1 of Case I

Receptor 1	location room	1				(Reflect value in the input file)
	time fraction in room		1			(Reflect value in the input file)
	breathing rate	18	m3/d			(Reflect value in the input file)
	ingestion rate	0	m2/hr			(Reflect value in the input file)
	direct ingestion rate		1.00E-02	g/hr		
	In the same room as source?			1	(1-Yes, 0-No)	(reflect selection in the input file)

Radiation Dose (mrem/yr) at time = 0.00 yr

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	Ingestion (deposition)	Ingestion (deposition)	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RRB-Inhalation	Inhalation	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RRB-Air submersion	Air submersion	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	1.14E-02	1.13E-02	0.49	0.00E+00	0.00E+00	-	6.27E-01	6.24E-01	0.48	2.65E-05	2.63E-05	0.70
Pb-210	1.08E-04	1.09E-04	0.49	0.00E+00	0.00E+00	-	1.51E-03	1.51E-03	0.25	3.86E-10	3.85E-10	0.34
Po-210	2.57E-05	2.57E-05	0.15	0.00E+00	0.00E+00	-	1.58E-04	1.58E-04	0.21	6.86E-14	6.85E-14	0.18
Cs-137	5.25E-04	5.25E-04	0.06	0.00E+00	0.00E+00	-	2.56E-03	2.55E-03	0.54	8.05E-06	8.01E-06	0.54
Co-60	1.36E-04	1.35E-04	0.45	0.00E+00	0.00E+00	-	2.01E-03	2.00E-03	0.72	3.70E-05	3.68E-05	0.59
Total	1.22E-02	1.21E-02	0.46	0.00E+00	0.00E+00	-	6.33E-01	6.30E-01	0.48	7.16E-05	7.11E-05	0.62

Radiation Dose (mrem/yr) at time = 0.75 yr

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	1.14E-02	1.13E-02	0.44	0.00E+00	0.00E+00	-	6.95E-01	6.95E-01	0.06	2.93E-05	2.93E-05	0.03
Pb-210	7.51E-04	7.51E-04	0.03	0.00E+00	0.00E+00	-	1.11E-02	1.11E-02	0.28	2.85E-09	2.84E-09	0.24
Po-210	6.57E-04	6.57E-04	0.06	0.00E+00	0.00E+00	-	4.24E-03	4.24E-03	0.01	1.84E-12	1.84E-12	0.08
Cs-137	5.16E-04	5.16E-04	0.03	0.00E+00	0.00E+00	-	2.79E-03	2.79E-03	0.11	8.77E-06	8.76E-06	0.08
Co-60	1.23E-04	1.23E-04	0.17	0.00E+00	0.00E+00	-	2.01E-03	2.01E-03	0.25	3.72E-05	3.71E-05	0.16
Total	1.34E-02	1.34E-02	0.37	0.00E+00	0.00E+00	-	7.15E-01	7.15E-01	0.05	7.53E-05	7.52E-05	0.10

Cancer Risk at time = 1 yr

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	5.63E-09	5.63E-09	0.05	0.00E+00	0.00E+00	-	5.57E-07	5.57E-07	0.02	2.36E-11	2.36E-11	0.08
Pb-210	4.49E-10	4.49E-10	0.07	0.00E+00	0.00E+00	-	1.10E-08	1.10E-08	0.01	9.32E-16	9.31E-16	0.09
Po-210	4.90E-10	4.90E-10	0.01	0.00E+00	0.00E+00	-	5.68E-09	5.68E-09	0.08	2.18E-18	2.18E-18	0.04
Cs-137	3.99E-10	3.99E-10	0.01	0.00E+00	0.00E+00	-	2.15E-09	2.15E-09	0.04	6.99E-12	6.98E-12	0.18
Co-60	2.11E-10	2.11E-10	0.18	0.00E+00	0.00E+00	-	1.72E-09	1.72E-09	0.17	2.91E-11	2.91E-11	0.05
Total	7.18E-09	7.18E-09	0.03	0.00E+00	0.00E+00	-	5.78E-07	5.77E-07	0.02	5.97E-11	5.96E-11	0.08

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

Table 3.13 Comparison of Radiation Doses and Cancer Risks to Receptor 3 of Case I

Receptor 3	location room	6				(Reflect value in the input file)
	time fraction in room		0.3			(Reflect value in the input file)
	breathing rate	25	m3/d			(Reflect value in the input file)
	ingestion rate	0.0002	m2/hr			(Reflect value in the input file)
	direct ingestion rate		1.00E-02	g/hr		
	In the same room as source?			0	(1-Yes, 0-No)	(reflect selection in the input file)

Radiation Dose (mrem/yr) at time = 0.00E+00 yr

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	0.00E+00	0.00E+00	-	3.80E-04	3.75E-04	1.26	1.19E-01	1.18E-01	0.94	3.62E-06	3.58E-06	1.13
Pb-210	0.00E+00	0.00E+00	-	4.48E-06	4.44E-06	0.85	2.97E-04	2.95E-04	0.54	5.46E-11	5.43E-11	0.51
Po-210	0.00E+00	0.00E+00	-	1.14E-06	1.13E-06	0.94	3.14E-05	3.13E-05	0.30	9.82E-15	9.79E-15	0.30
Cs-137	0.00E+00	0.00E+00	-	1.76E-05	1.73E-05	1.46	4.86E-04	4.81E-04	1.04	1.10E-06	1.09E-06	1.02
Co-60	0.00E+00	0.00E+00	-	4.52E-06	4.46E-06	1.31	3.81E-04	3.77E-04	1.12	5.06E-06	5.00E-06	1.19
Total	0.00E+00	0.00E+00	-	4.08E-04	4.03E-04	1.26	1.20E-01	1.19E-01	0.94	9.78E-06	9.67E-06	1.15

Radiation Dose (mrem/yr) at time = 1.50 yr

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	0.00E+00	0.00E+00	-	6.37E-04	6.37E-04	0.03	1.45E-01	1.45E-01	0.23	4.40E-06	4.39E-06	0.17
Pb-210	0.00E+00	0.00E+00	-	7.74E-05	7.74E-05	0.04	4.26E-03	4.26E-03	0.07	7.84E-10	7.83E-10	0.15
Po-210	0.00E+00	0.00E+00	-	9.20E-05	9.20E-05	0.00	2.20E-03	2.20E-03	0.06	6.89E-13	6.88E-13	0.09
Cs-137	0.00E+00	0.00E+00	-	2.85E-05	2.85E-05	0.04	5.71E-04	5.71E-04	0.05	1.29E-06	1.29E-06	0.16
Co-60	0.00E+00	0.00E+00	-	6.25E-06	6.25E-06	0.03	3.80E-04	3.80E-04	0.10	5.05E-06	5.05E-06	0.03
Total	0.00E+00	0.00E+00	-	8.41E-04	8.41E-04	0.02	1.52E-01	1.52E-01	0.22	1.07E-05	1.07E-05	0.07

Cancer Risk at time = 1 yr

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	0.00E+00	0.00E+00	-	3.16E-10	3.16E-10	0.10	1.16E-07	1.16E-07	0.01	3.54E-12	3.54E-12	0.08
Pb-210	0.00E+00	0.00E+00	-	2.52E-11	2.52E-11	0.01	2.29E-09	2.29E-09	0.08	1.40E-16	1.40E-16	0.23
Po-210	0.00E+00	0.00E+00	-	2.75E-11	2.75E-11	0.07	1.18E-09	1.18E-09	0.36	3.27E-19	3.27E-19	0.04
Cs-137	0.00E+00	0.00E+00	-	2.24E-11	2.24E-11	0.04	4.48E-10	4.48E-10	0.02	1.05E-12	1.05E-12	0.33
Co-60	0.00E+00	0.00E+00	-	1.18E-11	1.18E-11	0.24	3.58E-10	3.58E-10	0.08	4.37E-12	4.36E-12	0.17
Total	0.00E+00	0.00E+00	-	4.03E-10	4.03E-10	0.09	1.20E-07	1.20E-07	0.02	8.96E-12	8.95E-12	0.15

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

3.2 CASE II – A VOLUME SOURCE IN ROOM 1 WITH SCHEDULED VACUUMING

Case II considered the same source as in Case I in Room 1. However, the air fraction of released source materials was changed from 0.1 to 1. Furthermore, vacuuming to clean the floor of every room was assumed to be conducted every 30 days, with an efficiency of 90%. The estimated concentrations of source particles and radionuclides in the air and on the floor of each room from RESRAD-BUILD and the verification spreadsheets were compared.

Table 3.14 shows the room dimensions, ventilation rates between rooms and with the outside environment, deposition velocity, and resuspension rate assumed for the case. Table 3.15 lists the properties assumed for the radiation source as well as its releases over time.

Table 3.16 shows the air release rate calculated by RESRAD-BUILD, obtained from the intermediate output file "AirRelRate1.out," and part of the estimated air release rates in the spreadsheet. The air release rate calculated by RESRAD-BUILD in terms of the fraction of the initial source per second was converted to mass of source materials per hour. The converted air release rate matches those estimated in the spreadsheet.

Equations B.10 and B.11 in the User's Manual of RESRAD-BUILD, Vol.1 (Yu et al. 2022) were solved numerically in the spreadsheets to obtain source particulate concentrations in each room. Table 3.17 presents part of the calculations and results at different time steps in the spreadsheets.

During the analysis of Case II, the RESRAD-BUILD code generated an intermediate output file "AirRelConcSource1.out" that listed the concentrations in the air and on the floor of each room at various time points. The concentrations were expressed as the fraction of the initial source per m^3 of air and the fraction of the initial source per m^2 on the floor. They were multiplied by the total mass of source (materials) to convert the concentration to mass of source (particulate) per unit volume in the air (g/m^3) and mass of source (particulate) per unit area on the floor (g/m^2) for comparison with spreadsheet calculations.

Figure 3.5 compares the air concentrations of source particles (g/m^3) in Room 1, where the volume source was assumed to be located. Figure 3.6 compares the floor deposition concentrations of source particles (g/m^2) in the same room. Figures 3.7 and 3.8 compare the air concentrations and floor deposition concentrations, respectively, in Room 4. In the figures, the blue solid curve displays the results from the spreadsheets while the red dashed curve displays the results from RESRAD-BUILD. The comparison of concentrations in the air and on the floor for the other rooms were like those for Room 4. As shown in the figures, the concentration results from RESRAD-BUILD and from the spreadsheets are in good agreement.

Table 3.14 Air Flows, Vacuuming, and Resuspension and Deposition of Particulates Assumed for Case II

Deposition Velocity		0.00039	(m/s) =	1.404	(m/hr)					
	Outdoors	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9
Area (m2)		36	36	36	36	36	36	36	36	36
Volume (m3)		90	90	90	90	90	90	90	90	90
Resuspension rate (1/s)		5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07
Resuspension rate (1/h)		1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03
Air flow (m3/hr) from										
Outdoors	0	72	72	72	72	72	72	72	72	72
Room 1	72	0	72	72	72	72	72	72	72	72
Room 2	72	72	0	72	72	72	72	72	72	72
Room 3	72	72	72	0	72	72	72	72	72	72
Room 4	72	72	72	72	0	72	72	72	72	72
Room 5	72	72	72	72	72	0	72	72	72	72
Room 6	72	72	72	72	72	72	0	72	72	72
Room 7	72	72	72	72	72	72	72	0	72	72
Room 8	72	72	72	72	72	72	72	72	0	72
Room 9	72	72	72	72	72	72	72	72	72	0
Vacuum frequency (once in)		30	day(s) =	720	hr(s)					
Vacuum efficiency		0.9								

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

Table 3.15 Source Releases Assumed for Case II

Source Releases							
Location (Room No.)	1	Air Fraction	1	Area of source		36	m2
	Region 1	Region 2	Region 3	Region 4	Region 5		
Contamination? 1-Yes, 2-No	1	2	2	2	2		
thickness (cm)	15	0	0	0	0		
density (g/cm3)	2.4	2.4	2.4	2.4	2.4		
erosion rate (cm/d)	2.40E-03	2.40E-08	2.40E-08	2.40E-08	2.40E-08		
Start time (d)	0.00E+00	6.25E+03	6.25E+03	6.25E+03	6.25E+03		
Start time (hr)	0	150000	150000	150000	150000		
End time (d)	6.25E+03	6.25E+03	6.25E+03	6.25E+03	6.25E+03		
End time (hr)	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05		
Release rate (g/hr)	86.4	0	0	0	0		

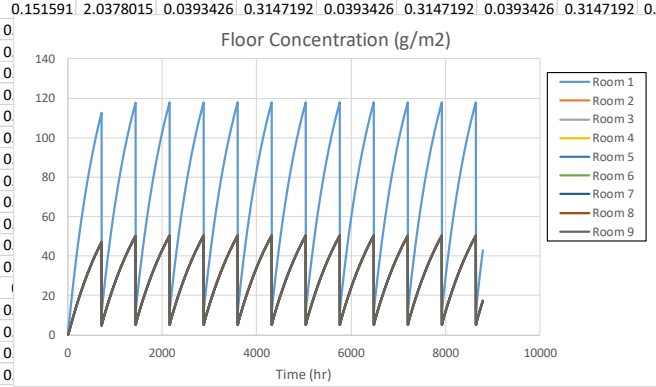
Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

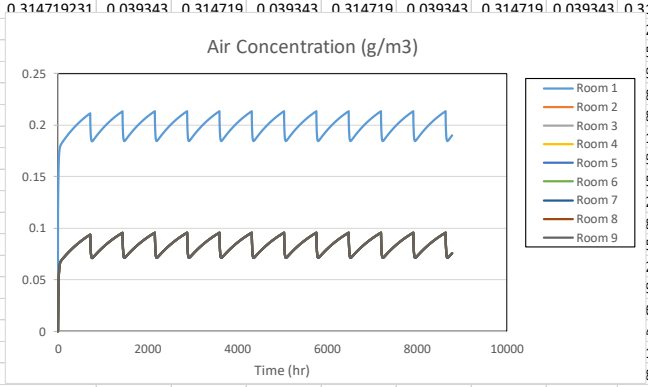
Table 3.16 Comparison of Calculated Air Release Rates from RESRAD-BUILD and Spreadsheets for Case II

From "AirRelRate1.out"							
Rate of release of source material to air							
fraction of source per second per volume (m3) of the room of release							
2.06E-11	from	time	0.00E+00	to	time	5.4E+08	seconds
8.64E+01	from	time	0.00E+00	to	time	150000	hrs
Initial source mass		1.30E+07	g				
Volume of source room		90	m3				
time (hr)	Estimated Air release rate (g/hr)						
0	0						
2	86.4						
4	86.4						
6	86.4						
8	86.4						
10	86.4						
12	86.4						
14	86.4						

Table 3.17 Calculations of Source Particulate Concentrations in the Air and on the Floor of Each Room for Case II

	time interval	2 hr																		
			Room 1		Room 2		Room 3		Room 4		Room 5		Room 6		Room 7		Room 8		Room 9	
	Source_Rm (1-Yes, 0-No)		1		0		0		0		0		0		0		0		0	
time (hr)	Air release rate (g/hr)	Vacuum Removal (1-Yes, 0-No)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	86.4	0	0.1162003	0.1625599	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	86.4	0	0.123247	0.4969548	0.0112521	0.0157413	0.0112521	0.0157413	0.0112521	0.0157413	0.011252	0.015741255	0.011252	0.015741	0.011252	0.015741	0.011252	0.015741	0.011252	0.015741
6	86.4	0	0.1324192	0.8528399	0.0202439	0.0597465	0.0202439	0.0597465	0.0202439	0.0597465	0.020244	0.059746459	0.020244	0.059746	0.020244	0.059746	0.020244	0.059746	0.020244	0.059746
8	86.4	0	0.139971	1.2308447	0.027775	0.1267088	0.027775	0.1267088	0.027775	0.1267088	0.027775	0.126708768	0.027775	0.126709	0.027775	0.126709	0.027775	0.126709	0.027775	0.126709
10	86.4	0	0.1462951	1.6269055	0.0340728	0.212777	0.0340728	0.212777	0.0340728	0.212777	0.034073	0.212777013	0.034073	0.212777	0.034073	0.212777	0.034073	0.212777	0.034073	0.212777
12	86.4	0	0.151591	2.0378015	0.0393426	0.3147192	0.0393426	0.3147192	0.0393426	0.3147192	0.039343	0.314719231	0.039343	0.314719	0.039343	0.314719	0.039343	0.314719	0.039343	0.314719
14	86.4	0	0								043755									29841
16	86.4	0	0								047453									55897
18	86.4	0	0								050555									91014
20	86.4	0	0								053161									83363
22	86.4	0	0								055351									82444
24	86.4	0	0								057196									13637
26	86.4	0	0								058753									94502
28	86.4	0	0								.06007									56088
30	86.4	0	0								061186									20496
32	86.4	0	0								062135									87204
34	86.4	0	0								062944									55774
36	86.4	0	0								063637									25841
38	86.4	0	(								064234									97102
40	86.4	0	0								064749									69304
42	86.4	0	0								065197									42235
44	86.4	0	0								065588									15721
46	86.4	0	0								065932									89613
48	86.4	0	0.1789406	10.2743	0.0662377	3.16379	0.0662377	3.16379	0.0662377	3.16379	0.066238	3.163790028	0.066238	3.16379	0.066238	3.16379	0.066238	3.16379	0.066238	3.16379
50	86.4	0	0.1792376	10.738524	0.0665102	3.3381507	0.0665102	3.3381507	0.0665102	3.3381507	0.06651	3.338150705	0.06651	3.338151	0.06651	3.338151	0.06651	3.338151	0.06651	3.338151
52	86.4	0	0.1795071	11.201874	0.0667553	3.51261	0.0667553	3.51261	0.0667553	3.51261	0.066755	3.512610032	0.066755	3.51261	0.066755	3.51261	0.066755	3.51261	0.066755	3.51261
54	86.4	0	0.1797537	11.664285	0.0669776	3.6870975	0.0669776	3.6870975	0.0669776	3.6870975	0.066978	3.687097458	0.066978	3.687097	0.066978	3.687097	0.066978	3.687097	0.066978	3.687097





Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It was chosen to generate results for comparison.

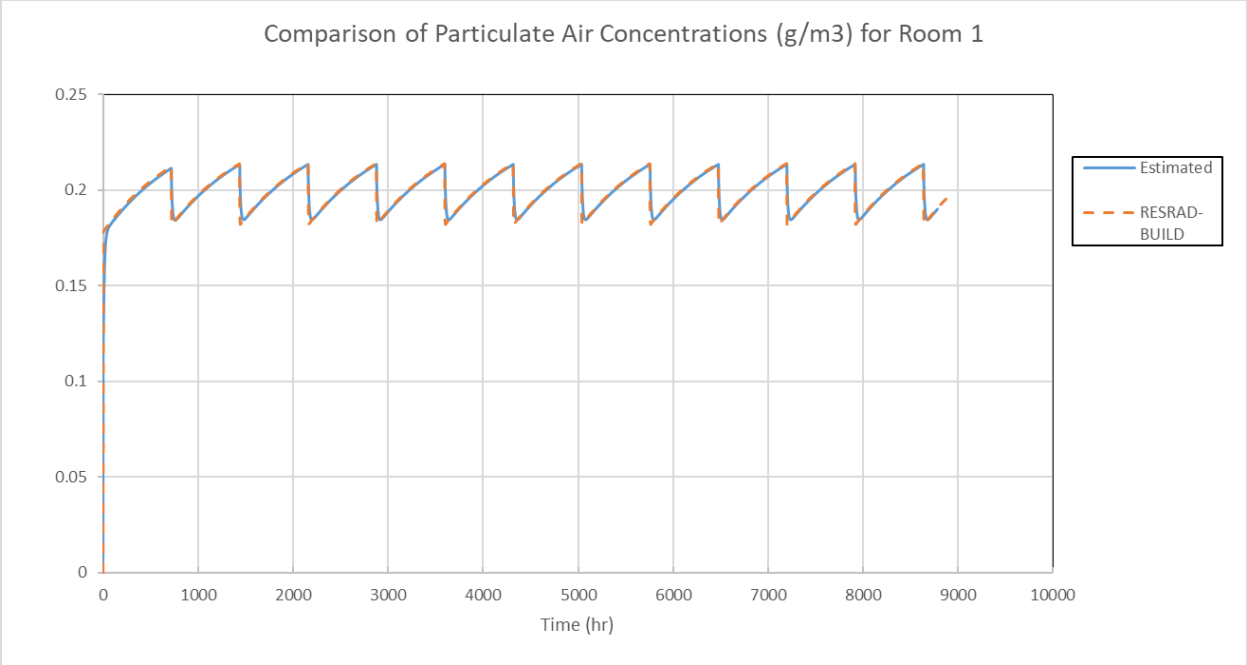


Figure 3.5 Comparison of Calculated Source Particulate Concentrations in the Air of Room 1 for Case II

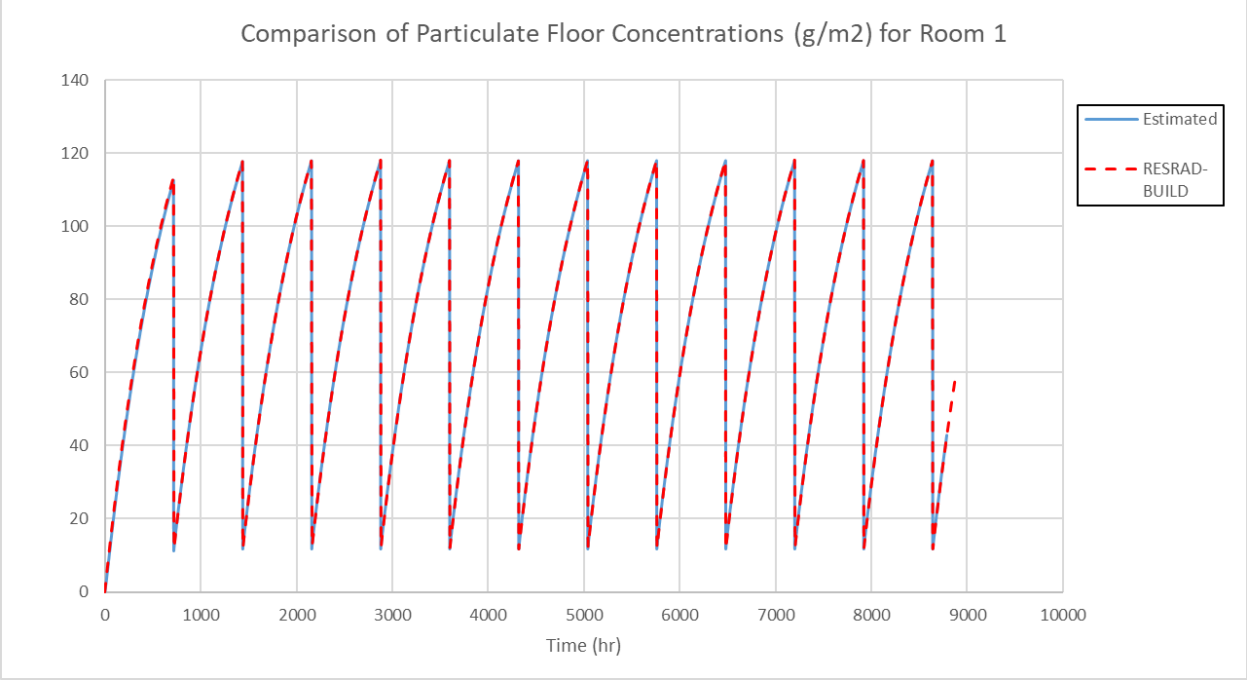


Figure 3.6 Comparison of Calculated Source Particulate Concentrations on the Floor or Room 1 for Case II

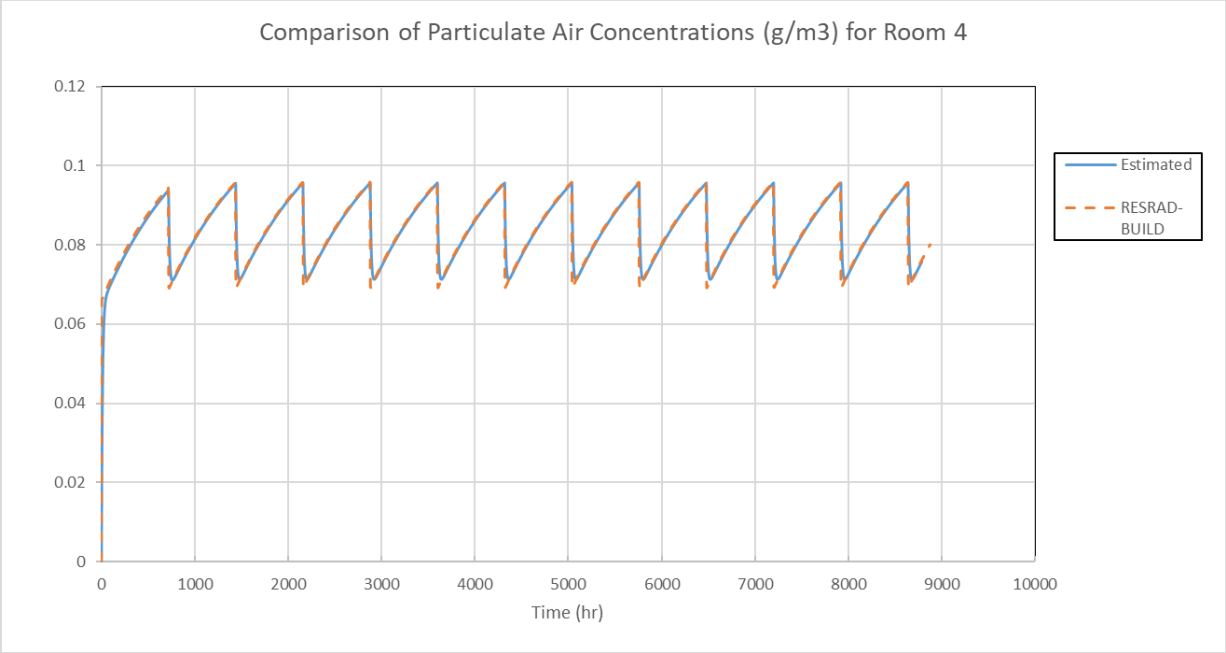


Figure 3.7 Comparison of Calculated Source Particulate Concentrations in the Air of Room 4 for Case II

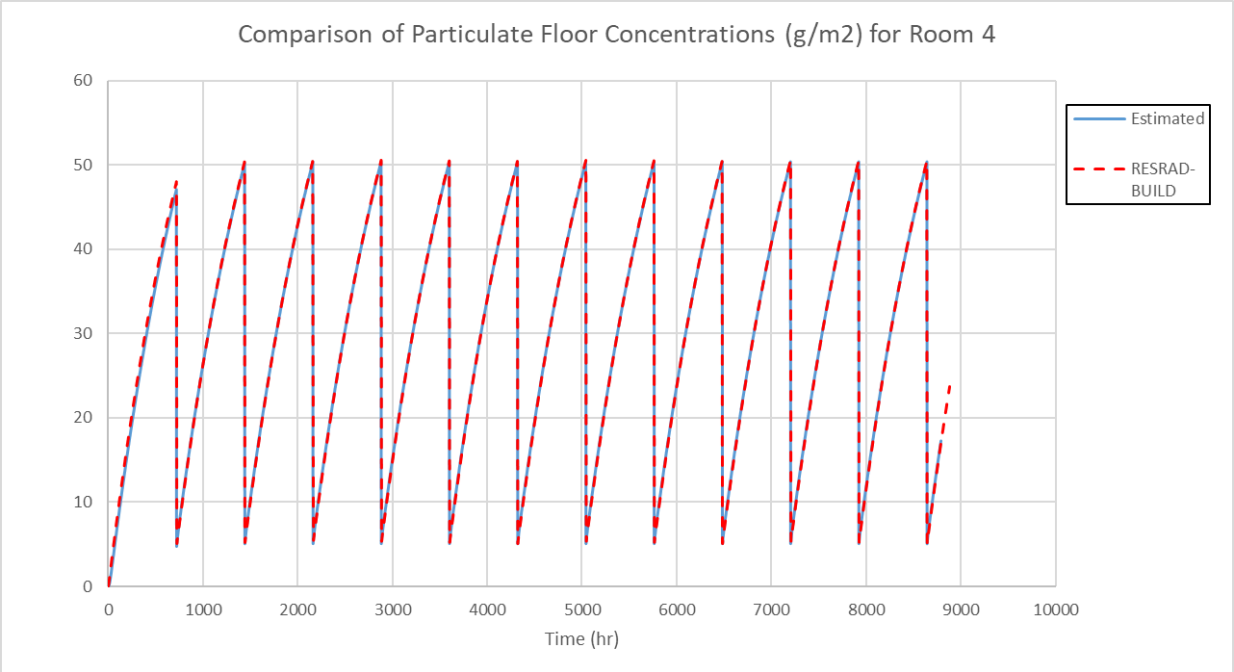


Figure 3.8 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 4 for Case II

Table 3.18 compares calculated average concentrations of radionuclides in the air and on the floor over the exposure duration in Room 1. Table 3.19 compares the same calculated results in Room 6. The comparisons show good agreement between the calculated results from RESRAD-BUILD and the spreadsheets. All but three results differ by less than 1%. The three exceptions are the calculated concentrations of Ra-226, Cs-137, and Co-60 at time 0 in Room 6; for them, the difference is more than 1% but less than 1.5%. The same calculated results in the other rooms from RESRAD-BUILD and from the spreadsheets also show good agreement.

3.3 CASE III – A VOLUME SOURCE IN ROOM 2 WITH NO SCHEDULED VACUUMING

Case III considers the same cylindrical volume source as that in Cases I and II, but the source was in Room 2 where no receptor was located. Unlike Cases I and II that assumed there was air exchange between each pair of rooms, in Case III, the air exchange was limited to just a few pairs of rooms. Vacuuming to remove dust deposition on the floor was not considered. The estimated concentrations of source particles and radionuclides in the air and on the floor of each room from RESRAD-BUILD and the verification spreadsheets were compared.

Table 3.20 shows the room dimensions, ventilation rates between rooms and with the outside environment, deposition velocity, and resuspension rate assumed for the case. Table 3.21 lists the properties assumed for the radiation source as well as its releases over time.

Table 3.22 shows the air release rate calculated by RESRAD-BUILD, obtained from the intermediate output file "AirRelRate1.out," and part of the estimated air release rates in the spreadsheet. The air release rate calculated by RESRAD-BUILD in terms of the fraction of the initial source per second was converted to mass of source materials per hour. The converted air release rate matches those estimated in the spreadsheet.

Equations B.10 and B.11 in the User's Manual of RESRAD-BUILD, Vol. 1 (Yu et al. 2022) were solved numerically in the spreadsheets to obtain source particulate concentrations in each room. Table 3.23 presents part of the calculations and results at different time steps in the spreadsheets.

During the analysis of Case III, the RESRAD-BUILD code generated an intermediate output file "AirRelConcSource1.out" that listed the concentrations in the air and on the floor of each room at various time points. The concentrations were expressed as the fraction of the initial source per m^3 of air and the fraction of the initial source per m^2 on the floor. They were multiplied by the total mass of source (materials) to convert the concentration to mass of source (particulate) per unit volume in the air (g/m^3) and mass of source (particulate) per unit area on the floor (g/m^2) for comparison with spreadsheet calculations.

Figure 3.9 compares the air concentrations of source particles (g/m^3) in Room 2, where the volume source was assumed to be located. Figure 3.10 compares the floor deposition concentrations of source particles (g/m^2) in the same room. Figures 3.11 and 3.12 compare the air concentrations and floor deposition concentrations, respectively, in Room 9, which did not have direct air exchange with Room 2. In the figures, the blue solid curve displays the results from the spreadsheets while the red dashed curve displays the results from RESRAD-BUILD.

Table 3.18 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 1 for Case II

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m^3) or (pCi/m^2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
1	0	RA-226	RA-226	Air	1.99E-01	1.98E-01	0.34
1	0	RA-226	RA-226	Floor	7.03E+01	6.97E+01	0.77
1	0	RA-226	PB-210	Air	7.78E-04	7.78E-04	0.04
1	0	RA-226	PB-210	Floor	2.98E-01	2.97E-01	0.38
1	0	RA-226	PO-210	Air	1.07E-04	1.07E-04	0.20
1	0	RA-226	PO-210	Floor	4.18E-02	4.17E-02	0.23
1	0.25	RA-226	RA-226	Air	2.00E-01	2.00E-01	0.04
1	0.25	RA-226	RA-226	Floor	7.30E+01	7.28E+01	0.23
1	0.25	RA-226	PB-210	Air	2.32E-03	2.32E-03	0.00
1	0.25	RA-226	PB-210	Floor	8.58E-01	8.56E-01	0.25
1	0.25	RA-226	PO-210	Air	6.57E-04	6.57E-04	0.06
1	0.25	RA-226	PO-210	Floor	2.46E-01	2.45E-01	0.23
1	0.5	RA-226	RA-226	Air	2.00E-01	2.00E-01	0.03
1	0.5	RA-226	RA-226	Floor	7.31E+01	7.29E+01	0.26
1	0.5	RA-226	PB-210	Air	3.84E-03	3.84E-03	0.01
1	0.5	RA-226	PB-210	Floor	1.41E+00	1.41E+00	0.23
1	0.5	RA-226	PO-210	Air	1.57E-03	1.57E-03	0.03
1	0.5	RA-226	PO-210	Floor	5.78E-01	5.77E-01	0.19
1	0.75	RA-226	RA-226	Air	2.00E-01	2.00E-01	0.02
1	0.75	RA-226	RA-226	Floor	7.30E+01	7.30E+01	0.10
1	0.75	RA-226	PB-210	Air	5.36E-03	5.36E-03	0.01
1	0.75	RA-226	PB-210	Floor	1.96E+00	1.96E+00	0.05
1	0.75	RA-226	PO-210	Air	2.70E-03	2.70E-03	0.02
1	0.75	RA-226	PO-210	Floor	9.90E-01	9.90E-01	0.00
1	1	RA-226	RA-226	Air	2.00E-01	2.00E-01	0.04
1	1	RA-226	RA-226	Floor	7.33E+01	7.31E+01	0.32
1	1	RA-226	PB-210	Air	6.86E-03	6.86E-03	0.03
1	1	RA-226	PB-210	Floor	2.52E+00	2.51E+00	0.31
1	1	RA-226	PO-210	Air	3.97E-03	3.97E-03	0.01
1	1	RA-226	PO-210	Floor	1.46E+00	1.45E+00	0.29
1	1.25	RA-226	RA-226	Air	2.00E-01	2.00E-01	0.04
1	1.25	RA-226	RA-226	Floor	7.34E+01	7.31E+01	0.34
1	1.25	RA-226	PB-210	Air	8.35E-03	8.35E-03	0.03
1	1.25	RA-226	PB-210	Floor	3.07E+00	3.06E+00	0.32
1	1.25	RA-226	PO-210	Air	5.33E-03	5.33E-03	0.01
1	1.25	RA-226	PO-210	Floor	1.95E+00	1.95E+00	0.30
1	1.5	RA-226	RA-226	Air	2.00E-01	2.00E-01	0.03
1	1.5	RA-226	RA-226	Floor	7.33E+01	7.32E+01	0.17
1	1.5	RA-226	PB-210	Air	9.83E-03	9.83E-03	0.02
1	1.5	RA-226	PB-210	Floor	3.61E+00	3.60E+00	0.15
1	1.5	RA-226	PO-210	Air	6.73E-03	6.73E-03	0.01
1	1.5	RA-226	PO-210	Floor	2.47E+00	2.46E+00	0.12

Table 3.18 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m^3) or (pCi/m^2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
1	0	CS-137	CS-137	Air	1.98E-01	1.97E-01	0.34
1	0	CS-137	CS-137	Floor	7.00E+01	6.95E+01	0.77
1	0.25	CS-137	CS-137	Air	1.98E-01	1.98E-01	0.03
1	0.25	CS-137	CS-137	Floor	7.24E+01	7.22E+01	0.23
1	0.5	CS-137	CS-137	Air	1.97E-01	1.97E-01	0.02
1	0.5	CS-137	CS-137	Floor	7.21E+01	7.19E+01	0.25
1	0.75	CS-137	CS-137	Air	1.96E-01	1.96E-01	0.01
1	0.75	CS-137	CS-137	Floor	7.16E+01	7.15E+01	0.09
1	1	CS-137	CS-137	Air	1.95E-01	1.95E-01	0.03
1	1	CS-137	CS-137	Floor	7.14E+01	7.12E+01	0.30
1	1.25	CS-137	CS-137	Air	1.94E-01	1.93E-01	0.02
1	1.25	CS-137	CS-137	Floor	7.11E+01	7.09E+01	0.33
1	1.5	CS-137	CS-137	Air	1.92E-01	1.92E-01	0.01
1	1.5	CS-137	CS-137	Floor	7.07E+01	7.06E+01	0.16
1	0	CO-60	CO-60	Air	1.95E-01	1.95E-01	0.35
1	0	CO-60	CO-60	Floor	6.90E+01	6.85E+01	0.78
1	0.25	CO-60	CO-60	Air	1.90E-01	1.90E-01	0.03
1	0.25	CO-60	CO-60	Floor	6.94E+01	6.93E+01	0.23
1	0.5	CO-60	CO-60	Air	1.84E-01	1.84E-01	0.02
1	0.5	CO-60	CO-60	Floor	6.73E+01	6.71E+01	0.25
1	0.75	CO-60	CO-60	Air	1.78E-01	1.78E-01	0.01
1	0.75	CO-60	CO-60	Floor	6.51E+01	6.51E+01	0.09
1	1	CO-60	CO-60	Air	1.72E-01	1.72E-01	0.03
1	1	CO-60	CO-60	Floor	6.32E+01	6.30E+01	0.30
1	1.25	CO-60	CO-60	Air	1.67E-01	1.67E-01	0.02
1	1.25	CO-60	CO-60	Floor	6.13E+01	6.11E+01	0.33
1	1.5	CO-60	CO-60	Air	1.61E-01	1.61E-01	0.01
1	1.5	CO-60	CO-60	Floor	5.93E+01	5.92E+01	0.16

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.19 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 6 for Case II

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m^3) or (pCi/m^2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
6	0	RA-226	RA-226	Air	8.31E-02	8.25E-02	0.77
6	0	RA-226	RA-226	Floor	2.88E+01	2.84E+01	1.34
6	0	RA-226	PB-210	Air	3.29E-04	3.29E-04	0.03
6	0	RA-226	PB-210	Floor	1.23E-01	1.23E-01	0.51
6	0	RA-226	PO-210	Air	4.52E-05	4.53E-05	0.25
6	0	RA-226	PO-210	Floor	1.73E-02	1.73E-02	0.24
6	0.25	RA-226	RA-226	Air	8.40E-02	8.39E-02	0.06
6	0.25	RA-226	RA-226	Floor	3.02E+01	3.01E+01	0.09
6	0.25	RA-226	PB-210	Air	9.76E-04	9.76E-04	0.00
6	0.25	RA-226	PB-210	Floor	3.55E-01	3.55E-01	0.12
6	0.25	RA-226	PO-210	Air	2.77E-04	2.77E-04	0.08
6	0.25	RA-226	PO-210	Floor	1.02E-01	1.02E-01	0.11
6	0.5	RA-226	RA-226	Air	8.39E-02	8.39E-02	0.04
6	0.5	RA-226	RA-226	Floor	3.02E+01	3.02E+01	0.12
6	0.5	RA-226	PB-210	Air	1.62E-03	1.62E-03	0.00
6	0.5	RA-226	PB-210	Floor	5.84E-01	5.84E-01	0.10
6	0.5	RA-226	PO-210	Air	6.60E-04	6.60E-04	0.05
6	0.5	RA-226	PO-210	Floor	2.39E-01	2.39E-01	0.06
6	0.75	RA-226	RA-226	Air	8.39E-02	8.39E-02	0.03
6	0.75	RA-226	RA-226	Floor	3.02E+01	3.02E+01	0.05
6	0.75	RA-226	PB-210	Air	2.25E-03	2.25E-03	0.01
6	0.75	RA-226	PB-210	Floor	8.11E-01	8.12E-01	0.10
6	0.75	RA-226	PO-210	Air	1.14E-03	1.14E-03	0.03
6	0.75	RA-226	PO-210	Floor	4.09E-01	4.10E-01	0.15
6	1	RA-226	RA-226	Air	8.40E-02	8.39E-02	0.07
6	1	RA-226	RA-226	Floor	3.03E+01	3.02E+01	0.18
6	1	RA-226	PB-210	Air	2.89E-03	2.88E-03	0.05
6	1	RA-226	PB-210	Floor	1.04E+00	1.04E+00	0.17
6	1	RA-226	PO-210	Air	1.67E-03	1.67E-03	0.03
6	1	RA-226	PO-210	Floor	6.03E-01	6.02E-01	0.15
6	1.25	RA-226	RA-226	Air	8.40E-02	8.39E-02	0.05
6	1.25	RA-226	RA-226	Floor	3.03E+01	3.03E+01	0.21
6	1.25	RA-226	PB-210	Air	3.51E-03	3.51E-03	0.04
6	1.25	RA-226	PB-210	Floor	1.27E+00	1.26E+00	0.19
6	1.25	RA-226	PO-210	Air	2.24E-03	2.24E-03	0.02
6	1.25	RA-226	PO-210	Floor	8.08E-01	8.06E-01	0.16
6	1.5	RA-226	RA-226	Air	8.40E-02	8.39E-02	0.03
6	1.5	RA-226	RA-226	Floor	3.03E+01	3.03E+01	0.03
6	1.5	RA-226	PB-210	Air	4.14E-03	4.13E-03	0.02
6	1.5	RA-226	PB-210	Floor	1.49E+00	1.49E+00	0.00
6	1.5	RA-226	PO-210	Air	2.83E-03	2.83E-03	0.00
6	1.5	RA-226	PO-210	Floor	1.02E+00	1.02E+00	0.02

Table 3.19 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m^3) or (pCi/m^2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
6	0	CS-137	CS-137	Air	8.29E-02	8.23E-02	0.77
6	0	CS-137	CS-137	Floor	2.87E+01	2.84E+01	1.34
6	0.25	CS-137	CS-137	Air	8.33E-02	8.32E-02	0.06
6	0.25	CS-137	CS-137	Floor	2.99E+01	2.99E+01	0.08
6	0.5	CS-137	CS-137	Air	8.28E-02	8.27E-02	0.04
6	0.5	CS-137	CS-137	Floor	2.98E+01	2.97E+01	0.11
6	0.75	CS-137	CS-137	Air	8.23E-02	8.23E-02	0.02
6	0.75	CS-137	CS-137	Floor	2.96E+01	2.96E+01	0.06
6	1	CS-137	CS-137	Air	8.19E-02	8.18E-02	0.06
6	1	CS-137	CS-137	Floor	2.95E+01	2.95E+01	0.17
6	1.25	CS-137	CS-137	Air	8.14E-02	8.14E-02	0.04
6	1.25	CS-137	CS-137	Floor	2.94E+01	2.93E+01	0.20
6	1.5	CS-137	CS-137	Air	8.09E-02	8.09E-02	0.01
6	1.5	CS-137	CS-137	Floor	2.92E+01	2.92E+01	0.02
6	0	CO-60	CO-60	Air	8.18E-02	8.11E-02	0.78
6	0	CO-60	CO-60	Floor	2.83E+01	2.79E+01	1.36
6	0.25	CO-60	CO-60	Air	7.99E-02	7.99E-02	0.06
6	0.25	CO-60	CO-60	Floor	2.87E+01	2.87E+01	0.08
6	0.5	CO-60	CO-60	Air	7.73E-02	7.73E-02	0.04
6	0.5	CO-60	CO-60	Floor	2.78E+01	2.78E+01	0.11
6	0.75	CO-60	CO-60	Air	7.49E-02	7.48E-02	0.02
6	0.75	CO-60	CO-60	Floor	2.69E+01	2.69E+01	0.05
6	1	CO-60	CO-60	Air	7.25E-02	7.24E-02	0.06
6	1	CO-60	CO-60	Floor	2.61E+01	2.61E+01	0.17
6	1.25	CO-60	CO-60	Air	7.01E-02	7.01E-02	0.04
6	1.25	CO-60	CO-60	Floor	2.53E+01	2.53E+01	0.20
6	1.5	CO-60	CO-60	Air	6.79E-02	6.79E-02	0.01
6	1.5	CO-60	CO-60	Floor	2.45E+01	2.45E+01	0.02

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.20 Air Flows, Vacuuming, and Resuspension and Deposition of Particulates Assumed for Case III

Deposition Velocity		0.00039	(m/s) =	1.404	(m/hr)					
	Outdoors	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8	Room 9
Area (m2)		36	36	36	36	36	36	36	36	36
Volume (m3)		90	90	90	90	90	90	90	90	90
Resuspension rate (1/s)		5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07	5.00E-07
Resuspension rate (1/h)		1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03	1.80E-03
Air flow (m3/hr) from										
Outdoors	0	90	0	0	36	0	0	0	0	0
Room 1	0	0	72	0	36	0	0	0	0	0
Room 2	0	0	0	72	0	0	0	0	0	0
Room 3	36	0	0	0	18	0	18	0	0	0
Room 4	0	0	0	0	0	36	0	54	0	0
Room 5	0	0	0	0	0	0	36	0	18	0
Room 6	0	0	0	0	0	0	0	0	0	54
Room 7	0	0	0	0	0	0	0	0	54	0
Room 8	0	0	0	0	0	18	0	0	0	72
Room 9	90	18	0	0	0	0	0	0	18	0
Vacuum frequency (once in)		366	day(s) =	8784	hr(s)					
Vacuum efficiency		0								

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

Table 3.21 Source Releases Assumed for Case III

Source Releases							
Location (Room No.)	2	Air Fraction	1	Area of source		36	m2
	Region 1	Region 2	Region 3	Region 4	Region 5		
Contamination? 1-Yes, 2-No	1	2	2	2	2		
thickness (cm)	15	0	0	0	0		
density (g/cm3)	2.4	2.4	2.4	2.4	2.4		
erosion rate (cm/d)	2.40E-03	2.40E-08	2.40E-08	2.40E-08	2.40E-08		
Start time (d)	0.00E+00	6.25E+03	6.25E+03	6.25E+03	6.25E+03		
Start time (hr)	0	150000	150000	150000	150000		
End time (d)	6.25E+03	6.25E+03	6.25E+03	6.25E+03	6.25E+03		
End time (hr)	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05		
Release rate (g/hr)	86.4	0	0	0	0		

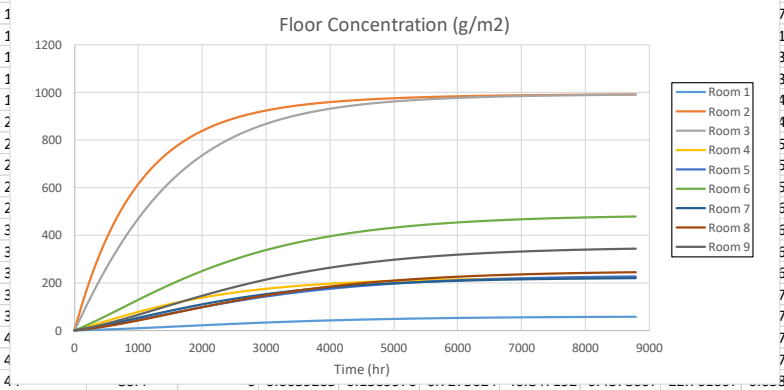
Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

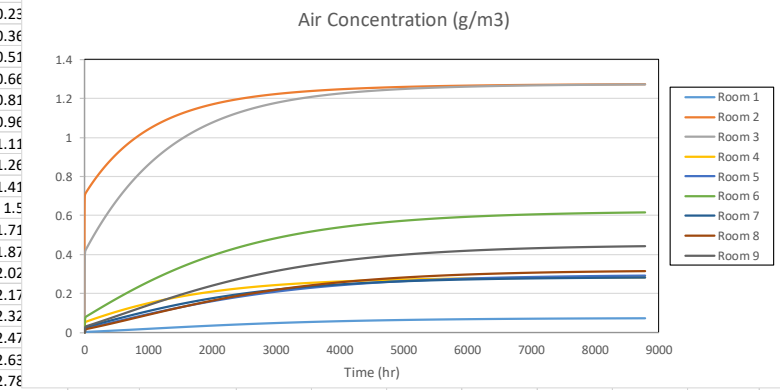
Table 3.22 Comparison of Calculated Air Release Rates from RESRAD-BUILD and Spreadsheets for Case III

From "AirRelRate1.out"							
Rate of release of source material to air							
fraction of source per second per volume (m3) of the room of release							
2.06E-11	from	time	0.00E+00	to	time	5.4E+08	seconds
8.64E+01	from	time	0.00E+00	to	time	150000	hrs
Initial source mass		1.30E+07	g				
Volume of source room		90	m3				
time (hr)	Estimated Air release rate (g/hr)						
0	0						
2	86.4						
4	86.4						
6	86.4						
8	86.4						
10	86.4						
12	86.4						
14	86.4						
16	86.4						

Table 3.23 Calculations of Source Particulate Concentrations in the Air and on the Floor of Each Room for Case III

	time interval	2 hr																		
			Room 1		Room 2		Room 3		Room 4		Room 5		Room 6		Room 7		Room 8		Room 9	
	Source_Rm (1-Yes, 0-No)		0		1		0		0		0		0		0		0		0	
time (hr)	Air release rate (g/hr)	Vacuum Removal (1-Yes, 0-No)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	86.4	0	0	0	0.5156854	0.7214252	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	86.4	0	0	0	0.6544704	2.355843	0.2216096	0.3100237	0	0	0	0	0	0	0	0	0	0	0	0
6	86.4	0	0	0	0.6923783	4.2315849	0.3408919	1.0958308	0.0214988	0.030076	0	0	0.026674	0.037316	0	0	0	0	0	0
8	86.4	0	0	0	0.7032853	6.1688885	0.3895238	2.113725	0.0382952	0.1136178	0.005175	0.007240258	0.049075	0.143152	0.007763	0.01086	0	0	0.006502	0.009096
1										71159	0.23									36744
1										11684	0.36									81998
1										30077	0.51									14168
1										39414	0.66									11994
1										45189	0.81									89459
2										49465	0.96									71435
2										52996	1.11									56163
2										55609	1.26									42569
2										58904	1.41									30034
2										61533	1.5									18211
3										64046	1.71									06905
3										66484	1.87									96008
3										68878	2.02									85458
3										71244	2.17									75219
3										73594	2.32									65272
4										75933	2.47									55602
4										78267	2.63									46203
4										80595	2.78									37069
46	86.4	0	0.0039487	0.1614648	0.7285816	42.737762	0.4390676	23.906152	0.0582921	2.9372871	0.023895	1.078528761	0.085882	4.233316	0.030748	1.422808	0.019496	0.820698	0.034518	1.528197
48	86.4	0	0.0039769	0.1719733	0.7295987	44.6244	0.4402726	25.050564	0.0585244	3.0901729	0.024037	1.141714569	0.086278	4.458977	0.030918	1.503973	0.01963	0.87249	0.034727	1.619587
50	86.4	0	0.004005	0.1825228	0.7306137	46.507112	0.441476	26.19424	0.0587565	3.2431599	0.024179	1.205072008	0.086675	4.684937	0.031088	1.585323	0.019765	0.924473	0.034937	1.711235
52	86.4	0	0.0040331	0.1931131	0.7316265	48.385908	0.4426777	27.337178	0.0589884	3.3962473	0.024322	1.268600424	0.087071	4.911197	0.031259	1.666858	0.019899	0.976646	0.035147	1.803141





Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It was chosen to generate results for comparison.

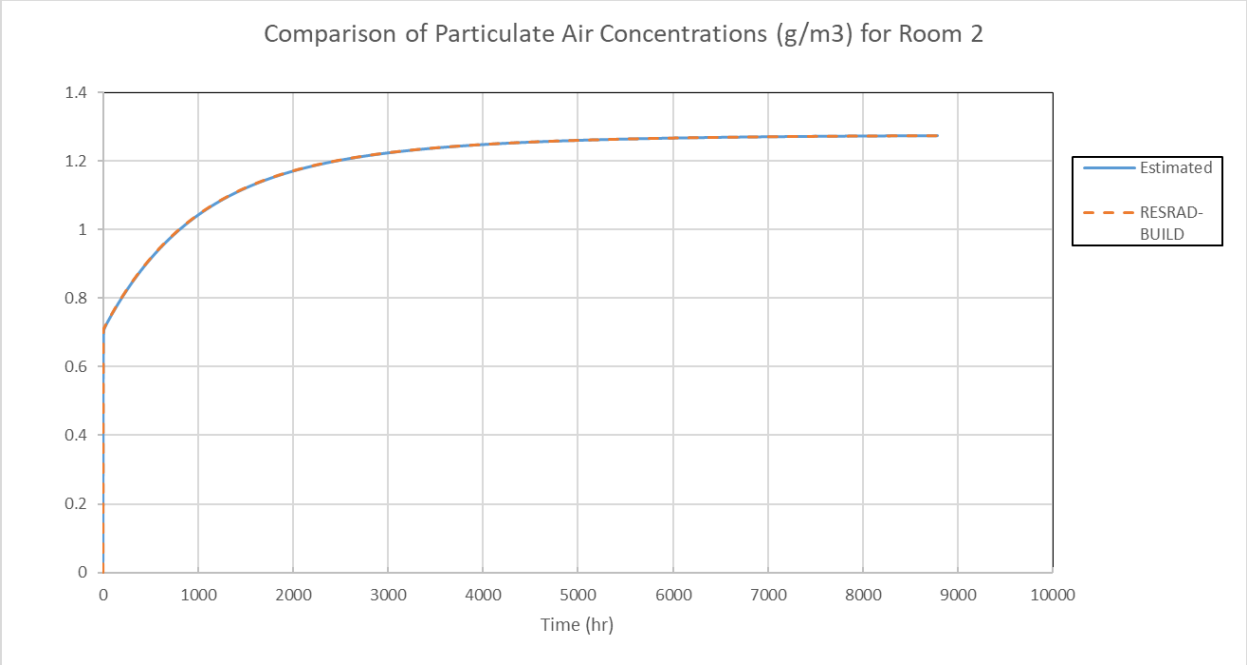


Figure 3.9 Comparison of Calculated Source Particulate Concentrations in the Air of Room 2 for Case III

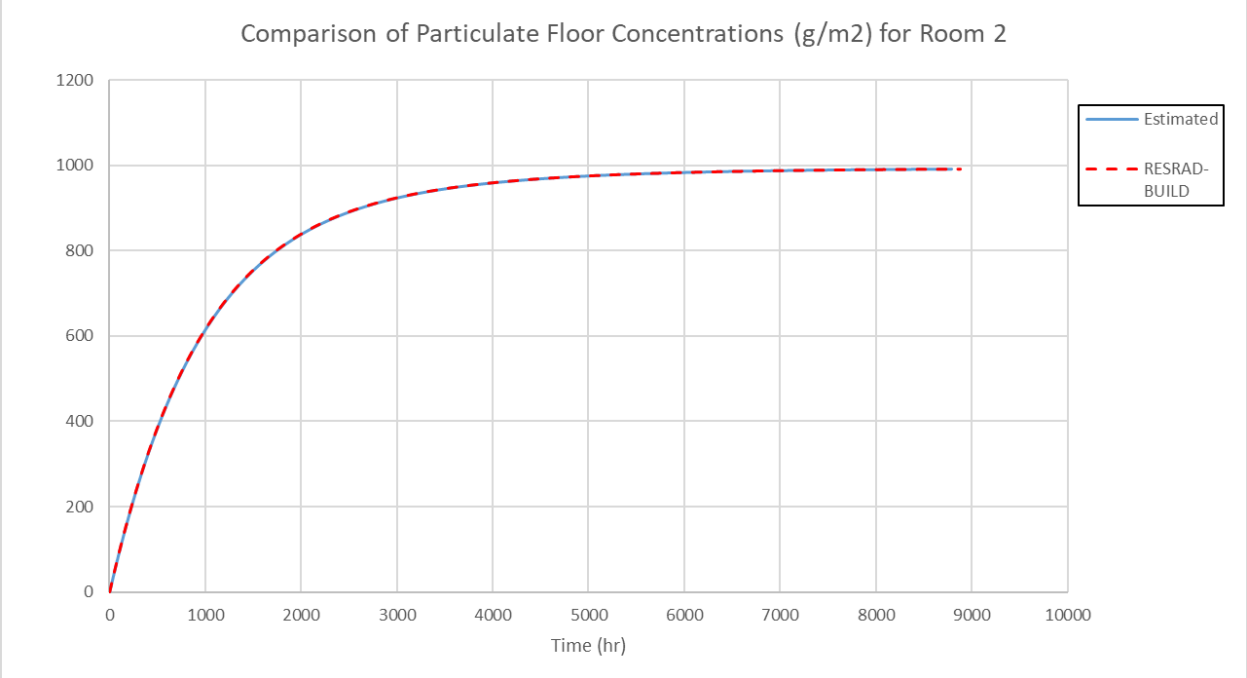


Figure 3.10 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 2 for Case III

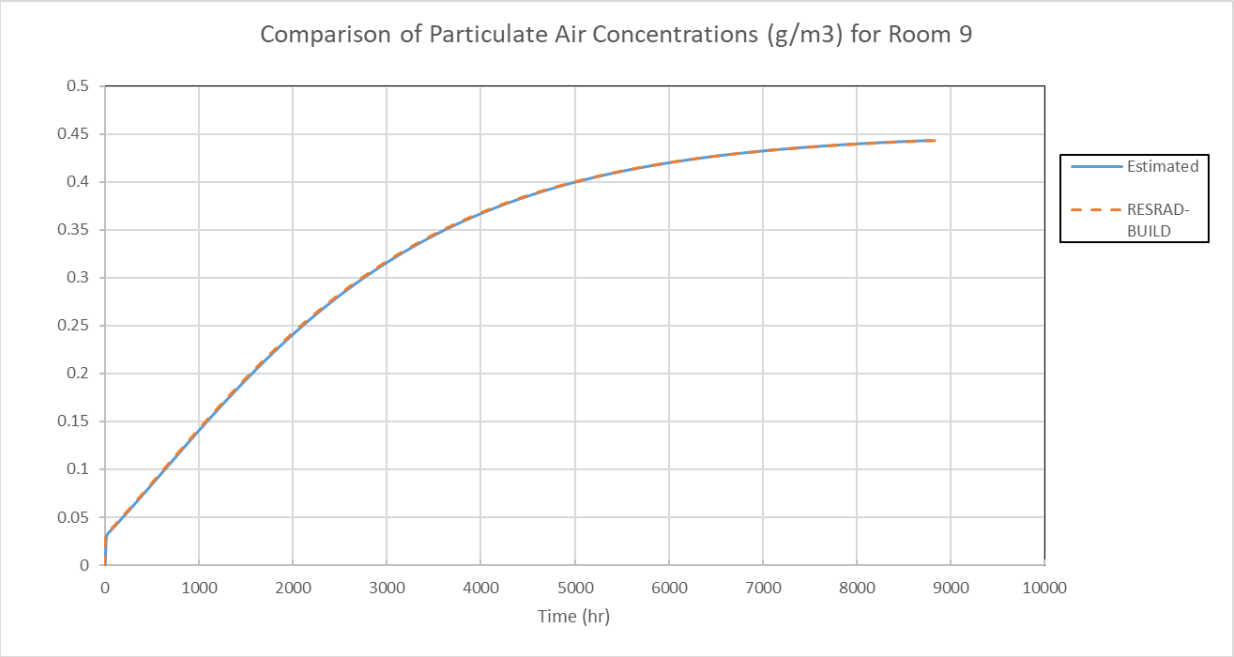


Figure 3.11 Comparison of Calculated Source Particulate Concentrations in the Air of Room 9 for Case III

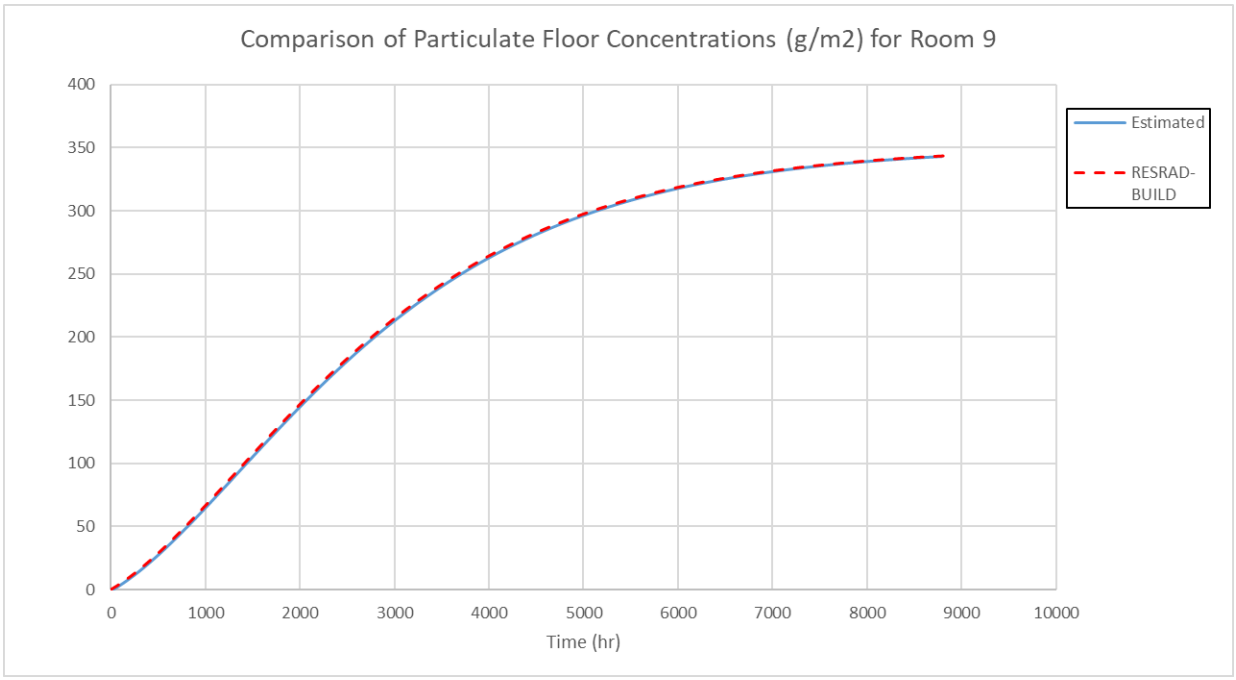


Figure 3.12 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 9 for Case III

The comparison of concentrations in the air and on the floor for the other rooms were like those for Room 9. As shown in the figures, the concentration results from RESRAD-BUILD and the spreadsheets are in good agreement.

Table 3.24 compares calculated average concentrations of radionuclides in the air and on the floor over the exposure duration in Room 3. Table 3.25 compares the same calculated results in Room 9. The comparisons show good agreement between the calculated results from RESRAD-BUILD and the spreadsheets. All but eight results differ by less than 1%. The eight exceptions are the calculated concentrations at time 0 in Room 9; for them, the difference is more than 1% but less than 1.6%. The same calculated results in the other rooms from RESRAD-BUILD and the spreadsheets also show good agreement.

3.4 CASE IV – A VOLUME SOURCE IN ROOM 2 WITH SCHEDULED VACUUMING

Case IV considers the same cylindrical volume source in Room 2 as Case III. The more limited air exchange between rooms considered in Case III was also retained. However, vacuuming to remove dust deposition on the floor was assumed to occur every 14 days, with a dust removal efficiency of 80%. The estimated concentrations of source particles and radionuclides in the air and on the floor of each room from RESRAD-BUILD and the verification spreadsheets were compared.

The room dimensions, ventilation rates between rooms and with the outside environment, deposition velocity, and resuspension rate assumed for Case III were applicable to Case IV (Table 3.20). The properties of the radiation source as well as its releases over time assumed in Case III were also applicable to Case IV (Table 3.21). The air release rate calculated by RESRAD-BUILD, obtained from the intermediate output file "AirRelRate1.out," matched those calculated in the spreadsheet, after being converted from fraction of the initial source per second to mass of source materials per hour (Table 3.22).

Equations B.10 and B.11 in the User's Manual of RESRAD-BUILD, Vol. 1 (Yu et al. 2022) were solved numerically in the spreadsheets to obtain source particulate concentrations in each room. Table 3.26 presents part of the calculations and results at different time steps in the spreadsheets.

During the analysis of Case IV, the RESRAD-BUILD code generated an intermediate output file "AirRelConcSource1.out" that listed the concentrations in the air and on the floor of each room at various time points. The concentrations were expressed as the fraction of the initial source per m^3 of air and the fraction of the initial source per m^2 on the floor. They were multiplied by the total mass of source (materials) to convert the concentration to mass of source (particulate) per unit volume in the air (g/m^3) and mass of source (particulate) per unit area on the floor (g/m^2) for comparison with spreadsheet calculations.

Table 3.24 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 3 for Case III

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
3	0	RA-226	RA-226	Air	8.47E-01	8.43E-01	0.42
3	0	RA-226	RA-226	Floor	4.65E+02	4.63E+02	0.53
3	0	RA-226	PB-210	Air	3.71E-03	3.70E-03	0.19
3	0	RA-226	PB-210	Floor	2.29E+00	2.28E+00	0.32
3	0	RA-226	PO-210	Air	5.29E-04	5.29E-04	0.04
3	0	RA-226	PO-210	Floor	3.40E-01	3.40E-01	0.16
3	0.25	RA-226	RA-226	Air	1.19E+00	1.19E+00	0.11
3	0.25	RA-226	RA-226	Floor	8.82E+02	8.80E+02	0.17
3	0.25	RA-226	PB-210	Air	1.38E-02	1.38E-02	0.09
3	0.25	RA-226	PB-210	Floor	1.03E+01	1.03E+01	0.14
3	0.25	RA-226	PO-210	Air	3.93E-03	3.93E-03	0.04
3	0.25	RA-226	PO-210	Floor	2.94E+00	2.94E+00	0.09
3	0.5	RA-226	RA-226	Air	1.25E+00	1.25E+00	0.04
3	0.5	RA-226	RA-226	Floor	9.69E+02	9.68E+02	0.06
3	0.5	RA-226	PB-210	Air	2.41E-02	2.41E-02	0.04
3	0.5	RA-226	PB-210	Floor	1.87E+01	1.87E+01	0.05
3	0.5	RA-226	PO-210	Air	9.84E-03	9.84E-03	0.01
3	0.5	RA-226	PO-210	Floor	7.61E+00	7.61E+00	0.03
3	0.75	RA-226	RA-226	Air	1.27E+00	1.27E+00	0.02
3	0.75	RA-226	RA-226	Floor	9.87E+02	9.87E+02	0.03
3	0.75	RA-226	PB-210	Air	3.40E-02	3.40E-02	0.02
3	0.75	RA-226	PB-210	Floor	2.65E+01	2.65E+01	0.03
3	0.75	RA-226	PO-210	Air	1.72E-02	1.72E-02	0.00
3	0.75	RA-226	PO-210	Floor	1.34E+01	1.34E+01	0.00
3	1	RA-226	RA-226	Air	1.27E+00	1.27E+00	0.02
3	1	RA-226	RA-226	Floor	9.92E+02	9.92E+02	0.02
3	1	RA-226	PB-210	Air	4.37E-02	4.37E-02	0.01
3	1	RA-226	PB-210	Floor	3.41E+01	3.41E+01	0.02
3	1	RA-226	PO-210	Air	2.53E-02	2.53E-02	0.00
3	1	RA-226	PO-210	Floor	1.97E+01	1.97E+01	0.00
3	1.25	RA-226	RA-226	Air	1.27E+00	1.27E+00	0.01
3	1.25	RA-226	RA-226	Floor	9.93E+02	9.93E+02	0.01
3	1.25	RA-226	PB-210	Air	5.33E-02	5.33E-02	0.01
3	1.25	RA-226	PB-210	Floor	4.16E+01	4.16E+01	0.01
3	1.25	RA-226	PO-210	Air	3.40E-02	3.40E-02	0.00
3	1.25	RA-226	PO-210	Floor	2.65E+01	2.65E+01	0.00
3	1.5	RA-226	RA-226	Air	1.27E+00	1.27E+00	0.02
3	1.5	RA-226	RA-226	Floor	9.94E+02	9.93E+02	0.02
3	1.5	RA-226	PB-210	Air	6.28E-02	6.28E-02	0.01
3	1.5	RA-226	PB-210	Floor	4.90E+01	4.89E+01	0.02
3	1.5	RA-226	PO-210	Air	4.30E-02	4.30E-02	0.00
3	1.5	RA-226	PO-210	Floor	3.35E+01	3.35E+01	0.00

Table 3.24 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
3	0	CS-137	CS-137	Air	8.44E-01	8.41E-01	0.42
3	0	CS-137	CS-137	Floor	4.63E+02	4.61E+02	0.53
3	0.25	CS-137	CS-137	Air	1.18E+00	1.18E+00	0.11
3	0.25	CS-137	CS-137	Floor	8.74E+02	8.73E+02	0.17
3	0.5	CS-137	CS-137	Air	1.24E+00	1.24E+00	0.04
3	0.5	CS-137	CS-137	Floor	9.55E+02	9.55E+02	0.05
3	0.75	CS-137	CS-137	Air	1.24E+00	1.24E+00	0.01
3	0.75	CS-137	CS-137	Floor	9.68E+02	9.68E+02	0.02
3	1	CS-137	CS-137	Air	1.24E+00	1.24E+00	0.00
3	1	CS-137	CS-137	Floor	9.67E+02	9.67E+02	0.01
3	1.25	CS-137	CS-137	Air	1.23E+00	1.23E+00	0.00
3	1.25	CS-137	CS-137	Floor	9.63E+02	9.63E+02	0.00
3	1.5	CS-137	CS-137	Air	1.23E+00	1.23E+00	0.00
3	1.5	CS-137	CS-137	Floor	9.58E+02	9.58E+02	0.00
3	0	CO-60	CO-60	Air	8.31E-01	8.28E-01	0.42
3	0	CO-60	CO-60	Floor	4.55E+02	4.53E+02	0.54
3	0.25	CO-60	CO-60	Air	1.13E+00	1.13E+00	0.11
3	0.25	CO-60	CO-60	Floor	8.39E+02	8.38E+02	0.17
3	0.5	CO-60	CO-60	Air	1.16E+00	1.15E+00	0.04
3	0.5	CO-60	CO-60	Floor	8.93E+02	8.92E+02	0.05
3	0.75	CO-60	CO-60	Air	1.13E+00	1.13E+00	0.01
3	0.75	CO-60	CO-60	Floor	8.81E+02	8.80E+02	0.02
3	1	CO-60	CO-60	Air	1.10E+00	1.10E+00	0.00
3	1	CO-60	CO-60	Floor	8.56E+02	8.56E+02	0.00
3	1.25	CO-60	CO-60	Air	1.06E+00	1.06E+00	0.00
3	1.25	CO-60	CO-60	Floor	8.30E+02	8.30E+02	0.00
3	1.5	CO-60	CO-60	Air	1.03E+00	1.03E+00	0.00
3	1.5	CO-60	CO-60	Floor	8.03E+02	8.03E+02	0.00

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.25 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 9 for Case III

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
9	0	RA-226	RA-226	Air	1.50E-01	1.48E-01	1.29
9	0	RA-226	RA-226	Floor	7.60E+01	7.48E+01	1.53
9	0	RA-226	PB-210	Air	7.30E-04	7.23E-04	0.94
9	0	RA-226	PB-210	Floor	4.02E-01	3.97E-01	1.21
9	0	RA-226	PO-210	Air	1.09E-04	1.08E-04	0.74
9	0	RA-226	PO-210	Floor	6.20E-02	6.14E-02	1.01
9	0.25	RA-226	RA-226	Air	3.30E-01	3.28E-01	0.52
9	0.25	RA-226	RA-226	Floor	2.27E+02	2.26E+02	0.67
9	0.25	RA-226	PB-210	Air	3.90E-03	3.88E-03	0.48
9	0.25	RA-226	PB-210	Floor	2.71E+00	2.69E+00	0.62
9	0.25	RA-226	PO-210	Air	1.12E-03	1.11E-03	0.42
9	0.25	RA-226	PO-210	Floor	7.82E-01	7.78E-01	0.55
9	0.5	RA-226	RA-226	Air	4.09E-01	4.08E-01	0.23
9	0.5	RA-226	RA-226	Floor	3.07E+02	3.06E+02	0.30
9	0.5	RA-226	PB-210	Air	7.90E-03	7.88E-03	0.22
9	0.5	RA-226	PB-210	Floor	5.93E+00	5.92E+00	0.29
9	0.5	RA-226	PO-210	Air	3.23E-03	3.22E-03	0.19
9	0.5	RA-226	PO-210	Floor	2.43E+00	2.42E+00	0.25
9	0.75	RA-226	RA-226	Air	4.37E-01	4.36E-01	0.10
9	0.75	RA-226	RA-226	Floor	3.37E+02	3.36E+02	0.13
9	0.75	RA-226	PB-210	Air	1.17E-02	1.17E-02	0.10
9	0.75	RA-226	PB-210	Floor	9.04E+00	9.03E+00	0.13
9	0.75	RA-226	PO-210	Air	5.92E-03	5.91E-03	0.07
9	0.75	RA-226	PO-210	Floor	4.56E+00	4.56E+00	0.10
9	1	RA-226	RA-226	Air	4.46E-01	4.46E-01	0.05
9	1	RA-226	RA-226	Floor	3.46E+02	3.46E+02	0.06
9	1	RA-226	PB-210	Air	1.53E-02	1.53E-02	0.04
9	1	RA-226	PB-210	Floor	1.19E+01	1.19E+01	0.06
9	1	RA-226	PO-210	Air	8.87E-03	8.87E-03	0.03
9	1	RA-226	PO-210	Floor	6.90E+00	6.89E+00	0.04
9	1.25	RA-226	RA-226	Air	4.48E-01	4.48E-01	0.03
9	1.25	RA-226	RA-226	Floor	3.49E+02	3.49E+02	0.03
9	1.25	RA-226	PB-210	Air	1.88E-02	1.88E-02	0.03
9	1.25	RA-226	PB-210	Floor	1.46E+01	1.46E+01	0.03
9	1.25	RA-226	PO-210	Air	1.20E-02	1.20E-02	0.01
9	1.25	RA-226	PO-210	Floor	9.33E+00	9.32E+00	0.01
9	1.5	RA-226	RA-226	Air	4.49E-01	4.49E-01	0.02
9	1.5	RA-226	RA-226	Floor	3.50E+02	3.50E+02	0.02
9	1.5	RA-226	PB-210	Air	2.21E-02	2.21E-02	0.02
9	1.5	RA-226	PB-210	Floor	1.73E+01	1.73E+01	0.02
9	1.5	RA-226	PO-210	Air	1.52E-02	1.51E-02	0.01
9	1.5	RA-226	PO-210	Floor	1.18E+01	1.18E+01	0.01

Table 3.25 (Continued)

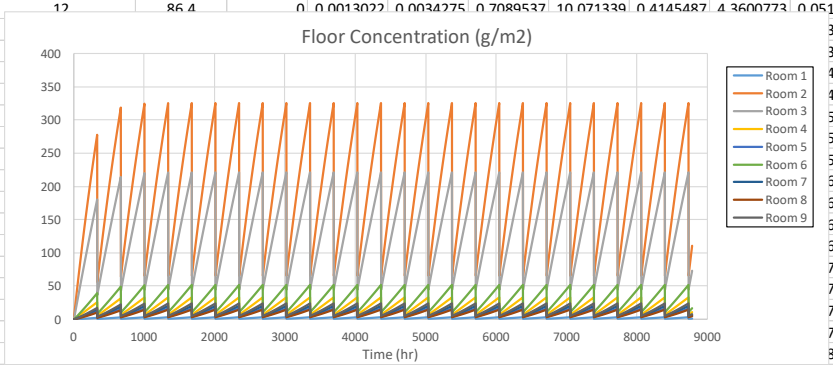
iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
9	0	CS-137	CS-137	Air	1.49E-01	1.47E-01	1.29
9	0	CS-137	CS-137	Floor	7.57E+01	7.45E+01	1.53
9	0.25	CS-137	CS-137	Air	3.27E-01	3.25E-01	0.52
9	0.25	CS-137	CS-137	Floor	2.25E+02	2.24E+02	0.67
9	0.5	CS-137	CS-137	Air	4.03E-01	4.02E-01	0.22
9	0.5	CS-137	CS-137	Floor	3.03E+02	3.02E+02	0.29
9	0.75	CS-137	CS-137	Air	4.28E-01	4.28E-01	0.09
9	0.75	CS-137	CS-137	Floor	3.30E+02	3.30E+02	0.12
9	1	CS-137	CS-137	Air	4.35E-01	4.34E-01	0.03
9	1	CS-137	CS-137	Floor	3.38E+02	3.37E+02	0.05
9	1.25	CS-137	CS-137	Air	4.35E-01	4.35E-01	0.01
9	1.25	CS-137	CS-137	Floor	3.39E+02	3.39E+02	0.02
9	1.5	CS-137	CS-137	Air	4.33E-01	4.33E-01	0.00
9	1.5	CS-137	CS-137	Floor	3.38E+02	3.38E+02	0.01
9	0	CO-60	CO-60	Air	1.47E-01	1.45E-01	1.30
9	0	CO-60	CO-60	Floor	7.43E+01	7.31E+01	1.53
9	0.25	CO-60	CO-60	Air	3.13E-01	3.12E-01	0.52
9	0.25	CO-60	CO-60	Floor	2.16E+02	2.15E+02	0.67
9	0.5	CO-60	CO-60	Air	3.77E-01	3.76E-01	0.22
9	0.5	CO-60	CO-60	Floor	2.83E+02	2.82E+02	0.29
9	0.75	CO-60	CO-60	Air	3.90E-01	3.89E-01	0.09
9	0.75	CO-60	CO-60	Floor	3.00E+02	3.00E+02	0.12
9	1	CO-60	CO-60	Air	3.85E-01	3.85E-01	0.03
9	1	CO-60	CO-60	Floor	2.99E+02	2.99E+02	0.04
9	1.25	CO-60	CO-60	Air	3.75E-01	3.75E-01	0.01
9	1.25	CO-60	CO-60	Floor	2.92E+02	2.92E+02	0.01
9	1.5	CO-60	CO-60	Air	3.63E-01	3.63E-01	0.00
9	1.5	CO-60	CO-60	Floor	2.83E+02	2.83E+02	0.00

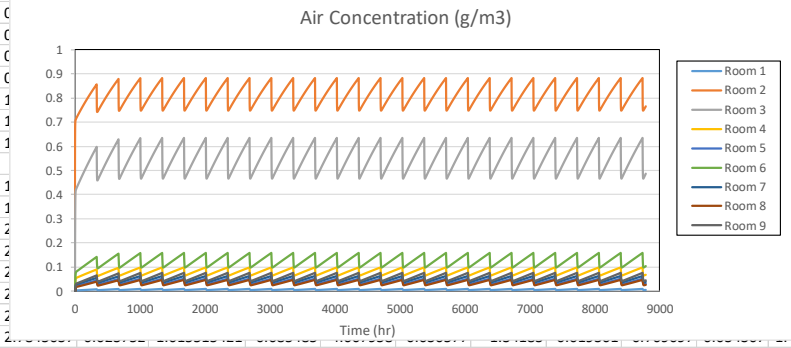
Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.26 Calculations of Source Particulate Concentrations in the Air and on the Floor of Each Room for Case IV

time interval 2 hr

		Room 1		Room 2		Room 3		Room 4		Room 5		Room 6		Room 7		Room 8		Room 9	
	Source_Rm (1-Yes, 0-No)	0		1		0		0		0		0		0		0		0	
time (hr)	Air release rate (g/hr)	Vacuum Removal (1-Yes, 0-No)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	86.4	0	0	0	0.5156854	0.7214252	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	86.4	0	0	0	0.6544704	2.355843	0.2216096	0.3100237	0	0	0	0	0	0	0	0	0	0	0	0
6	86.4	0	0	0	0.6923783	4.2315849	0.3408919	1.0958308	0.0214988	0.030076	0	0	0.026674	0.037316	0	0	0	0	0	0
8	86.4	0	0	0	0.7032853	6.1688885	0.3895238	2.113725	0.0382952	0.1136178	0.005175	0.007240258	0.049075	0.143152	0.007763	0.01086	0	0	0.006502	0.009096
10	86.4	0	0.000575	0.0008044	0.706964	8.1196479	0.4076665	3.2213833	0.0471159	0.2326973	0.010779	0.02953451	0.062961	0.299372	0.016169	0.044302	0.003392	0.004746	0.013285	0.036744
12	86.4	0	0.0013022	0.0034275	0.7089537	10.071339	0.4145487	4.3600773	0.0511684	0.3693588	0.015007	0.065502892	0.07074	0.48534	0.021898	0.097398	0.007865	0.020476	0.019158	0.081998
46	86.4	0	0.0039487	0.1614648	0.7285816	42.737762	0.4390676	23.906152	0.0582921	2.9372871	0.023895	1.078528761	0.085882	4.233316	0.030748	1.422808	0.019496	0.820698	0.034518	1.528197
48	86.4	0	0.0039769	0.1719733	0.7295987	44.6244	0.4402726	25.050564	0.0585244	3.0901729	0.024037	1.141714569	0.086278	4.458977	0.030918	1.503973	0.01963	0.87249	0.034727	1.619587
50	86.4	0	0.004005	0.1825228	0.7306137	46.507112	0.441476	26.19424	0.0587565	3.2431599	0.024179	1.205072008	0.086675	4.684937	0.031088	1.585323	0.019765	0.924473	0.034937	1.711235
52	86.4	0	0.0040331	0.1931131	0.7316265	48.385908	0.4426777	27.337178	0.0589884	3.3962473	0.024322	1.268600424	0.087071	4.911197	0.031259	1.666858	0.019899	0.976646	0.035147	1.803141





Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It was chosen to generate results for comparison.

Figure 3.13 compares the air concentrations of source particles (g/m^3) in Room 2, where the volume source was assumed to be located. Figure 3.14 compares the floor deposition concentrations of source particles (g/m^2) in the same room. Figures 3.15 and 3.16 compare the air concentrations and floor deposition concentrations, respectively, in Room 9 which did not have direct air exchange with Room 2. In the figures, the blue solid curve displays the results from the spreadsheets while the red dashed curve displays the results from RESRAD-BUILD. The comparison of concentrations in the air and on the floor for the other rooms were like those for Room 9. As shown in the figures, the concentration results from RESRAD-BUILD and the spreadsheets are in good agreement.

Table 3.27 compares calculated average concentrations of radionuclides in the air and on the floor over the exposure duration in Room 1. Table 3.28 compares the same calculated results in Room 6. The comparisons show good agreement between the calculated results from RESRAD-BUILD and the spreadsheets. All but six results differ by less than 1%. The six exceptions are the calculated concentrations on the floor at time 0; for them, the difference is more than 1% but less than 1.2%. The same calculated results in the other rooms from RESRAD-BUILD and the spreadsheets also show good agreement.

3.5 CASE V – AN AREA SOURCE IN ROOM 3 WITH NO SCHEDULED VACUUMING

Case V considers an area source of 36 m^2 located in Room 3. The air exchange rates between rooms and with the outside environment were the same as in Cases III and IV. Vacuuming to remove dust deposition on the floor was not considered. The estimated concentrations of source particles and radionuclides in the air and on the floor of each room from RESRAD-BUILD and the verification spreadsheets were compared.

The room dimensions, ventilation rates between rooms and with the outside environment, deposition velocity, and resuspension rate assumed for Cases III and IV were applicable to Case IV (Table 3.20). The contaminated source materials were assumed to be eroded and released to the indoor air over several phases with a constant erosion/release rate in each phase. Table 3.29 lists the beginning and ending time and fraction of the source materials involved in each release phase.

The air release rates calculated by RESRAD-BUILD, listed in the intermediate output file "AirRelRate1.out," were in terms of the fraction of the initial source inventory. They were multiplied by the initial mass assumed for the source materials for comparison with the calculated source release rates from the spreadsheets. Table 3.30 shows the comparison of source release rates.

Equations B.10 and B.11 in the User's Manual of RESRAD-BUILD, Vol. 1 (Yu et al. 2022) were solved numerically in the spreadsheets to obtain source particulate concentrations in each room. Table 3.31 presents part of the calculations and results at different time steps in the spreadsheets.

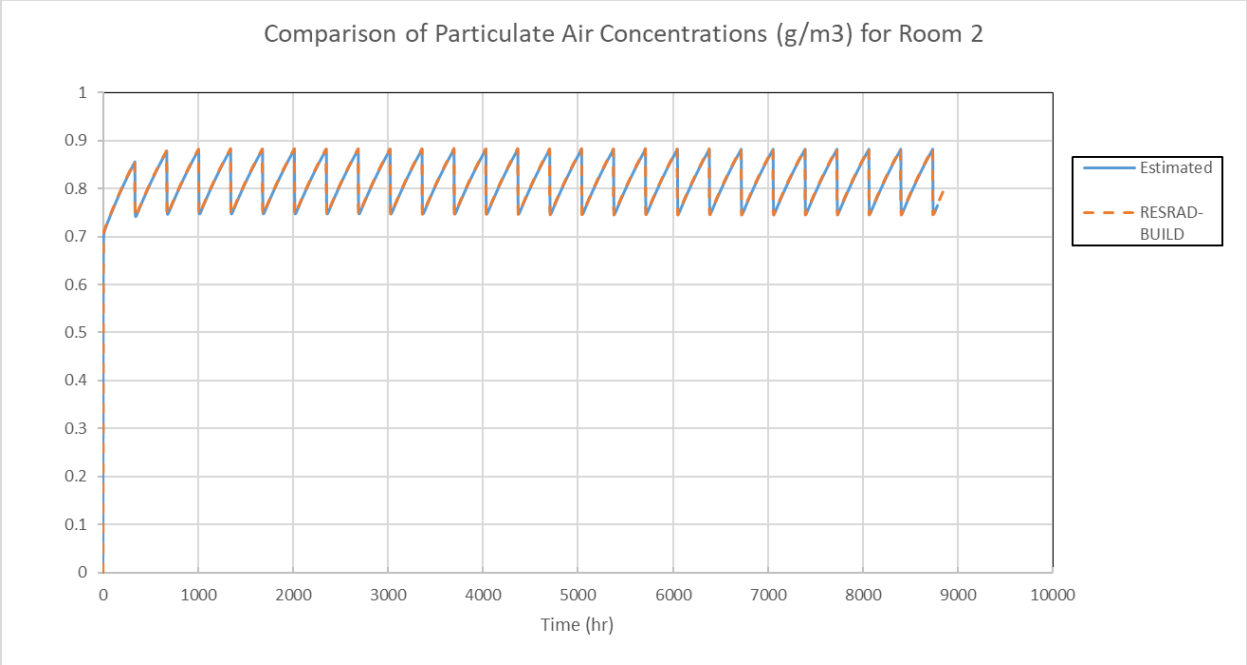


Figure 3.13 Comparison of Calculated Source Particulate Concentrations in the Air of Room 2 for Case IV

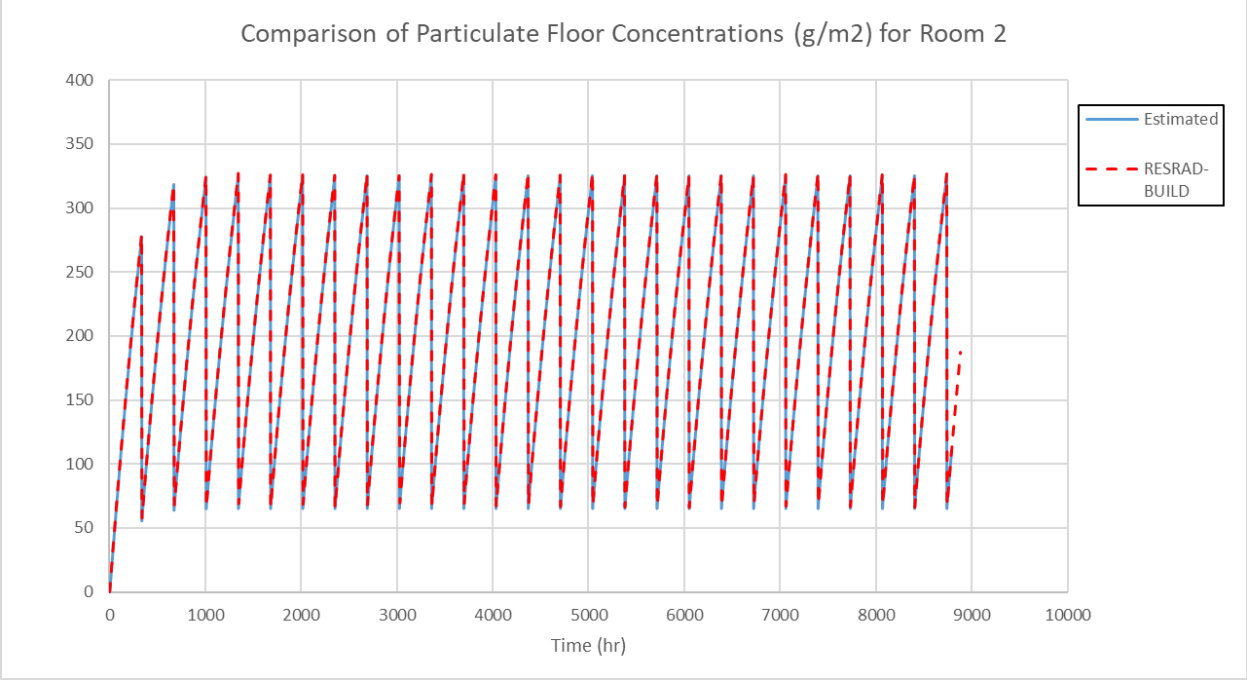


Figure 3.14 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 2 for Case IV

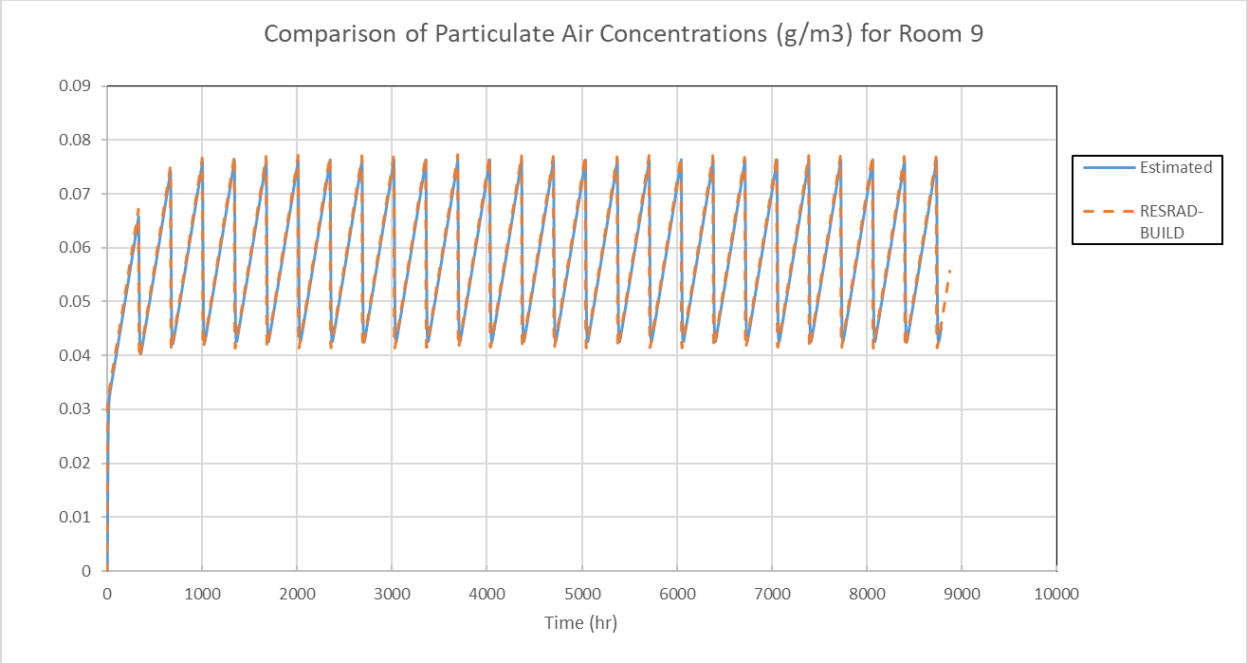


Figure 3.15 Comparison of Calculated Source Particulate Concentrations in the Air of Room 9 for Case IV

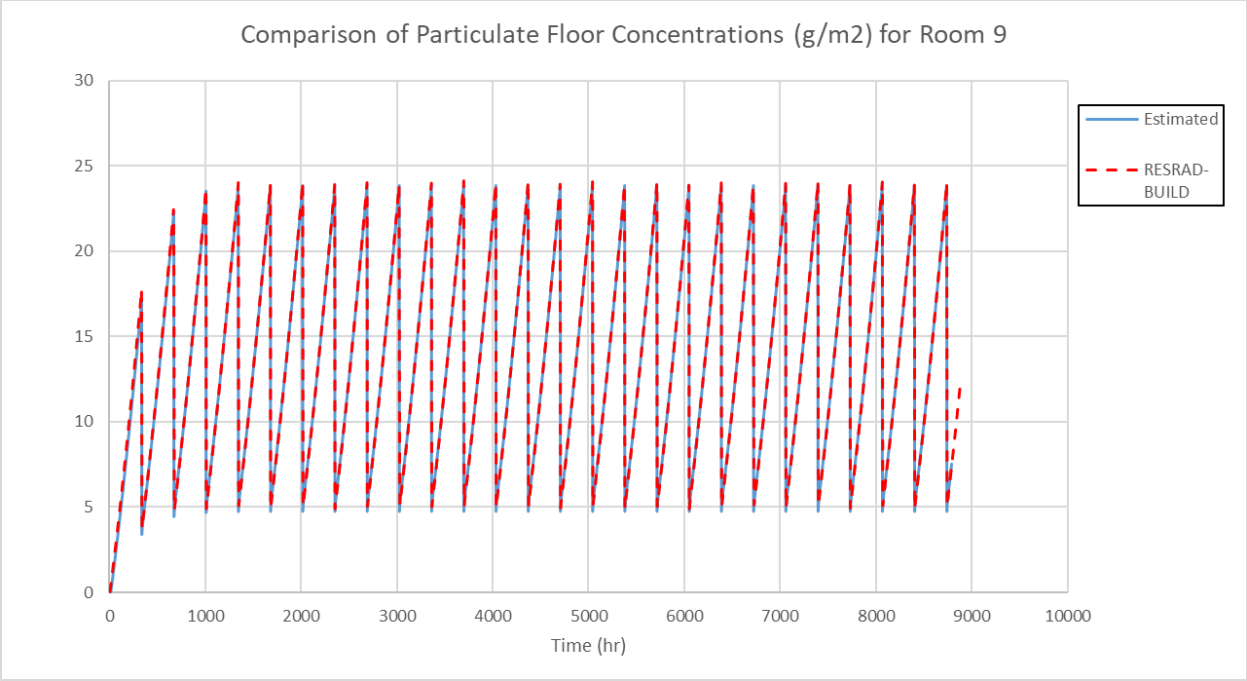


Figure 3.16 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 9 for Case IV

Table 3.27 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 1 for Case IV

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
1	0	RA-226	RA-226	Air	7.02E-03	6.95E-03	0.91
1	0	RA-226	RA-226	Floor	1.55E+00	1.54E+00	1.17
1	0	RA-226	PB-210	Air	2.81E-05	2.81E-05	0.22
1	0	RA-226	PB-210	Floor	6.52E-03	6.50E-03	0.35
1	0	RA-226	PO-210	Air	3.85E-06	3.85E-06	0.03
1	0	RA-226	PO-210	Floor	8.97E-04	8.96E-04	0.07
1	0.25	RA-226	RA-226	Air	7.48E-03	7.48E-03	0.10
1	0.25	RA-226	RA-226	Floor	1.79E+00	1.79E+00	0.14
1	0.25	RA-226	PB-210	Air	8.68E-05	8.67E-05	0.06
1	0.25	RA-226	PB-210	Floor	2.08E-02	2.08E-02	0.10
1	0.25	RA-226	PO-210	Air	2.46E-05	2.46E-05	0.00
1	0.25	RA-226	PO-210	Floor	5.90E-03	5.89E-03	0.03
1	0.5	RA-226	RA-226	Air	7.31E-03	7.29E-03	0.29
1	0.5	RA-226	RA-226	Floor	1.71E+00	1.71E+00	0.11
1	0.5	RA-226	PB-210	Air	1.41E-04	1.40E-04	0.27
1	0.5	RA-226	PB-210	Floor	3.30E-02	3.30E-02	0.11
1	0.5	RA-226	PO-210	Air	5.74E-05	5.73E-05	0.23
1	0.5	RA-226	PO-210	Floor	1.35E-02	1.34E-02	0.08
1	0.75	RA-226	RA-226	Air	7.46E-03	7.46E-03	0.03
1	0.75	RA-226	RA-226	Floor	1.78E+00	1.78E+00	0.04
1	0.75	RA-226	PB-210	Air	2.00E-04	2.00E-04	0.02
1	0.75	RA-226	PB-210	Floor	4.79E-02	4.79E-02	0.05
1	0.75	RA-226	PO-210	Air	1.01E-04	1.01E-04	0.01
1	0.75	RA-226	PO-210	Floor	2.41E-02	2.41E-02	0.03
1	1	RA-226	RA-226	Air	7.33E-03	7.30E-03	0.36
1	1	RA-226	RA-226	Floor	1.72E+00	1.72E+00	0.33
1	1	RA-226	PB-210	Air	2.52E-04	2.51E-04	0.34
1	1	RA-226	PB-210	Floor	5.92E-02	5.91E-02	0.32
1	1	RA-226	PO-210	Air	1.46E-04	1.45E-04	0.31
1	1	RA-226	PO-210	Floor	3.43E-02	3.42E-02	0.29
1	1.25	RA-226	RA-226	Air	7.45E-03	7.45E-03	0.00
1	1.25	RA-226	RA-226	Floor	1.78E+00	1.78E+00	0.05
1	1.25	RA-226	PB-210	Air	3.12E-04	3.12E-04	0.01
1	1.25	RA-226	PB-210	Floor	7.43E-02	7.44E-02	0.05
1	1.25	RA-226	PO-210	Air	1.99E-04	1.99E-04	0.03
1	1.25	RA-226	PO-210	Floor	4.74E-02	4.74E-02	0.07
1	1.5	RA-226	RA-226	Air	7.35E-03	7.32E-03	0.41
1	1.5	RA-226	RA-226	Floor	1.73E+00	1.72E+00	0.25
1	1.5	RA-226	PB-210	Air	3.62E-04	3.60E-04	0.40
1	1.5	RA-226	PB-210	Floor	8.51E-02	8.49E-02	0.23
1	1.5	RA-226	PO-210	Air	2.48E-04	2.47E-04	0.39
1	1.5	RA-226	PO-210	Floor	5.83E-02	5.81E-02	0.22

Table 3.27 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
1	0	CS-137	CS-137	Air	6.99E-03	6.93E-03	0.91
1	0	CS-137	CS-137	Floor	1.55E+00	1.53E+00	1.17
1	0.25	CS-137	CS-137	Air	7.42E-03	7.41E-03	0.10
1	0.25	CS-137	CS-137	Floor	1.78E+00	1.77E+00	0.14
1	0.5	CS-137	CS-137	Air	7.21E-03	7.19E-03	0.29
1	0.5	CS-137	CS-137	Floor	1.69E+00	1.69E+00	0.11
1	0.75	CS-137	CS-137	Air	7.32E-03	7.32E-03	0.02
1	0.75	CS-137	CS-137	Floor	1.75E+00	1.75E+00	0.03
1	1	CS-137	CS-137	Air	7.14E-03	7.12E-03	0.35
1	1	CS-137	CS-137	Floor	1.68E+00	1.67E+00	0.32
1	1.25	CS-137	CS-137	Air	7.22E-03	7.22E-03	0.02
1	1.25	CS-137	CS-137	Floor	1.72E+00	1.72E+00	0.06
1	1.5	CS-137	CS-137	Air	7.08E-03	7.05E-03	0.40
1	1.5	CS-137	CS-137	Floor	1.67E+00	1.66E+00	0.23
1	0	CO-60	CO-60	Air	6.90E-03	6.83E-03	0.92
1	0	CO-60	CO-60	Floor	1.53E+00	1.51E+00	1.19
1	0.25	CO-60	CO-60	Air	7.12E-03	7.12E-03	0.10
1	0.25	CO-60	CO-60	Floor	1.71E+00	1.70E+00	0.14
1	0.5	CO-60	CO-60	Air	6.75E-03	6.72E-03	0.47
1	0.5	CO-60	CO-60	Floor	1.59E+00	1.58E+00	0.95
1	0.75	CO-60	CO-60	Air	6.66E-03	6.65E-03	0.02
1	0.75	CO-60	CO-60	Floor	1.59E+00	1.59E+00	0.03
1	1	CO-60	CO-60	Air	6.32E-03	6.30E-03	0.35
1	1	CO-60	CO-60	Floor	1.49E+00	1.48E+00	0.32
1	1.25	CO-60	CO-60	Air	6.22E-03	6.22E-03	0.02
1	1.25	CO-60	CO-60	Floor	1.48E+00	1.48E+00	0.07
1	1.5	CO-60	CO-60	Air	5.94E-03	5.91E-03	0.40
1	1.5	CO-60	CO-60	Floor	1.40E+00	1.39E+00	0.23

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.28 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 6 for Case IV

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
6	0	RA-226	RA-226	Air	1.24E-01	1.23E-01	0.60
6	0	RA-226	RA-226	Floor	2.80E+01	2.76E+01	1.16
6	0	RA-226	PB-210	Air	4.90E-04	4.89E-04	0.19
6	0	RA-226	PB-210	Floor	1.16E-01	1.15E-01	0.72
6	0	RA-226	PO-210	Air	6.70E-05	6.69E-05	0.04
6	0	RA-226	PO-210	Floor	1.59E-02	1.58E-02	0.54
6	0.25	RA-226	RA-226	Air	1.29E-01	1.29E-01	0.16
6	0.25	RA-226	RA-226	Floor	3.16E+01	3.14E+01	0.59
6	0.25	RA-226	PB-210	Air	1.50E-03	1.49E-03	0.13
6	0.25	RA-226	PB-210	Floor	3.67E-01	3.65E-01	0.54
6	0.25	RA-226	PO-210	Air	4.24E-04	4.24E-04	0.07
6	0.25	RA-226	PO-210	Floor	1.04E-01	1.04E-01	0.47
6	0.5	RA-226	RA-226	Air	1.27E-01	1.27E-01	0.29
6	0.5	RA-226	RA-226	Floor	3.03E+01	3.01E+01	0.65
6	0.5	RA-226	PB-210	Air	2.44E-03	2.44E-03	0.27
6	0.5	RA-226	PB-210	Floor	5.83E-01	5.80E-01	0.64
6	0.5	RA-226	PO-210	Air	9.97E-04	9.94E-04	0.23
6	0.5	RA-226	PO-210	Floor	2.38E-01	2.36E-01	0.61
6	0.75	RA-226	RA-226	Air	1.29E-01	1.29E-01	0.12
6	0.75	RA-226	RA-226	Floor	3.15E+01	3.13E+01	0.49
6	0.75	RA-226	PB-210	Air	3.46E-03	3.45E-03	0.11
6	0.75	RA-226	PB-210	Floor	8.45E-01	8.41E-01	0.50
6	0.75	RA-226	PO-210	Air	1.74E-03	1.74E-03	0.08
6	0.75	RA-226	PO-210	Floor	4.26E-01	4.24E-01	0.48
6	1	RA-226	RA-226	Air	1.27E-01	1.27E-01	0.31
6	1	RA-226	RA-226	Floor	3.05E+01	3.02E+01	0.85
6	1	RA-226	PB-210	Air	4.37E-03	4.36E-03	0.30
6	1	RA-226	PB-210	Floor	1.05E+00	1.04E+00	0.84
6	1	RA-226	PO-210	Air	2.53E-03	2.52E-03	0.28
6	1	RA-226	PO-210	Floor	6.06E-01	6.01E-01	0.82
6	1.25	RA-226	RA-226	Air	1.29E-01	1.29E-01	0.09
6	1.25	RA-226	RA-226	Floor	3.13E+01	3.12E+01	0.41
6	1.25	RA-226	PB-210	Air	5.38E-03	5.38E-03	0.09
6	1.25	RA-226	PB-210	Floor	1.31E+00	1.31E+00	0.40
6	1.25	RA-226	PO-210	Air	3.43E-03	3.43E-03	0.07
6	1.25	RA-226	PO-210	Floor	8.36E-01	8.33E-01	0.39
6	1.5	RA-226	RA-226	Air	1.27E-01	1.27E-01	0.35
6	1.5	RA-226	RA-226	Floor	3.06E+01	3.03E+01	0.77
6	1.5	RA-226	PB-210	Air	6.28E-03	6.26E-03	0.34
6	1.5	RA-226	PB-210	Floor	1.51E+00	1.49E+00	0.76
6	1.5	RA-226	PO-210	Air	4.30E-03	4.28E-03	0.33
6	1.5	RA-226	PO-210	Floor	1.03E+00	1.02E+00	0.74

Table 3.28 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\lvert\frac{RESRAD - Spreadsheet}{RESRAD}\right\rvert$
6	0	CS-137	CS-137	Air	1.23E-01	1.23E-01	0.60
6	0	CS-137	CS-137	Floor	2.79E+01	2.76E+01	1.15
6	0.25	CS-137	CS-137	Air	1.28E-01	1.28E-01	0.15
6	0.25	CS-137	CS-137	Floor	3.14E+01	3.12E+01	0.59
6	0.5	CS-137	CS-137	Air	1.25E-01	1.25E-01	0.28
6	0.5	CS-137	CS-137	Floor	2.99E+01	2.97E+01	0.64
6	0.75	CS-137	CS-137	Air	1.26E-01	1.26E-01	0.11
6	0.75	CS-137	CS-137	Floor	3.09E+01	3.07E+01	0.49
6	1	CS-137	CS-137	Air	1.24E-01	1.24E-01	0.30
6	1	CS-137	CS-137	Floor	2.97E+01	2.95E+01	0.84
6	1.25	CS-137	CS-137	Air	1.25E-01	1.25E-01	0.08
6	1.25	CS-137	CS-137	Floor	3.04E+01	3.03E+01	0.39
6	1.5	CS-137	CS-137	Air	1.23E-01	1.22E-01	0.33
6	1.5	CS-137	CS-137	Floor	2.94E+01	2.92E+01	0.76
6	0	CO-60	CO-60	Air	1.22E-01	1.21E-01	0.61
6	0	CO-60	CO-60	Floor	2.75E+01	2.72E+01	1.16
6	0.25	CO-60	CO-60	Air	1.23E-01	1.23E-01	0.15
6	0.25	CO-60	CO-60	Floor	3.01E+01	2.99E+01	0.59
6	0.5	CO-60	CO-60	Air	1.17E-01	1.17E-01	0.28
6	0.5	CO-60	CO-60	Floor	2.79E+01	2.77E+01	0.64
6	0.75	CO-60	CO-60	Air	1.15E-01	1.15E-01	0.11
6	0.75	CO-60	CO-60	Floor	2.81E+01	2.79E+01	0.48
6	1	CO-60	CO-60	Air	1.10E-01	1.09E-01	0.30
6	1	CO-60	CO-60	Floor	2.63E+01	2.61E+01	0.84
6	1.25	CO-60	CO-60	Air	1.07E-01	1.07E-01	0.08
6	1.25	CO-60	CO-60	Floor	2.62E+01	2.61E+01	0.39
6	1.5	CO-60	CO-60	Air	1.03E-01	1.03E-01	0.33
6	1.5	CO-60	CO-60	Floor	2.47E+01	2.45E+01	0.75

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.29 Source Releases Assumed for Case V

Source Releases											
Location (Room No.)		3		Air Fraction		1		Initial mass		1.000E+03	g
	Release 1	Release 2	Release 3	Release 4	Release 5	Release 6	Release 7	Release 8	Release 9	Release 10	
Start time (d)	0	30	60	100	120	200	280	350	1000	1100	
Start time (hr)	0	720	1440	2400	2880	4800	6720	8400	24000	26400	
End time (d)	30	60	100	120	200	280	350	1000	1100	1500	
End time (hr)	720	1440	2400	2880	4800	6720	8400	24000	26400	36000	
Fraction released	0.1	0.15	0.25	0.3	0.1	0	0.1	0	0	0	
Release rate (1/hr)	0.000138889	0.000208	0.00026	0.000625	5.20833E-05	0	5.95238E-05	0	0	0	

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

Table 3.30 Comparison of Calculated Air Release Rates from RESRAD-BUILD and Spreadsheets for Case V

From "AirRelRate1.out"													
Rate of release of source material to air								Volume of source room				90	m3
fraction of source per second per volume (m3) of the room of release													
4.29E-10	from	time	0	to	time	2592000	seconds						
6.43E-10	from	time	2592000	to	time	5184000	seconds						
8.04E-10	from	time	5184000	to	time	8640000	seconds						
1.93E-09	from	time	8640000	to	time	10368000	seconds						
1.61E-10	from	time	10368000	to	time	17280000	seconds						
1.84E-10	from	time	24192000	to	time	30240000	seconds						

	Estimated		RESRAD-BUILD	
time (hr)	Air release rate (1/hr)		time (hr)	Air release rate (1/hr)
0	0		0.00	0.00E+00
2	0.0001389		0.10	1.39E-04
4	0.0001389		720.00	1.39E-04
6	0.0001389		720.01	2.08E-04
8	0.0001389		1440.00	2.08E-04
10	0.0001389		1440.01	2.60E-04
12	0.0001389		2400.00	2.60E-04
14	0.0001389		2400.01	6.26E-04
16	0.0001389		2880.00	6.26E-04
18	0.0001389		2880.01	5.21E-05
20	0.0001389		4800.00	5.21E-05
22	0.0001389		4800.01	0.00E+00
24	0.0001389		6720.00	0.00E+00
26	0.0001389		6720.01	5.95E-05
28	0.0001389		8400.00	5.95E-05
30	0.0001389		8400.01	0.00E+00
32	0.0001389		8800.00	0.00E+00

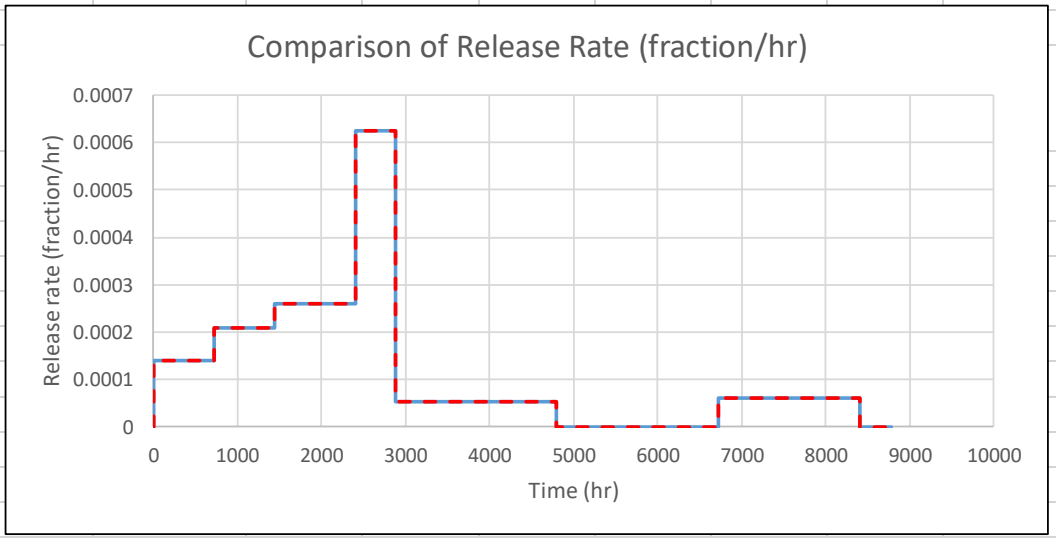
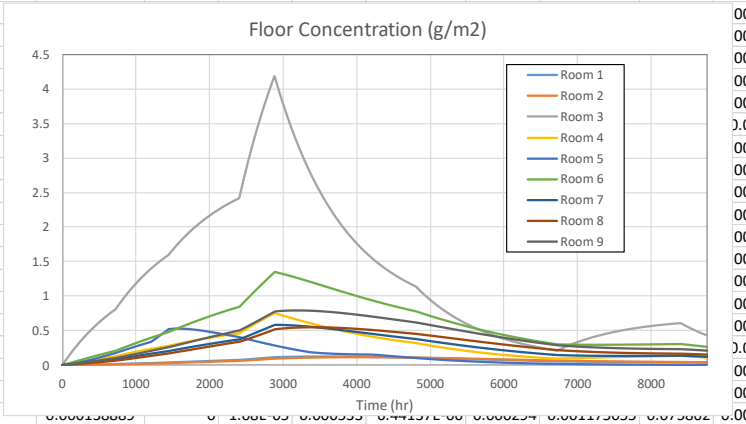
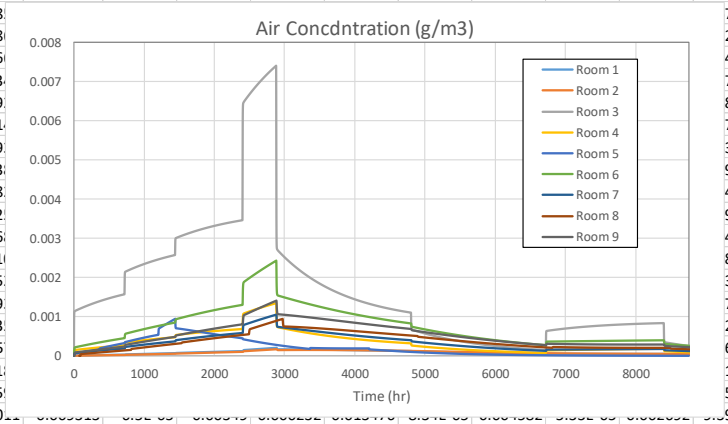


Table 3.31 Calculations of Source Particulate Concentrations in the Air and on the Floor of Each Room for Case V

	time interval	2	hr																			
			Room 1		Room 2		Room 3		Room 4		Room 5		Room 6		Room 7		Room 8		Room 9	
	Source_Rm (1-Yes, 0-No)		0		0		1		0		0		0		0		0		0	
time (hr)	Release rate (1/hr)	Vacuum Removal (1-Yes, 0-No)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.000138889	0	0	0	0	0	0.00082897	0.002319	0	0	0	0	0	0	0	0	0	0	0	0
4	0.000138889	0	0	0	0	0	0.001052516	0.004943	8.042E-05	0.000113	0	0	9.98E-05	0.00014	0	0	0	0	0	0
6	0.000138889	0	0	0	0	0	0.001113573	0.007956	0.00012165	0.000395	1.94E-05	2.71E-05	0.000157	0.000498	2.9E-05	4.06E-05	0	0	2.43E-05	3.4E-05
8	0.000138889	0	2.15E-06	3.01E-06	0	0	0.001131137	0.011067	0.000137672	0.000756	3.51E-05	0.000103	0.000186	0.000976	5.27E-05	0.000155	1.27E-05	1.78E-05	4.32E-05	0.000128
10	0.000138889	0	4.29E-06	1.2E-05	9.24259E-07	1.29E-06	0.001137058	0.014201	0.000143805	0.001147	4.53E-05	0.000215	0.000201	0.001514	6.56E-05	0.00032	2.6E-05	7.18E-05	5.83E-05	0.00027
12	0.000138889	0	6.11E-06	2.65E-05	2.09379E-06	5.51E-06	0.001140257	0.017336	0.000146419	0.001549	5.15E-05	0.00035	0.000209	0.002082	7.18E-05	0.000511	3.55E-05	0.000158	6.94E-05	0.000447
14									0001478										7E-05	0.00065
16									0001488										2E-05	0.000869
18									0001496										4E-05	0.001097
20									0001503										7E-05	0.00133
22									0001509										8E-05	0.001566
24									0.000151										7E-05	0.001805
26									0001519										3E-05	0.002045
28									0001523										9E-05	0.002285
30									0001528										4E-05	0.002527
32									0001532										9E-05	0.002768
34									0001536										4E-05	0.003011
36									0001541										8E-05	0.003253
38									0001545										3E-05	0.003497
40									0001549										7E-05	0.00374
42									0001553										2E-05	0.003984
44									0.000155										6E-05	0.004228
46									0001561										1E-05	0.004473
48									0001565										5E-05	0.004718
50									0.000157										9E-05	0.004963
52	0.000138889	0	1.09E-05	0.000561	6.48659E-06	0.000311	0.001176682	0.07888	0.000157423	0.00972	6.53E-05	0.003659	0.000233	0.014078	8.38E-05	0.0048	5.36E-05	0.002832	9.44E-05	0.005209
54	0.000138889	0	1.09E-05	0.00059	6.53183E-06	0.000328	0.001178305	0.081891	0.000157835	0.010126	6.56E-05	0.003829	0.000233	0.014679	8.41E-05	0.005017	5.39E-05	0.002972	9.48E-05	0.005455





Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It was chosen to generate results for comparison.

During the analysis of Case V, the RESRAD-BUILD code generated an intermediate output file "AirRelConcSource1.out" that listed the concentrations in the air and on the floor of each room at various time points. The concentrations were expressed as the fraction of the initial source per m^3 of air and the fraction of the initial source per m^2 on the floor. They were multiplied by the total mass of source (materials) to convert the concentration to mass of source (particulate) per unit volume in the air (g/m^3) and mass of source (particulate) per unit area on the floor (g/m^2) for comparison with spreadsheet calculations.

Figures 3.17 and 3.18 compare the air concentrations (g/m^3) and floor deposition concentrations (g/m^2), respectively, in Room 1, which did not have direct air exchange with Room 3, where the area source was located. Figures 3.19 and 3.20 compare the air concentrations and floor deposition concentrations, respectively, in Room 3. Figures 3.21 and 3.22 compare the air concentrations and floor deposition concentrations, respectively, in Room 5. In the figures, the blue solid curve displays the results from the spreadsheets while the red dashed curve displays the results from RESRAD-BUILD. As shown in the figures, the concentration results from RESRAD-BUILD and the spreadsheets are in good agreement. Good agreement was observed with the concentration results in other rooms.

Table 3.32 compares calculated average concentrations of radionuclides in the air and on the floor over the exposure duration in Room 3. Table 3.33 compares the same calculated results in Room 9. The comparisons show good agreement between the calculated results from RESRAD-BUILD and the spreadsheets; all results differ by less than 3%. The differences seem to increase with time, which is typical with numerical analysis solutions.

3.6 CASE VI – AN AREA SOURCE IN ROOM 3 WITH SCHEDULED VACUUMING

Case VI considered the same area source as Case V that had an area of 36 m^2 and was in Room 3 of the building. It was assumed that regular vacuuming was conducted to remove dust deposition on the floor. The efficiency of vacuuming was 80%. Potential radiation dose and cancer risk to four receptors, located in Rooms 1, 3, 6, and 9, respectively, via the inhalation of airborne particulates, ingestion of source particles, and external radiation emitted by airborne particulates were evaluated.

The room dimensions, ventilation rates between rooms and with the outside environment, deposition velocity, and resuspension rate assumed for Case V (same as Cases III and IV) were applicable to Case VI (Table 3.20). The contaminated source materials were assumed to be eroded away over several phases with a constant erosion rate in each phase, as assumed in Case V (Table 3.29). However, only 50% of the eroded materials were assumed to become airborne and get into the indoor air.

3.6.1 Calculation and Comparison of Release Rates and Source Concentrations

The air release rates calculated by RESRAD-BUILD, listed in the intermediate output file "AirRelRate1.out," were in terms of the fraction of the initial source inventory. They were multiplied by the initial mass assumed for the source materials for comparison with the calculated air release rates from the spreadsheets. Table 3.34 shows that the converted air release rates from RESRAD-BUILD match those from the spreadsheets.

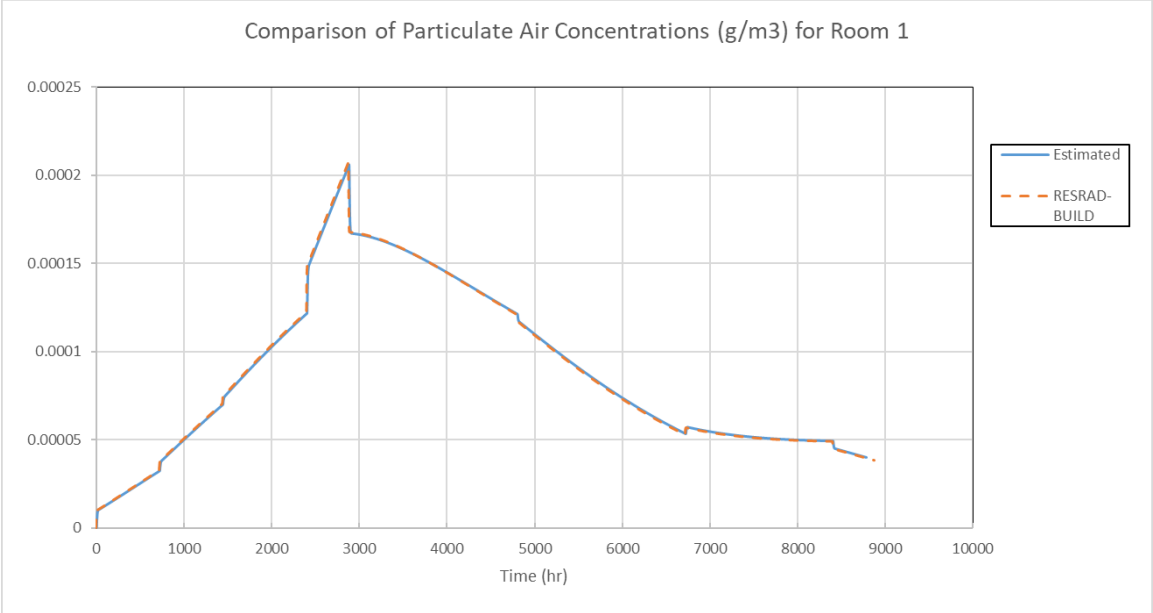


Figure 3.17 Comparison of Calculated Source Particulate Concentrations in the Air of Room 1 for Case V

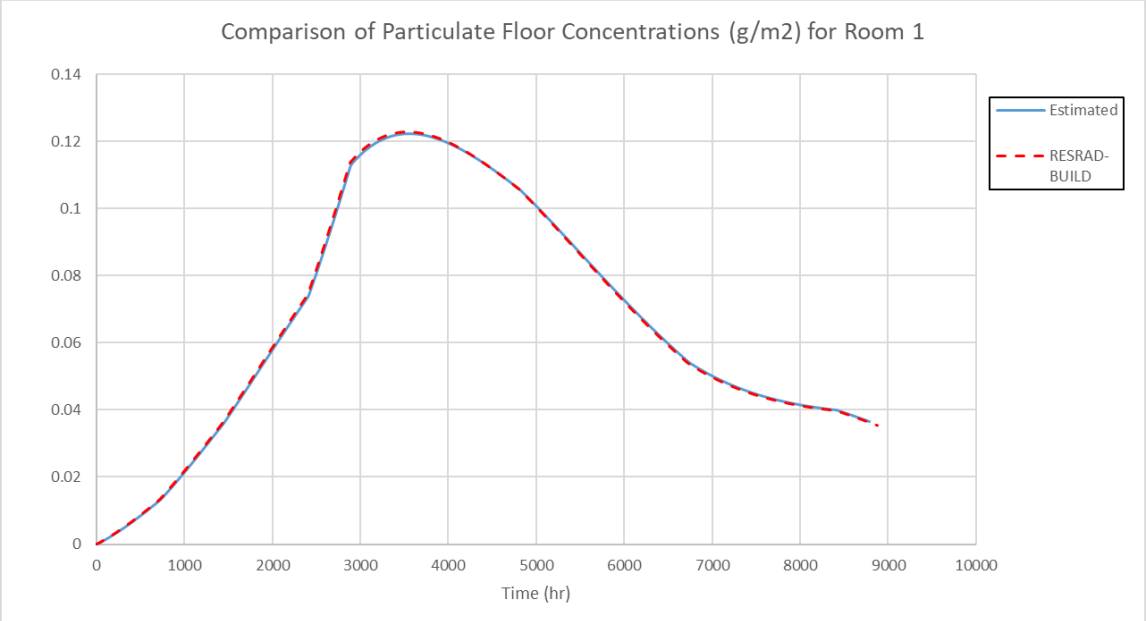


Figure 3.18 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 1 for Case V

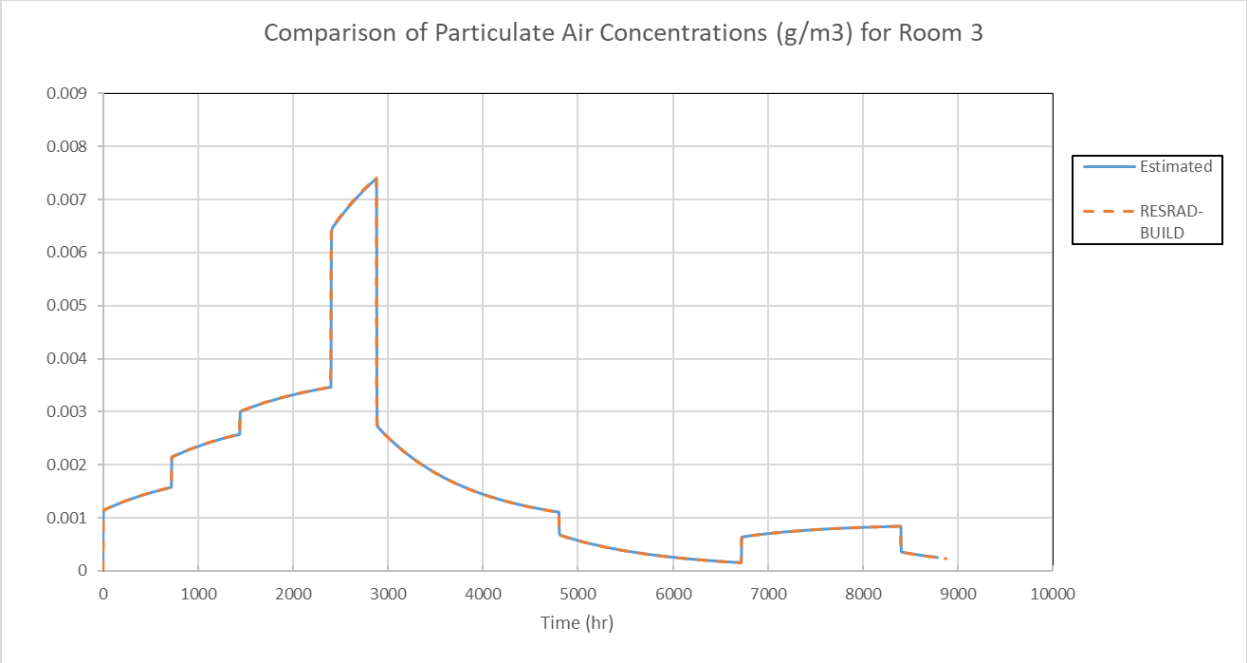


Figure 3.19 Comparison of Calculated Source Particulate Concentrations in the Air of Room 3 for Case V

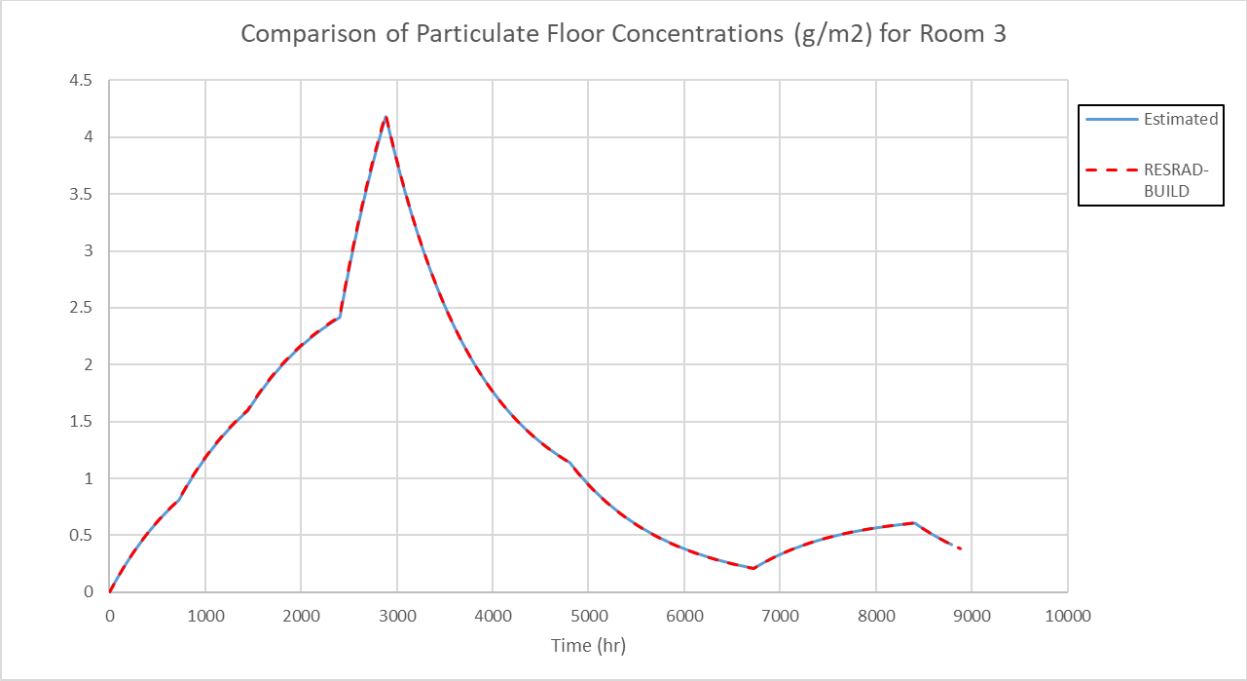


Figure 3.20 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 3 for Case V

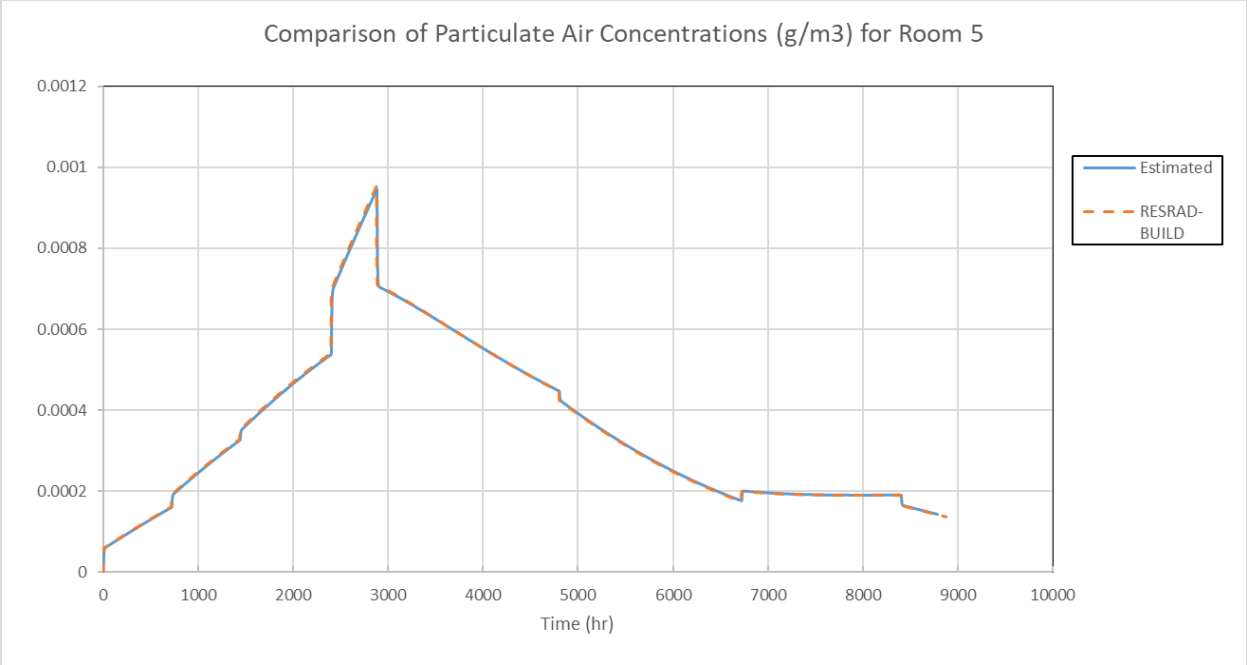


Figure 3.21 Comparison of Calculated Source Particulate Concentrations in the Air of Room 5 for Case V

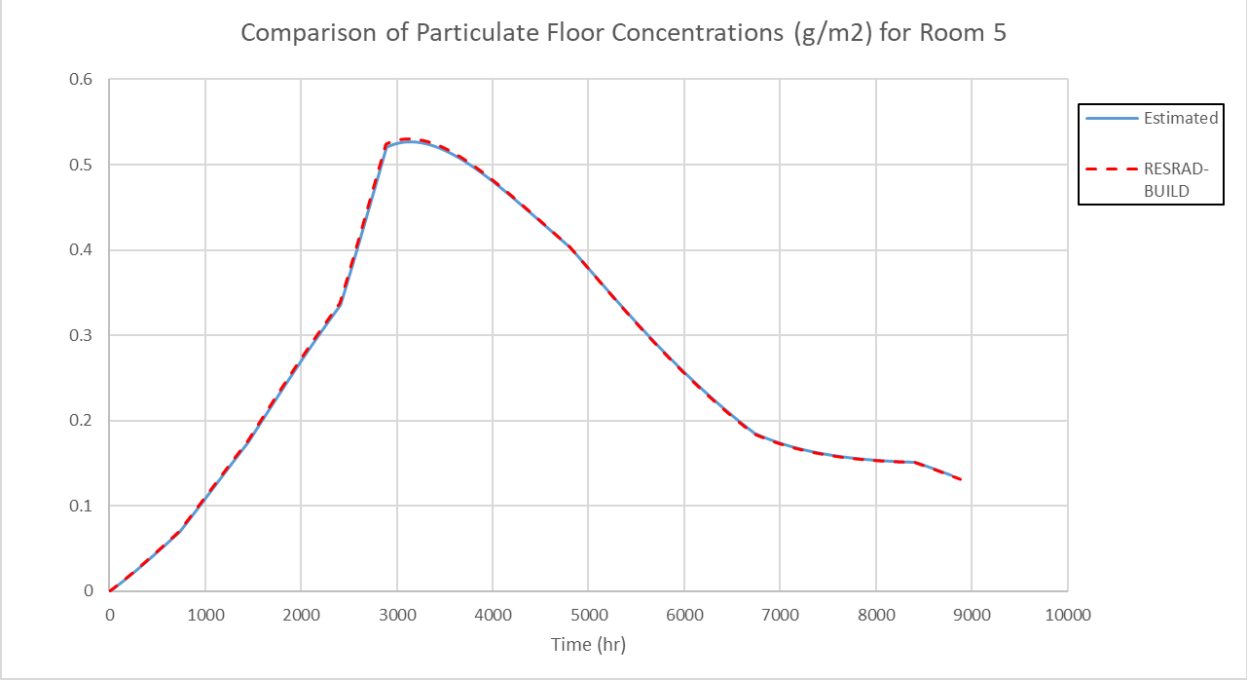


Figure 3.22 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 5 for Case V

Table 3.32 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 3 for Case V

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
3	0	RA-226	RA-226	Air	8.43E-05	8.41E-05	0.27
3	0	RA-226	RA-226	Floor	4.48E-02	4.46E-02	0.33
3	0	RA-226	PB-210	Air	3.87E-07	3.86E-07	0.12
3	0	RA-226	PB-210	Floor	2.27E-04	2.27E-04	0.20
3	0	RA-226	PO-210	Air	5.65E-08	5.65E-08	0.01
3	0	RA-226	PO-210	Floor	3.43E-05	3.43E-05	0.07
3	0.25	RA-226	RA-226	Air	1.11E-04	1.11E-04	0.08
3	0.25	RA-226	RA-226	Floor	9.51E-02	9.50E-02	0.10
3	0.25	RA-226	PB-210	Air	1.16E-06	1.16E-06	0.15
3	0.25	RA-226	PB-210	Floor	1.06E-03	1.06E-03	0.04
3	0.25	RA-226	PO-210	Air	3.03E-07	3.03E-07	0.24
3	0.25	RA-226	PO-210	Floor	2.90E-04	2.90E-04	0.04
3	0.5	RA-226	RA-226	Air	1.82E-05	1.84E-05	1.05
3	0.5	RA-226	RA-226	Floor	2.49E-02	2.51E-02	0.70
3	0.5	RA-226	PB-210	Air	3.26E-07	3.30E-07	1.06
3	0.5	RA-226	PB-210	Floor	4.51E-04	4.54E-04	0.71
3	0.5	RA-226	PO-210	Air	1.26E-07	1.28E-07	1.09
3	0.5	RA-226	PO-210	Floor	1.76E-04	1.77E-04	0.75
3	0.75	RA-226	RA-226	Air	2.33E-05	2.33E-05	0.06
3	0.75	RA-226	RA-226	Floor	1.64E-02	1.64E-02	0.09
3	0.75	RA-226	PB-210	Air	6.23E-07	6.23E-07	0.01
3	0.75	RA-226	PB-210	Floor	4.48E-04	4.48E-04	0.07
3	0.75	RA-226	PO-210	Air	3.14E-07	3.14E-07	0.07
3	0.75	RA-226	PO-210	Floor	2.28E-04	2.28E-04	0.04
3	1	RA-226	RA-226	Air	4.11E-06	4.17E-06	1.37
3	1	RA-226	RA-226	Floor	6.52E-03	6.60E-03	1.19
3	1	RA-226	PB-210	Air	1.37E-07	1.39E-07	1.37
3	1	RA-226	PB-210	Floor	2.17E-04	2.19E-04	1.19
3	1	RA-226	PO-210	Air	7.80E-08	7.91E-08	1.39
3	1	RA-226	PO-210	Floor	1.23E-04	1.25E-04	1.21
3	1.25	RA-226	RA-226	Air	8.40E-07	8.58E-07	2.16
3	1.25	RA-226	RA-226	Floor	1.09E-03	1.11E-03	2.00
3	1.25	RA-226	PB-210	Air	3.44E-08	3.52E-08	2.16
3	1.25	RA-226	PB-210	Floor	4.45E-05	4.54E-05	2.00
3	1.25	RA-226	PO-210	Air	2.18E-08	2.22E-08	2.18
3	1.25	RA-226	PO-210	Floor	2.81E-05	2.87E-05	2.02
3	1.5	RA-226	RA-226	Air	2.32E-07	2.39E-07	2.96
3	1.5	RA-226	RA-226	Floor	2.68E-04	2.75E-04	2.78
3	1.5	RA-226	PB-210	Air	1.13E-08	1.16E-08	2.97
3	1.5	RA-226	PB-210	Floor	1.30E-05	1.34E-05	2.79
3	1.5	RA-226	PO-210	Air	7.67E-09	7.90E-09	2.98
3	1.5	RA-226	PO-210	Floor	8.84E-06	9.08E-06	2.80

Table 3.32 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\lvert\frac{RESRAD - Spreadsheet}{RESRAD}\right\rvert$
3	0	CS-137	CS-137	Air	8.40E-05	8.38E-05	0.27
3	0	CS-137	CS-137	Floor	4.46E-02	4.44E-02	0.33
3	0.25	CS-137	CS-137	Air	1.10E-04	1.11E-04	0.09
3	0.25	CS-137	CS-137	Floor	9.44E-02	9.43E-02	0.10
3	0.5	CS-137	CS-137	Air	1.80E-05	1.82E-05	1.06
3	0.5	CS-137	CS-137	Floor	2.46E-02	2.47E-02	0.70
3	0.75	CS-137	CS-137	Air	2.28E-05	2.28E-05	0.05
3	0.75	CS-137	CS-137	Floor	1.61E-02	1.61E-02	0.09
3	1	CS-137	CS-137	Air	4.01E-06	4.07E-06	1.38
3	1	CS-137	CS-137	Floor	6.36E-03	6.44E-03	1.20
3	1.25	CS-137	CS-137	Air	8.14E-07	8.32E-07	2.17
3	1.25	CS-137	CS-137	Floor	1.06E-03	1.08E-03	2.01
3	1.5	CS-137	CS-137	Air	2.24E-07	2.31E-07	2.98
3	1.5	CS-137	CS-137	Floor	2.58E-04	2.65E-04	2.80
3	0	CO-60	CO-60	Air	8.27E-05	8.25E-05	0.27
3	0	CO-60	CO-60	Floor	4.38E-02	4.37E-02	0.33
3	0.25	CO-60	CO-60	Air	1.06E-04	1.07E-04	0.08
3	0.25	CO-60	CO-60	Floor	9.08E-02	9.07E-02	0.10
3	0.5	CO-60	CO-60	Air	1.69E-05	1.71E-05	1.06
3	0.5	CO-60	CO-60	Floor	2.30E-02	2.32E-02	0.70
3	0.75	CO-60	CO-60	Air	2.08E-05	2.07E-05	0.05
3	0.75	CO-60	CO-60	Floor	1.46E-02	1.46E-02	0.09
3	1	CO-60	CO-60	Air	3.57E-06	3.62E-06	1.38
3	1	CO-60	CO-60	Floor	5.66E-03	5.73E-03	1.20
3	1.25	CO-60	CO-60	Air	7.04E-07	7.19E-07	2.18
3	1.25	CO-60	CO-60	Floor	9.12E-04	9.31E-04	2.01
3	1.5	CO-60	CO-60	Air	1.88E-07	1.94E-07	2.98
3	1.5	CO-60	CO-60	Floor	2.17E-04	2.23E-04	2.80

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.33 Comparison of Calculated Average Concentrations of Radionuclides in the Air and on the Floor of Room 9 for Case V

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
9	0	RA-226	RA-226	Air	1.44E-05	1.43E-05	0.94
9	0	RA-226	RA-226	Floor	7.13E-03	7.03E-03	1.34
9	0	RA-226	PB-210	Air	7.23E-08	7.18E-08	0.75
9	0	RA-226	PB-210	Floor	3.84E-05	3.80E-05	1.09
9	0	RA-226	PO-210	Air	1.10E-08	1.09E-08	0.65
9	0	RA-226	PO-210	Floor	5.99E-06	5.93E-06	0.91
9	0.25	RA-226	RA-226	Air	3.52E-05	3.50E-05	0.35
9	0.25	RA-226	RA-226	Floor	2.54E-02	2.52E-02	0.58
9	0.25	RA-226	PB-210	Air	4.01E-07	4.00E-07	0.25
9	0.25	RA-226	PB-210	Floor	2.99E-04	2.97E-04	0.48
9	0.25	RA-226	PO-210	Air	1.12E-07	1.12E-07	0.18
9	0.25	RA-226	PO-210	Floor	8.53E-05	8.50E-05	0.38
9	0.5	RA-226	RA-226	Air	1.82E-05	1.83E-05	0.69
9	0.5	RA-226	RA-226	Floor	1.76E-02	1.77E-02	0.46
9	0.5	RA-226	PB-210	Air	3.39E-07	3.41E-07	0.72
9	0.5	RA-226	PB-210	Floor	3.30E-04	3.31E-04	0.49
9	0.5	RA-226	PO-210	Air	1.35E-07	1.36E-07	0.76
9	0.5	RA-226	PO-210	Floor	1.32E-04	1.33E-04	0.53
9	0.75	RA-226	RA-226	Air	1.01E-05	1.02E-05	0.77
9	0.75	RA-226	RA-226	Floor	8.81E-03	8.87E-03	0.68
9	0.75	RA-226	PB-210	Air	2.71E-07	2.73E-07	0.74
9	0.75	RA-226	PB-210	Floor	2.35E-04	2.36E-04	0.64
9	0.75	RA-226	PO-210	Air	1.36E-07	1.37E-07	0.57
9	0.75	RA-226	PO-210	Floor	1.18E-04	1.19E-04	0.66
9	1	RA-226	RA-226	Air	5.08E-06	5.15E-06	1.28
9	1	RA-226	RA-226	Floor	5.07E-03	5.13E-03	1.09
9	1	RA-226	PB-210	Air	1.72E-07	1.74E-07	1.29
9	1	RA-226	PB-210	Floor	1.72E-04	1.73E-04	1.10
9	1	RA-226	PO-210	Air	9.84E-08	9.97E-08	1.32
9	1	RA-226	PO-210	Floor	9.85E-05	9.96E-05	1.13
9	1.25	RA-226	RA-226	Air	1.74E-06	1.78E-06	2.11
9	1.25	RA-226	RA-226	Floor	1.88E-03	1.91E-03	1.92
9	1.25	RA-226	PB-210	Air	7.18E-08	7.33E-08	2.12
9	1.25	RA-226	PB-210	Floor	7.73E-05	7.87E-05	1.93
9	1.25	RA-226	PO-210	Air	4.54E-08	4.64E-08	2.14
9	1.25	RA-226	PO-210	Floor	4.89E-05	4.99E-05	1.94
9	1.5	RA-226	RA-226	Air	5.51E-07	5.67E-07	2.95
9	1.5	RA-226	RA-226	Floor	6.07E-04	6.24E-04	2.75
9	1.5	RA-226	PB-210	Air	2.67E-08	2.75E-08	2.95
9	1.5	RA-226	PB-210	Floor	2.95E-05	3.03E-05	2.76
9	1.5	RA-226	PO-210	Air	1.82E-08	1.87E-08	2.97
9	1.5	RA-226	PO-210	Floor	2.01E-05	2.06E-05	2.78

Table 3.33 (Continued)

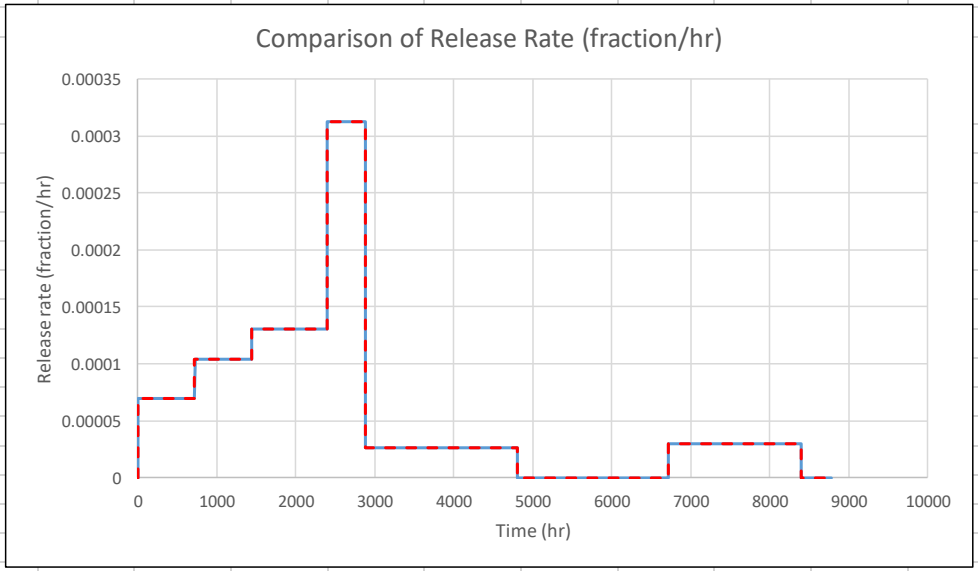
iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration [(pCi/m3) or (pCi/m2)]		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD - Spreadsheet}{RESRAD}\right\|$
9	0	CS-137	CS-137	Air	1.44E-05	1.42E-05	0.94
9	0	CS-137	CS-137	Floor	7.10E-03	7.01E-03	1.34
9	0.25	CS-137	CS-137	Air	3.49E-05	3.48E-05	0.34
9	0.25	CS-137	CS-137	Floor	2.52E-02	2.50E-02	0.57
9	0.5	CS-137	CS-137	Air	1.79E-05	1.81E-05	0.70
9	0.5	CS-137	CS-137	Floor	1.74E-02	1.74E-02	0.47
9	0.75	CS-137	CS-137	Air	9.93E-06	1.00E-05	0.78
9	0.75	CS-137	CS-137	Floor	8.64E-03	8.70E-03	0.69
9	1	CS-137	CS-137	Air	4.96E-06	5.02E-06	1.30
9	1	CS-137	CS-137	Floor	4.95E-03	5.00E-03	1.11
9	1.25	CS-137	CS-137	Air	1.69E-06	1.73E-06	2.13
9	1.25	CS-137	CS-137	Floor	1.82E-03	1.85E-03	1.93
9	1.5	CS-137	CS-137	Air	5.31E-07	5.47E-07	2.96
9	1.5	CS-137	CS-137	Floor	5.86E-04	6.02E-04	2.77
9	0	CO-60	CO-60	Air	1.41E-05	1.40E-05	0.94
9	0	CO-60	CO-60	Floor	6.97E-03	6.88E-03	1.34
9	0.25	CO-60	CO-60	Air	3.35E-05	3.34E-05	0.35
9	0.25	CO-60	CO-60	Floor	2.42E-02	2.40E-02	0.58
9	0.5	CO-60	CO-60	Air	1.68E-05	1.69E-05	0.70
9	0.5	CO-60	CO-60	Floor	1.62E-02	1.63E-02	0.46
9	0.75	CO-60	CO-60	Air	9.04E-06	9.11E-06	0.74
9	0.75	CO-60	CO-60	Floor	7.87E-03	7.92E-03	0.67
9	1	CO-60	CO-60	Air	4.40E-06	4.45E-06	1.30
9	1	CO-60	CO-60	Floor	4.39E-03	4.44E-03	1.11
9	1.25	CO-60	CO-60	Air	1.46E-06	1.49E-06	2.13
9	1.25	CO-60	CO-60	Floor	1.57E-03	1.60E-03	1.93
9	1.5	CO-60	CO-60	Air	4.46E-07	4.60E-07	2.97
9	1.5	CO-60	CO-60	Floor	4.92E-04	5.06E-04	2.77

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.34 Comparison of Calculated Air Release Rates from RESRAD-BUILD and Spreadsheets for Case VI

From "AirRelRate1.out"																
Rate of release of source material to air									Volume of source room			90	m3	(reflect value in input file)		
fraction of source per second per volume (m3) of the room of release																
2.14E-10	from	time	0	to	time	2592000	seconds	720	hr							
3.22E-10	from	time	2592000	to	time	5184000	seconds	1440	hr							
4.02E-10	from	time	5184000	to	time	8640000	seconds	2400	hr							
9.65E-10	from	time	8640000	to	time	10368000	seconds	2880	hr							
8.04E-11	from	time	10368000	to	time	17280000	seconds	4800	hr							
9.19E-11	from	time	24192000	to	time	30240000	seconds	8400	hr							

	Estimated			RRB
time (hr)	Air release rate (1/hr)		time (hr)	Air release rate (1/hr)
0	0		0.00	0.00E+00
2	6.944E-05		0.10	6.95E-05
4	6.944E-05		720.00	6.95E-05
6	6.944E-05		720.01	1.04E-04
8	6.944E-05		1440.00	1.04E-04
10	6.944E-05		1440.01	1.30E-04
12	6.944E-05		2400.00	1.30E-04
14	6.944E-05		2400.01	3.13E-04
16	6.944E-05		2880.00	3.13E-04
18	6.944E-05		2880.01	2.60E-05
20	6.944E-05		4800.00	2.60E-05
22	6.944E-05		4800.01	0.00E+00
24	6.944E-05		6720.00	0.00E+00
26	6.944E-05		6720.01	2.98E-05
28	6.944E-05		8400.00	2.98E-05
30	6.944E-05		8400.01	0.00E+00
32	6.944E-05		8800.00	0.00E+00



Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It reflected the input to the RESRAD-BUILD code.

The remaining mass of source materials were multiplied with the ingrowth and decay factors to estimate the remaining radioactivity in the source and the integrated radioactivity directly ingested over the exposure duration by a receptor located in the same room as the source, in this case, Receptor 2. Table 3.35 compares the average radioactivity remaining in the source over the exposure duration from RESRAD-BUILD and the spreadsheets. Table 3.36 compares the integrated radioactivity directly ingested over the exposure duration, based on full occupancy. The results from RESRAD-BUILD were listed in the intermediate output file "AirRelTimeIntegratedConcSource1.out." The comparisons show the RESRAD-BUILD results agree well with the spreadsheet results, with differences of less than 1.2%.

3.6.2 Calculation and Comparison of Air and Floor Concentrations

Equations B.10 and B.11 in the User's Manual of RESRAD-BUILD, Vol. 1 (Yu et al. 2022) describe the change in the fraction of source materials suspended in the air and deposited on the floor, respectively, in each room of the building as a function of time. They were solved numerically in the spreadsheets to obtain source particulate concentrations in each room. Table 3.37 presents part of the calculations and results at different time steps in the spreadsheets.

During the analysis of Case VI, the RESRAD-BUILD code generated an intermediate output file "AirRelConcSource1.out" that listed the concentrations in the air and on the floor of each room at various time points. The concentrations were expressed as the fraction of the initial source per m^3 of air and the fraction of the initial source per m^2 on the floor. They were multiplied by the initial mass of source (materials) (assumed to be 1,000 g) to convert the concentration to mass of source (particulate) per unit volume in the air (g/m^3) and mass of source (particulate) per unit area on the floor (g/m^2) for comparison with spreadsheet calculations.

Figure 3.23 compares the air concentrations of source particles (g/m^3) in Room 3, where the area source was assumed to be located. Figure 3.24 compares the floor deposition concentrations of source particles (g/m^2) in the same room. Figures 3.25 and 3.26 compare the air concentrations and floor deposition concentrations, respectively, in Room 6. In the figures, the blue solid curve displays the results from the spreadsheets while the red dashed curve displays the results from RESRAD-BUILD. As shown in the figures, the concentration results from RESRAD-BUILD and the spreadsheets are in good agreement. The comparison of concentrations in the air and on the floor of other rooms also shows good agreement.

Table 3.38 compares calculated average concentrations of radionuclides in the air and on the floor over the exposure duration in Room 1. Table 3.39 compares the same calculated results in Room 3. For most of the results, the comparisons show good agreement between RESRAD-BUILD and the spreadsheets. More than 10% of differences were observed when radionuclide concentrations were very small, i.e., close to 0. This is thought to be due to the different precisions used in RESRAD-BUILD and spreadsheets for numeric values.

Table 3.35 Comparison of Time-Averaged Radioactivity Remaining in the Source over the Exposure Duration for Case VI

iSrc	iTime	Begin Time (yr)	Parent	Porgeny	Time Averaged Radioactivity (pCi)		Difference (%)
					RESRAD-BUILD	Estimated	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
1	1	0	RA-226	RA-226	2.90E+01	2.91E+01	0.02
1	1	0	RA-226	PB-210	1.02E-01	1.02E-01	0.06
1	1	0	RA-226	PO-210	1.32E-02	1.32E-02	0.19
1	2	0.25	RA-226	RA-226	8.54E+00	8.56E+00	0.24
1	2	0.25	RA-226	PB-210	9.00E-02	9.02E-02	0.22
1	2	0.25	RA-226	PO-210	2.37E-02	2.38E-02	0.23
1	3	0.5	RA-226	RA-226	3.67E+00	3.67E+00	0.04
1	3	0.5	RA-226	PB-210	7.04E-02	7.04E-02	0.04
1	3	0.5	RA-226	PO-210	2.86E-02	2.87E-02	0.06
1	4	0.75	RA-226	RA-226	1.62E+00	1.63E+00	0.56
1	4	0.75	RA-226	PB-210	4.08E-02	4.10E-02	0.58
1	4	0.75	RA-226	PO-210	1.97E-02	1.99E-02	0.61
1	5	1	RA-226	RA-226	0.00E+00	0.00E+00	–
1	5	1	RA-226	PB-210	0.00E+00	0.00E+00	–
1	5	1	RA-226	PO-210	0.00E+00	0.00E+00	–
1	6	1.25	RA-226	RA-226	0.00E+00	0.00E+00	–
1	6	1.25	RA-226	PB-210	0.00E+00	0.00E+00	–
1	6	1.25	RA-226	PO-210	0.00E+00	0.00E+00	–
1	7	1.5	RA-226	RA-226	0.00E+00	0.00E+00	–
1	7	1.5	RA-226	PB-210	0.00E+00	0.00E+00	–
1	7	1.5	RA-226	PO-210	0.00E+00	0.00E+00	–
1	1	0	CS-137	CS-137	2.90E+01	2.90E+01	0.02
1	2	0.25	CS-137	CS-137	8.47E+00	8.49E+00	0.25
1	3	0.5	CS-137	CS-137	3.62E+00	3.62E+00	0.05
1	4	0.75	CS-137	CS-137	1.59E+00	1.60E+00	0.57
1	5	1	CS-137	CS-137	0.00E+00	0.00E+00	–
1	6	1.25	CS-137	CS-137	0.00E+00	0.00E+00	–
1	7	1.5	CS-137	CS-137	0.00E+00	0.00E+00	–
1	1	0	CO-60	CO-60	2.86E+01	2.86E+01	0.02
1	2	0.25	CO-60	CO-60	8.17E+00	8.19E+00	0.25
1	3	0.5	CO-60	CO-60	3.39E+00	3.39E+00	0.05
1	4	0.75	CO-60	CO-60	1.45E+00	1.46E+00	0.57
1	5	1	CO-60	CO-60	0.00E+00	0.00E+00	–
1	6	1.25	CO-60	CO-60	0.00E+00	0.00E+00	–
1	7	1.5	CO-60	CO-60	0.00E+00	0.00E+00	–

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

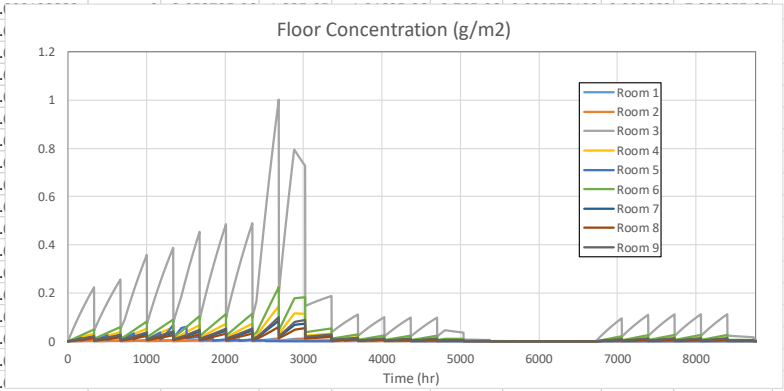
Table 3.36 Comparison of Time-Integrated Radioactivity Directly Ingested over the Exposure Duration for Case VI

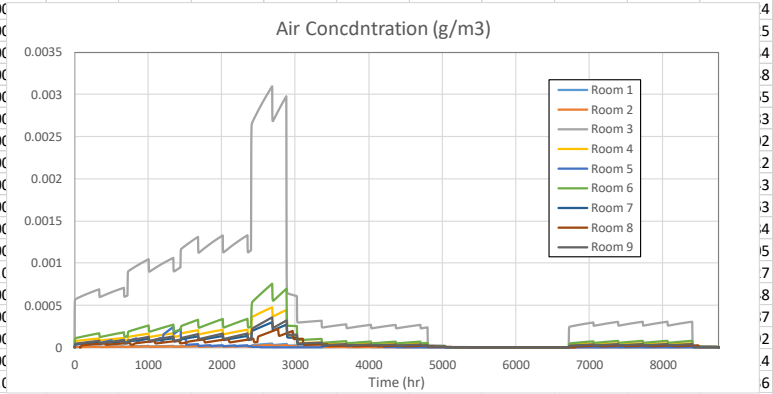
iSrc	iTime	Begin Time (yr)	Parent	Porgeny	Time Integrated Radioactivity (pCi)		Difference (%)
					RESRAD-BUILD	Estimated	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
1	1	0	RA-226	RA-226	7.88E-04	7.88E-04	0.09
1	1	0	RA-226	PB-210	3.05E-06	3.05E-06	0.06
1	1	0	RA-226	PO-210	4.17E-07	4.17E-07	0.18
1	2	0.25	RA-226	RA-226	7.88E-04	7.88E-04	0.00
1	2	0.25	RA-226	PB-210	9.13E-06	9.13E-06	0.01
1	2	0.25	RA-226	PO-210	2.59E-06	2.59E-06	0.05
1	3	0.5	RA-226	RA-226	1.50E-04	1.52E-04	1.10
1	3	0.5	RA-226	PB-210	2.42E-06	2.45E-06	1.13
1	3	0.5	RA-226	PO-210	8.67E-07	8.77E-07	1.17
1	4	0.75	RA-226	RA-226	6.05E-04	6.04E-04	0.10
1	4	0.75	RA-226	PB-210	1.60E-05	1.60E-05	0.03
1	4	0.75	RA-226	PO-210	7.99E-06	7.99E-06	0.04
1	5	1	RA-226	RA-226	0.00E+00	0.00E+00	–
1	5	1	RA-226	PB-210	0.00E+00	0.00E+00	–
1	5	1	RA-226	PO-210	0.00E+00	0.00E+00	–
1	6	1.25	RA-226	RA-226	0.00E+00	0.00E+00	–
1	6	1.25	RA-226	PB-210	0.00E+00	0.00E+00	–
1	6	1.25	RA-226	PO-210	0.00E+00	0.00E+00	–
1	7	1.5	RA-226	RA-226	0.00E+00	0.00E+00	–
1	7	1.5	RA-226	PB-210	0.00E+00	0.00E+00	–
1	7	1.5	RA-226	PO-210	0.00E+00	0.00E+00	–
1	1	0	CS-137	CS-137	7.86E-04	7.85E-04	0.09
1	2	0.25	CS-137	CS-137	7.82E-04	7.82E-04	0.00
1	3	0.5	CS-137	CS-137	1.48E-04	1.50E-04	1.11
1	4	0.75	CS-137	CS-137	5.93E-04	5.92E-04	0.09
1	5	1	CS-137	CS-137	0.00E+00	0.00E+00	–
1	6	1.25	CS-137	CS-137	0.00E+00	0.00E+00	–
1	7	1.5	CS-137	CS-137	0.00E+00	0.00E+00	–
1	1	0	CO-60	CO-60	7.76E-04	7.75E-04	0.09
1	2	0.25	CO-60	CO-60	7.50E-04	7.51E-04	0.00
1	3	0.5	CO-60	CO-60	1.40E-04	1.42E-04	1.11
1	4	0.75	CO-60	CO-60	5.40E-04	5.39E-04	0.10
1	5	1	CO-60	CO-60	0.00E+00	0.00E+00	–
1	6	1.25	CO-60	CO-60	0.00E+00	0.00E+00	–
1	7	1.5	CO-60	CO-60	0.00E+00	0.00E+00	–

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.37 Calculations of Source Particulate Concentrations in the Air and on the Floor of Each Room for Case VI

	time interval	2	hr																	
			Room 1		Room 2		Room 3		Room 4		Room 5		Room 6		Room 7		Room 8		Room 9	
	Source_Rm (1-Yes, 0-No)		0		0		1		0		0		0		0		0		0	
time (hr)	Release rate (1/hr)	Vacuum Removal (1-Yes, 0-No)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.000138889	0	0	0	0	0	0.000414485	0.00116	0	0	0	0	0	0	0	0	0	0	0	0
4	0.000138889	0	0	0	0	0	0.000526258	0.002472	4.021E-05	5.63E-05	0	0	4.99E-05	6.98E-05	0	0	0	0	0	0
6	0.000138889	0	0	0	0	0	0.000556786	0.003978	6.08252E-05	0.000197	9.68E-06	1.35E-05	7.84E-05	0.000249	1.45E-05	2.03E-05	0	0	1.22E-05	1.7E-05
8	0.000138889	0	1.07538E-06	1.5E-06	0	0	0.000565568	0.005534	6.88359E-05	0.000378	1.76E-05	5.16E-05	9.3E-05	0.000488	2.63E-05	7.74E-05	6.34E-06	8.88E-06	2.16E-05	6.42E-05
10	0.000138889	0	2.14671E-06	6.01E-06	4.6213E-07	6.47E-07	0.000568529	0.0071	7.19024E-05	0.000574	2.26E-05	0.000108	0.000101	0.000757	3.28E-05	0.00016	1.3E-05	3.59E-05	2.91E-05	0.000135
12	0.0									0.00										4
14	0.0									0.00										5
16	0.0									0.00										4
18	0.0									0.00										8
20	0.0									0.00										5
22	0.0									0.00										3
24	0.0									0.00										2
26	0.0									0.00										2
28	0.0									0.00										3
30	0.0									0.00										3
32	0.0									0.00										4
34	0.0									0.00										5
36	0.0									0.0										7
38	0.0									0.00										8
40	0.0									0.00										7
42	0.0									0.00										2
44	0.0									0.00										4
46	0.0									0.0										6
48	0.000138889	0	5.37127E-06	0.000252	3.19807E-06	0.000138	0.000586712	0.036419	7.8299E-05	0.004453	3.23E-05	0.00166	0.000116	0.006437	4.15E-05	0.002182	2.65E-05	0.001276	4.68E-05	0.002359
50	0.000138889	0	5.40212E-06	0.000266	3.22068E-06	0.000147	0.000587527	0.037931	7.85054E-05	0.004657	3.25E-05	0.001745	0.000116	0.006738	4.17E-05	0.002291	2.66E-05	0.001346	4.7E-05	0.002481
52	0.000138889	0	5.43297E-06	0.000281	3.2433E-06	0.000155	0.000588341	0.03944	7.87116E-05	0.00486	3.26E-05	0.00183	0.000116	0.007039	4.19E-05	0.0024	2.68E-05	0.001416	4.72E-05	0.002604
54	0.000138889	0	5.46381E-06	0.000295	3.26592E-06	0.000164	0.000589153	0.040946	7.89175E-05	0.005063	3.28E-05	0.001915	0.000117	0.00734	4.21E-05	0.002509	2.69E-05	0.001486	4.74E-05	0.002727





Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It was chosen to generate results for comparison.

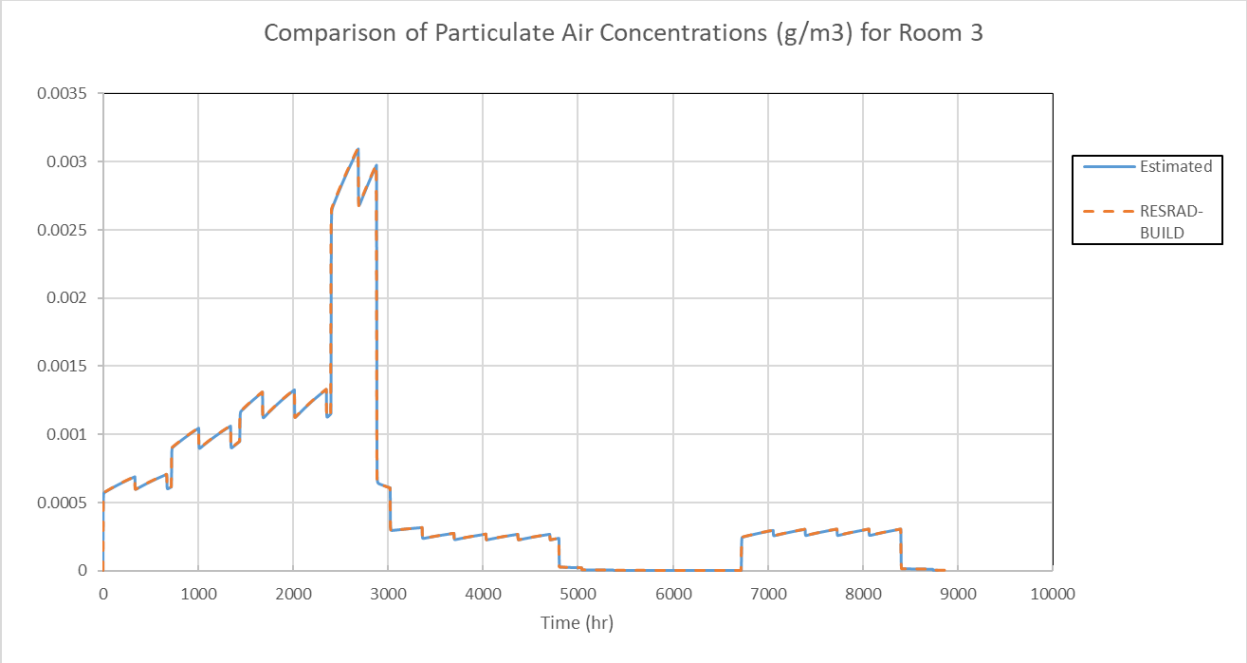


Figure 3.23 Comparison of Calculated Source Particulate Concentrations in the Air of Room 3 for Case VI

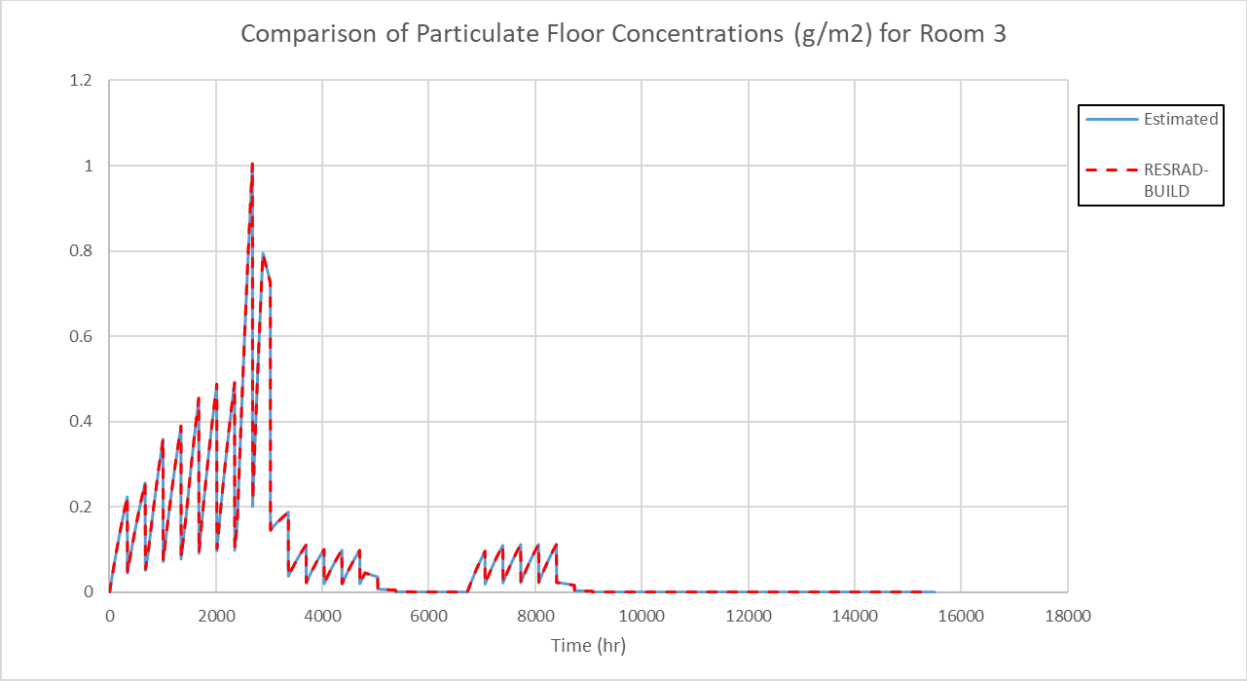


Figure 3.24 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 3 for Case VI

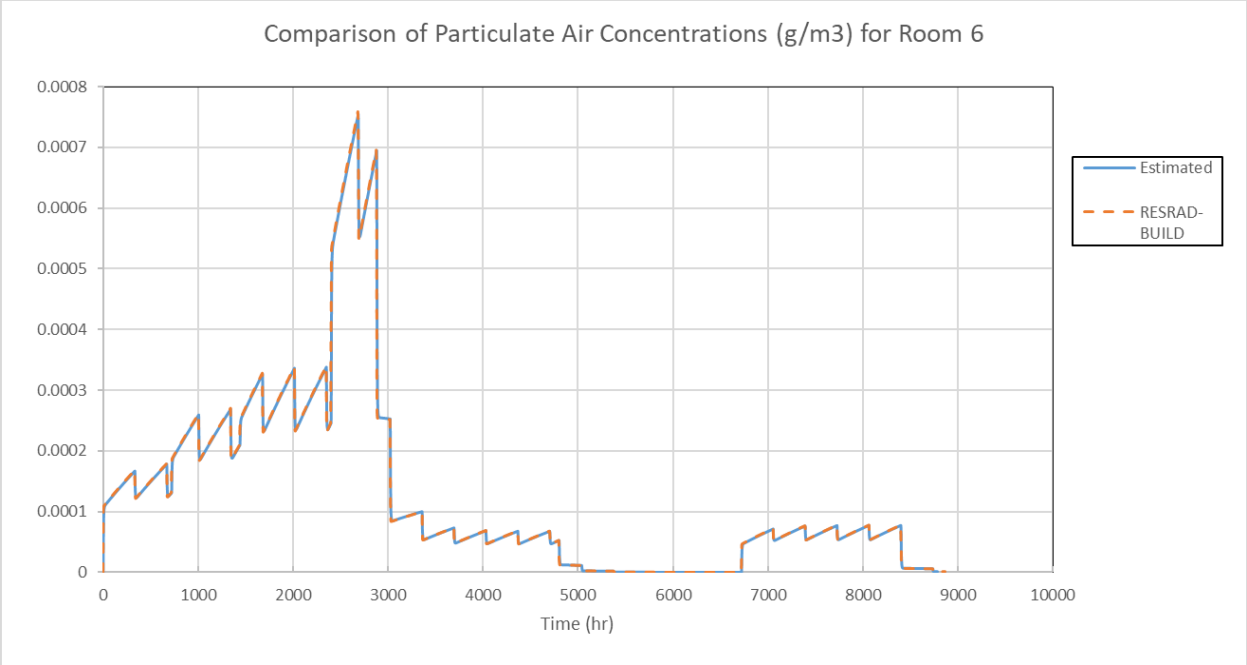


Figure 3.25 Comparison of Calculated Source Particulate Concentrations in the Air of Room 6 for Case VI

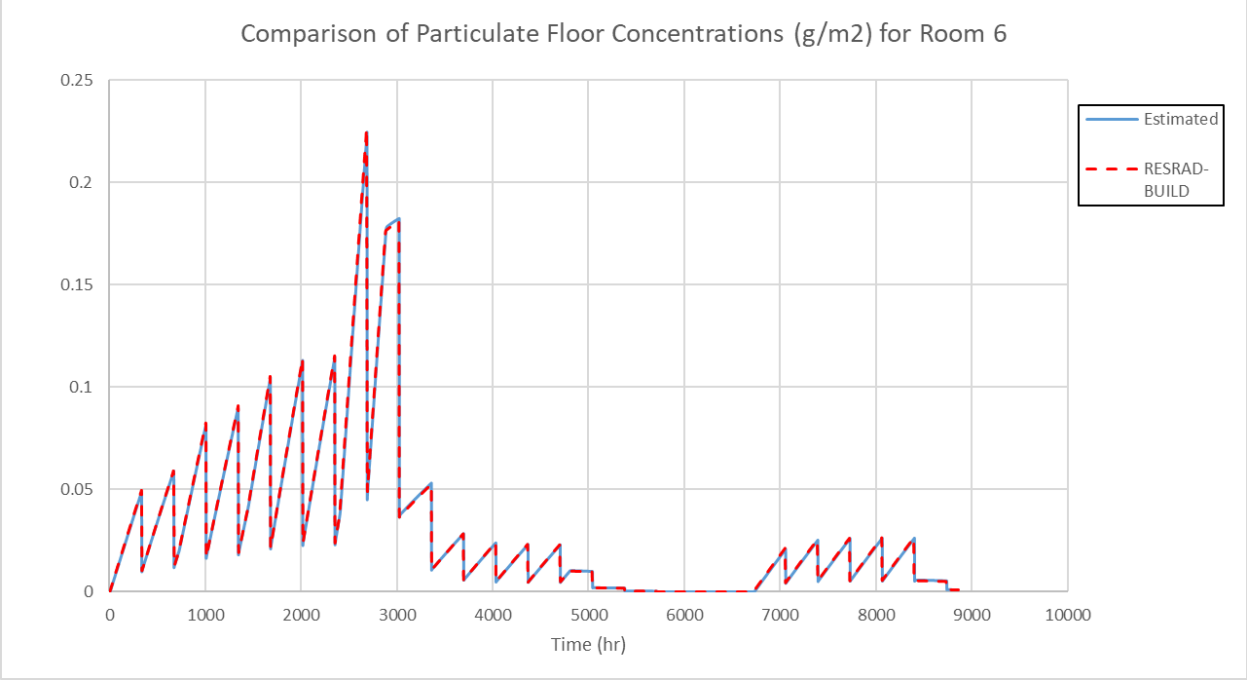


Figure 3.26 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 6 for Case VI

Table 3.38 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 1 for Case VI

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration (pCi/m3 or pCi/m2)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
1	0	RA-226	RA-226	Air	4.40E-07	4.35E-07	0.98
1	0	RA-226	RA-226	Floor	9.58E-05	9.44E-05	1.44
1	0	RA-226	PB-210	Air	1.97E-09	1.96E-09	0.51
1	0	RA-226	PB-210	Floor	4.43E-07	4.38E-07	0.92
1	0	RA-226	PO-210	Air	2.83E-10	2.82E-10	0.32
1	0	RA-226	PO-210	Floor	6.40E-08	6.36E-08	0.69
1	0.25	RA-226	RA-226	Air	4.85E-07	4.86E-07	0.17
1	0.25	RA-226	RA-226	Floor	1.26E-04	1.26E-04	0.22
1	0.25	RA-226	PB-210	Air	4.84E-09	4.86E-09	0.40
1	0.25	RA-226	PB-210	Floor	1.29E-06	1.29E-06	0.04
1	0.25	RA-226	PO-210	Air	1.21E-09	1.21E-09	0.60
1	0.25	RA-226	PO-210	Floor	3.28E-07	3.29E-07	0.27
1	0.5	RA-226	RA-226	Air	2.78E-08	2.85E-08	2.46
1	0.5	RA-226	RA-226	Floor	8.43E-06	8.64E-06	2.53
1	0.5	RA-226	PB-210	Air	4.58E-10	4.70E-10	2.63
1	0.5	RA-226	PB-210	Floor	1.42E-07	1.45E-07	2.70
1	0.5	RA-226	PO-210	Air	1.66E-10	1.71E-10	2.78
1	0.5	RA-226	PO-210	Floor	5.22E-08	5.37E-08	2.85
1	0.75	RA-226	RA-226	Air	1.04E-07	1.04E-07	0.45
1	0.75	RA-226	RA-226	Floor	2.45E-05	2.44E-05	0.73
1	0.75	RA-226	PB-210	Air	2.78E-09	2.77E-09	0.24
1	0.75	RA-226	PB-210	Floor	6.65E-07	6.62E-07	0.48
1	0.75	RA-226	PO-210	Air	1.40E-09	1.40E-09	0.09
1	0.75	RA-226	PO-210	Floor	3.37E-07	3.36E-07	0.30
1	1	RA-226	RA-226	Air	7.48E-10	8.49E-10	13.54
1	1	RA-226	RA-226	Floor	5.35E-07	6.13E-07	14.67
1	1	RA-226	PB-210	Air	2.35E-11	2.67E-11	13.59
1	1	RA-226	PB-210	Floor	1.68E-08	1.93E-08	14.69
1	1	RA-226	PO-210	Air	1.29E-11	1.47E-11	13.64
1	1	RA-226	PO-210	Floor	9.28E-09	1.06E-08	14.73
1	1.25	RA-226	RA-226	Air	1.40E-14	1.78E-14	26.72
1	1.25	RA-226	RA-226	Floor	1.36E-11	1.72E-11	26.29
1	1.25	RA-226	PB-210	Air	5.43E-16	6.89E-16	26.73
1	1.25	RA-226	PB-210	Floor	5.27E-13	6.66E-13	26.29
1	1.25	RA-226	PO-210	Air	3.34E-16	4.23E-16	26.76
1	1.25	RA-226	PO-210	Floor	3.24E-13	4.09E-13	26.32
1	1.5	RA-226	RA-226	Air	1.14E-19	1.53E-19	34.52
1	1.5	RA-226	RA-226	Floor	1.21E-16	1.63E-16	34.73
1	1.5	RA-226	PB-210	Air	5.28E-21	7.10E-21	34.57
1	1.5	RA-226	PB-210	Floor	5.62E-18	7.57E-18	34.76
1	1.5	RA-226	PO-210	Air	3.52E-21	4.74E-21	34.61
1	1.5	RA-226	PO-210	Floor	3.74E-18	5.05E-18	34.79

Table 3.38 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration (pCi/m3 or pCi/m2)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
1	0	CS-137	CS-137	Air	4.38E-07	4.34E-07	0.97
1	0	CS-137	CS-137	Floor	9.55E-05	9.41E-05	1.44
1	0.25	CS-137	CS-137	Air	4.81E-07	4.82E-07	0.17
1	0.25	CS-137	CS-137	Floor	1.25E-04	1.25E-04	0.22
1	0.5	CS-137	CS-137	Air	2.75E-08	2.82E-08	2.47
1	0.5	CS-137	CS-137	Floor	8.33E-06	8.54E-06	2.54
1	0.75	CS-137	CS-137	Air	1.02E-07	1.02E-07	0.45
1	0.75	CS-137	CS-137	Floor	2.41E-05	2.39E-05	0.73
1	1	CS-137	CS-137	Air	7.30E-10	8.29E-10	13.55
1	1	CS-137	CS-137	Floor	5.23E-07	5.99E-07	14.68
1	1.25	CS-137	CS-137	Air	1.36E-14	1.73E-14	26.73
1	1.25	CS-137	CS-137	Floor	1.32E-11	1.67E-11	26.30
1	1.5	CS-137	CS-137	Air	1.10E-19	1.48E-19	34.54
1	1.5	CS-137	CS-137	Floor	1.17E-16	1.58E-16	34.75
1	0	CO-60	CO-60	Air	4.31E-07	4.27E-07	0.98
1	0	CO-60	CO-60	Floor	9.40E-05	9.26E-05	1.45
1	0.25	CO-60	CO-60	Air	4.65E-07	4.65E-07	0.17
1	0.25	CO-60	CO-60	Floor	1.21E-04	1.21E-04	0.23
1	0.5	CO-60	CO-60	Air	2.59E-08	2.66E-08	2.46
1	0.5	CO-60	CO-60	Floor	7.85E-06	8.05E-06	2.53
1	0.75	CO-60	CO-60	Air	9.29E-08	9.24E-08	0.47
1	0.75	CO-60	CO-60	Floor	2.19E-05	2.17E-05	0.75
1	1	CO-60	CO-60	Air	6.53E-10	7.42E-10	13.55
1	1	CO-60	CO-60	Floor	4.68E-07	5.36E-07	14.68
1	1.25	CO-60	CO-60	Air	1.19E-14	1.51E-14	26.73
1	1.25	CO-60	CO-60	Floor	1.15E-11	1.46E-11	26.30
1	1.5	CO-60	CO-60	Air	9.34E-20	1.26E-19	34.54
1	1.5	CO-60	CO-60	Floor	9.93E-17	1.34E-16	34.75

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.39 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 3 for Case VI

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration (pCi/m3 or pCi/m2)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
3	0	RA-226	RA-226	Air	3.41E-05	3.41E-05	0.25
3	0	RA-226	RA-226	Floor	7.78E-03	7.71E-03	0.90
3	0	RA-226	PB-210	Air	1.51E-07	1.50E-07	0.12
3	0	RA-226	PB-210	Floor	3.54E-05	3.51E-05	0.84
3	0	RA-226	PO-210	Air	2.16E-08	2.16E-08	0.02
3	0	RA-226	PO-210	Floor	5.10E-06	5.06E-06	0.74
3	0.25	RA-226	RA-226	Air	3.43E-05	3.43E-05	0.12
3	0.25	RA-226	RA-226	Floor	9.52E-03	9.46E-03	0.66
3	0.25	RA-226	PB-210	Air	3.37E-07	3.37E-07	0.04
3	0.25	RA-226	PB-210	Floor	9.61E-05	9.56E-05	0.58
3	0.25	RA-226	PO-210	Air	8.32E-08	8.33E-08	0.06
3	0.25	RA-226	PO-210	Floor	2.42E-05	2.41E-05	0.48
3	0.5	RA-226	RA-226	Air	1.78E-06	1.80E-06	1.16
3	0.5	RA-226	RA-226	Floor	5.83E-04	5.85E-04	0.32
3	0.5	RA-226	PB-210	Air	2.89E-08	2.92E-08	1.20
3	0.5	RA-226	PB-210	Floor	9.70E-06	9.73E-06	0.38
3	0.5	RA-226	PO-210	Air	1.04E-08	1.05E-08	1.26
3	0.5	RA-226	PO-210	Floor	3.54E-06	3.56E-06	0.45
3	0.75	RA-226	RA-226	Air	7.76E-06	7.75E-06	0.17
3	0.75	RA-226	RA-226	Floor	1.93E-03	1.91E-03	0.84
3	0.75	RA-226	PB-210	Air	2.06E-07	2.06E-07	0.06
3	0.75	RA-226	PB-210	Floor	5.19E-05	5.15E-05	0.73
3	0.75	RA-226	PO-210	Air	1.03E-07	1.03E-07	0.02
3	0.75	RA-226	PO-210	Floor	2.62E-05	2.60E-05	0.65
3	1	RA-226	RA-226	Air	8.91E-09	9.53E-09	6.98
3	1	RA-226	RA-226	Floor	1.61E-05	1.70E-05	5.77
3	1	RA-226	PB-210	Air	2.79E-10	2.98E-10	7.01
3	1	RA-226	PB-210	Floor	5.04E-07	5.33E-07	5.78
3	1	RA-226	PO-210	Air	1.53E-10	1.64E-10	7.04
3	1	RA-226	PO-210	Floor	2.77E-07	2.93E-07	5.81
3	1.25	RA-226	RA-226	Air	4.83E-14	5.76E-14	19.15
3	1.25	RA-226	RA-226	Floor	7.33E-11	8.44E-11	15.14
3	1.25	RA-226	PB-210	Air	1.87E-15	2.23E-15	19.16
3	1.25	RA-226	PB-210	Floor	2.84E-12	3.26E-12	15.14
3	1.25	RA-226	PO-210	Air	1.15E-15	1.37E-15	19.19
3	1.25	RA-226	PO-210	Floor	1.74E-12	2.00E-12	15.17
3	1.5	RA-226	RA-226	Air	2.49E-19	3.28E-19	31.75
3	1.5	RA-226	RA-226	Floor	3.06E-16	3.92E-16	28.08
3	1.5	RA-226	PB-210	Air	1.15E-20	1.52E-20	31.80
3	1.5	RA-226	PB-210	Floor	1.42E-17	1.82E-17	28.12
3	1.5	RA-226	PO-210	Air	7.69E-21	1.01E-20	31.83
3	1.5	RA-226	PO-210	Floor	9.45E-18	1.21E-17	28.15

Table 3.39 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration (pCi/m3 or pCi/m2)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
3	0	CS-137	CS-137	Air	3.40E-05	3.39E-05	0.24
3	0	CS-137	CS-137	Floor	7.75E-03	7.68E-03	0.89
3	0.25	CS-137	CS-137	Air	3.41E-05	3.40E-05	0.12
3	0.25	CS-137	CS-137	Floor	9.45E-03	9.39E-03	0.66
3	0.5	CS-137	CS-137	Air	1.76E-06	1.78E-06	1.16
3	0.5	CS-137	CS-137	Floor	5.76E-04	5.78E-04	0.32
3	0.75	CS-137	CS-137	Air	7.61E-06	7.60E-06	0.16
3	0.75	CS-137	CS-137	Floor	1.89E-03	1.88E-03	0.83
3	1	CS-137	CS-137	Air	8.70E-09	9.31E-09	6.99
3	1	CS-137	CS-137	Floor	1.57E-05	1.66E-05	5.78
3	1.25	CS-137	CS-137	Air	4.70E-14	5.60E-14	19.16
3	1.25	CS-137	CS-137	Floor	7.13E-11	8.21E-11	15.15
3	1.5	CS-137	CS-137	Air	2.41E-19	3.17E-19	31.77
3	1.5	CS-137	CS-137	Floor	2.96E-16	3.79E-16	28.10
3	0	CO-60	CO-60	Air	3.35E-05	3.34E-05	0.25
3	0	CO-60	CO-60	Floor	7.63E-03	7.56E-03	0.90
3	0.25	CO-60	CO-60	Air	3.29E-05	3.29E-05	0.12
3	0.25	CO-60	CO-60	Floor	9.12E-03	9.06E-03	0.66
3	0.5	CO-60	CO-60	Air	1.66E-06	1.68E-06	1.16
3	0.5	CO-60	CO-60	Floor	5.43E-04	5.45E-04	0.32
3	0.75	CO-60	CO-60	Air	6.93E-06	6.92E-06	0.17
3	0.75	CO-60	CO-60	Floor	1.72E-03	1.70E-03	0.84
3	1	CO-60	CO-60	Air	7.79E-09	8.33E-09	6.99
3	1	CO-60	CO-60	Floor	1.41E-05	1.49E-05	5.78
3	1.25	CO-60	CO-60	Air	4.09E-14	4.88E-14	19.16
3	1.25	CO-60	CO-60	Floor	6.21E-11	7.15E-11	15.15
3	1.5	CO-60	CO-60	Air	2.04E-19	2.69E-19	31.77
3	1.5	CO-60	CO-60	Floor	2.51E-16	3.21E-16	28.10

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

3.6.3 Calculation and Comparison of Radiation Doses and Cancer Risks

Table 3.40 compares the radiation doses at t = 0 and 0.75 year and the cancer risks at t = 1 year that RESRAD-BUILD and the spreadsheets estimated to Receptor 1. Receptor 1 was assumed to spend 100% of the time in Room 1, while he was in the building. He was also assumed to inhale 18 m^3 of air per day and would not ingest dust particles deposited on floor. Although a direct ingestion of a fraction of 1E-8 of source particles per hour was specified, no direct ingestion of radionuclide would be considered because the receptor was not in the same room as the source. The comparison shows that for radiation dose estimates, the RESRAD-BUILD results agree well with the spreadsheet results, with a difference of less than 1.5 %. The differences in cancer risk estimates at t = 1 year were greater, because the values were very small ($< 1\times 10^{-13}$), essentially 0s. The greater differences were due to the different precisions used to save numeric values.

Table 3.41 compares the radiation doses at t = 0 and 0.75 years and the cancer risks at t = 0.75, 1, and 1.25 years that RESRAD-BUILD and the spreadsheets estimated to Receptor 2 in Room 3, where the source was located. Receptor 2 would spend 50% of the time in Room 3 while he was in the building. He was assumed to inhale 20 m^3 of air per day, would ingest dust particles deposited on floor, 0.0001 m^2 per hour, and would ingest a fraction of 1E-8 of source particles per hour. The comparison shows the radiation dose estimates agree very well. For cancer risk estimates, the differences were less than 1% for t = 0.75 year, less than 6% for t = 1 year, and less than 20% at t = 1.25 years. The difference increases because the values of estimated cancer risk became smaller and closer to 0s.

From the above comparisons, it is concluded that the calculations of radiation dose and cancer risk using the air and floor deposition concentrations of radionuclides are accurately implemented in the RESRAD-BUILD code.

3.7 CASE VII – AN AREA SOURCE IN ROOM 5 WITH SCHEDULED VACUUMING

Case VII considers an area source of 36 m^2 located in Room 5. The air exchange rates between rooms and with the outside environment were the same as in Case VI. Vacuuming to remove dust deposition on the floor was assumed to be conducted every 14 days with a dust removal efficiency of 0.8. The estimated concentrations of source particles and radionuclides in the air and on the floor of each room from RESRAD-BUILD and the verification spreadsheets were compared.

The room dimensions, ventilation rates between rooms and with the outside environment, deposition velocity, and resuspension rate assumed for Cases III, IV, V, and VI were applicable to Case VII (Table 3.20). The contaminated source materials were assumed to be eroded and released to the indoor air over several phases with a constant erosion/release rate in each phase. Table 3.42 lists the beginning and ending time and fraction of the source materials involved in each release phase.

Table 3.40 Comparison of Radiation Doses and Cancer Risks to Receptor 1 of Case VI

Receptor 1	location room	1			(Reflect value in the input file)
	time fraction in room		1		(Reflect value in the input file)
	breathing rate	18	m3/d		(Reflect value in the input file)
	ingestion rate	0	m2/hr		(Reflect value in the input file)
	direct ingestion rate		1.00E-08	1/hr	
	In the same room as source?			0	(1-Yes, 0-No) election in the input file)
)ose (mrem/yr) at time =			0.00	yr	

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$
Ra-226	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	1.27E-05	1.26E-05	0.74	5.37E-10	5.32E-10	1.01
Pb-210	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	3.40E-08	3.38E-08	0.46	8.70E-15	8.64E-15	0.65
Po-210	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	3.70E-09	3.69E-09	0.33	1.61E-18	1.60E-18	0.51
Cs-137	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	5.19E-08	5.14E-08	0.92	1.63E-10	1.62E-10	0.81
Co-60	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	4.06E-08	4.02E-08	0.90	7.50E-10	7.42E-10	1.12
Total	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	1.28E-05	1.27E-05	0.74	1.45E-09	1.43E-09	1.04

Radiation Dose (mrem/yr) at time =			0.75	yr								
	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$
Ra-226	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	3.01E-06	3.00E-06	0.30	1.27E-10	1.27E-10	0.35
Pb-210	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	4.81E-08	4.80E-08	0.25	1.23E-14	1.23E-14	0.36
Po-210	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	1.83E-08	1.82E-08	0.36	7.94E-18	7.92E-18	0.25
Cs-137	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	1.21E-08	1.20E-08	0.48	3.81E-11	3.79E-11	0.62
Co-60	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	8.75E-09	8.71E-09	0.48	1.61E-10	1.61E-10	0.31
Total	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	3.10E-06	3.09E-06	0.30	3.26E-10	3.25E-10	0.36

Cancer Risk at time =			1	yr								
	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet\rvert}{RESRAD}$
Ra-226	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	1.74E-14	1.97E-14	13.25	7.36E-19	8.34E-19	13.38
Pb-210	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	3.13E-16	3.56E-16	13.74	2.66E-23	3.01E-23	13.29
Po-210	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	1.54E-16	1.75E-16	13.73	5.92E-26	6.72E-26	13.51
Cs-137	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	6.72E-17	7.63E-17	13.51	2.18E-19	2.47E-19	13.51
Co-60	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	5.42E-17	6.15E-17	13.54	9.19E-19	1.04E-18	13.43
Total	0.00E+00	0.00E+00	-	0.00E+00	0.00E+00	-	1.80E-14	2.04E-14	13.27	1.87E-18	2.12E-18	13.42

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

Table 3.41 Comparison of Radiation Doses and Cancer Risks to Receptor 2 of Case VI

Receptor 2	location room	3			(Reflect value in the input file)
	time fraction in room		0.5		(Reflect value in the input file)
	breathing rate	20	m3/d		(Reflect value in the input file)
	ingestion rate	0.0001	m2/hr		(Reflect value in the input file)
	direct ingestion rate		1.00E-08	1/hr	
	In the same room as source?			1	(1-Yes, 0-No) election in the input file)
)ose (mrem/yr) at time =			0.00E+00	yr	**Cancer Risk at time**

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	2.04E-07	2.04E-07	0.09	4.42E-07	4.38E-07	0.97	5.49E-04	5.48E-04	0.21	2.09E-08	2.08E-08	0.51
Pb-210	1.95E-09	1.95E-09	0.18	4.95E-09	4.91E-09	0.78	1.45E-06	1.44E-06	0.38	3.33E-13	3.32E-13	0.29
Po-210	4.62E-10	4.63E-10	0.28	1.24E-09	1.23E-09	0.83	1.57E-07	1.57E-07	0.02	6.14E-17	6.14E-17	0.07
Cs-137	9.45E-09	9.44E-09	0.06	2.04E-08	2.02E-08	0.80	2.24E-06	2.23E-06	0.23	6.35E-09	6.32E-09	0.40
Co-60	2.44E-09	2.44E-09	0.13	5.26E-09	5.21E-09	0.97	1.75E-06	1.75E-06	0.04	2.91E-08	2.90E-08	0.28
Total	2.18E-07	2.18E-07	0.09	4.74E-07	4.69E-07	0.96	5.55E-04	5.53E-04	0.21	5.64E-08	5.61E-08	0.38

Radiation Dose (mrem/yr) at time =	0.75	yr	

	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
Nuclide	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	1.57E-07	1.57E-07	0.27	1.10E-07	1.09E-07	1.27	1.25E-04	1.25E-04	0.26	4.75E-09	4.73E-09	0.38
Pb-210	1.02E-08	1.02E-08	0.25	7.27E-09	7.22E-09	0.74	1.98E-06	1.98E-06	0.17	4.55E-13	4.54E-13	0.14
Po-210	8.86E-09	8.87E-09	0.09	6.37E-09	6.32E-09	0.71	7.47E-07	7.47E-07	0.03	2.92E-16	2.92E-16	0.04
Cs-137	7.13E-09	7.12E-09	0.10	4.98E-09	4.94E-09	0.84	5.01E-07	5.00E-07	0.12	1.42E-09	1.42E-09	0.28
Co-60	1.70E-09	1.70E-09	0.20	1.18E-09	1.17E-09	0.48	3.63E-07	3.62E-07	0.24	6.02E-09	6.01E-09	0.21
Total	1.85E-07	1.84E-07	0.21	1.30E-07	1.28E-07	1.19	1.29E-04	1.28E-04	0.25	1.22E-08	1.22E-08	0.28

Table 3.41 (Continued)

Cancer Risk at time = 0.75 yr

Nuclide	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	7.78E-14	7.77E-14	0.11	5.44E-14	5.39E-14	0.92	1.00E-10	1.00E-10	0.04	3.82E-15	3.81E-15	0.27
Pb-210	4.77E-15	4.77E-15	0.03	3.39E-15	3.37E-15	0.72	1.53E-12	1.53E-12	0.32	1.16E-19	1.16E-19	0.16
Po-210	4.49E-15	4.49E-15	0.08	3.23E-15	3.21E-15	0.77	6.81E-13	6.81E-13	0.01	2.35E-22	2.35E-22	0.07
Cs-137	5.54E-15	5.54E-15	0.03	3.87E-15	3.84E-15	0.78	3.89E-13	3.88E-13	0.16	1.14E-15	1.13E-15	0.54
Co-60	3.01E-15	3.01E-15	0.09	2.10E-15	2.08E-15	0.87	3.19E-13	3.19E-13	0.04	4.88E-15	4.86E-15	0.38
Total	9.56E-14	9.55E-14	0.09	6.70E-14	6.64E-14	0.89	1.03E-10	1.03E-10	0.04	9.84E-15	9.80E-15	0.36

Cancer Risk at time = 1 yr

Nuclide	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	0.00E+00	0.00E+00	-	4.53E-16	4.79E-16	5.81	1.15E-13	1.23E-13	6.87	4.38E-18	4.68E-18	6.93
Pb-210	0.00E+00	0.00E+00	-	3.29E-17	3.48E-17	5.75	2.07E-15	2.21E-15	6.90	1.58E-22	1.69E-22	6.70
Po-210	0.00E+00	0.00E+00	-	3.41E-17	3.61E-17	5.88	1.02E-15	1.09E-15	6.53	3.51E-25	3.75E-25	6.90
Cs-137	0.00E+00	0.00E+00	-	3.22E-17	3.40E-17	5.70	4.45E-16	4.76E-16	6.91	1.30E-18	1.39E-18	6.85
Co-60	0.00E+00	0.00E+00	-	1.72E-17	1.82E-17	5.60	3.59E-16	3.84E-16	6.96	5.48E-18	5.85E-18	6.82
Total	0.00E+00	0.00E+00	-	5.69E-16	6.02E-16	5.80	1.19E-13	1.27E-13	6.86	1.12E-17	1.19E-17	6.87

Cancer Risk at time = 1.25 yr

Nuclide	Direct Ingestion (mrem/yr)			Ingestion (deposition)			Inhalation			Air submersion		
	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$	RESRAD-BUILD	Estimate	Difference (%) $\frac{\lvert RESRAD-Spreadsheet \rvert}{RESRAD}$
Ra-226	0.00E+00	0.00E+00	-	2.07E-21	2.38E-21	14.94	6.23E-19	7.43E-19	19.24	2.38E-23	2.83E-23	18.95
Pb-210	0.00E+00	0.00E+00	-	1.85E-22	2.13E-22	15.26	1.39E-20	1.65E-20	18.82	1.06E-27	1.26E-27	18.70
Po-210	0.00E+00	0.00E+00	-	2.14E-22	2.47E-22	15.42	7.60E-21	9.05E-21	19.11	2.63E-30	3.13E-30	18.85
Cs-137	0.00E+00	0.00E+00	-	1.46E-22	1.68E-22	15.08	2.40E-21	2.86E-21	19.16	7.02E-24	8.35E-24	18.94
Co-60	0.00E+00	0.00E+00	-	7.58E-23	8.73E-23	15.19	1.89E-21	2.25E-21	18.92	2.88E-23	3.43E-23	18.98
Total	0.00E+00	0.00E+00	-	2.69E-21	3.09E-21	15.02	6.49E-19	7.74E-19	19.23	5.96E-23	7.09E-23	18.96

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

Table 3.42 Source Releases Assumed for Case VII

Source Releases											
Location (Room No.)		5		Air Fraction		1		Initial mass		1.000E+03	g
	Release 1	Release 2	Release 3	Release 4	Release 5	Release 6	Release 7	Release 8	Release 9	Release 10	
Start time (d)	0	60	120	200	240	400	560	700	1000	1100	
Start time (hr)	0	1440	2880	4800	5760	9600	13440	16800	24000	26400	
End time (d)	60	120	200	240	400	560	700	1000	1100	1500	
End time (hr)	1440	2880	4800	5760	9600	13440	16800	24000	26400	36000	
Fraction released	0.1	0.15	0.25	0.3	0.1	0.05	0.05	0	0	0	
Release rate (1/hr)	6.94444E-05	0.000104	0.00013	0.000313	2.60417E-05	1.3E-05	1.4881E-05	0	0	0	

Note: The yellow highlights indicate the values were specified, not calculated, in the spreadsheet. They reflected the inputs to the RESRAD-BUILD code.

The air release rates calculated by RESRAD-BUILD, listed in the intermediate output file "AirRelRate1.out," were in terms of the fraction of the initial source inventory. They were multiplied by the initial mass assumed for the source materials (1,000 g) for comparison with the calculated source release rates from the spreadsheets. Table 3.43 shows the comparison of source release rates.

Equations B.10 and B.11 in the User's Manual of RESRAD-BUILD, Vol. 1 (Yu et al. 2022) were solved numerically in the spreadsheets to obtain source particulate concentrations in each room. Table 3.44 presents part of the calculations and results at different time steps in the spreadsheets.

During the analysis of Case V, the RESRAD-BUILD code generated an intermediate output file "AirRelConcSource1.out" that listed the concentrations in the air and on the floor of each room at various time points. The concentrations were expressed as the fraction of the initial source per m^3 of air and the fraction of the initial source per m^2 on the floor. They were multiplied by the total mass of source (materials) to convert the concentration to mass of source (particulate) per unit volume in the air (g/m^3) and mass of source (particulate) per unit area on the floor (g/m^2) for comparison with spreadsheet calculations.

Figures 3.27 and 3.28 compare the air concentrations (g/m^3) and floor deposition concentrations (g/m^2), respectively, in Room 2, which did not have direct air exchange with Room 5, where the area source was located. Figures 3.29 and 3.30 compare the air concentrations and floor deposition concentrations, respectively, in Room 5. Figures 3.31 and 3.32 compare the air concentrations and floor deposition concentrations, respectively, in Room 8, which had air exchange with Room 5. In the figures, the blue solid curve displays the results from the spreadsheets while the red dashed curve displays the results from RESRAD-BUILD. As shown in the figures, the concentration results from RESRAD-BUILD and the spreadsheets are in good agreement. Good agreement was observed with the concentration results in other rooms.

Table 3.45 compares calculated average concentrations of radionuclides in the air and on the floor over the exposure duration in Room 3. Table 3.46 compares the same calculated results in Room 7. The comparisons show good agreement between the calculated results from RESRAD-BUILD and the spreadsheets; all results differ by less than 2%. The comparisons of results for the other rooms also show good agreement.

Table 3.43 Comparison of Calculated Air Release Rates from RESRAD-BUILD and Spreadsheets for Case VII

From "AirRelRate1.out"													
Rate of release of source material to air								Volume of source room			90	m3	
fraction of source per second per volume (m3) of the room of release													
2.14E-10	from	time	0.00E+00	to	time	5184000	seconds						
3.22E-10	from	time	5184000	to	time	10368000	seconds						
4.02E-10	from	time	10368000	to	time	17280000	seconds						
9.65E-10	from	time	17280000	to	time	20736000	seconds						
8.04E-11	from	time	20736000	to	time	34560000	seconds						
4.02E-11	from	time	34560000	to	time	48384000	seconds						
4.59E-11	from	time	48384000	to	time	60480000	seconds						
	Estimated		RESRAD-BUILD										
time (hr)	Air release rate (1/hr)		time (hr)	Air release rate (1/hr)									
0	0		0.00	0.00E+00									
2	6.944E-05		0.10	6.95E-05									
4	6.944E-05		1440.00	6.95E-05									
6	6.944E-05		1440.10	1.04E-04									
8	6.944E-05		2880.00	1.04E-04									
10	6.944E-05		2880.10	1.30E-04									
12	6.944E-05		4800.00	1.30E-04									
14	6.944E-05		4800.10	3.13E-04									
16	6.944E-05		5760.00	3.13E-04									
18	6.944E-05		5760.10	2.60E-05									
20	6.944E-05		9600.00	2.60E-05									
22	6.944E-05		9600.10	1.30E-05									
24	6.944E-05		13440.00	1.30E-05									
26	6.944E-05		13440.10	1.49E-05									
28	6.944E-05		16800.00	1.49E-05									
30	6.944E-05		16800.10	0.00E+00									
32	6.944E-05		20000.00	0.00E+00									

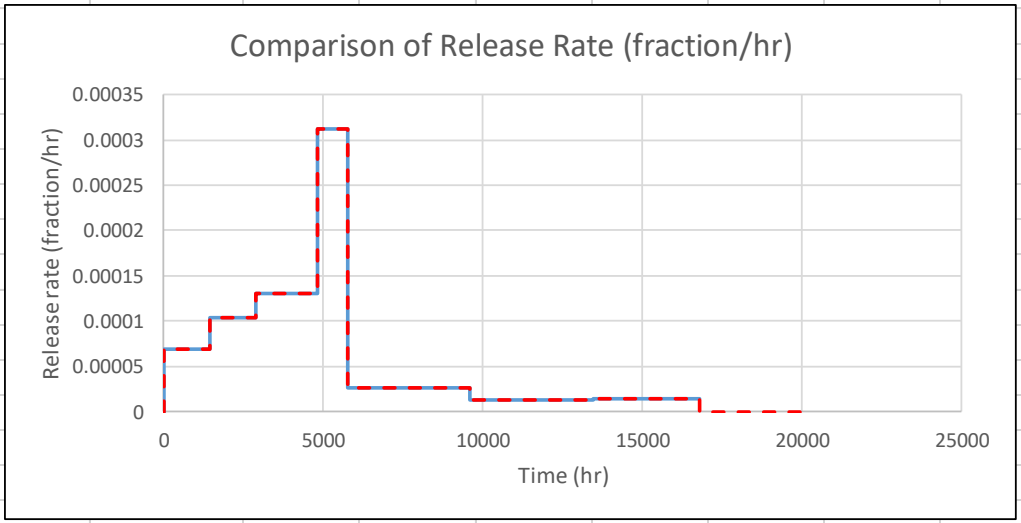
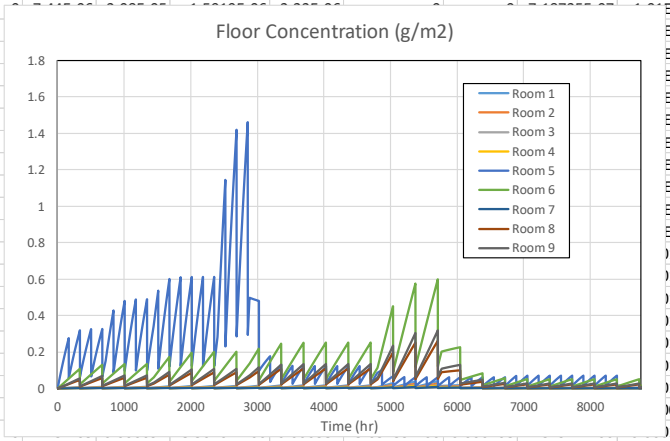
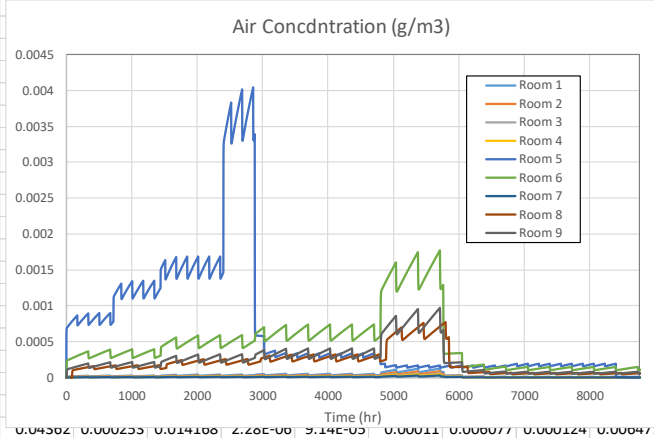


Table 3.44 Calculations of Source Particulate Concentrations in the Air and on the Floor of Each Room for Case VII

	time interval	2 hr																		
			Room 1		Room 2		Room 3		Room 4		Room 5		Room 6		Room 7		Room 8		Room 9	
	Source_Rm (1-Yes, 0-No)		0		0		0		0		1		0		0		0		0	
time (hr)	Release rate (1/hr)	Vacuum Removal (1-Yes, 0-No)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)	Air conc. (g/m3)	Floor conc. (g/m2)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	6.94444E-05	0	0	0	0	0	0	0	0	0	0.000464	0.001299	0	0	0	0	0	0	0	0
4	6.94444E-05	0	0	0	0	0	0	0	0	0	0.000605	0.00279	0.000112	0.000156	0	0	4.5E-05	6.3E-05	0	0
6	6.94444E-05	0	0	0	0	0	0	0	0	0	0.000653	0.00454	0.000179	0.000563	0	0	6.96E-05	0.000223	4.19E-05	5.86E-05
8	6.94444E-05	0	3.7E-06	5.18E-06	0	0	0	0	0	0	0.000671	0.006376	0.000211	0.001107	0	0	8.44E-05	0.000438	7.48E-05	0.000222
10	6.94444E-05										0.000679									
12	6.94444E-05										0.000684									
14	6.94444E-05										0.000687									
16	6.94444E-05										0.000689									
18	6.94444E-05										0.000691									
20	6.94444E-05										0.000692									
22	6.94444E-05										0.000694									
24	6.94444E-05										0.000695									
26	6.94444E-05										0.000696									
28	6.94444E-05										0.000698									
30	6.94444E-05										0.000699									
32	6.94444E-05										0.0007									
34	6.94444E-05										0.000701									
36	6.94444E-05										0.000703									
38	6.94444E-05										0.000704									
40	6.94444E-05										0.000705									
42	6.94444E-05										0.000706									
44	6.94444E-05										0.000708									
46	6.94444E-05										0.000709									
48	6.94444E-05										0.00071									
50	6.94444E-05	0	1.43E-05	0.000731	8.56035E-06	0.000404	5.09241E-06	0.000222	4.37876E-06	0.000203	0.000711	0.045451	0.000254	0.014826	2.29E-06	9.74E-05	0.00011	0.006364	0.000124	0.006795
52	6.94444E-05	0	1.44E-05	0.000769	8.61607E-06	0.000427	5.13224E-06	0.000235	4.40827E-06	0.000214	0.000712	0.04728	0.000255	0.015485	2.31E-06	0.000104	0.000111	0.00665	0.000125	0.00712
54	6.94444E-05	0	1.45E-05	0.000807	8.67181E-06	0.000449	5.17211E-06	0.000249	4.43781E-06	0.000226	0.000714	0.049105	0.000255	0.016143	2.33E-06	0.00011	0.000111	0.006937	0.000126	0.007445
56	6.94444E-05	0	1.46E-05	0.000844	8.72759E-06	0.000472	5.21203E-06	0.000263	4.46736E-06	0.000238	0.000715	0.050928	0.000256	0.016801	2.35E-06	0.000116	0.000111	0.007223	0.000126	0.00777





Note: The yellow highlight indicates the value was specified, not calculated, in the spreadsheet. It was chosen to generate results for comparison.

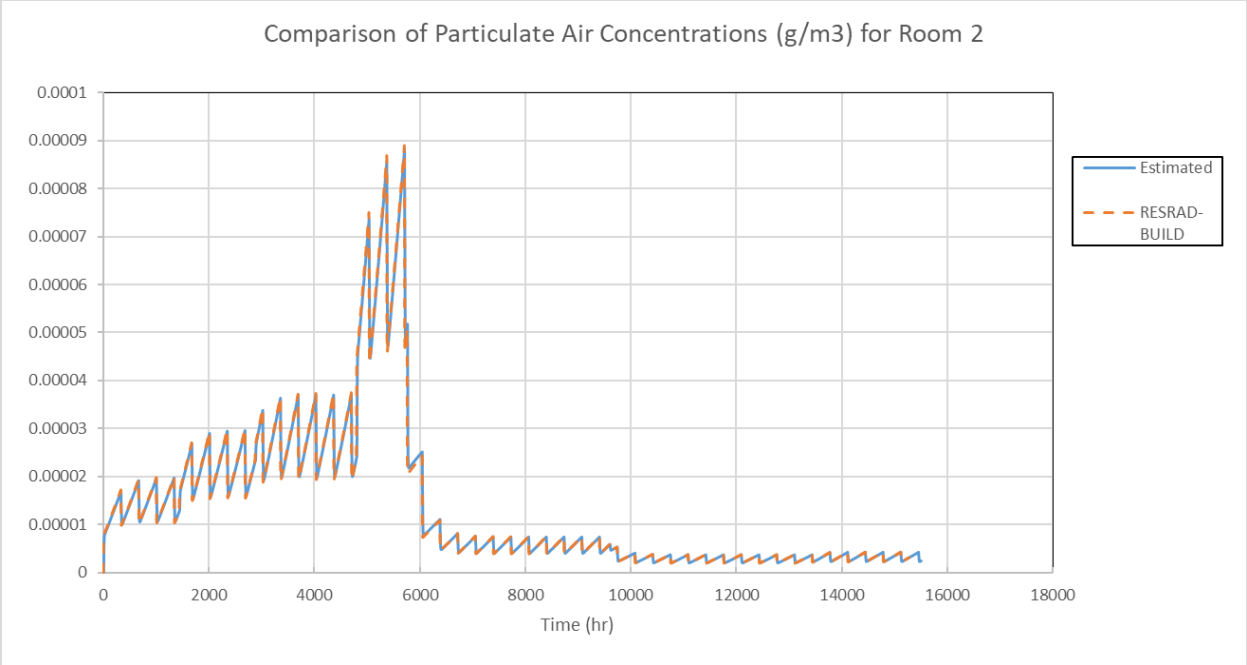


Figure 3.27 Comparison of Calculated Source Particulate Concentrations in the Air of Room 2 for Case VII

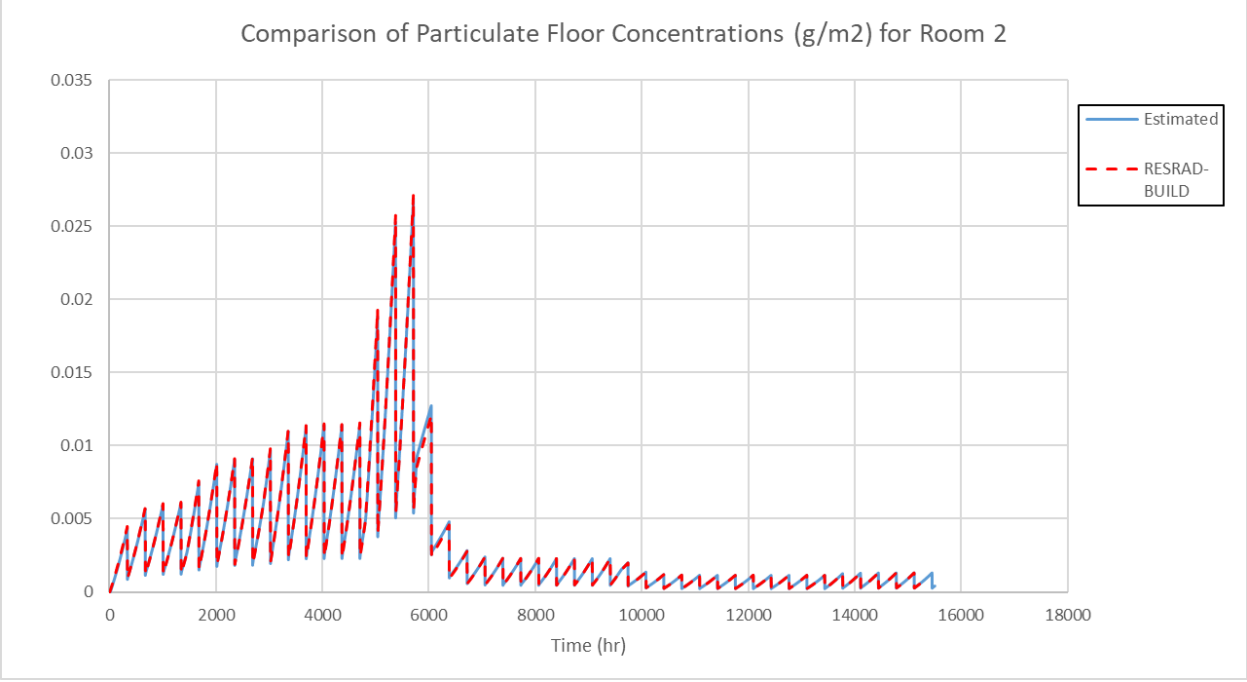


Figure 3.28 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 2 for Case VII

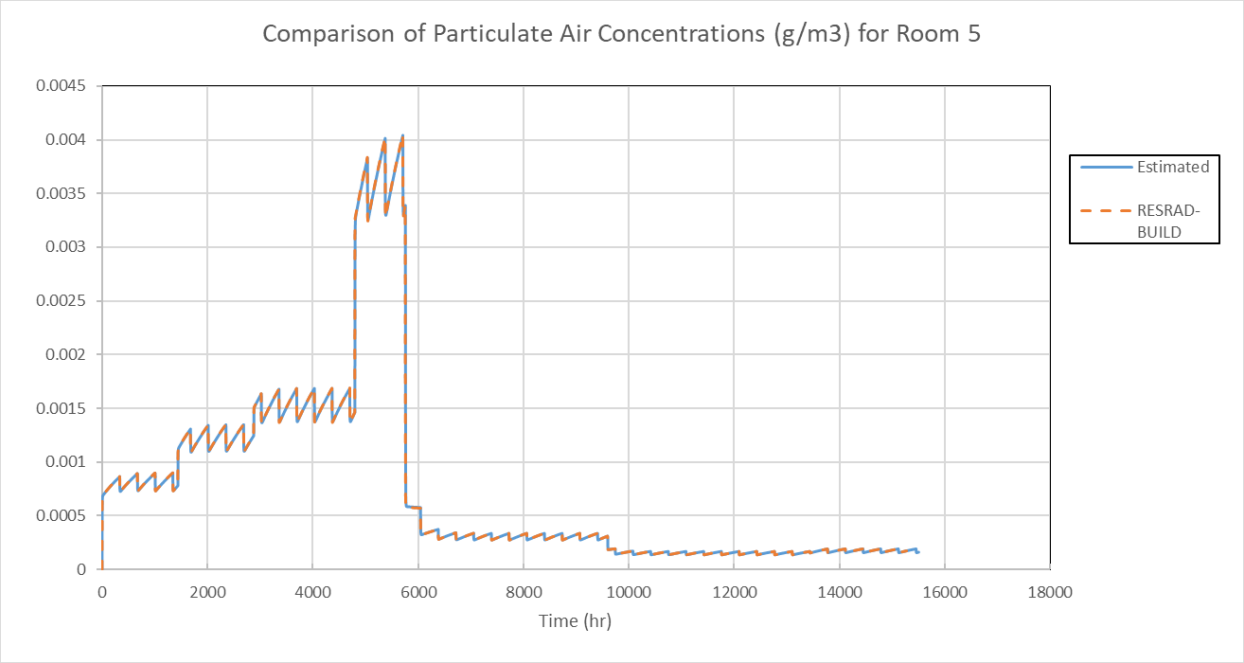


Figure 3.29 Comparison of Calculated Source Particulate Concentrations in the Air of Room 5 for Case VII

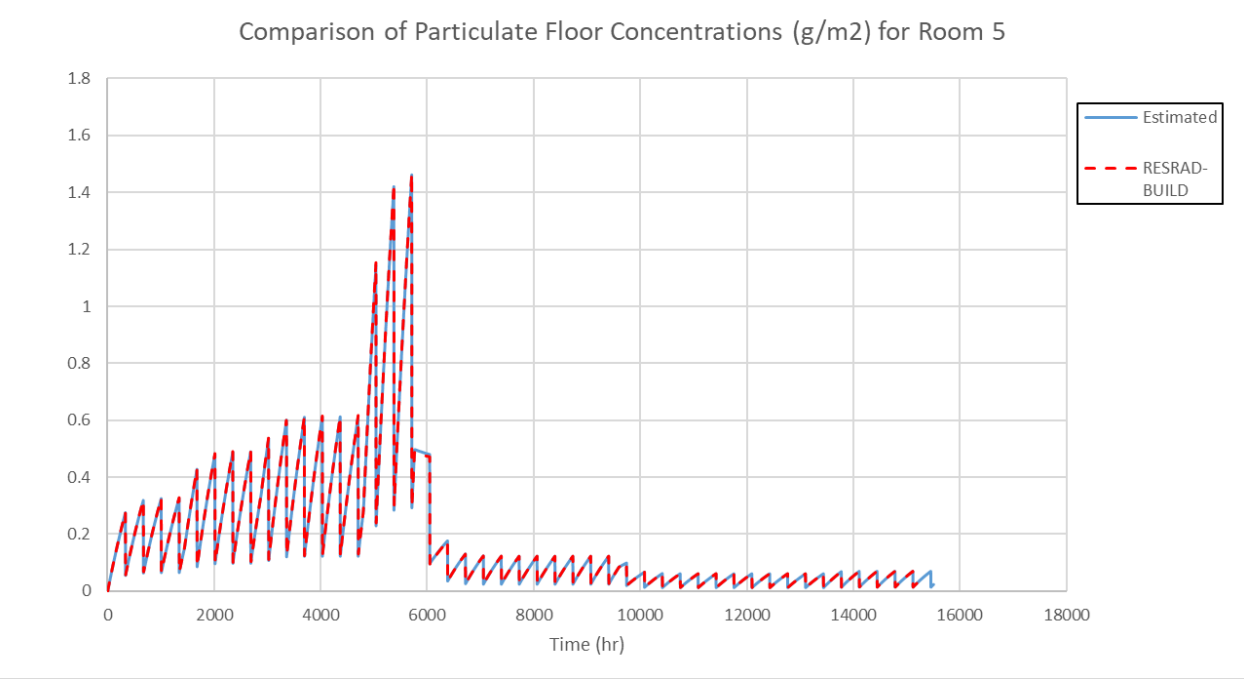


Figure 3.30 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 5 for Case VII

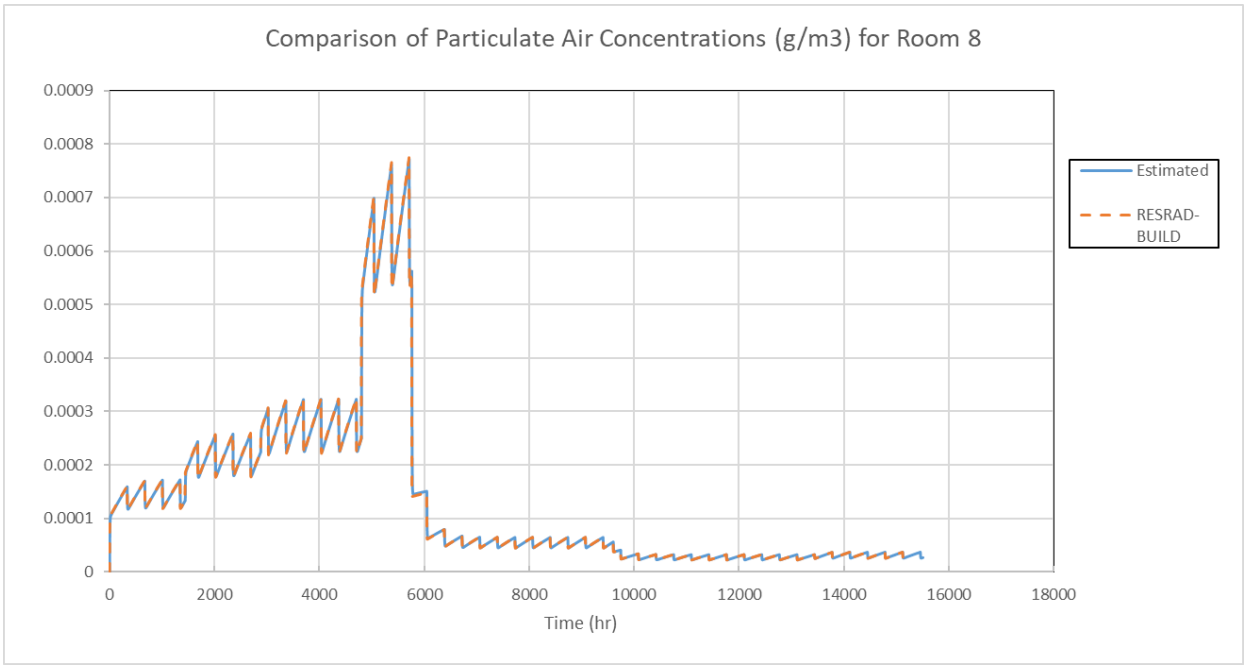


Figure 3.31 Comparison of Calculated Source Particulate Concentrations in the Air of Room 8 for Case VII

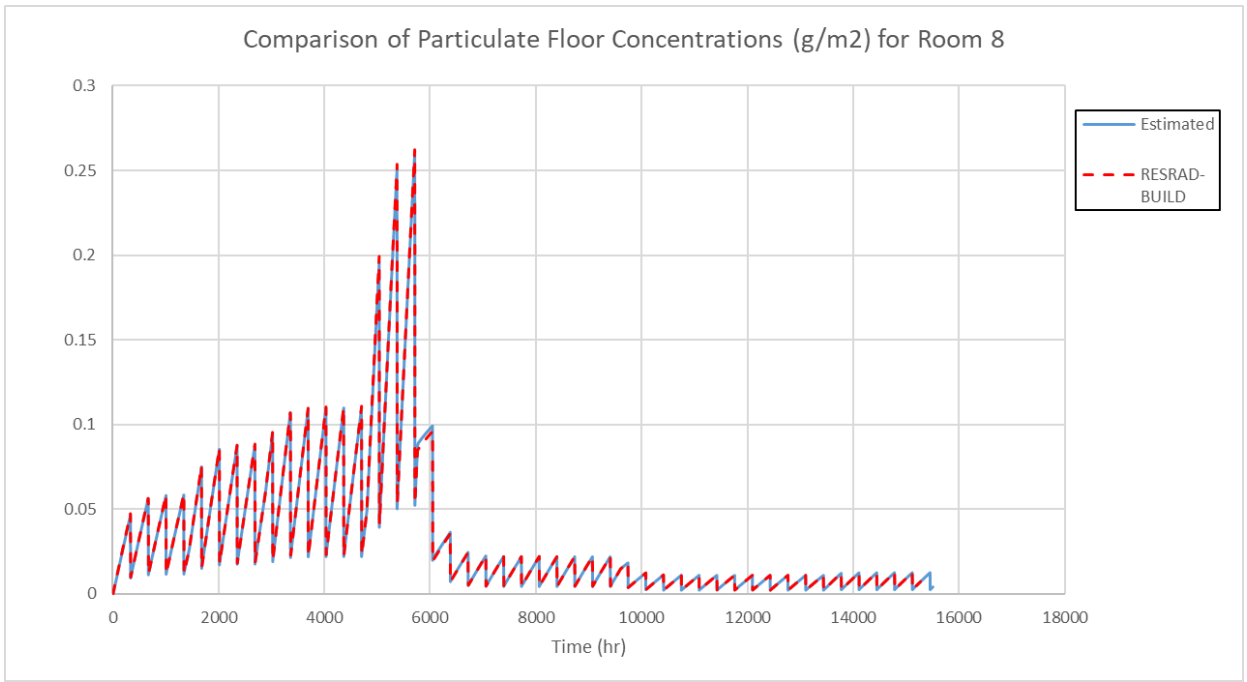


Figure 3.32 Comparison of Calculated Source Particulate Concentrations on the Floor of Room 8 for Case VII

Table 3.45 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 3 for Case VII

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration (pCi/m3 or pCi/m2)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
3	0	RA-226	RA-226	Air	3.92E-07	3.88E-07	1.21
3	0	RA-226	RA-226	Floor	8.43E-05	8.30E-05	1.57
3	0	RA-226	PB-210	Air	1.70E-09	1.69E-09	0.63
3	0	RA-226	PB-210	Floor	3.77E-07	3.74E-07	0.85
3	0	RA-226	PO-210	Air	2.45E-10	2.44E-10	0.46
3	0	RA-226	PO-210	Floor	5.41E-08	5.38E-08	0.62
3	0.25	RA-226	RA-226	Air	6.36E-07	6.34E-07	0.24
3	0.25	RA-226	RA-226	Floor	1.49E-04	1.49E-04	0.30
3	0.25	RA-226	PB-210	Air	7.49E-09	7.48E-09	0.17
3	0.25	RA-226	PB-210	Floor	1.76E-06	1.75E-06	0.23
3	0.25	RA-226	PO-210	Air	2.15E-09	2.15E-09	0.08
3	0.25	RA-226	PO-210	Floor	5.05E-07	5.05E-07	0.13
3	0.5	RA-226	RA-226	Air	9.15E-07	9.17E-07	0.26
3	0.5	RA-226	RA-226	Floor	2.21E-04	2.22E-04	0.45
3	0.5	RA-226	PB-210	Air	1.71E-08	1.72E-08	0.50
3	0.5	RA-226	PB-210	Floor	4.19E-06	4.22E-06	0.73
3	0.5	RA-226	PO-210	Air	6.80E-09	6.85E-09	0.69
3	0.5	RA-226	PO-210	Floor	1.69E-06	1.71E-06	0.96
3	0.75	RA-226	RA-226	Air	1.40E-07	1.40E-07	0.26
3	0.75	RA-226	RA-226	Floor	3.42E-05	3.45E-05	0.74
3	0.75	RA-226	PB-210	Air	3.74E-09	3.75E-09	0.24
3	0.75	RA-226	PB-210	Floor	9.14E-07	9.20E-07	0.65
3	0.75	RA-226	PO-210	Air	1.88E-09	1.89E-09	0.26
3	0.75	RA-226	PO-210	Floor	4.59E-07	4.62E-07	0.62
3	1	RA-226	RA-226	Air	9.73E-08	9.75E-08	0.25
3	1	RA-226	RA-226	Floor	2.39E-05	2.39E-05	0.36
3	1	RA-226	PB-210	Air	3.28E-09	3.29E-09	0.27
3	1	RA-226	PB-210	Floor	8.06E-07	8.09E-07	0.38
3	1	RA-226	PO-210	Air	1.88E-09	1.89E-09	0.30
3	1	RA-226	PO-210	Floor	4.63E-07	4.65E-07	0.42
3	1.25	RA-226	RA-226	Air	6.85E-08	6.85E-08	0.03
3	1.25	RA-226	RA-226	Floor	1.63E-05	1.63E-05	0.01
3	1.25	RA-226	PB-210	Air	2.87E-09	2.87E-09	0.04
3	1.25	RA-226	PB-210	Floor	6.81E-07	6.81E-07	0.00
3	1.25	RA-226	PO-210	Air	1.83E-09	1.83E-09	0.07
3	1.25	RA-226	PO-210	Floor	4.34E-07	4.34E-07	0.02
3	1.5	RA-226	RA-226	Air	7.54E-08	7.49E-08	0.57
3	1.5	RA-226	RA-226	Floor	1.75E-05	1.74E-05	0.38
3	1.5	RA-226	PB-210	Air	3.72E-09	3.70E-09	0.55
3	1.5	RA-226	PB-210	Floor	8.64E-07	8.61E-07	0.36
3	1.5	RA-226	PO-210	Air	2.55E-09	2.53E-09	0.53
3	1.5	RA-226	PO-210	Floor	5.92E-07	5.90E-07	0.33

Table 3.45 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration (pCi/m3 or pCi/m2)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
3	0	CS-137	CS-137	Air	3.91E-07	3.86E-07	1.21
3	0	CS-137	CS-137	Floor	8.40E-05	8.27E-05	1.57
3	0.25	CS-137	CS-137	Air	6.30E-07	6.29E-07	0.24
3	0.25	CS-137	CS-137	Floor	1.48E-04	1.47E-04	0.30
3	0.5	CS-137	CS-137	Air	9.02E-07	9.05E-07	0.26
3	0.5	CS-137	CS-137	Floor	2.18E-04	2.19E-04	0.46
3	0.75	CS-137	CS-137	Air	1.37E-07	1.37E-07	0.27
3	0.75	CS-137	CS-137	Floor	3.36E-05	3.38E-05	0.75
3	1	CS-137	CS-137	Air	9.49E-08	9.51E-08	0.26
3	1	CS-137	CS-137	Floor	2.33E-05	2.33E-05	0.37
3	1.25	CS-137	CS-137	Air	6.64E-08	6.64E-08	0.04
3	1.25	CS-137	CS-137	Floor	1.58E-05	1.58E-05	0.00
3	1.5	CS-137	CS-137	Air	7.26E-08	7.22E-08	0.56
3	1.5	CS-137	CS-137	Floor	1.69E-05	1.68E-05	0.36
3	0	CO-60	CO-60	Air	3.85E-07	3.80E-07	1.22
3	0	CO-60	CO-60	Floor	8.27E-05	8.14E-05	1.59
3	0.25	CO-60	CO-60	Air	6.05E-07	6.03E-07	0.24
3	0.25	CO-60	CO-60	Floor	1.42E-04	1.41E-04	0.30
3	0.5	CO-60	CO-60	Air	8.45E-07	8.47E-07	0.24
3	0.5	CO-60	CO-60	Floor	2.04E-04	2.05E-04	0.44
3	0.75	CO-60	CO-60	Air	1.25E-07	1.25E-07	0.27
3	0.75	CO-60	CO-60	Floor	3.05E-05	3.08E-05	0.76
3	1	CO-60	CO-60	Air	8.42E-08	8.44E-08	0.26
3	1	CO-60	CO-60	Floor	2.06E-05	2.07E-05	0.37
3	1.25	CO-60	CO-60	Air	5.72E-08	5.72E-08	0.05
3	1.25	CO-60	CO-60	Floor	1.36E-05	1.36E-05	0.00
3	1.5	CO-60	CO-60	Air	6.09E-08	6.05E-08	0.56
3	1.5	CO-60	CO-60	Floor	1.41E-05	1.41E-05	0.36

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

Table 3.46 Comparison of Calculated Average Concentrations of Radionuclide in the Air and on the Floor of Room 7 for Case VII

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration (pCi/m3 or pCi/m2)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
7	0	RA-226	RA-226	Air	1.84E-07	1.82E-07	1.25
7	0	RA-226	RA-226	Floor	3.95E-05	3.88E-05	1.57
7	0	RA-226	PB-210	Air	8.02E-10	7.97E-10	0.64
7	0	RA-226	PB-210	Floor	1.77E-07	1.75E-07	0.80
7	0	RA-226	PO-210	Air	1.15E-10	1.15E-10	0.46
7	0	RA-226	PO-210	Floor	2.54E-08	2.53E-08	0.55
7	0.25	RA-226	RA-226	Air	3.00E-07	2.99E-07	0.22
7	0.25	RA-226	RA-226	Floor	7.01E-05	6.99E-05	0.22
7	0.25	RA-226	PB-210	Air	3.54E-09	3.53E-09	0.15
7	0.25	RA-226	PB-210	Floor	8.27E-07	8.26E-07	0.14
7	0.25	RA-226	PO-210	Air	1.01E-09	1.01E-09	0.06
7	0.25	RA-226	PO-210	Floor	2.38E-07	2.38E-07	0.05
7	0.5	RA-226	RA-226	Air	4.33E-07	4.34E-07	0.32
7	0.5	RA-226	RA-226	Floor	1.04E-04	1.05E-04	0.59
7	0.5	RA-226	PB-210	Air	8.09E-09	8.14E-09	0.57
7	0.5	RA-226	PB-210	Floor	1.98E-06	2.00E-06	0.88
7	0.5	RA-226	PO-210	Air	3.22E-09	3.25E-09	0.78
7	0.5	RA-226	PO-210	Floor	7.98E-07	8.06E-07	1.11
7	0.75	RA-226	RA-226	Air	6.62E-08	6.64E-08	0.36
7	0.75	RA-226	RA-226	Floor	1.62E-05	1.64E-05	0.95
7	0.75	RA-226	PB-210	Air	1.77E-09	1.78E-09	0.34
7	0.75	RA-226	PB-210	Floor	4.32E-07	4.36E-07	0.86
7	0.75	RA-226	PO-210	Air	8.92E-10	8.95E-10	0.35
7	0.75	RA-226	PO-210	Floor	2.17E-07	2.19E-07	0.82
7	1	RA-226	RA-226	Air	4.61E-08	4.62E-08	0.31
7	1	RA-226	RA-226	Floor	1.13E-05	1.13E-05	0.50
7	1	RA-226	PB-210	Air	1.56E-09	1.56E-09	0.34
7	1	RA-226	PB-210	Floor	3.81E-07	3.83E-07	0.53
7	1	RA-226	PO-210	Air	8.92E-10	8.95E-10	0.37
7	1	RA-226	PO-210	Floor	2.18E-07	2.20E-07	0.56
7	1.25	RA-226	RA-226	Air	3.24E-08	3.24E-08	0.08
7	1.25	RA-226	RA-226	Floor	7.66E-06	7.67E-06	0.09
7	1.25	RA-226	PB-210	Air	1.35E-09	1.36E-09	0.09
7	1.25	RA-226	PB-210	Floor	3.21E-07	3.21E-07	0.10
7	1.25	RA-226	PO-210	Air	8.64E-10	8.65E-10	0.11
7	1.25	RA-226	PO-210	Floor	2.04E-07	2.05E-07	0.13
7	1.5	RA-226	RA-226	Air	3.56E-08	3.54E-08	0.55
7	1.5	RA-226	RA-226	Floor	8.24E-06	8.22E-06	0.27
7	1.5	RA-226	PB-210	Air	1.75E-09	1.75E-09	0.53
7	1.5	RA-226	PB-210	Floor	4.06E-07	4.05E-07	0.25
7	1.5	RA-226	PO-210	Air	1.20E-09	1.20E-09	0.51
7	1.5	RA-226	PO-210	Floor	2.78E-07	2.78E-07	0.23

Table 3.46 (Continued)

iRoom	Begin Time (yr)	Parent	Progeny	Media	Concentration (pCi/m3 or pCi/m2)		Difference (%)
					RESRAD-BUILD	Spreadsheet	$\left\|\frac{RESRAD-Spreadsheet}{RESRAD}\right\|$
7	0	CS-137	CS-137	Air	1.84E-07	1.81E-07	1.25
7	0	CS-137	CS-137	Floor	3.93E-05	3.87E-05	1.57
7	0.25	CS-137	CS-137	Air	2.98E-07	2.97E-07	0.22
7	0.25	CS-137	CS-137	Floor	6.95E-05	6.93E-05	0.21
7	0.5	CS-137	CS-137	Air	4.27E-07	4.28E-07	0.33
7	0.5	CS-137	CS-137	Floor	1.03E-04	1.03E-04	0.59
7	0.75	CS-137	CS-137	Air	6.49E-08	6.51E-08	0.36
7	0.75	CS-137	CS-137	Floor	1.59E-05	1.60E-05	0.96
7	1	CS-137	CS-137	Air	4.49E-08	4.51E-08	0.32
7	1	CS-137	CS-137	Floor	1.10E-05	1.10E-05	0.51
7	1.25	CS-137	CS-137	Air	3.14E-08	3.14E-08	0.09
7	1.25	CS-137	CS-137	Floor	7.43E-06	7.43E-06	0.10
7	1.5	CS-137	CS-137	Air	3.43E-08	3.41E-08	0.54
7	1.5	CS-137	CS-137	Floor	7.94E-06	7.92E-06	0.26
7	0	CO-60	CO-60	Air	1.81E-07	1.79E-07	1.26
7	0	CO-60	CO-60	Floor	3.87E-05	3.81E-05	1.58
7	0.25	CO-60	CO-60	Air	2.85E-07	2.85E-07	0.22
7	0.25	CO-60	CO-60	Floor	6.66E-05	6.65E-05	0.22
7	0.5	CO-60	CO-60	Air	4.00E-07	4.01E-07	0.31
7	0.5	CO-60	CO-60	Floor	9.61E-05	9.67E-05	0.57
7	0.75	CO-60	CO-60	Air	5.90E-08	5.92E-08	0.37
7	0.75	CO-60	CO-60	Floor	1.45E-05	1.46E-05	0.97
7	1	CO-60	CO-60	Air	3.99E-08	4.00E-08	0.32
7	1	CO-60	CO-60	Floor	9.74E-06	9.79E-06	0.51
7	1.25	CO-60	CO-60	Air	2.70E-08	2.71E-08	0.09
7	1.25	CO-60	CO-60	Floor	6.40E-06	6.41E-06	0.10
7	1.5	CO-60	CO-60	Air	2.87E-08	2.86E-08	0.54
7	1.5	CO-60	CO-60	Floor	6.66E-06	6.64E-06	0.26

Note: The difference (%) listed in the last column was calculated by dividing the difference between the RESRAD-BUILD result and the spreadsheet result with the RESRAD-BUILD result, and then multiplying the ratio by 100.

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APPENDIX A. RESRAD-BUILD Test Cases

A total of 41 test cases were developed by the RESRAD team for testing the RESRAD-BUILD code, to verify that it meets each of 36 software requirements established for its development. The 36 requirements, each was assigned a Requirement Identification (RID) number of 1 to 36, cover various components, designs, and functions of the software, as shown in Table A.1. Table A.2 presents the test cases for each requirement, while Table A.3 presents the requirements each test case aims to verify. The establishment of software requirements and the development of test cases were consistent with the RESRAD Quality Assurance (QA) Program, and the testing of the RESRAD-BUILD code followed the protocol of the QA Program.

This appendix presents the 41 test cases which were compiled in a RESRAD program document, RESBLD-TEST-00, that was approved by RESRAD Program Manager. The results of the release testing of RESRAD-BUILD Version 4.0 are presented in Appendix B.

Table A.1 Topics of the RESRAD-BUILD Software Requirements

RID	Type	Topic	Specific Topic
1	Installation/Operating System	**Install**	Computer Configurations
2	Functional	**Model> Building Compartments Ventilation**	Conceptualization of air exchanges
3	Functional	**Model> Receptor Location and Occupancy**	Receptor Location and Occupancy
4	Functional	**Model> Source Geometry and Location**	Conceptualization of primary contamination
5	Functional	**Model> Source/Receptor Shielding**	Conceptualization of shielding
6	Functional	**Model> Source Radionuclide Decay and Ingrowth Chains**	Transformation chains
7	Functional	**Model> Source Radionuclide Concentrations**	Concentration in source
8	Functional	**Model> Source Releases**	Release to Air
9	Functional	**Model> Source Special Radionuclides**	Tritium
10	Functional	**Model> Source Special Radionuclides**	Radon
11	Functional	**Model> Air Quality**	Air quality model
12	Functional	**Model> Exposure Pathway**	Direct External Radiation Model
13	Functional	**Model> Exposure Pathways**	Particulate Inhalation
14	Functional	**Model> Exposure Pathways**	Special Inhalation (for radon)
15	Functional	**Model> Exposure Pathways**	Air submersion
16	Functional	**Model> Exposure Pathways**	Ingestion
17	Functional	**GUI>Tools**	Reports
18	Functional	**GUI>Tools**	Graphics
19	Functional	**GUI>Tools**	DCF Editor
20	Functional	**GUI>Tools**	Sensitivity
21	Functional	**GUI>Tools**	Probabilistic
22	Functional	**GUI**	Navigation
23	Functional	**GUI**	Form level
24	Functional	**GUI**	Control Level
25	Functional	**GUI**	3D Display
26	Functional	**GUI**	Help
27	Inputs	**Data**	DCFs
28	Inputs	**Data**	Slope factors
29	Inputs	**Data**	Nuclide decay and ingrowth
30	Inputs	**Data**	External radiation factors
31	Inputs	**Data**	Uncertainty distributions
32	Performance / Timing	**Calculational Time**	Default
33	Security / Access Control	**Software Download Access**	Valid email
34	Interface	**Model Connections**	Output for IND
35	Design Constraints	**Platform**	Computer Type
36	Design Constraints	**Compatibility**	Input files from previous versions

Table A.2 Test Cases for Each Requirement

RID	Test Case(s)	RID	Test Case(s)
1	1	19	19
2	2	20	20
3	2	21	21
4	2	22	22-1, 22-2, 22-3
5	5	23	22-3
6	6	24	22-3
7	7-1, 7-2	25	25
8	7-1, 7-2, 8-1, 8-2, 8-3, 8-4, 8-5	26	26
9	9	27	27-1, 27-3, 27-3
10	10	28	28
11	7-1, 7-2, 8-1, 8-2, 8-3, 8-4, 8-5	29	6
12	12-1, 12-2, 12-3, 12-4, 12-5, 12-6	30	30-1, 30-2, 30-3
13	7-1, 7-2	31	31
14	10	32	32
15	7-1, 7-2	33	33
16	7-1, 7-2	34	34
17	17	35	1
18	18	36	36

Table A.3 Requirements for Each Test Case

Test Case	RID(s)	Test Case	RID(s)
1	1, 35	19	19
2	2, 3, 4	20	20
5	5	21	21
6	6, 29	22-1	22
7-1	7, 8,11, 13, 15, 16	22-2	22
7-2	7, 8, 11, 13, 15, 16	22-3	22, 23, 24
8-1	8, 11	25	25
8-2	8, 11	26	26
8-3	8, 11	27-1	27
8-4	8, 11	27-2	27
8-5	8, 11	27-3	27
9	9	28	28
10	10, 14	30-1	30
12-1	12	30-2	30
12-2	12	30-3	30
12-3	12	31	31
12-4	12	32	32
12-5	12	33	33
12-6	12	34	34
17	17	36	36
18	18		

TEST CASE 001

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-001
Requirements Tested	1, 35
Test Summary	Test installation and operation on various Windows PC operating systems.
Test Objective	Test installation and operation on various Windows PC operating systems.

Procedure	Install and run software on the range of operating systems the version is designed for. Note and document any issues. Specifically test for font installation.
	
	Steps for each operating system:
	• Install.
	• Look at ReadMe.
	• Launch RESRAD-BUILD.
	• Run one of the QA files in the QA_files subfolder of the folder installed for this version of RESRAD-BUILD (e.g., C:\RESRAD_Family\BUILD\4.0\QA_files\qa1.bld).
	• Open graphics, open report, look at font.
	• Do file comparison (fc) in DOS (fc as follows) or alternative equivalent approach for the output result file.
	  o Open Command Prompt.
	  o Navigate to the installation directory (e.g., type cd "C:\RESRAD_Family\BUILD\4.0" and press Enter).
	  o Run fc (e.g., type "fc RESRADB.RPT QA_files\QAoutputforComparison\qa1.RPT > difference.gra" and press Enter).
	  o Open the comparison results (e.g., type "type difference.gra" and press Enter).
	  o Review differences reported.

Required Data	NA
Expected Results	Successful installation. Should see only expected differences (e.g., date and time in reports).

TEST CASE 002

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-002
Requirements Tested	2, 3, 4
Test Summary	Test the specifications of receptors, radiation sources, and compartments in a contaminated building. Eight input files are constructed to test the code's capability of conceptualizing the radiation exposures of different receptors in a contaminated building. The number of rooms in the building ranges from 1 to 9, while the number of radiation sources and the number of receptors range from 1 to 10. The code is tested for constructing four different types of radiation sources, point, line, area, and volume; the first three types would release radionuclides through multiple time periods with different release rates. After each input file is constructed, calculations are launched to generate summary reports. The summary dose/risk reports are examined to check whether the radiation exposure conditions associated with the dose/risk results reflect the input specifications.
Test Objective	Test and verify the code provides input options to consider different exposure conditions with a contaminated building. The code allows up to 9 rooms in the building, up to 10 receptors in different rooms, and up to 10 radiation sources of different types, as specified by the code requirements 2, 3, and 4, respectively.
Procedure	Repeat the following steps to construct an input file based on specifications in the Input Specifications table and examine the dose/risk results: • Choose to create a new input file. • Choose the "Traditional Appearance" or "New Appearance" associated with the Advanced menu. • In the Building Parameters input form, specify the number of rooms in the building according to the specification. Click the Air Flow button to bring up the input form for specifying air flow rates. Change air flow rates between rooms and from each room to outdoors (as long as the values are accepted by the code). • In the Receptor Parameters input form, specify the number of receptors and their rooms according to the Input Specifications table. Change the receptor characteristics (as long as the values are accepted by the code). • Use the Source Parameter input form to create the number of sources and specify the source types and locations, and then click the source Details button to bring up input form(s) to specify source releases, according to the Input Specifications table. • Save the input file and launch calculations. • Open the dose summary report to verify the listings in the Input Parameters section are consistent with the input specifications. Examine the dose results to verify the number of receptors and the number of sources are also consistent with the input specifications.

Table. Input Specifications

Test No.	Form Appearance	No. of Rooms in Building	No. of Receptors	Receptor Room No.	No. of Sources	Source Room No.	Source Type	No. of Release Phases of Each Source
1	Traditional	1	1	1	3	1, 1, 1	A, V, L	1, 1, 1
2	Traditional	2	3	1, 2, 1	2	1, 2	A, V	1, 1
3	Traditional	3	5	1, 2, 3, 2, 1	5	3, 2, 1, 2, 3	A, L, P, A, V	1, 1, 1, 1, 1
4	New	2	6	1, 1, 1, 2, 2, 2	1	2	V	1
5	New	4	8	1, 2, 3, 4, 4, 3, 2, 1	4	4, 3, 2, 1	V, V, A, L	1, 1, 2, 3
6	New	6	10	1, 2, 3, 4, 5, 6, 1, 2, 4, 6	5	2, 4, 6, 5, 3	A, A, V, V, L	5, 7, 1, 1, 4
7	New	8	5	2, 4, 6, 8, 1	7	1, 2, 3, 4, 5, 6, 7	A, V, A, V, L, P, V	5, 1, 4, 1, 6, 9, 1
8	New	9	3	3, 6, 9	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 9	V, V, V, V, A, A, A, A, L, P	1, 1, 1, 1, 3, 6, 9, 10, 5, 3

Source Type —A: Area, L: Line, P: Point, V: Volume.

Required Data None.

Expected Results The code should allow the considerations of up to 9 rooms, up to 10 receptors, and up to 10 radiation sources of 4 different types in each run of the calculations.

TEST CASE 005

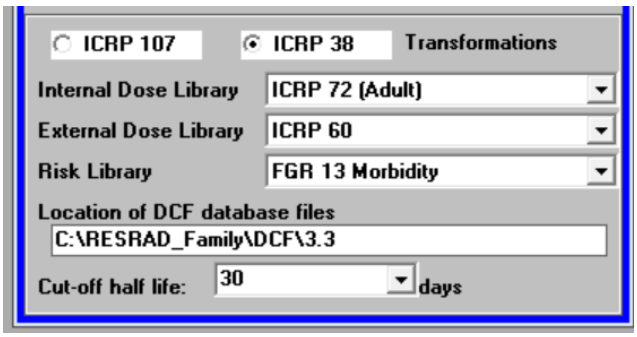
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-005
Requirements Tested	5
Test Summary	Test the specification of shielding between radiation sources and receptors.
Test Objective	To test the functionality of shielding parameters input and output in the GUI.
Procedure	1. Launch the code and specify values to Thickness, Density, and Material input boxes in the Shielding Parameter window. 2. Save the project as Site5.bld and open the saved project file. If the values for parameters DSOR, DSTH, DSDEN, and MTLC match the specified values, go to Step 3; otherwise, the test has failed. 3. Add 1 source and 1 receptor to the project and specify different values to the input boxes in the Shielding Parameter window. 4. Save the project as "Site5-1.bld" and check the values for the parameters DSOR, DSTH, DSDEN, and MTLC. If they match the input values, go to the next step; otherwise, the test has failed. 5. Open project file "Site5-1.bld" and click View Table button in the Shielding Parameter window. If the values shown in the pop-up Source Receptor Table window match the input values, go to the next step; otherwise, the test has failed. 6. Open project file "Site5-1.bld" and click the View Table button in the Shielding Parameter window. Change the value in each input box in the pop-up Source Receptor Table window and then click the Save and Exit button. The pop-up window should close and the values in Shielding Parameter window should be updated accordingly. If the values do not match the input in the Source Receptor Table window, the test has failed. 7. Repeat Step 6 but click the Cancel button in the Source Receptor Table window. All the values in the Shielding Parameter window should not be changed. 8. Open project file "Site5-1.bld" and click the Copy Shielding button in the Shielding Parameter window. 9. Select each of the three options in the pop-up Copy Shielding window and then click the Save button. Check the values for shielding between each receptor and each source in the Shielding Parameter window. If the values in the Shielding Parameter window match with the selected option, the test has passed.
Required Data	None.
Expected Results	In Steps 2, 4, 5, 6, 7, and 8, the values in either the input file or interface windows should match with the input values or the specified options.

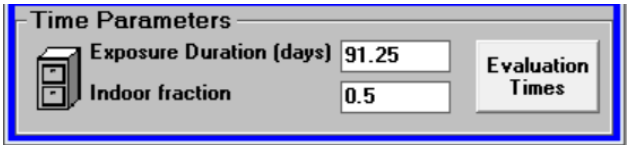
TEST CASE 006

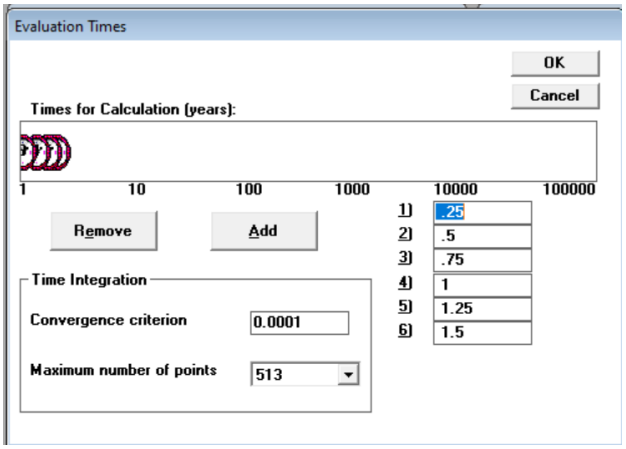
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-006
Requirements Tested	6, 29
Test Summary	Test the assembly of decay chains based on specified transformation database and input cut-off half-life.
Test Objective	To test the functionality of decay chain assembling in GUI. Correct decay chains assembled also verify the decay data used.
Procedure	1. Launch the code, remove evaluation times from Evaluation Times window, select ICRP 38 radionuclide data and set cut-off half-life at 30 days, and click Details button in the Source Parameters window 2. Remove CO-60 from the contamination radionuclide list and add the following radionuclides to source: AM-242M, BK-247, CD-115M, CF-248, CF-251, CF-252, CM-241 , CM-243, FE-60, FM-257, GD-146, GD-151, HF-182, IR-192M, LU-174M, MD-258, MO-93, NP-235, NP-236A, PM-146, RE-184M, RH-102M , SB-125, SM-145, TC-97M, TE-123M, TE-129M, U-238, ZR-88, ZR-93, ZR-95. 3. Save the project to Site6.bld and run the code. 4. Open the summary report and check the decay chain shown in the Nuclide Detail of Doses section. The decay chain for each nuclide should be correct compared with ICRP 38 data. 5. Change the radionuclides database to ICRP 107, select cut-off half-life at 30 days, and repeat Steps 1 to 4. Compare the decay chain results with ICRP 107 data.
Required Data	The following files can be used as optional input and output files for testing: “Test Case 006-38.bld” and “Test006-38.rpt” for ICRP 38 case and “Test Case 006-107.bld” and “Test006-107.rpt” for ICRP 107.
Expected Results	When radionuclides are selected in the GUI, a decay chain should be correctly generated for each source radionuclide.

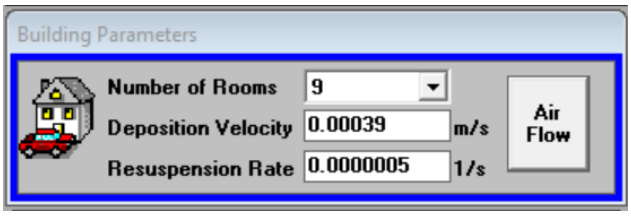
TEST CASE 007-1

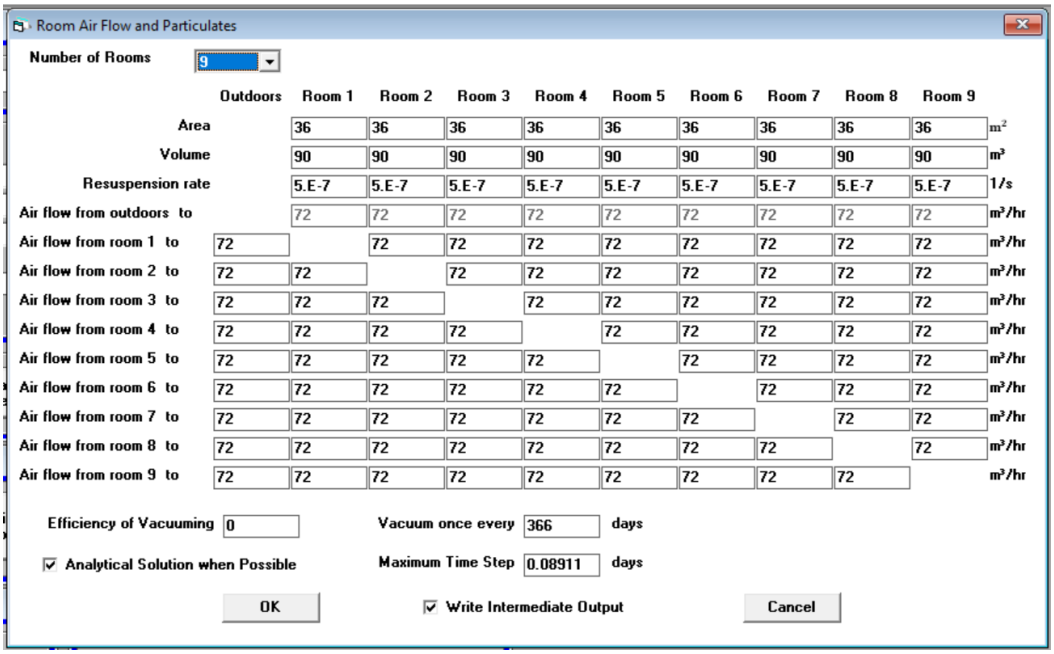
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-007-1
Requirements Tested	7, 8, 11, 13, 15, 16
Test Summary	Test the modeling of source release; transport of released particles; radionuclide concentrations in the source, air, and floor (deposition); and the radiation dose and risk from the inhalation, ingestion, and air submersion pathways. With a volume source (in Room 1), a 9-room building, and 4 receptors in different rooms, this test case tests and verifies the contaminant releases, the remaining nuclide inventory in the source, the air concentrations and floor deposition concentrations in different rooms, and the radiation dose and cancer risks received by each receptor over time.
Test Objective	Test and verify the modeling of concentrations in the source, the particulate releases to air, the air ventilation and transport, and the dose and risk associated with the particulate inhalation, air submersion, and ingestion pathways, as required by the code requirements 7, 8, 11, 13, 15, and 16, respectively.
Procedure	Read in an input file that was used in previous code verification effort (the verification results were documented in the Excel file "Vol1_S=1.xlsx"), run the RESRAD-BUILD code to generate intermediate outputs and summary reports, and then compare the results in these outputs and reports with those previously obtained. The results obtained from the current run should match what were obtained previously. Steps: • Read in the input file "Volume 1_S=1_EXP.BLD." • Check to see the "new appearance" and "write intermediate output" features are selected and the number of receptors is 4. If not, change the input selections to match. • Check to see the inputs match the following. If not, change the inputs to match.

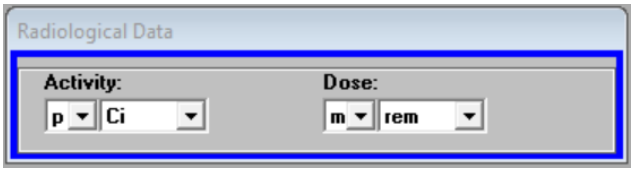


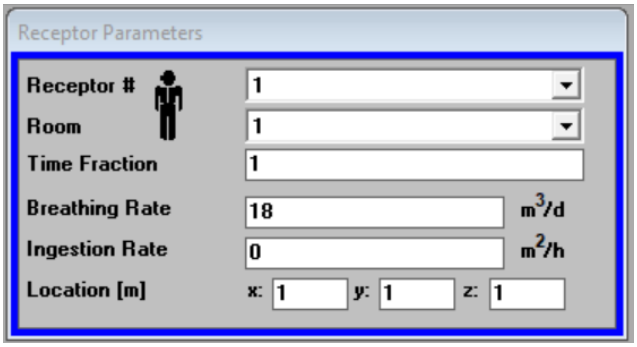


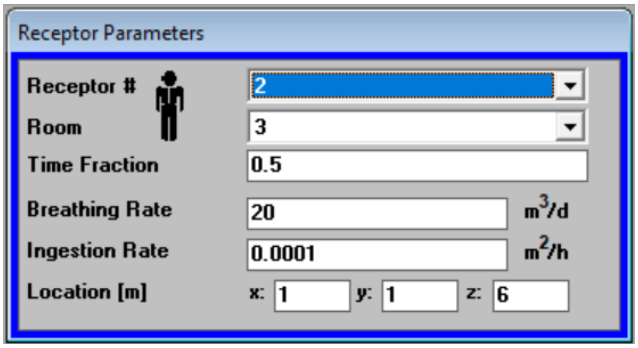

Evaluation Times
OK
Cancel
Times for Calculation (years):
1
10
100
1000
10000
100000
Remove
Add
1) .25
2) .5
3) .75
4) 1
5) 1.25
6) 1.5
Time Integration
Convergence criterion
0.0001
Maximum number of points
513

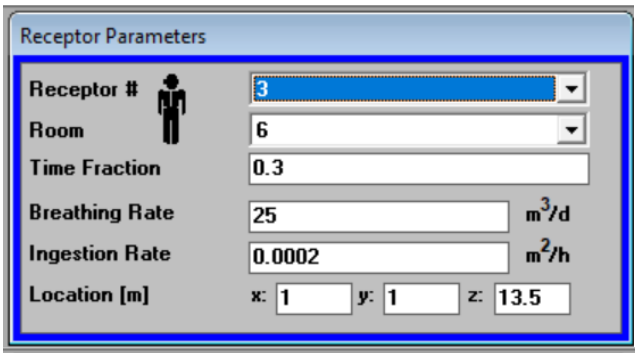

Building Parameters
Number of Rooms
9
Deposition Velocity
0.00039
m/s
Resuspension Rate
0.0000005
1/s
Air Flow

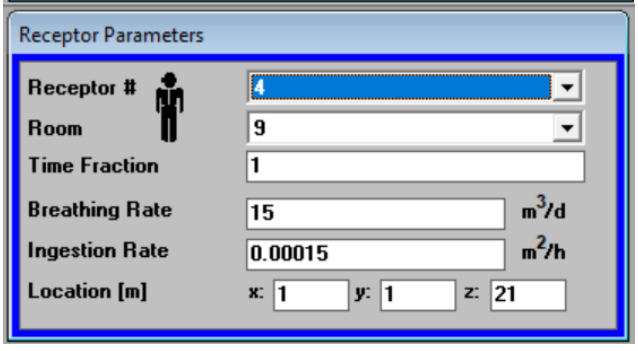

Room Air Flow and Particulates
Number of Rooms
9
Outdoors
Room 1
Room 2
Room 3
Room 4
Room 5
Room 6
Room 7
Room 8
Room 9
Area
Volume
Resuspension rate
Air flow from outdoors to
Air flow from room 1 to
Air flow from room 2 to
Air flow from room 3 to
Air flow from room 4 to
Air flow from room 5 to
Air flow from room 6 to
Air flow from room 7 to
Air flow from room 8 to
Air flow from room 9 to
Efficiency of Vacuuming
0
Vacuum once every
366
days
Analytical Solution when Possible
Maximum Time Step
0.08911
days
OK
Write Intermediate Output
Cancel

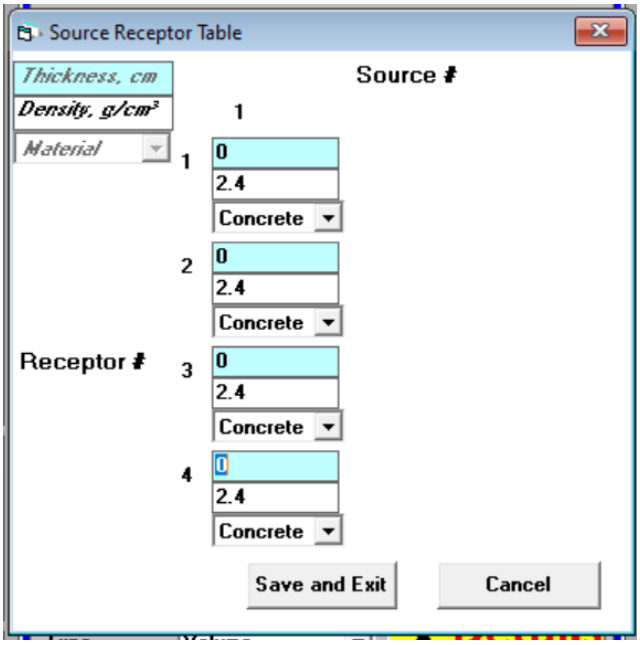

Radiological Data
Activity:
p
Ci
Dose:
m
rem

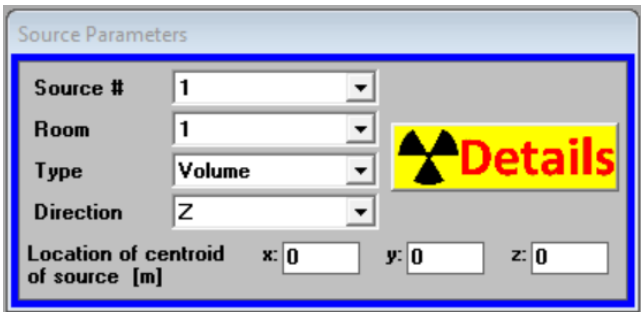

Receptor Parameters
Receptor #
1
Room
1
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0
m2/h
Location [m]
x: 1
y: 1
z: 1

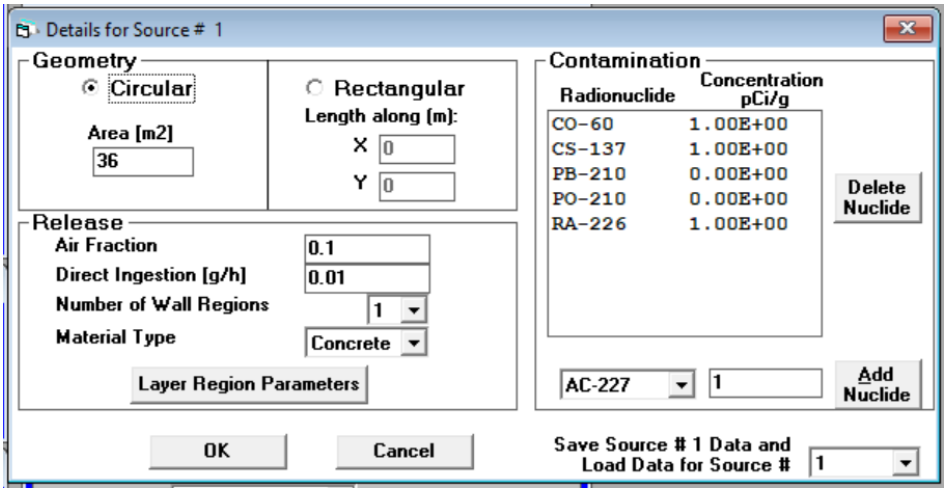

Receptor Parameters
Receptor #
2
Room
3
Time Fraction
0.5
Breathing Rate
20
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 6

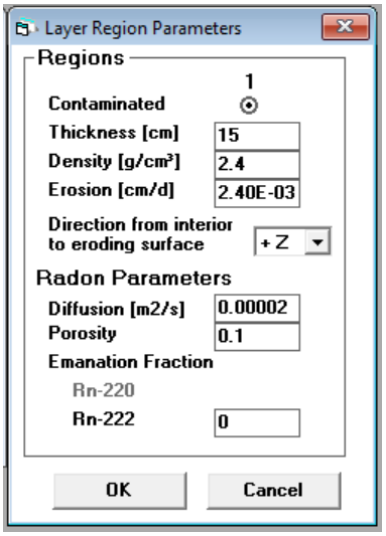

Receptor Parameters
Receptor #
3
Room
6
Time Fraction
0.3
Breathing Rate
25
m3/d
Ingestion Rate
0.0002
m2/h
Location [m]
x: 1
y: 1
z: 13.5


Receptor Parameters
Receptor #
4
Room
9
Time Fraction
1
Breathing Rate
15
m3/d
Ingestion Rate
0.00015
m2/h
Location [m]
x: 1
y: 1
z: 21


Source Receptor Table
Thickness, cm
Density, g/cm³
Material
Source #
1
Receptor #
1
0
2.4
Concrete
2
0
2.4
Concrete
3
0
2.4
Concrete
4
0
2.4
Concrete
Save and Exit
Cancel


Source Parameters
Source #
1
Room
1
Type
Volume
Direction
Z
Details
Location of centroid of source [m]
x: 0
y: 0
z: 0


Details for Source # 1
Geometry
Circular
Area [m2]
36
Rectangular
Length along (m):
X 0
Y 0
Release
Air Fraction 0.1
Direct Ingestion [g/h] 0.01
Number of Wall Regions 1
Material Type Concrete
Layer Region Parameters
Contamination
Radionuclide
Concentration pCi/g
CO-60 1.00E+00
CS-137 1.00E+00
PB-210 0.00E+00
PO-210 0.00E+00
RA-226 1.00E+00
Delete Nuclide
AC-227
1
Add Nuclide
OK
Cancel
Save Source # 1 Data and Load Data for Source #
1



- Run the code.
- After the calculations are completed, choose the menu option, View – dose coefficient and slope factors.
- The aggregated dose and slope factors (including those of short-live progeny) used for the calculations should match the following.

Dose and Slope Factors including contribution of Associated Radionuclides
External Dose Factors from ICRP 60
Internal Dose Factors from ICRP 72 (Adult)
Slope Factors from FGR 13 Morbidity

Isotope	External Air (mrem/y) /(pCi/m³)	Inhalation mrem/pCi	Ingestion mrem/pCi	External Air risk/y /(pCi/m³)	Inhalation risk /pCi	Ingestion risk /pCi
Ra-226	9.77E-03	3.53E-02	1.04E-03	7.87E-09	2.83E-08	5.15E-10
Pb-210	3.53E-05	2.11E-02	2.56E-03	9.04E-12	1.63E-08	1.19E-09
Po-210	4.54E-08	1.59E-02	4.44E-03	3.66E-14	1.45E-08	2.25E-09
Cs-137	2.98E-03	1.44E-04	4.81E-05	2.39E-09	1.12E-10	3.74E-11
Co-60	1.39E-02	1.15E-04	1.26E-05	1.12E-08	1.01E-10	2.23E-11

- Choose to view “Time Integrated Source Concentrations” and “Time Averaged Direct Ingestion” outputs for Source 1 or open the file “DirectTimeIntegratedConcSource1.out” in the directory where the code was installed to view. The intermediate outputs (for time-averaged activity in the source and time-integrated direct ingestion of radionuclides) should match those listed as “from RRB” in the tab “RRB_DirectTimeIntegratedSource1” in the “Vol1_S=1.xlsx” Excel file.
- Open the file “AirRelRate1.out” in the directory where the code was installed to view. The intermediate outputs (for release rate of source material) should match those obtained from the code previously in the tab “RRB_AirRelrate1” in the “Vol1_S=1.xlsx” Excel file.
- Choose to view “Time averaged concentrations of radionuclides on particulates suspended in air and deposited on floor” outputs for Source 1 or open the file “AirRelTimeIntegratedConcSource1.out” in the directory where the code was installed to view. The intermediate outputs (for time-averaged nuclide concentrations in the air and on the floor) should match those listed as “from RRB” in the tab “RRB_TimeIntegratedConcSource1” in the “Vol1_S=1.xlsx” Excel file.

- Choose to view "Component of dose and risk" outputs or open the file "Dose and risk components.rpt" in the directory where the code was installed to view. The outputs (for inhalation, external immersion, ingestion deposition, and ingestion source pathway doses and risks of each nuclide) should match those listed as "from RRB" in the tab "RRB_DoseRiskComponents" in the "Vol1_S=1.xlsx" Excel file.
- Choose to view "last report," or open the file "RESRADB.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway doses for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	6.33E-01	1.90E-04	7.16E-05	0.00E+00	1.30E-04	1.21E-02	2.92E+00
2	1.74E-01	1.60E-01	4.27E-05	1.63E-05	3.40E-04	6.29E-05	0.00E+00	3.35E-01
3	2.38E-02	1.20E-01	2.56E-05	9.78E-06	4.08E-04	3.78E-05	0.00E+00	1.45E-01
4	3.29E-02	2.41E-01	8.53E-05	3.26E-05	1.02E-03	1.26E-04	0.00E+00	2.75E-01
Total	2.51E+00	1.15E+00	3.44E-04	1.30E-04	1.77E-03	3.56E-04	1.21E-02	3.68E+00

Evaluation Time: 0.250000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.23E+00	6.99E-01	2.75E-04	7.72E-05	0.00E+00	2.04E-04	1.25E-02	2.94E+00
2	1.70E-01	1.93E-01	6.75E-05	1.91E-05	5.60E-04	9.91E-05	0.00E+00	3.63E-01
3	2.33E-02	1.44E-01	4.05E-05	1.15E-05	6.72E-04	5.94E-05	0.00E+00	1.68E-01
4	3.22E-02	2.89E-01	1.35E-04	3.83E-05	1.68E-03	1.98E-04	0.00E+00	3.23E-01
Total	2.46E+00	1.33E+00	5.18E-04	1.46E-04	2.91E-03	5.60E-04	1.25E-02	3.80E+00

Evaluation Time: 0.500000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.18E+00	7.09E-01	2.76E-04	7.65E-05	0.00E+00	2.11E-04	1.29E-02	2.90E+00
2	1.66E-01	1.97E-01	6.90E-05	1.91E-05	6.02E-04	1.03E-04	0.00E+00	3.63E-01
3	2.27E-02	1.48E-01	4.14E-05	1.15E-05	7.22E-04	6.16E-05	0.00E+00	1.71E-01
4	3.14E-02	2.95E-01	1.38E-04	3.82E-05	1.81E-03	2.05E-04	0.00E+00	3.29E-01
Total	2.40E+00	1.35E+00	5.25E-04	1.45E-04	3.13E-03	5.80E-04	1.29E-02	3.77E+00

Evaluation Time: 0.750000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.13E+00	7.15E-01	2.72E-04	7.53E-05	0.00E+00	2.11E-04	1.34E-02	2.86E+00
2	1.62E-01	1.99E-01	6.81E-05	1.88E-05	6.27E-04	1.03E-04	0.00E+00	3.61E-01
3	2.21E-02	1.49E-01	4.08E-05	1.13E-05	7.52E-04	6.18E-05	0.00E+00	1.72E-01
4	3.06E-02	2.98E-01	1.36E-04	3.76E-05	1.88E-03	2.06E-04	0.00E+00	3.31E-01
Total	2.35E+00	1.36E+00	5.17E-04	1.43E-04	3.26E-03	5.82E-04	1.34E-02	3.73E+00

Evaluation Time: 1.00000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.09E+00	7.20E-01	2.68E-04	7.41E-05	0.00E+00	2.11E-04	1.39E-02	2.82E+00
2	1.58E-01	2.00E-01	6.70E-05	1.85E-05	6.51E-04	1.03E-04	0.00E+00	3.59E-01
3	2.16E-02	1.50E-01	4.02E-05	1.11E-05	7.81E-04	6.18E-05	0.00E+00	1.72E-01
4	2.99E-02	3.00E-01	1.34E-04	3.70E-05	1.95E-03	2.06E-04	0.00E+00	3.32E-01
Total	2.30E+00	1.37E+00	5.09E-04	1.41E-04	3.39E-03	5.82E-04	1.39E-02	3.68E+00

Evaluation Time: 1.25000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.04E+00	7.25E-01	2.64E-04	7.28E-05	0.00E+00	2.11E-04	1.44E-02	2.78E+00
2	1.54E-01	2.01E-01	6.59E-05	1.82E-05	6.76E-04	1.03E-04	0.00E+00	3.56E-01
3	2.11E-02	1.51E-01	3.95E-05	1.09E-05	8.11E-04	6.18E-05	0.00E+00	1.73E-01
4	2.92E-02	3.02E-01	1.32E-04	3.64E-05	2.03E-03	2.06E-04	0.00E+00	3.34E-01
Total	2.25E+00	1.38E+00	5.01E-04	1.38E-04	3.51E-03	5.82E-04	1.44E-02	3.65E+00

Evaluation Time: 1.50000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.00E+00	7.30E-01	2.59E-04	7.17E-05	0.00E+00	2.11E-04	1.50E-02	2.74E+00
2	1.50E-01	2.03E-01	6.49E-05	1.79E-05	7.01E-04	1.03E-04	0.00E+00	3.54E-01
3	2.06E-02	1.52E-01	3.89E-05	1.07E-05	8.41E-04	6.18E-05	0.00E+00	1.74E-01
4	2.85E-02	3.04E-01	1.30E-04	3.58E-05	2.10E-03	2.06E-04	0.00E+00	3.35E-01
Total	2.20E+00	1.39E+00	4.93E-04	1.36E-04	3.65E-03	5.82E-04	1.50E-02	3.61E+00

- Choose to view "last risk report," or open the file "RESRADB_r.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway risks for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	5.08E-07	1.53E-10	5.77E-11	0.00E+00	1.43E-10	6.35E-09	2.34E-06
2	1.40E-07	1.29E-07	3.42E-11	1.32E-11	1.78E-10	7.54E-11	0.00E+00	2.68E-07
3	1.91E-08	9.65E-08	2.05E-11	7.89E-12	2.13E-10	5.65E-11	0.00E+00	1.16E-07
4	2.64E-08	1.93E-07	6.84E-11	2.63E-11	5.33E-10	1.13E-10	0.00E+00	2.20E-07
Total	2.01E-06	9.26E-07	2.76E-10	1.05E-10	9.24E-10	3.88E-10	6.35E-09	2.95E-06

Evaluation Time: 0.250000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.79E-06	5.61E-07	2.20E-10	6.23E-11	0.00E+00	2.24E-10	6.51E-09	2.36E-06
2	1.36E-07	1.54E-07	5.41E-11	1.54E-11	2.92E-10	1.19E-10	0.00E+00	2.91E-07
3	1.87E-08	1.16E-07	3.25E-11	9.26E-12	3.50E-10	8.90E-11	0.00E+00	1.35E-07
4	2.58E-08	2.32E-07	1.08E-10	3.09E-11	8.75E-10	1.78E-10	0.00E+00	2.59E-07
Total	1.97E-06	1.06E-06	4.15E-10	1.18E-10	1.52E-09	6.09E-10	6.51E-09	3.04E-06

Evaluation Time: 0.500000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.75E-06	5.69E-07	2.22E-10	6.17E-11	0.00E+00	2.31E-10	6.71E-09	2.33E-06
2	1.33E-07	1.58E-07	5.53E-11	1.54E-11	3.13E-10	1.23E-10	0.00E+00	2.91E-07
3	1.82E-08	1.18E-07	3.32E-11	9.25E-12	3.75E-10	9.22E-11	0.00E+00	1.37E-07
4	2.52E-08	2.37E-07	1.11E-10	3.08E-11	9.38E-10	1.84E-10	0.00E+00	2.63E-07
Total	1.93E-06	1.08E-06	4.21E-10	1.17E-10	1.63E-09	6.31E-10	6.71E-09	3.02E-06

Evaluation Time: 0.750000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.71E-06	5.73E-07	2.18E-10	6.07E-11	0.00E+00	2.32E-10	6.94E-09	2.29E-06
2	1.30E-07	1.59E-07	5.46E-11	1.52E-11	3.24E-10	1.23E-10	0.00E+00	2.89E-07
3	1.78E-08	1.19E-07	3.27E-11	9.11E-12	3.89E-10	9.25E-11	0.00E+00	1.38E-07
4	2.46E-08	2.39E-07	1.09E-10	3.04E-11	9.73E-10	1.85E-10	0.00E+00	2.65E-07
Total	1.88E-06	1.09E-06	4.15E-10	1.15E-10	1.69E-09	6.33E-10	6.94E-09	2.98E-06

Evaluation Time: 1.00000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.67E-06	5.77E-07	2.15E-10	5.97E-11	0.00E+00	2.32E-10	7.18E-09	2.26E-06
2	1.27E-07	1.60E-07	5.37E-11	1.49E-11	3.36E-10	1.23E-10	0.00E+00	2.87E-07
3	1.73E-08	1.20E-07	3.22E-11	8.96E-12	4.03E-10	9.25E-11	0.00E+00	1.38E-07
4	2.40E-08	2.41E-07	1.07E-10	2.99E-11	1.01E-09	1.85E-10	0.00E+00	2.66E-07
Total	1.84E-06	1.10E-06	4.08E-10	1.13E-10	1.75E-09	6.33E-10	7.18E-09	2.95E-06

Evaluation Time: 1.25000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.64E-06	5.82E-07	2.11E-10	5.87E-11	0.00E+00	2.32E-10	7.44E-09	2.23E-06
2	1.24E-07	1.62E-07	5.28E-11	1.47E-11	3.48E-10	1.23E-10	0.00E+00	2.86E-07
3	1.69E-08	1.21E-07	3.17E-11	8.81E-12	4.18E-10	9.25E-11	0.00E+00	1.39E-07
4	2.34E-08	2.42E-07	1.06E-10	2.94E-11	1.04E-09	1.85E-10	0.00E+00	2.67E-07
Total	1.80E-06	1.11E-06	4.02E-10	1.12E-10	1.81E-09	6.33E-10	7.44E-09	2.92E-06

Evaluation Time: 1.50000000 years

Pathway Detail of Risks

[Risk]

Source: 1

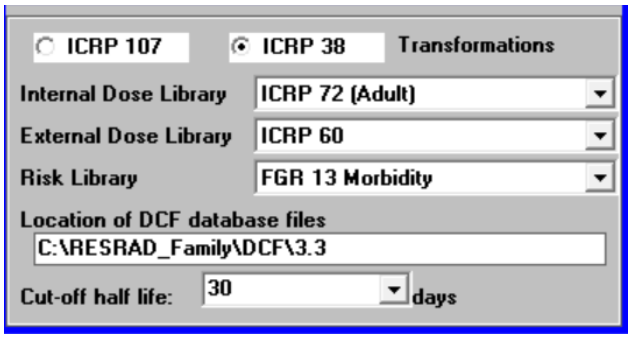
Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.60E-06	5.86E-07	2.08E-10	5.78E-11	0.00E+00	2.32E-10	7.70E-09	2.20E-06
2	1.21E-07	1.63E-07	5.20E-11	1.44E-11	3.60E-10	1.23E-10	0.00E+00	2.84E-07
3	1.65E-08	1.22E-07	3.12E-11	8.67E-12	4.32E-10	9.25E-11	0.00E+00	1.39E-07
4	2.28E-08	2.44E-07	1.04E-10	2.89E-11	1.08E-09	1.85E-10	0.00E+00	2.68E-07
Total	1.76E-06	1.11E-06	3.95E-10	1.10E-10	1.87E-09	6.33E-10	7.70E-09	2.89E-06

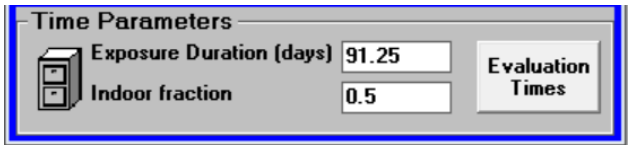
Required Data Input file “Volume 1_S=1_EXP.BLD” and the verification Excel file “Vol1_S=1.xlsx.”

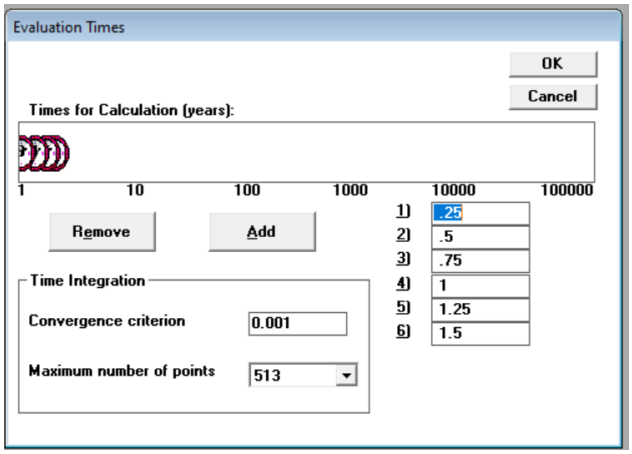
Expected Results The intermediate and final outputs should match those previously obtained (and verified) with the same input file or input selections/values.

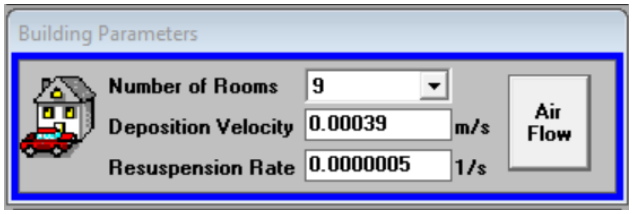
TEST CASE 007-2

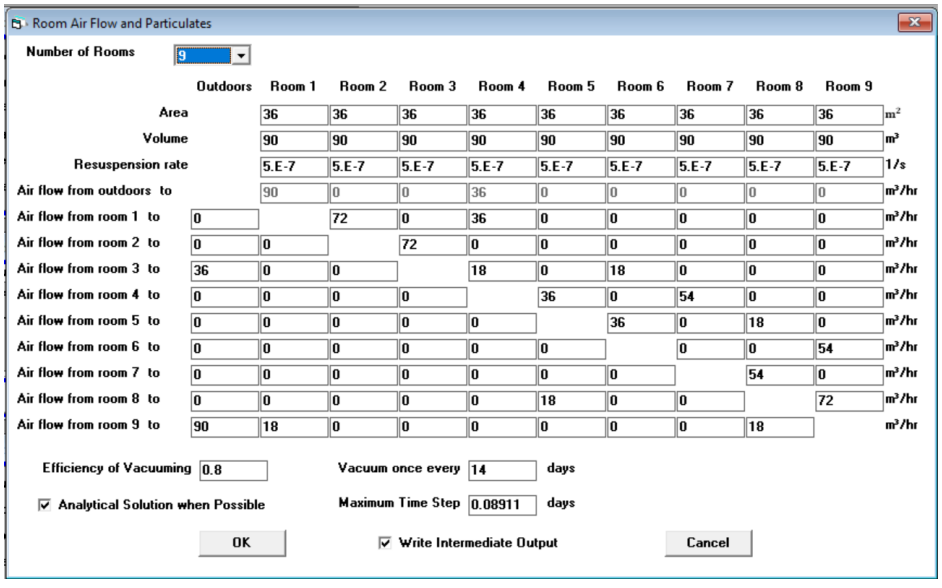
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-007-2
Requirements Tested	7, 8, 11, 13, 15, 16
Test Summary	Test the modeling of source release; transport of released particles; radionuclide concentrations in source, air, and floor (deposition); and radiation dose and risk from the inhalation, ingestion, and air submersion pathways. With an area source (in Room 3), a 9-room building which is vacuumed every 14 days, and 4 receptors in different rooms, this test case tests and verifies the contaminant releases, the remaining nuclide inventory in the source, the air concentrations and floor deposition concentrations in different rooms, and the radiation dose and cancer risks received by each receptor over time.
Test Objective	Test and verify the modeling of concentrations in the source, the particulate releases to air (during different release phases), the air ventilation and transport (involving periodical vacuuming), and the dose and risk associated with the particulate inhalation, air submersion, and ingestion pathways, as required by the code requirements 7, 8, 11, 13, 15, and 16, respectively.
Procedure	Read in an input file that was used in previous code verification effort (the verification results were documented in the Excel file "Area 1_S=3_V=14.xlsx"), run the RESRAD-BUILD code to generate intermediate outputs and summary reports, and then compare the results in these outputs and reports with those previously obtained. The results obtained from the current run should match what were obtained previously. Steps: • Read in the input file "Area 1_S=3_V=14_exp.BLD." • Check to see the "new appearance" and "write intermediate output" features are selected and the number of receptors is 4. If not, change the input selections to match. • Check to see the inputs match the following. If not, change the inputs to match.

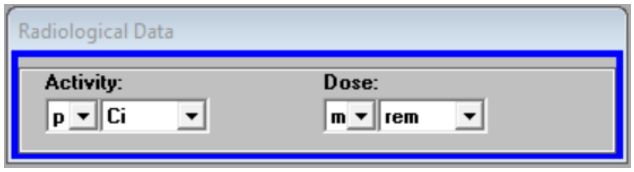


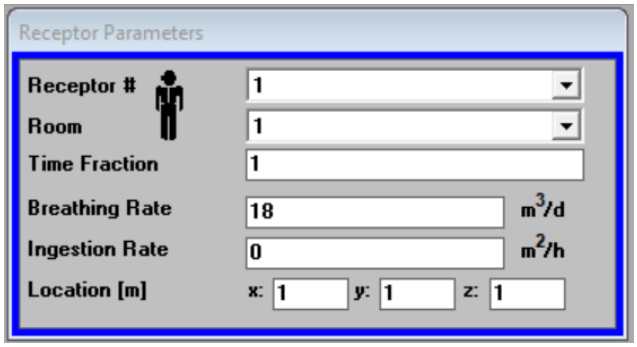

Time Parameters
Exposure Duration (days)
91.25
Indoor fraction
0.5
Evaluation Times

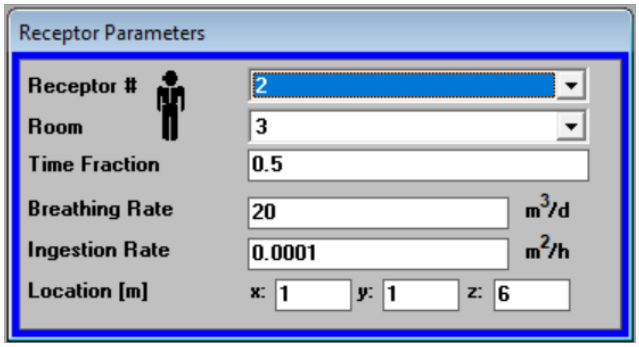

Evaluation Times
OK
Cancel
Times for Calculation (years):
1
10
100
1000
10000
100000
Remove
Add
1) .25
2) .5
3) .75
4) 1
5) 1.25
6) 1.5
Time Integration
Convergence criterion
0.001
Maximum number of points
513

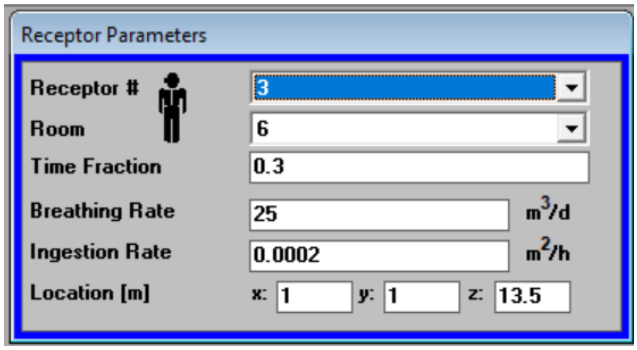

Building Parameters
Number of Rooms
9
Deposition Velocity
0.00039
m/s
Resuspension Rate
0.0000005
1/s
Air Flow

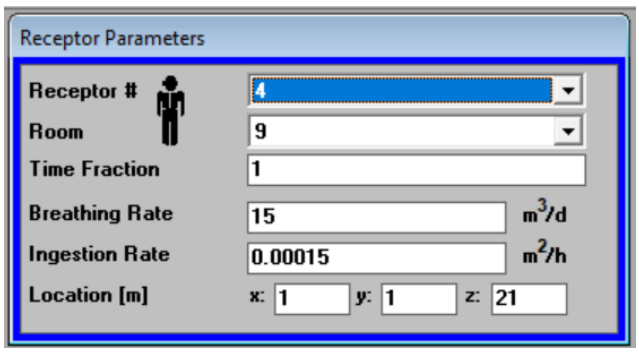

Room Air Flow and Particulates
Number of Rooms
9
Outdoors
Room 1
Room 2
Room 3
Room 4
Room 5
Room 6
Room 7
Room 8
Room 9
Area
Volume
Resuspension rate
Air flow from outdoors to
Air flow from room 1 to
Air flow from room 2 to
Air flow from room 3 to
Air flow from room 4 to
Air flow from room 5 to
Air flow from room 6 to
Air flow from room 7 to
Air flow from room 8 to
Air flow from room 9 to
Efficiency of Vacuuming
0.8
Vacuum once every
14
days
Analytical Solution when Possible
Maximum Time Step
0.08911
days
OK
Write Intermediate Output
Cancel

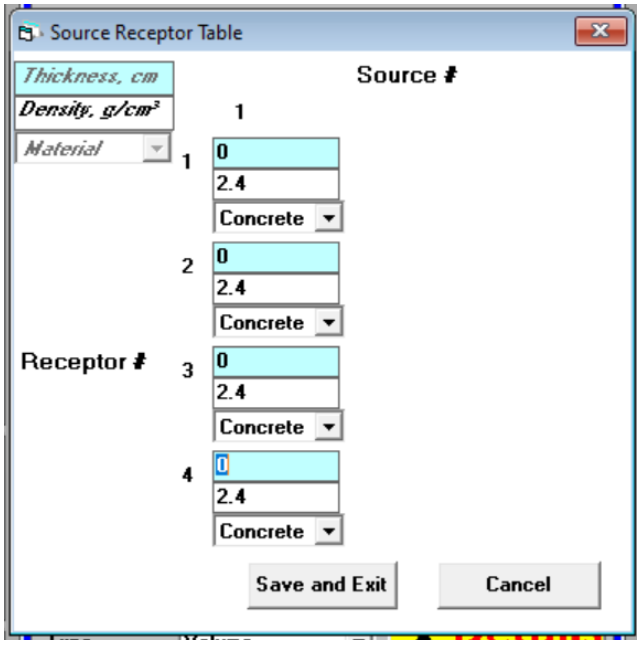

Radiological Data
Activity:
p
Ci
Dose:
m
rem

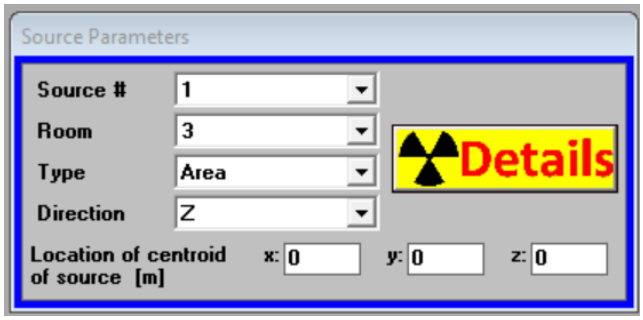

Receptor Parameters
Receptor #
1
Room
1
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0
m2/h
Location [m]
x: 1
y: 1
z: 1

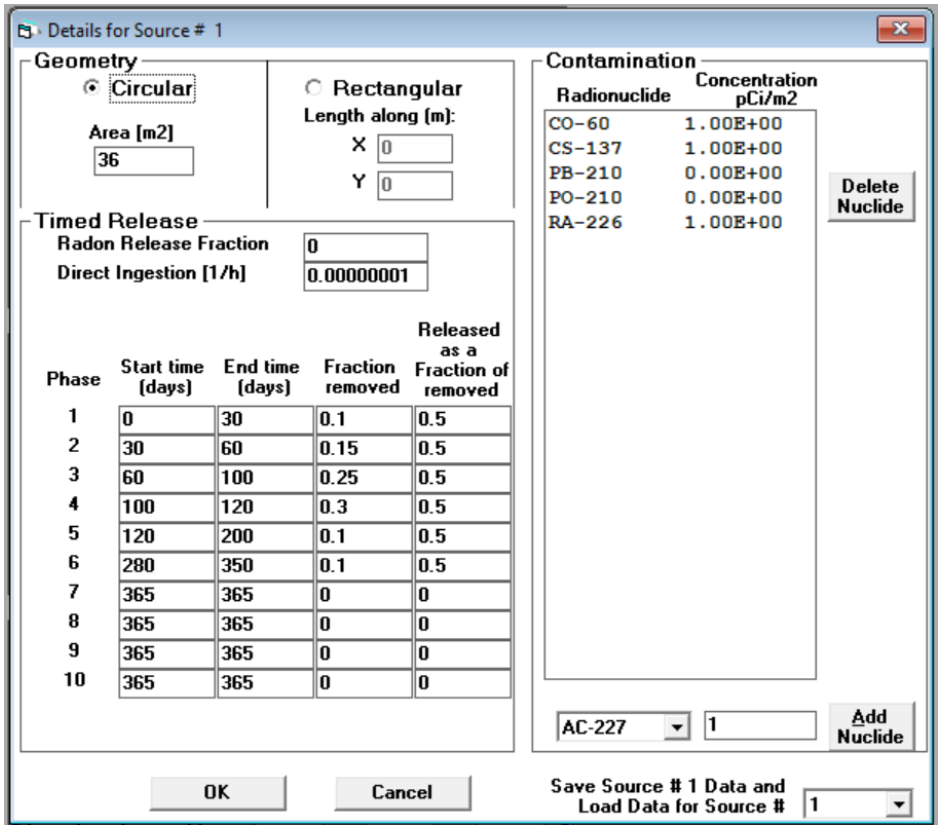

Receptor Parameters
Receptor #
2
Room
3
Time Fraction
0.5
Breathing Rate
20
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 6


Receptor Parameters
Receptor #
3
Room
6
Time Fraction
0.3
Breathing Rate
25
m3/d
Ingestion Rate
0.0002
m2/h
Location [m]
x: 1
y: 1
z: 13.5


Receptor Parameters
Receptor #
4
Room
9
Time Fraction
1
Breathing Rate
15
m3/d
Ingestion Rate
0.00015
m2/h
Location [m]
x: 1
y: 1
z: 21


Source Receptor Table
Thickness, cm
Density, g/cm³
Material
Source #
1
Receptor #
1
0
2.4
Concrete
2
0
2.4
Concrete
3
0
2.4
Concrete
4
0
2.4
Concrete
Save and Exit
Cancel


Source Parameters
Source #
1
Room
3
Type
Area
Direction
Z
Details
Location of centroid of source [m]
x: 0
y: 0
z: 0



- Run the code.
- After the calculations are completed, choose to view the "last intermediate output files."
- The dose and slope factors used for the calculations should match the following.

Dose and Slope Factors including contribution of Associated Radionuclides

External Dose Factors from ICRP 60
Internal Dose Factors from ICRP 72 (Adult)

Slope Factors from FGR 13 Morbidity

Isotope	External Air (mrem/y) /(pCi/m³)	Inhalation mrem/pCi	Ingestion mrem/pCi	External Air risk/y /(pCi/m³)	Inhalation risk /pCi	Ingestion risk /pCi
Ra-226	9.77E-03	3.53E-02	1.04E-03	7.87E-09	2.83E-08	5.15E-10
Pb-210	3.53E-05	2.11E-02	2.56E-03	9.04E-12	1.63E-08	1.19E-09
Po-210	4.54E-08	1.59E-02	4.44E-03	3.66E-14	1.45E-08	2.25E-09
Cs-137	2.98E-03	1.44E-04	4.81E-05	2.39E-09	1.12E-10	3.74E-11
Co-60	1.39E-02	1.15E-04	1.26E-05	1.12E-08	1.01E-10	2.23E-11

- Choose to view "Time integrated source concentrations" and "Time averaged direct ingestion" outputs for Source 1 or open the file "DirectTimeIntegratedConcSource1.out" in the directory where the code was installed to view. The intermediate outputs (for time-averaged activity in the source and time-integrated direct ingestion of radionuclides) should match those listed as "from RRB" in the tab "RRB_DirectTimeIntegratedSource1" in the "Area1_S=3_V=14.xlsx" Excel file.

- Open the file “AirRelRate1.out” in the directory where the code was installed to view. The intermediate outputs (for release rate of source material) should match those obtained from the code previously in the tab “RRB_AirRelrate1” in the “Area1_S=3_V=14.xlsx” Excel file.
- Choose to view “Time averaged concentrations of radionuclides on particulates suspended in air and deposited on floor” outputs for Source 1 or open the file “AirRelTimeIntegratedConcSource1.out” in the directory where the code was installed to view. The intermediate outputs (for time-averaged nuclide concentrations in the air and on the floor) should match those listed as “from RBB” in the tab “RRB_TimeIntegratedConcSource1” in the “Area1_S=3_V=14.xlsx” Excel file.
- Choose to view “Component of dose and risk” outputs or open the file “Dose and risk components.rpt” in the directory where the code was installed to view. The outputs (for inhalation, external immersion, ingestion deposition, and ingestion source pathway doses and risks of each nuclide) should match those listed in the tab “RRB_DoseRiskComponents” in the “Area1_S=3_V=14.xlsx” Excel file.
- Choose to view “last report,” or open the file “RESRADB.rpt” in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway doses for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.16E-05	1.29E-05	1.46E-09	1.45E-09	0.00E+00	3.30E-08	0.00E+00	2.45E-05
2	6.48E-07	5.55E-04	5.95E-08	5.64E-08	4.74E-07	9.56E-08	2.19E-07	5.56E-04
3	8.77E-08	9.48E-05	7.96E-09	7.71E-09	1.27E-07	6.43E-08	0.00E+00	9.51E-05
4	1.23E-07	8.60E-05	1.19E-08	1.16E-08	1.42E-07	1.85E-07	0.00E+00	8.65E-05
Total	1.25E-05	7.49E-04	8.07E-08	7.72E-08	7.42E-07	3.78E-07	2.19E-07	7.63E-04

Evaluation Time: 0.250000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	3.37E-06	1.42E-05	1.90E-09	1.58E-09	0.00E+00	4.13E-08	0.00E+00	1.76E-05
2	1.88E-07	5.60E-04	7.19E-08	5.59E-08	5.91E-07	1.17E-07	2.25E-07	5.61E-04
3	2.54E-08	9.99E-05	9.94E-09	7.99E-09	1.63E-07	8.00E-08	0.00E+00	1.00E-04
4	3.55E-08	9.34E-05	1.52E-08	1.24E-08	1.87E-07	2.31E-07	0.00E+00	9.39E-05
Total	3.62E-06	7.67E-04	9.89E-08	7.79E-08	9.42E-07	4.70E-07	2.25E-07	7.73E-04

Evaluation Time: 0.500000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.42E-06	8.21E-07	1.25E-10	8.93E-11	0.00E+00	2.61E-09	0.00E+00	2.25E-06
2	7.92E-08	2.92E-05	4.34E-09	2.86E-09	3.72E-08	7.24E-09	4.36E-08	2.94E-05
3	1.07E-08	5.46E-06	6.25E-10	4.28E-10	1.07E-08	5.01E-09	0.00E+00	5.49E-06
4	1.50E-08	5.27E-06	9.81E-10	6.89E-10	1.26E-08	1.46E-08	0.00E+00	5.32E-06
Total	1.53E-06	4.07E-05	6.07E-09	4.07E-09	6.06E-08	2.94E-08	4.36E-08	4.24E-05

Evaluation Time: 0.750000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	6.19E-07	3.10E-06	3.57E-10	3.27E-10	0.00E+00	8.27E-09	0.00E+00	3.73E-06
2	3.45E-08	1.28E-04	1.40E-08	1.22E-08	1.29E-07	2.37E-08	1.85E-07	1.29E-04
3	4.66E-09	2.24E-05	1.91E-09	1.70E-09	3.51E-08	1.61E-08	0.00E+00	2.24E-05
4	6.52E-09	2.06E-05	2.87E-09	2.60E-09	3.97E-08	4.63E-08	0.00E+00	2.07E-05
Total	6.64E-07	1.75E-04	1.92E-08	1.68E-08	2.04E-07	9.44E-08	1.85E-07	1.76E-04

Evaluation Time: 1.00000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	2.24E-08	7.71E-12	2.32E-12	0.00E+00	1.05E-10	0.00E+00	2.25E-08
2	0.00E+00	1.48E-07	1.16E-10	1.38E-11	1.10E-09	2.20E-10	0.00E+00	1.50E-07
3	0.00E+00	7.93E-08	2.63E-11	5.93E-12	4.99E-10	1.84E-10	0.00E+00	8.01E-08
4	0.00E+00	1.16E-07	5.26E-11	1.45E-11	7.50E-10	5.68E-10	0.00E+00	1.17E-07
Total	0.00E+00	3.66E-07	2.02E-10	3.66E-11	2.35E-09	1.08E-09	0.00E+00	3.69E-07

Evaluation Time: 1.25000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	4.23E-13	1.93E-16	4.29E-17	0.00E+00	1.46E-15	0.00E+00	4.25E-13
2	0.00E+00	8.09E-13	5.20E-16	7.39E-17	5.21E-15	1.71E-15	0.00E+00	8.17E-13
3	0.00E+00	9.69E-13	3.57E-16	7.08E-17	7.17E-15	2.13E-15	0.00E+00	9.79E-13
4	0.00E+00	1.87E-12	1.06E-15	2.27E-16	1.60E-14	7.32E-15	0.00E+00	1.89E-12
Total	0.00E+00	4.07E-12	2.14E-15	4.15E-16	2.84E-14	1.26E-14	0.00E+00	4.11E-12

Evaluation Time: 1.50000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	3.46E-18	1.69E-21	3.43E-22	0.00E+00	1.08E-20	0.00E+00	3.47E-18
2	0.00E+00	4.20E-18	2.14E-21	3.75E-22	2.26E-20	1.10E-20	0.00E+00	4.24E-18
3	0.00E+00	6.87E-18	2.52E-21	4.90E-22	5.33E-20	1.50E-20	0.00E+00	6.94E-18
4	0.00E+00	1.43E-17	8.56E-21	1.70E-21	1.36E-19	5.27E-20	0.00E+00	1.45E-17
Total	0.00E+00	2.88E-17	1.49E-20	2.91E-21	2.12E-19	8.95E-20	0.00E+00	2.92E-17

- Choose to view "last risk report," or open the file "RESRADB_r.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway risks for the 4 receptors at different time periods should match the values listed in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	5.33E-12	1.03E-11	1.17E-15	1.17E-15	0.00E+00	3.34E-14	0.00E+00	1.97E-11
2	5.20E-13	4.45E-10	4.77E-14	4.55E-14	2.47E-13	1.13E-13	1.14E-13	4.46E-10
3	7.03E-14	7.60E-11	6.38E-15	6.21E-15	6.62E-14	9.12E-14	0.00E+00	7.63E-11
4	9.84E-14	6.90E-11	9.51E-15	9.40E-15	7.40E-14	1.56E-13	0.00E+00	6.93E-11
Total	1.00E-11	6.00E-10	6.48E-14	6.22E-14	3.88E-13	3.94E-13	1.14E-13	6.11E-10

Evaluation Time: 0.25000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.70E-12	1.14E-11	1.53E-15	1.27E-15	0.00E+00	4.18E-14	0.00E+00	1.42E-11
2	1.50E-13	4.49E-10	5.76E-14	4.51E-14	3.08E-13	1.39E-13	1.17E-13	4.50E-10
3	2.03E-14	8.01E-11	7.97E-15	6.44E-15	8.52E-14	1.14E-13	0.00E+00	8.04E-11
4	2.85E-14	7.49E-11	1.22E-14	1.00E-14	9.76E-14	1.96E-13	0.00E+00	7.52E-11
Total	2.90E-12	6.15E-10	7.93E-14	6.29E-14	4.91E-13	4.90E-13	1.17E-13	6.19E-10

Evaluation Time: 0.500000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.14E-12	6.58E-13	1.01E-16	7.20E-17	0.00E+00	2.64E-15	0.00E+00	1.80E-12
2	6.35E-14	2.34E-11	3.48E-15	2.31E-15	1.93E-14	8.57E-15	2.27E-14	2.35E-11
3	8.59E-15	4.38E-12	5.01E-16	3.45E-16	5.57E-15	7.11E-15	0.00E+00	4.40E-12
4	1.20E-14	4.23E-12	7.87E-16	5.55E-16	6.57E-15	1.23E-14	0.00E+00	4.26E-12
Total	1.22E-12	3.27E-11	4.87E-15	3.28E-15	3.15E-14	3.06E-14	2.27E-14	3.40E-11

Evaluation Time: 0.750000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	4.96E-13	2.49E-12	2.86E-16	2.64E-16	0.00E+00	8.37E-15	0.00E+00	2.99E-12
2	2.76E-14	1.03E-10	1.13E-14	9.83E-15	6.69E-14	2.81E-14	9.56E-14	1.03E-10
3	3.74E-15	1.79E-11	1.53E-15	1.37E-15	1.82E-14	2.28E-14	0.00E+00	1.80E-11
4	5.23E-15	1.65E-11	2.30E-15	2.10E-15	2.06E-14	3.92E-14	0.00E+00	1.66E-11
Total	5.33E-13	1.40E-10	1.54E-14	1.36E-14	1.06E-13	9.85E-14	9.56E-14	1.41E-10

Evaluation Time: 1.00000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	1.79E-14	6.18E-18	1.87E-18	0.00E+00	1.07E-16	0.00E+00	1.81E-14
2	0.00E+00	1.19E-13	9.29E-17	1.12E-17	5.70E-16	2.59E-16	0.00E+00	1.20E-13
3	0.00E+00	6.36E-14	2.10E-17	4.78E-18	2.58E-16	2.62E-16	0.00E+00	6.42E-14
4	0.00E+00	9.31E-14	4.21E-17	1.17E-17	3.88E-16	4.82E-16	0.00E+00	9.40E-14
Total	0.00E+00	2.93E-13	1.62E-16	2.95E-17	1.22E-15	1.11E-15	0.00E+00	2.96E-13

Evaluation Time: 1.25000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	3.39E-19	1.55E-22	3.46E-23	0.00E+00	1.49E-21	0.00E+00	3.41E-19
2	0.00E+00	6.49E-19	4.17E-22	5.96E-23	2.69E-21	1.97E-21	0.00E+00	6.54E-19
3	0.00E+00	7.77E-19	2.86E-22	5.71E-23	3.69E-21	3.04E-21	0.00E+00	7.85E-19
4	0.00E+00	1.50E-18	8.53E-22	1.83E-22	8.25E-21	6.24E-21	0.00E+00	1.51E-18
Total	0.00E+00	3.26E-18	1.71E-21	3.34E-22	1.46E-20	1.27E-20	0.00E+00	3.29E-18

Evaluation Time: 1.50000000 years

Pathway Detail of Risks

[Risk]

Source: 1

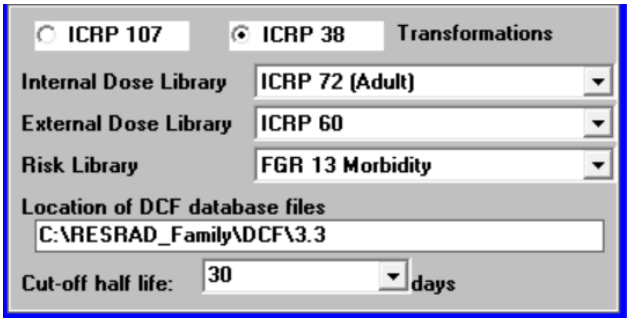
Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	2.78E-24	1.36E-27	2.76E-28	0.00E+00	1.11E-26	0.00E+00	2.79E-24
2	0.00E+00	3.37E-24	1.71E-27	3.02E-28	1.16E-26	1.25E-26	0.00E+00	3.40E-24
3	0.00E+00	5.51E-24	2.02E-27	3.95E-28	2.74E-26	2.14E-26	0.00E+00	5.56E-24
4	0.00E+00	1.15E-23	6.86E-27	1.37E-27	6.99E-26	4.50E-26	0.00E+00	1.16E-23
Total	0.00E+00	2.32E-23	1.19E-26	2.35E-27	1.09E-25	9.01E-26	0.00E+00	2.34E-23

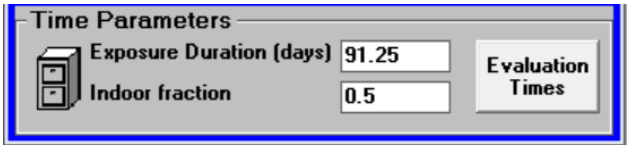
Required Data Input file “Area 1_S=3_V=14_EXP.BLD” and the verification Excel file “Area1_S=3_V=14.xlsx.”

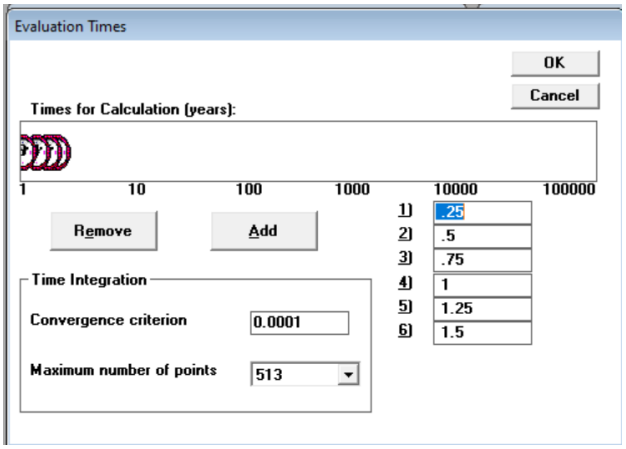
Expected Results The intermediate and final outputs should match those previously obtained (and verified) with the same input file or input selections/values.

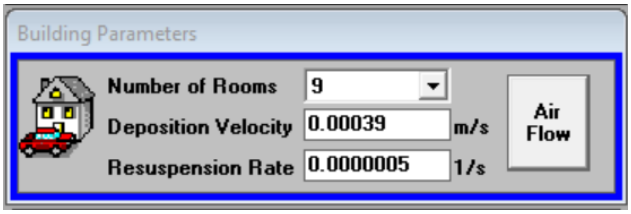
TEST CASE 008-1

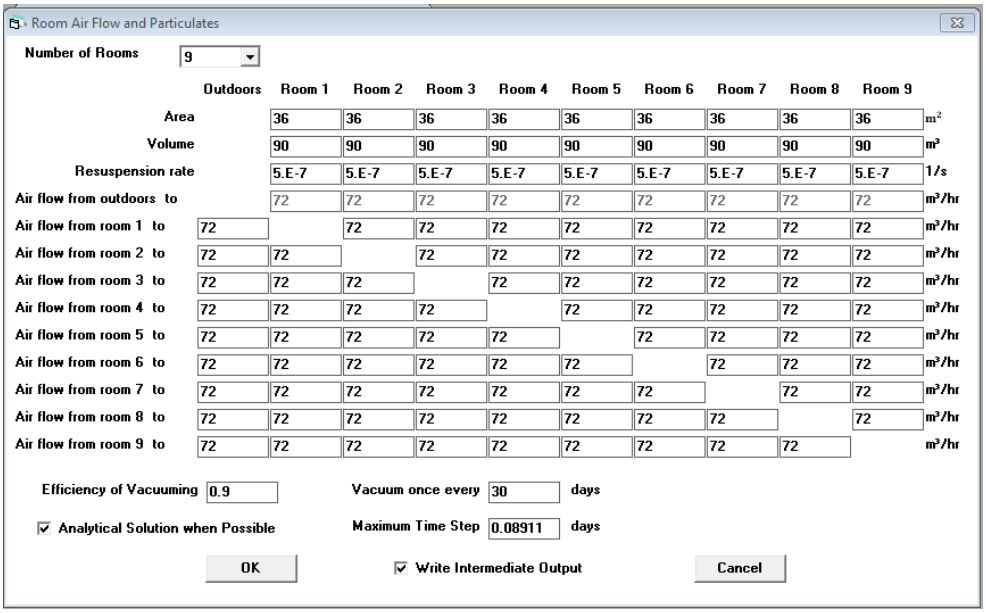
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-008-1
Requirements Tested	8, 11
Test Summary	Test the modeling of source release over multiple phases and transport of the released particles, resulting in radionuclide concentrations in air and on floors. With a volume source (in Room 1), a 9-room building that is vacuumed every 30 days, and 4 receptors in different rooms, this test case tests and verifies the contaminant releases and air concentrations and the floor deposition concentrations in different rooms as functions of time.
Test Objective	Test and verify the modeling of the particulate releases to air, the air ventilation and transport, and the air and deposition concentrations of source particles and radionuclides, as required by the code requirements 7 and 8.
Procedure	Read in an input file that was used in a previous code verification effort (the verification results were documented in the Excel file "Vol1_S=1_V=30.xlsx"), run the RESRAD-BUILD code to generate intermediate outputs and summary outputs, and then compare the results in these outputs with those previously obtained. The results obtained from the current run should match those that were obtained previously. Steps: • Read in the input file "Volume 1_S=1_V=30_EXP.BLD." • Check to see the "new appearance" and "write intermediate output" features are selected and the number of receptors is 4. If not, change the input selections to match. • Check to see the inputs match the following. If not, change the inputs to match.

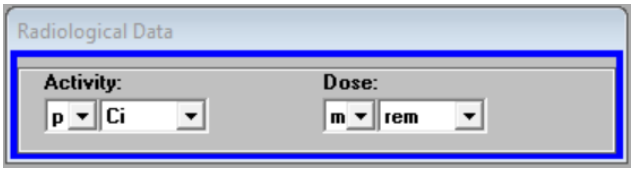


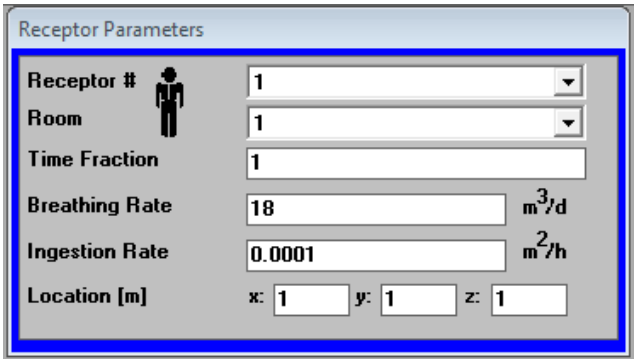


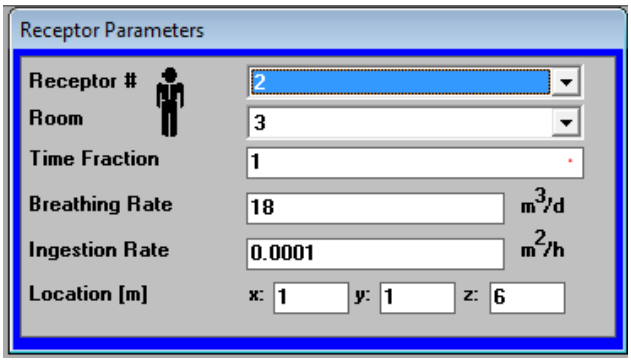

Evaluation Times
OK
Cancel
Times for Calculation (years):
1
10
100
1000
10000
100000
Remove
Add
1) .25
2) .5
3) .75
4) 1
5) 1.25
6) 1.5
Time Integration
Convergence criterion
0.0001
Maximum number of points
513

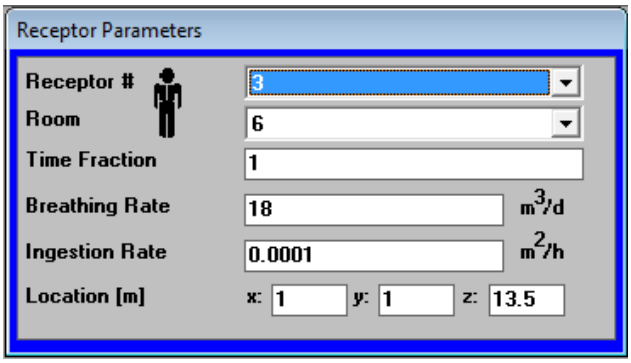

Building Parameters
Number of Rooms
9
Deposition Velocity
0.00039
m/s
Resuspension Rate
0.0000005
1/s
Air Flow

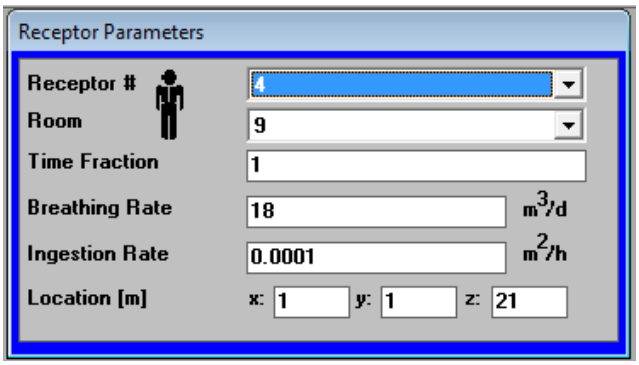

Room Air Flow and Particulates
Number of Rooms
9
Outdoors
Room 1
Room 2
Room 3
Room 4
Room 5
Room 6
Room 7
Room 8
Room 9
Area
Volume
Resuspension rate
Air flow from outdoors to
Air flow from room 1 to
Air flow from room 2 to
Air flow from room 3 to
Air flow from room 4 to
Air flow from room 5 to
Air flow from room 6 to
Air flow from room 7 to
Air flow from room 8 to
Air flow from room 9 to
Efficiency of Vacuuming
0.9
Vacuum once every
30
days
Analytical Solution when Possible
Maximum Time Step
0.08911
days
OK
Write Intermediate Output
Cancel

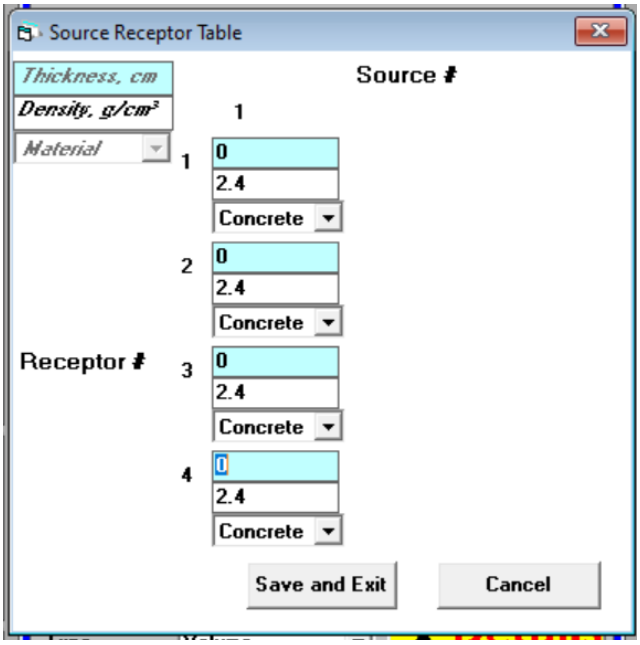

Radiological Data
Activity:
p
Ci
Dose:
m
rem

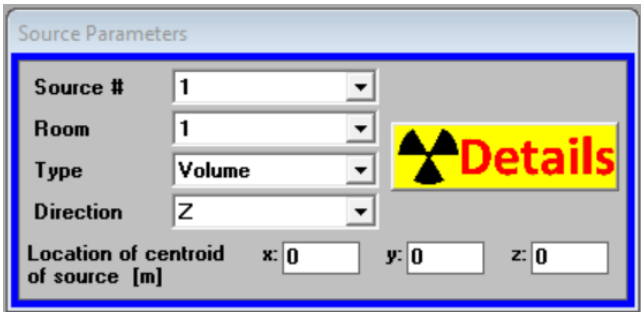

Receptor Parameters
Receptor #
1
Room
1
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 1

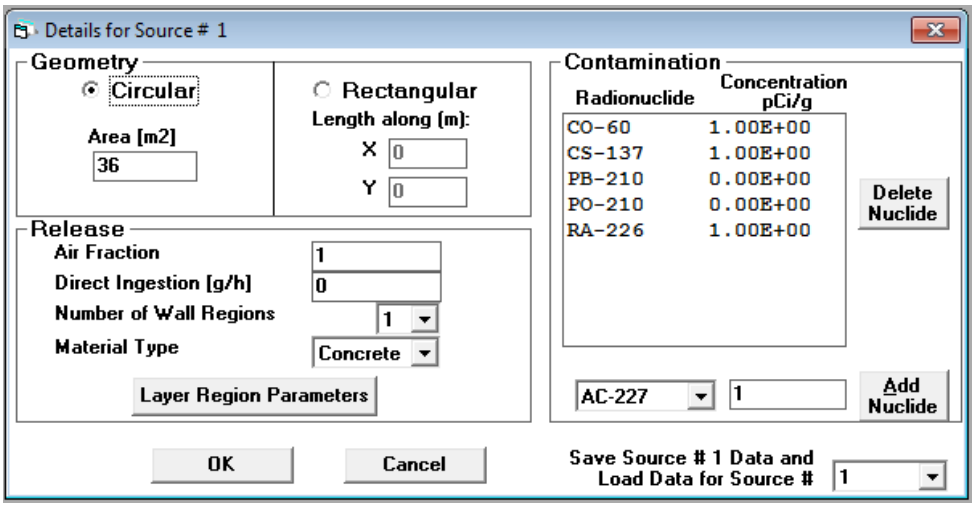

Receptor Parameters
Receptor #
2
Room
3
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 6

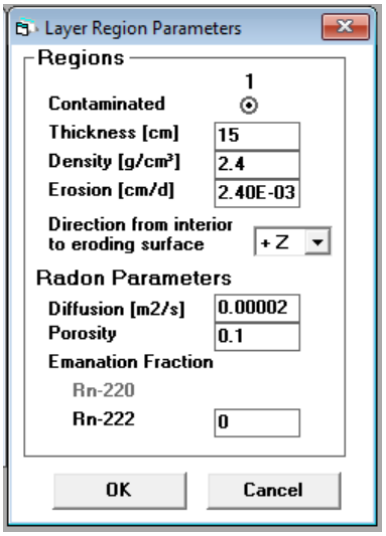

Receptor Parameters
Receptor #
3
Room
6
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 13.5


Receptor Parameters
Receptor #
4
Room
9
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 21


Source Receptor Table
Thickness, cm
Density, g/cm³
Material
Source #
1
Receptor #
1
0
2.4
Concrete
2
0
2.4
Concrete
3
0
2.4
Concrete
4
0
2.4
Concrete
Save and Exit
Cancel


Source Parameters
Source #
1
Room
1
Type
Volume
Direction
Z
Details
Location of centroid of source [m]
x: 0
y: 0
z: 0


Details for Source # 1
Geometry
Circular
Area [m2]
36
Rectangular
Length along (m):
X
0
Y
0
Release
Air Fraction
1
Direct Ingestion [g/h]
0
Number of Wall Regions
1
Material Type
Concrete
Layer Region Parameters
Contamination
Radionuclide
Concentration pCi/g
CO-60 1.00E+00
CS-137 1.00E+00
PB-210 0.00E+00
PO-210 0.00E+00
RA-226 1.00E+00
Delete Nuclide
AC-227
1
Add Nuclide
OK
Cancel
Save Source # 1 Data and Load Data for Source #
1



- Run the code.
- After the calculations are completed, open the file "AirRelRate1.out" in the directory where the code was installed to view. The intermediate outputs (for release rate of source material) should match those obtained from the code previously in the tab "RRB_AirRelrate1" in the "Vol1_S=1_V=30.xlsx" Excel file.
- In the main interface of the code, choose the View -> "last intermediate output files" menu option. Then choose to view the "Time averaged concentrations of radionuclides on particulates suspended in air and deposited on floor" outputs for Source 1 or open the file "AirRelTimeIntegratedConcSource1.out" in the directory where the code was installed to view. The intermediate outputs (for time-averaged nuclide concentrations in the air and on the floor) should match those listed as "from RRB" in the tab "RRB_TimeIntegratedConcSource1" in the "Vol1_S=1_V=30.xlsx" Excel file.
- Choose to view "last report," or open the file "RESRADB.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway doses for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	5.81E+00	1.07E-03	6.57E-04	8.54E-03	6.89E-04	0.00E+00	8.10E+00
2	3.48E-01	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.78E+00
3	7.94E-02	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.52E+00
4	3.29E-02	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.47E+00
Total	2.74E+00	1.31E+01	2.40E-03	1.48E-03	1.91E-02	2.68E-03	0.00E+00	1.59E+01

Evaluation Time: 0.250000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.23E+00	5.87E+00	1.10E-03	6.49E-04	9.12E-03	7.19E-04	0.00E+00	8.11E+00
2	3.40E-01	2.47E+00	4.54E-04	2.73E-04	3.77E-03	6.94E-04	0.00E+00	2.81E+00
3	7.75E-02	2.47E+00	4.54E-04	2.73E-04	3.77E-03	6.94E-04	0.00E+00	2.55E+00
4	3.22E-02	2.47E+00	4.54E-04	2.73E-04	3.77E-03	6.94E-04	0.00E+00	2.51E+00
Total	2.68E+00	1.33E+01	2.46E-03	1.47E-03	2.04E-02	2.80E-03	0.00E+00	1.60E+01

Evaluation Time: 0.500000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.18E+00	5.91E+00	1.08E-03	6.37E-04	9.45E-03	7.20E-04	0.00E+00	8.10E+00
2	3.32E-01	2.48E+00	4.47E-04	2.68E-04	3.90E-03	6.95E-04	0.00E+00	2.82E+00
3	7.56E-02	2.48E+00	4.47E-04	2.68E-04	3.90E-03	6.95E-04	0.00E+00	2.57E+00
4	3.14E-02	2.48E+00	4.47E-04	2.68E-04	3.90E-03	6.95E-04	0.00E+00	2.52E+00
Total	2.62E+00	1.34E+01	2.42E-03	1.44E-03	2.12E-02	2.80E-03	0.00E+00	1.60E+01

Evaluation Time: 0.750000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.13E+00	5.95E+00	1.06E-03	6.27E-04	9.79E-03	7.19E-04	0.00E+00	8.09E+00
2	3.23E-01	2.50E+00	4.39E-04	2.64E-04	4.05E-03	6.94E-04	0.00E+00	2.83E+00
3	7.38E-02	2.50E+00	4.39E-04	2.64E-04	4.05E-03	6.94E-04	0.00E+00	2.58E+00
4	3.06E-02	2.50E+00	4.39E-04	2.64E-04	4.05E-03	6.94E-04	0.00E+00	2.54E+00
Total	2.56E+00	1.35E+01	2.38E-03	1.42E-03	2.19E-02	2.80E-03	0.00E+00	1.60E+01

Evaluation Time: 1.00000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.09E+00	5.99E+00	1.05E-03	6.16E-04	1.02E-02	7.22E-04	0.00E+00	8.09E+00
2	3.16E-01	2.52E+00	4.34E-04	2.59E-04	4.21E-03	6.96E-04	0.00E+00	2.84E+00
3	7.20E-02	2.52E+00	4.34E-04	2.59E-04	4.21E-03	6.96E-04	0.00E+00	2.60E+00
4	2.99E-02	2.52E+00	4.34E-04	2.59E-04	4.21E-03	6.96E-04	0.00E+00	2.56E+00
Total	2.50E+00	1.36E+01	2.35E-03	1.39E-03	2.28E-02	2.81E-03	0.00E+00	1.61E+01

Evaluation Time: 1.25000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.04E+00	6.03E+00	1.03E-03	6.06E-04	1.06E-02	7.23E-04	0.00E+00	8.09E+00
2	3.08E-01	2.54E+00	4.27E-04	2.55E-04	4.38E-03	6.97E-04	0.00E+00	2.85E+00
3	7.03E-02	2.54E+00	4.27E-04	2.55E-04	4.38E-03	6.97E-04	0.00E+00	2.61E+00
4	2.92E-02	2.54E+00	4.27E-04	2.55E-04	4.38E-03	6.97E-04	0.00E+00	2.57E+00
Total	2.45E+00	1.36E+01	2.32E-03	1.37E-03	2.37E-02	2.81E-03	0.00E+00	1.61E+01

Evaluation Time: 1.50000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.00E+00	6.08E+00	1.02E-03	5.96E-04	1.10E-02	7.22E-04	0.00E+00	8.09E+00
2	3.01E-01	2.56E+00	4.20E-04	2.51E-04	4.54E-03	6.97E-04	0.00E+00	2.86E+00
3	6.86E-02	2.56E+00	4.20E-04	2.51E-04	4.54E-03	6.97E-04	0.00E+00	2.63E+00
4	2.85E-02	2.56E+00	4.20E-04	2.51E-04	4.54E-03	6.97E-04	0.00E+00	2.59E+00
Total	2.40E+00	1.37E+01	2.28E-03	1.35E-03	2.46E-02	2.81E-03	0.00E+00	1.62E+01

- Choose to view "last risk report," or open the file "RESRADB_r.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway risks for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	4.66E-06	8.62E-10	5.30E-10	4.46E-09	7.61E-10	0.00E+00	6.49E-06
2	2.79E-07	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	2.23E-06
3	6.37E-08	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	2.02E-06
4	2.64E-08	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	1.98E-06
Total	2.20E-06	1.05E-05	1.92E-09	1.19E-09	9.96E-09	2.91E-09	0.00E+00	1.27E-05

Evaluation Time: 0.250000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.79E-06	4.71E-06	8.80E-10	5.23E-10	4.75E-09	7.94E-10	0.00E+00	6.50E-06
2	2.72E-07	1.98E-06	3.64E-10	2.20E-10	1.96E-09	7.47E-10	0.00E+00	2.26E-06
3	6.22E-08	1.98E-06	3.64E-10	2.20E-10	1.96E-09	7.47E-10	0.00E+00	2.05E-06
4	2.58E-08	1.98E-06	3.64E-10	2.20E-10	1.96E-09	7.47E-10	0.00E+00	2.01E-06
Total	2.15E-06	1.06E-05	1.97E-09	1.18E-09	1.06E-08	3.04E-09	0.00E+00	1.28E-05

Evaluation Time: 0.500000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.75E-06	4.74E-06	8.67E-10	5.14E-10	4.91E-09	7.95E-10	0.00E+00	6.50E-06
2	2.66E-07	1.99E-06	3.58E-10	2.16E-10	2.03E-09	7.48E-10	0.00E+00	2.26E-06
3	6.07E-08	1.99E-06	3.58E-10	2.16E-10	2.03E-09	7.48E-10	0.00E+00	2.06E-06
4	2.52E-08	1.99E-06	3.58E-10	2.16E-10	2.03E-09	7.48E-10	0.00E+00	2.02E-06
Total	2.10E-06	1.07E-05	1.94E-09	1.16E-09	1.10E-08	3.04E-09	0.00E+00	1.28E-05

Evaluation Time: 0.750000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.71E-06	4.77E-06	8.52E-10	5.05E-10	5.07E-09	7.94E-10	0.00E+00	6.49E-06
2	2.59E-07	2.01E-06	3.52E-10	2.12E-10	2.09E-09	7.48E-10	0.00E+00	2.27E-06
3	5.92E-08	2.01E-06	3.52E-10	2.12E-10	2.09E-09	7.48E-10	0.00E+00	2.07E-06
4	2.46E-08	2.01E-06	3.52E-10	2.12E-10	2.09E-09	7.48E-10	0.00E+00	2.03E-06
Total	2.05E-06	1.08E-05	1.91E-09	1.14E-09	1.14E-08	3.04E-09	0.00E+00	1.29E-05

Evaluation Time: 1.00000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.67E-06	4.81E-06	8.41E-10	4.97E-10	5.27E-09	7.97E-10	0.00E+00	6.49E-06
2	2.53E-07	2.02E-06	3.48E-10	2.09E-10	2.18E-09	7.50E-10	0.00E+00	2.28E-06
3	5.77E-08	2.02E-06	3.48E-10	2.09E-10	2.18E-09	7.50E-10	0.00E+00	2.08E-06
4	2.40E-08	2.02E-06	3.48E-10	2.09E-10	2.18E-09	7.50E-10	0.00E+00	2.05E-06
Total	2.01E-06	1.09E-05	1.88E-09	1.12E-09	1.18E-08	3.05E-09	0.00E+00	1.29E-05

Evaluation Time: 1.25000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.64E-06	4.84E-06	8.29E-10	4.89E-10	5.46E-09	7.98E-10	0.00E+00	6.49E-06
2	2.47E-07	2.04E-06	3.42E-10	2.06E-10	2.26E-09	7.51E-10	0.00E+00	2.29E-06
3	5.64E-08	2.04E-06	3.42E-10	2.06E-10	2.26E-09	7.51E-10	0.00E+00	2.10E-06
4	2.34E-08	2.04E-06	3.42E-10	2.06E-10	2.26E-09	7.51E-10	0.00E+00	2.06E-06
Total	1.96E-06	1.10E-05	1.86E-09	1.11E-09	1.22E-08	3.05E-09	0.00E+00	1.29E-05

Evaluation Time: 1.50000000 years

Pathway Detail of Risks

[Risk]

Source: 1

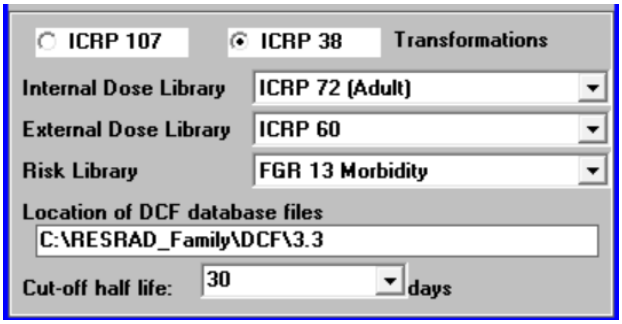
Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.60E-06	4.88E-06	8.15E-10	4.81E-10	5.65E-09	7.97E-10	0.00E+00	6.49E-06
2	2.41E-07	2.05E-06	3.37E-10	2.02E-10	2.33E-09	7.51E-10	0.00E+00	2.30E-06
3	5.50E-08	2.05E-06	3.37E-10	2.02E-10	2.33E-09	7.51E-10	0.00E+00	2.11E-06
4	2.28E-08	2.05E-06	3.37E-10	2.02E-10	2.33E-09	7.51E-10	0.00E+00	2.08E-06
Total	1.92E-06	1.10E-05	1.83E-09	1.09E-09	1.26E-08	3.05E-09	0.00E+00	1.30E-05

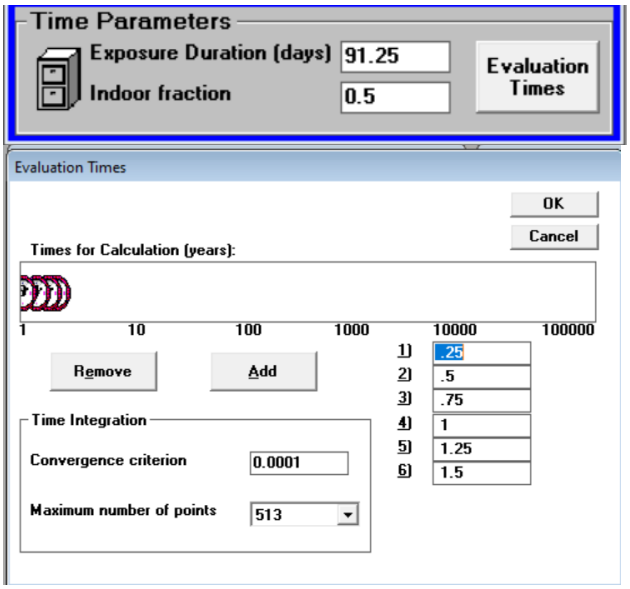
Required Data Input file "Volume 1_S=1_V=30_EXP.BLD" and the verification Excel file "Vol1_S=1_V=30.xlsx."

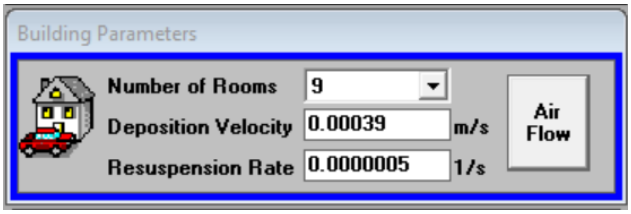
Expected Results The intermediate and final outputs should match those previously obtained (and verified) with the same input file or input selections/values.

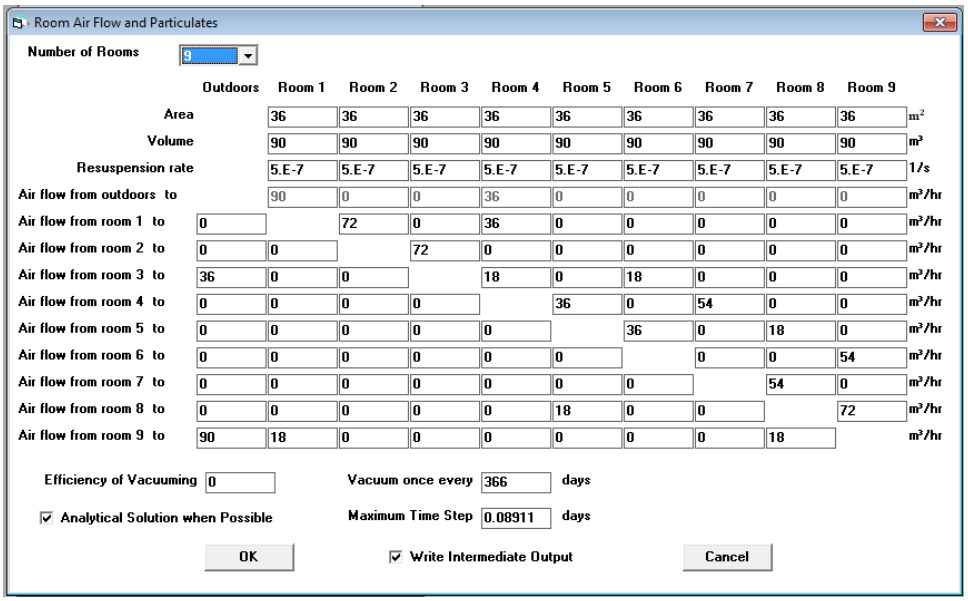
TEST CASE 008-2

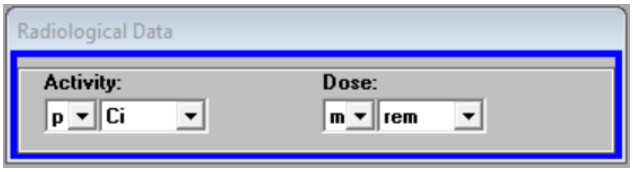
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-008-2
Requirements Tested	8, 11
Test Summary	Test the modeling of source release over multiple phases and transport of the released particles, resulting in radionuclide concentrations in air and on floors. With a volume source (in Room 2), a 9-room building, and 4 receptors in different rooms, this test case tests and verifies the contaminant releases and air concentrations and the floor deposition concentrations in different rooms as functions of time.
Test Objective	Test and verify the modeling of the particulate releases to air, the air ventilation and transport, and the air and deposition concentrations of source particles and radionuclides, as required by the code requirements 8 and 11.
Procedure	Read in an input file that was used in a previous code verification effort (the verification results were documented in the Excel file "Vol2_S=2.xlsx"), run the RESRAD-BUILD code to generate intermediate outputs and summary outputs, and then compare the results in these outputs with those previously obtained. The results obtained from the current run should match those that were obtained previously. Steps: • Read in the input file "Volume 2_S=2_EXP.BLD." • Check to see the "new appearance" and "write intermediate output" features are selected and the number of receptors is 4. If not, change the input selections to match. • Check to see the inputs match the following. If not, change the inputs to match.

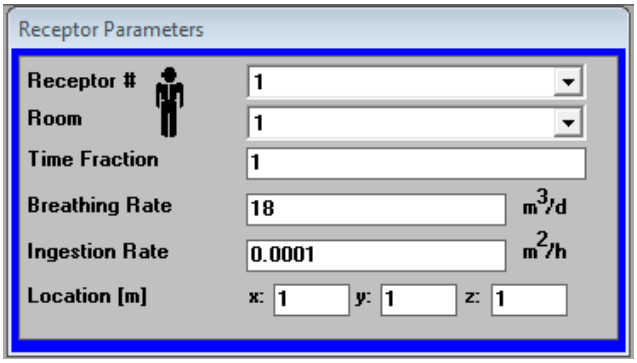


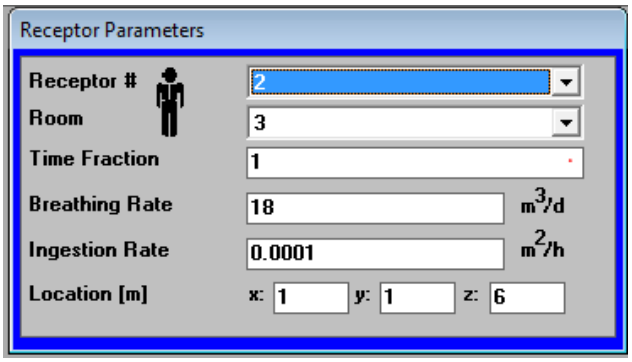

Time Parameters
Exposure Duration (days) 91.25
Indoor fraction 0.5
Evaluation Times
Evaluation Times
OK
Cancel
Times for Calculation (years):
1 10 100 1000 10000 100000
Remove
Add
1) .25
2) .5
3) .75
4) 1
5) 1.25
6) 1.5
Time Integration
Convergence criterion 0.0001
Maximum number of points 513

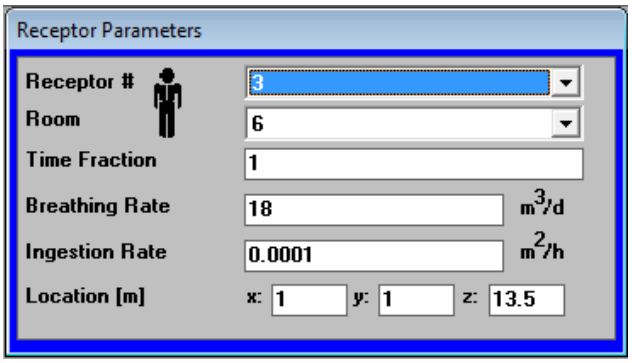

Building Parameters
Number of Rooms 9
Deposition Velocity 0.00039 m/s
Resuspension Rate 0.0000005 1/s
Air Flow

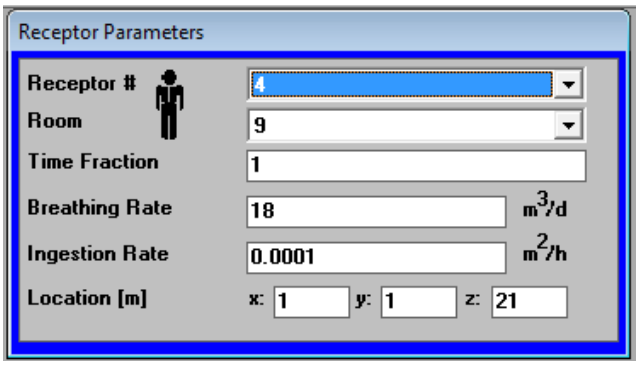

Room Air Flow and Particulates
Number of Rooms 9
Outdoors Room 1 Room 2 Room 3 Room 4 Room 5 Room 6 Room 7 Room 8 Room 9
Area 36 36 36 36 36 36 36 36 36 m²
Volume 90 90 90 90 90 90 90 90 90 m³
Resuspension rate 5.E-7 5.E-7 5.E-7 5.E-7 5.E-7 5.E-7 5.E-7 5.E-7 5.E-7 1/s
Air flow from outdoors to 90 0 0 36 0 0 0 0 0 m³/hr
Air flow from room 1 to 0 72 0 36 0 0 0 0 0 m³/hr
Air flow from room 2 to 0 0 72 0 0 0 0 0 0 m³/hr
Air flow from room 3 to 36 0 0 18 0 18 0 0 0 m³/hr
Air flow from room 4 to 0 0 0 0 36 0 54 0 0 m³/hr
Air flow from room 5 to 0 0 0 0 0 36 0 18 0 m³/hr
Air flow from room 6 to 0 0 0 0 0 0 0 0 54 m³/hr
Air flow from room 7 to 0 0 0 0 0 0 0 54 0 m³/hr
Air flow from room 8 to 0 0 0 0 0 18 0 0 72 m³/hr
Air flow from room 9 to 90 18 0 0 0 0 0 0 18 m³/hr
Efficiency of Vacuuming 0
Vacuum once every 366 days
Analytical Solution when Possible
Maximum Time Step 0.08911 days
OK
Write Intermediate Output
Cancel

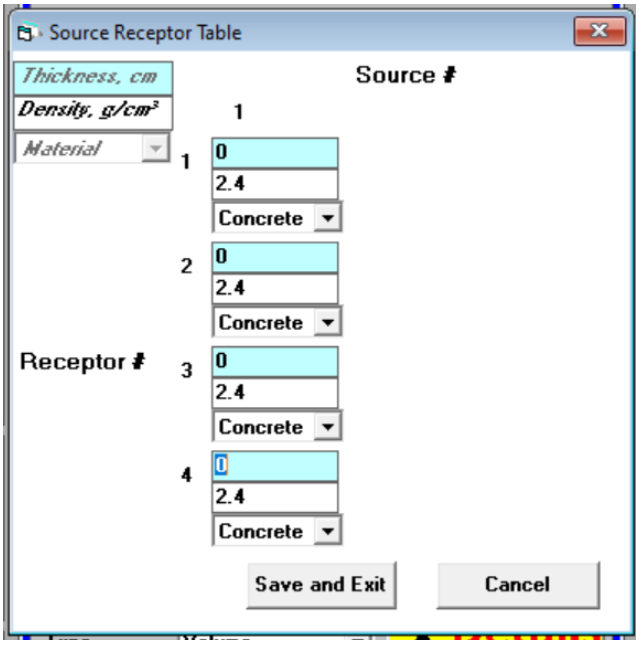

Radiological Data
Activity:
p Ci
Dose:
m rem

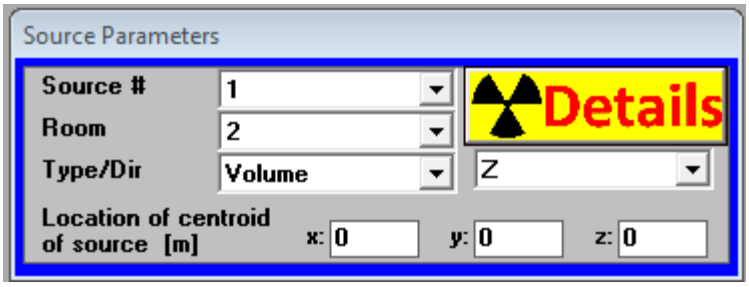

Receptor Parameters
Receptor #
1
Room
1
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 1

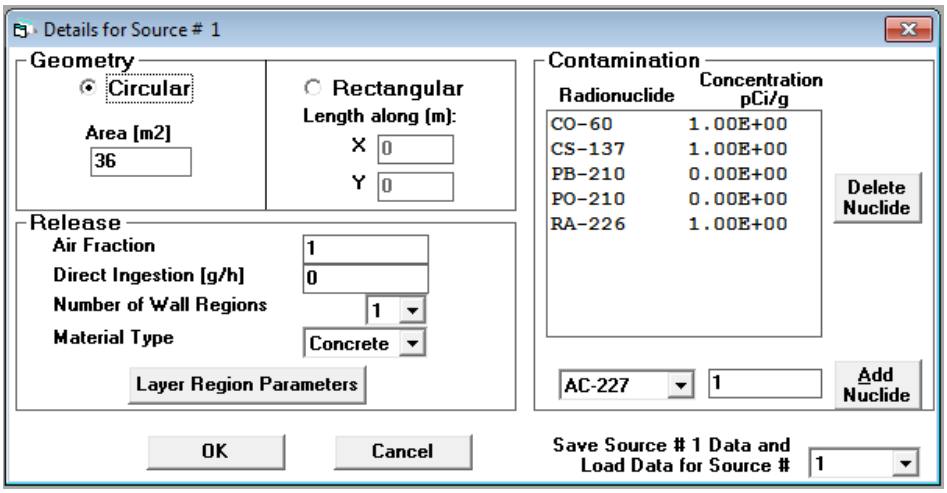

Receptor Parameters
Receptor #
2
Room
3
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 6

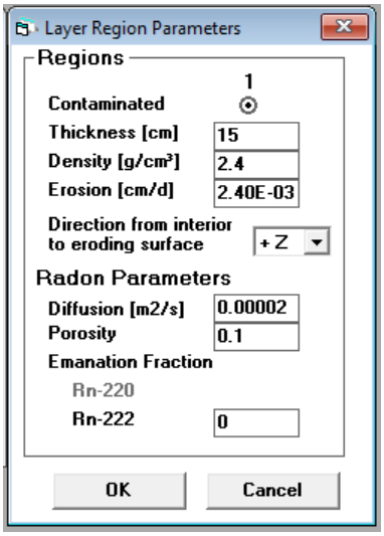

Receptor Parameters
Receptor #
3
Room
6
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 13.5


Receptor Parameters
Receptor #
4
Room
9
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 21


Source Receptor Table
Thickness, cm
Density, g/cm³
Material
Source #
1
Receptor #
1
0
2.4
Concrete
2
0
2.4
Concrete
3
0
2.4
Concrete
4
0
2.4
Concrete
Save and Exit
Cancel


Source Parameters
Source #
1
Room
2
Type/Dir
Volume
Z
Details
Location of centroid of source [m]
x: 0
y: 0
z: 0


Details for Source # 1
Geometry
Circular
Area [m2]
36
Rectangular
Length along (m):
X 0
Y 0
Release
Air Fraction 1
Direct Ingestion [g/h] 0
Number of Wall Regions 1
Material Type Concrete
Layer Region Parameters
Contamination
Radionuclide
Concentration pCi/g
CO-60 1.00E+00
CS-137 1.00E+00
PB-210 0.00E+00
PO-210 0.00E+00
RA-226 1.00E+00
Delete Nuclide
AC-227
1
Add Nuclide
OK
Cancel
Save Source # 1 Data and Load Data for Source # 1



- Run the code.
- After the calculations are completed, open the file "AirRelRate1.out" in the directory where the code was installed to view. The intermediate outputs (for release rate of source material) should match those obtained from the code previously in the tab "RRB_AirRelrate1" in the "Vol2_S=2.xlsx" Excel file.
- In the main interface of the code, choose the View -> "last intermediate output files" menu option. Then choose to view the "Time averaged concentrations of radionuclides on particulates suspended in air and deposited on floor" outputs for Source 1 or open the file "AirRelTimeIntegratedConcSource1.out" in the directory where the code was installed to view. The intermediate outputs (for time-averaged nuclide concentrations in the air and on the floor) should match those listed as "from RRB" in the tab "RRB_TimeIntegratedConcSource1" in the "Vol2_S=2.xlsx" Excel file.
- Choose to view "last report," or open the file "RESRADB.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway doses for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	6.24E-01	1.62E-04	7.03E-05	1.30E-03	3.49E-03	0.00E+00	2.91E+00
2	3.48E-01	2.48E+01	7.10E-03	2.80E-03	5.67E-02	2.78E-02	0.00E+00	2.52E+01
3	7.94E-02	7.81E+00	2.13E-03	8.80E-04	1.70E-02	2.34E-02	0.00E+00	7.93E+00
4	3.29E-02	4.38E+00	1.16E-03	4.94E-04	9.27E-03	1.96E-02	0.00E+00	4.45E+00
Total	2.74E+00	3.76E+01	1.06E-02	4.24E-03	8.43E-02	7.44E-02	0.00E+00	4.05E+01

Evaluation Time: 0.250000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.23E+00	1.52E+00	5.28E-04	1.68E-04	4.40E-03	7.73E-03	0.00E+00	3.77E+00
2	3.40E-01	3.49E+01	1.33E-02	3.86E-03	1.10E-01	4.96E-02	0.00E+00	3.54E+01
3	7.75E-02	1.47E+01	5.31E-03	1.62E-03	4.41E-02	4.83E-02	0.00E+00	1.48E+01
4	3.22E-02	9.69E+00	3.42E-03	1.07E-03	2.84E-02	4.24E-02	0.00E+00	9.80E+00
Total	2.68E+00	6.08E+01	2.25E-02	6.71E-03	1.87E-01	1.48E-01	0.00E+00	6.38E+01

Evaluation Time: 0.500000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.18E+00	1.98E+00	7.36E-04	2.13E-04	6.43E-03	9.35E-03	0.00E+00	4.17E+00
2	3.32E-01	3.71E+01	1.43E-02	4.00E-03	1.25E-01	5.43E-02	0.00E+00	3.76E+01
3	7.56E-02	1.73E+01	6.54E-03	1.86E-03	5.71E-02	5.64E-02	0.00E+00	1.74E+01
4	3.14E-02	1.21E+01	4.54E-03	1.31E-03	3.97E-02	5.06E-02	0.00E+00	1.22E+01
Total	2.62E+00	6.84E+01	2.62E-02	7.38E-03	2.28E-01	1.71E-01	0.00E+00	7.15E+01

Evaluation Time: 0.750000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.13E+00	2.15E+00	8.09E-04	2.27E-04	7.45E-03	9.90E-03	0.00E+00	4.31E+00
2	3.23E-01	3.78E+01	1.44E-02	3.98E-03	1.32E-01	5.56E-02	0.00E+00	3.83E+01
3	7.38E-02	1.82E+01	6.87E-03	1.92E-03	6.33E-02	5.90E-02	0.00E+00	1.84E+01
4	3.06E-02	1.30E+01	4.90E-03	1.37E-03	4.51E-02	5.32E-02	0.00E+00	1.32E+01
Total	2.56E+00	7.12E+01	2.69E-02	7.50E-03	2.48E-01	1.78E-01	0.00E+00	7.42E+01

Evaluation Time: 1.00000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.09E+00	2.22E+00	8.24E-04	2.29E-04	8.01E-03	1.01E-02	0.00E+00	4.33E+00
2	3.16E-01	3.82E+01	1.42E-02	3.93E-03	1.38E-01	5.59E-02	0.00E+00	3.87E+01
3	7.20E-02	1.86E+01	6.89E-03	1.91E-03	6.70E-02	5.98E-02	0.00E+00	1.88E+01
4	2.99E-02	1.34E+01	4.96E-03	1.38E-03	4.82E-02	5.41E-02	0.00E+00	1.35E+01
Total	2.50E+00	7.24E+01	2.69E-02	7.44E-03	2.61E-01	1.80E-01	0.00E+00	7.53E+01

Evaluation Time: 1.25000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.04E+00	2.26E+00	8.20E-04	2.27E-04	8.41E-03	1.01E-02	0.00E+00	4.32E+00
2	3.08E-01	3.85E+01	1.40E-02	3.87E-03	1.44E-01	5.60E-02	0.00E+00	3.90E+01
3	7.03E-02	1.88E+01	6.82E-03	1.89E-03	7.00E-02	6.00E-02	0.00E+00	1.90E+01
4	2.92E-02	1.36E+01	4.92E-03	1.36E-03	5.05E-02	5.43E-02	0.00E+00	1.37E+01
Total	2.45E+00	7.31E+01	2.66E-02	7.34E-03	2.72E-01	1.80E-01	0.00E+00	7.60E+01

Evaluation Time: 1.50000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.00E+00	2.28E+00	8.10E-04	2.24E-04	8.75E-03	1.01E-02	0.00E+00	4.30E+00
2	3.01E-01	3.88E+01	1.38E-02	3.81E-03	1.49E-01	5.61E-02	0.00E+00	3.93E+01
3	6.86E-02	1.89E+01	6.73E-03	1.86E-03	7.27E-02	6.01E-02	0.00E+00	1.91E+01
4	2.85E-02	1.37E+01	4.86E-03	1.34E-03	5.25E-02	5.44E-02	0.00E+00	1.38E+01
Total	2.40E+00	7.37E+01	2.62E-02	7.23E-03	2.83E-01	1.81E-01	0.00E+00	7.66E+01

- Choose to view "last risk report," or open the file "RESRADB_r.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway risks for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	5.01E-07	1.30E-10	5.67E-11	6.77E-10	3.53E-09	0.00E+00	2.33E-06
2	2.79E-07	1.99E-05	5.70E-09	2.26E-09	2.96E-08	2.88E-08	0.00E+00	2.02E-05
3	6.37E-08	6.26E-06	1.71E-09	7.10E-10	8.89E-09	2.38E-08	0.00E+00	6.36E-06
4	2.64E-08	3.51E-06	9.30E-10	3.98E-10	4.84E-09	1.99E-08	0.00E+00	3.57E-06
Total	2.20E-06	3.01E-05	8.46E-09	3.42E-09	4.40E-08	7.61E-08	0.00E+00	3.25E-05

Evaluation Time: 0.250000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.79E-06	1.22E-06	4.24E-10	1.36E-10	2.29E-09	7.85E-09	0.00E+00	3.02E-06
2	2.72E-07	2.80E-05	1.06E-08	3.11E-09	5.74E-08	5.15E-08	0.00E+00	2.84E-05
3	6.22E-08	1.18E-05	4.25E-09	1.30E-09	2.30E-08	4.92E-08	0.00E+00	1.19E-05
4	2.58E-08	7.77E-06	2.74E-09	8.63E-10	1.48E-08	4.31E-08	0.00E+00	7.86E-06
Total	2.15E-06	4.87E-05	1.81E-08	5.41E-09	9.75E-08	1.52E-07	0.00E+00	5.12E-05

Evaluation Time: 0.500000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.75E-06	1.58E-06	5.90E-10	1.72E-10	3.34E-09	9.50E-09	0.00E+00	3.35E-06
2	2.66E-07	2.98E-05	1.15E-08	3.23E-09	6.50E-08	5.64E-08	0.00E+00	3.02E-05
3	6.07E-08	1.38E-05	5.24E-09	1.50E-09	2.97E-08	5.76E-08	0.00E+00	1.40E-05
4	2.52E-08	9.71E-06	3.64E-09	1.05E-09	2.06E-08	5.14E-08	0.00E+00	9.81E-06
Total	2.10E-06	5.49E-05	2.10E-08	5.95E-09	1.19E-07	1.75E-07	0.00E+00	5.73E-05

Evaluation Time: 0.750000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.71E-06	1.73E-06	6.48E-10	1.83E-10	3.86E-09	1.01E-08	0.00E+00	3.45E-06
2	2.59E-07	3.03E-05	1.15E-08	3.21E-09	6.85E-08	5.77E-08	0.00E+00	3.07E-05
3	5.92E-08	1.46E-05	5.51E-09	1.54E-09	3.27E-08	6.02E-08	0.00E+00	1.47E-05
4	2.46E-08	1.04E-05	3.93E-09	1.11E-09	2.34E-08	5.42E-08	0.00E+00	1.05E-05
Total	2.05E-06	5.71E-05	2.16E-08	6.05E-09	1.28E-07	1.82E-07	0.00E+00	5.95E-05

Evaluation Time: 1.00000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.67E-06	1.78E-06	6.61E-10	1.85E-10	4.14E-09	1.02E-08	0.00E+00	3.47E-06
2	2.53E-07	3.06E-05	1.14E-08	3.17E-09	7.13E-08	5.80E-08	0.00E+00	3.10E-05
3	5.77E-08	1.49E-05	5.53E-09	1.54E-09	3.46E-08	6.10E-08	0.00E+00	1.51E-05
4	2.40E-08	1.07E-05	3.98E-09	1.11E-09	2.49E-08	5.50E-08	0.00E+00	1.08E-05
Total	2.01E-06	5.80E-05	2.16E-08	6.00E-09	1.35E-07	1.84E-07	0.00E+00	6.04E-05

Evaluation Time: 1.25000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.64E-06	1.81E-06	6.57E-10	1.83E-10	4.33E-09	1.03E-08	0.00E+00	3.47E-06
2	2.47E-07	3.09E-05	1.12E-08	3.12E-09	7.39E-08	5.81E-08	0.00E+00	3.13E-05
3	5.64E-08	1.51E-05	5.47E-09	1.52E-09	3.60E-08	6.13E-08	0.00E+00	1.52E-05
4	2.34E-08	1.09E-05	3.95E-09	1.10E-09	2.60E-08	5.53E-08	0.00E+00	1.10E-05
Total	1.96E-06	5.86E-05	2.13E-08	5.92E-09	1.40E-07	1.85E-07	0.00E+00	6.10E-05

Evaluation Time: 1.50000000 years

Pathway Detail of Risks

[Risk]

Source: 1

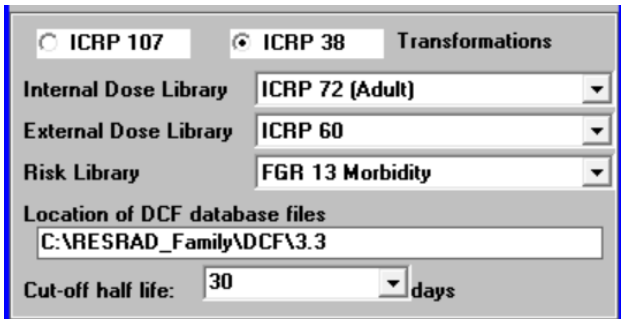
Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.60E-06	1.83E-06	6.49E-10	1.80E-10	4.50E-09	1.03E-08	0.00E+00	3.45E-06
2	2.41E-07	3.11E-05	1.10E-08	3.07E-09	7.65E-08	5.82E-08	0.00E+00	3.15E-05
3	5.50E-08	1.52E-05	5.39E-09	1.50E-09	3.74E-08	6.13E-08	0.00E+00	1.54E-05
4	2.28E-08	1.10E-05	3.89E-09	1.08E-09	2.70E-08	5.54E-08	0.00E+00	1.11E-05
Total	1.92E-06	5.91E-05	2.10E-08	5.83E-09	1.45E-07	1.85E-07	0.00E+00	6.14E-05

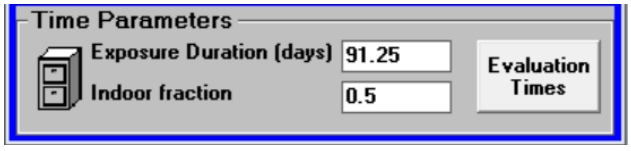
Required Data Input file "Volume 2_S=2_EXP.BLD" and the verification Excel file "Vol2_S=2.xlsx."

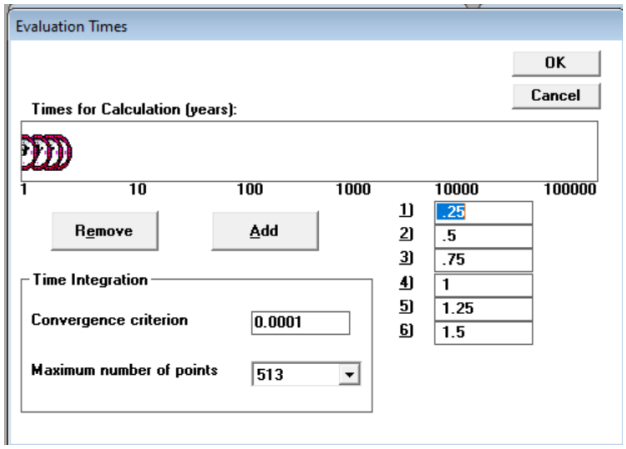
Expected Results The intermediate and final outputs should match those previously obtained (and verified) with the same input file or input selections/values.

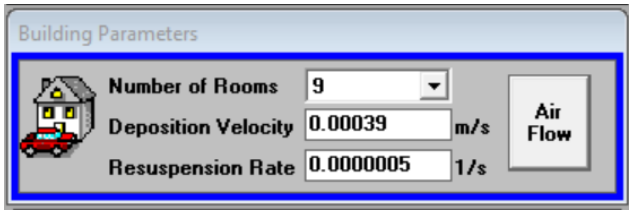
TEST CASE 008-3

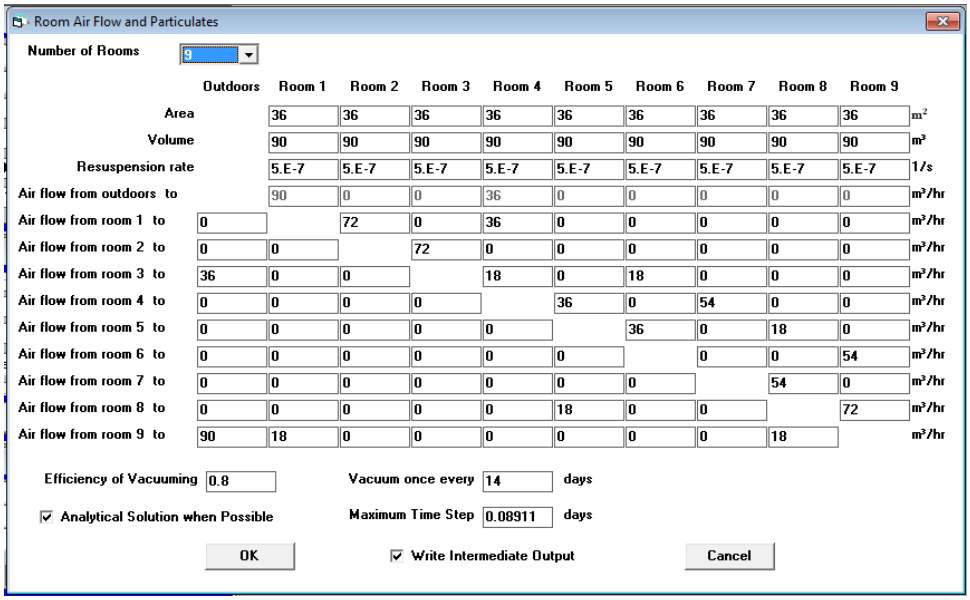
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-008-3
Requirements Tested	8, 11
Test Summary	Test the modeling of source release over multiple phases and transport of the released particles, resulting in radionuclide concentrations in air and on floors. With a volume source (in Room 2), a 9-room building that is vacuumed every 14 days, and 4 receptors in different rooms, this test case tests and verifies the contaminant releases and air concentrations and the floor deposition concentrations in different rooms as functions of time.
Test Objective	Test and verify the modeling of the particulate releases to air, the air ventilation and transport, and the air and deposition concentrations of source particles and radionuclides, as required by the code requirements 8 and 11.
Procedure	Read in an input file that was used in previous code verification effort (the verification results were documented in the Excel file "Vol2_S=2_V=14.xlsx"), run the RESRAD-BUILD code to generate intermediate outputs and summary outputs, and then compare the results in these outputs with those previously obtained. The results obtained from the current run should match those that were obtained previously. Steps: • Read in the input file "Volume 2_S=2_V=14_EXP.BLD." • Check to see the "new appearance" and "write intermediate output" features are selected and the number of receptors is 4. If not, change the input selections to match. • Check to see the inputs match the following. If not, change the inputs to match.

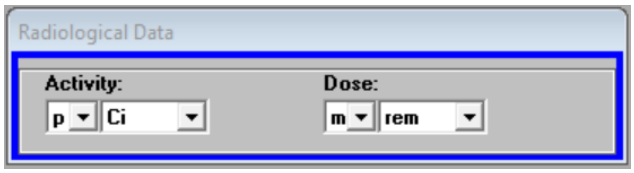


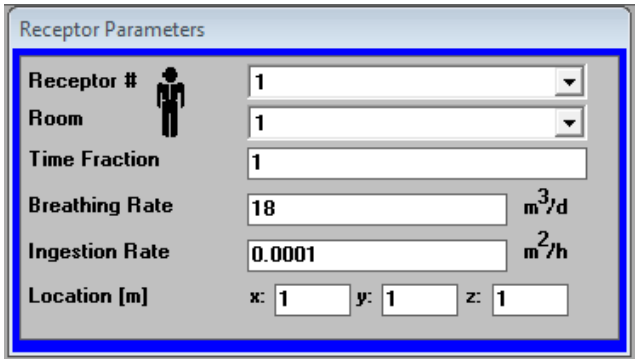


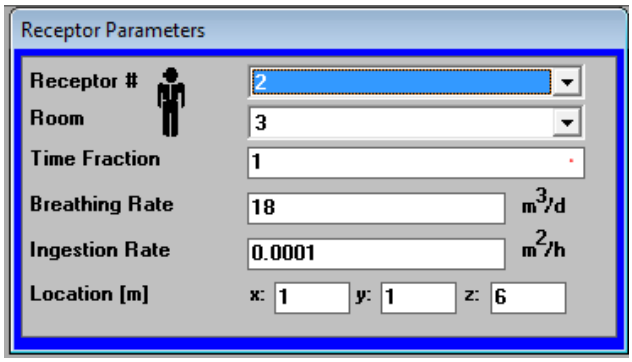

Evaluation Times
OK
Cancel
Times for Calculation (years):
1
10
100
1000
10000
100000
Remove
Add
1) .25
2) .5
3) .75
4) 1
5) 1.25
6) 1.5
Time Integration
Convergence criterion
0.0001
Maximum number of points
513

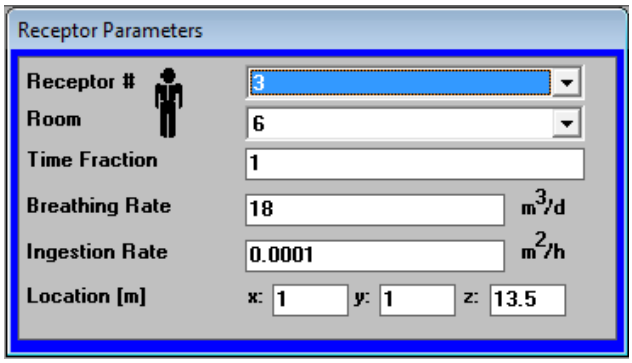

Building Parameters
Number of Rooms
9
Deposition Velocity
0.00039
m/s
Resuspension Rate
0.0000005
1/s
Air Flow

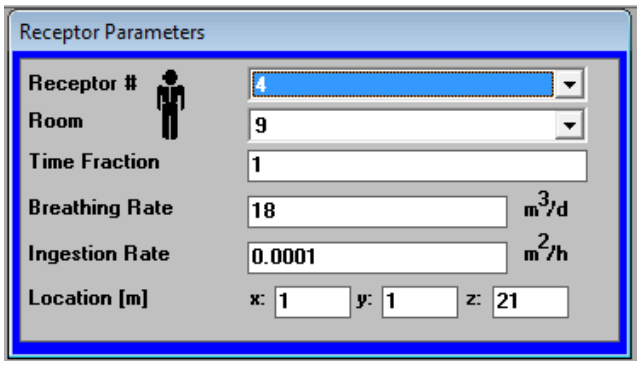

Room Air Flow and Particulates
Number of Rooms
9
Outdoors
Room 1
Room 2
Room 3
Room 4
Room 5
Room 6
Room 7
Room 8
Room 9
Area
Volume
Resuspension rate
Air flow from outdoors to
Air flow from room 1 to
Air flow from room 2 to
Air flow from room 3 to
Air flow from room 4 to
Air flow from room 5 to
Air flow from room 6 to
Air flow from room 7 to
Air flow from room 8 to
Air flow from room 9 to
Efficiency of Vacuuming
0.8
Vacuum once every
14
days
Analytical Solution when Possible
Maximum Time Step
0.08911
days
OK
Write Intermediate Output
Cancel

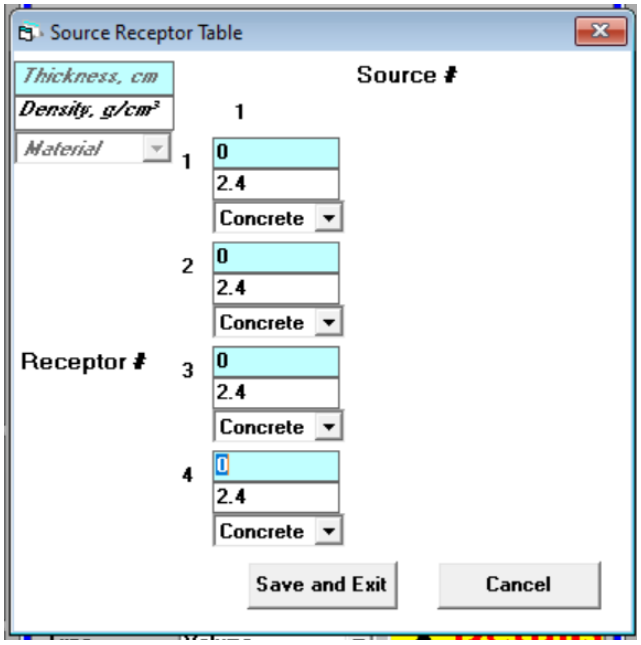

Radiological Data
Activity:
p
Ci
Dose:
m
rem

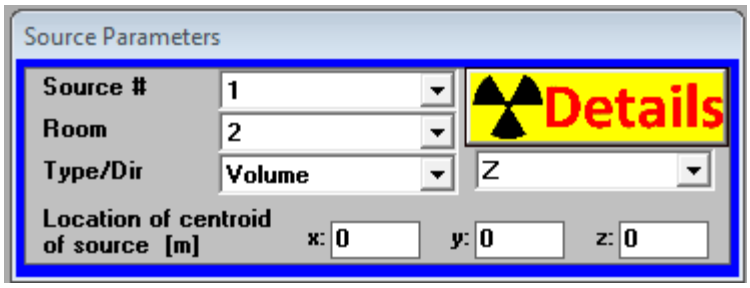

Receptor Parameters
Receptor #
1
Room
1
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 1

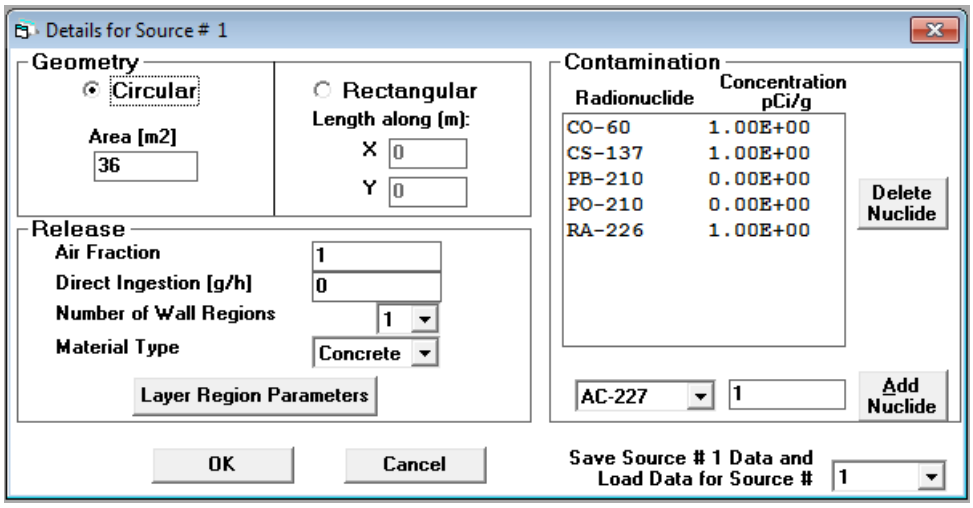

Receptor Parameters
Receptor #
2
Room
3
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 6

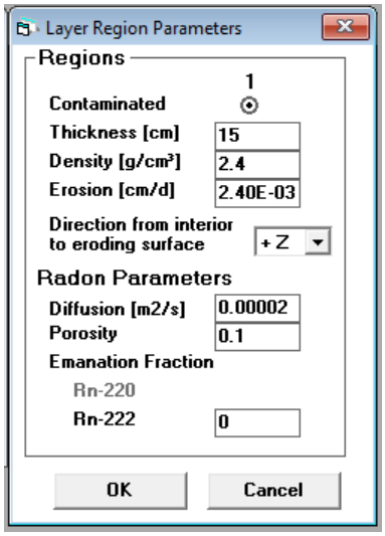

Receptor Parameters
Receptor #
3
Room
6
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 13.5


Receptor Parameters
Receptor #
4
Room
9
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 21


Source Receptor Table
Thickness, cm
Density, g/cm³
Material
Source #
1
Receptor #
1
0
2.4
Concrete
2
0
2.4
Concrete
3
0
2.4
Concrete
4
0
2.4
Concrete
Save and Exit
Cancel


Source Parameters
Source #
1
Room
2
Type/Dir
Volume
Details
Z
Location of centroid of source [m]
x: 0
y: 0
z: 0


Details for Source # 1
Geometry
Circular
Area [m2]
36
Rectangular
Length along (m):
X 0
Y 0
Release
Air Fraction
1
Direct Ingestion [g/h]
0
Number of Wall Regions
1
Material Type
Concrete
Layer Region Parameters
Contamination
Radionuclide
Concentration pCi/g
CO-60 1.00E+00
CS-137 1.00E+00
PB-210 0.00E+00
PO-210 0.00E+00
RA-226 1.00E+00
Delete Nuclide
AC-227
1
Add Nuclide
OK
Cancel
Save Source # 1 Data and Load Data for Source #
1



- Run the code.
- After the calculations are completed, open the file "AirRelRate1.out" in the directory where the code was installed to view. The intermediate outputs (for release rate of source material) should match those obtained from the code previously in the tab "RRB_AirRelrate1" in the "Vol2_S=2_V=14.xlsx" Excel file.
- In the main interface of the code, choose the View -> "last intermediate output files" menu option. Then choose to view the "Time averaged concentrations of radionuclides on particulates suspended in air and deposited on floor" outputs for Source 1 or open the file "AirRelTimeIntegratedConcSource1.out" in the directory where the code was installed to view. The intermediate outputs (for time-averaged nuclide concentrations in the air and on the floor) should match those listed as "from RRB" in the tab "RRB_TimeIntegratedConcSource1" in the "Vol2_S=2_V=14.xlsx" Excel file.
- Choose to view "last report," or open the file "RESRADB.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway doses for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	2.05E-01	2.38E-05	2.32E-05	1.89E-04	8.57E-04	0.00E+00	2.48E+00
2	3.48E-01	1.58E+01	1.91E-03	1.79E-03	1.52E-02	8.30E-03	0.00E+00	1.62E+01
3	7.94E-02	3.62E+00	4.28E-04	4.09E-04	3.40E-03	6.16E-03	0.00E+00	3.71E+00
4	3.29E-02	1.64E+00	1.92E-04	1.86E-04	1.53E-03	4.94E-03	0.00E+00	1.68E+00
Total	2.74E+00	2.13E+01	2.55E-03	2.41E-03	2.03E-02	2.03E-02	0.00E+00	2.41E+01

Evaluation Time: 0.250000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.23E+00	2.20E-01	2.70E-05	2.43E-05	2.24E-04	9.57E-04	0.00E+00	2.45E+00
2	3.40E-01	1.63E+01	2.09E-03	1.80E-03	1.74E-02	9.17E-03	0.00E+00	1.67E+01
3	7.75E-02	3.80E+00	4.76E-04	4.19E-04	3.95E-03	6.85E-03	0.00E+00	3.89E+00
4	3.22E-02	1.75E+00	2.16E-04	1.93E-04	1.79E-03	5.51E-03	0.00E+00	1.79E+00
Total	2.68E+00	2.21E+01	2.81E-03	2.44E-03	2.33E-02	2.25E-02	0.00E+00	2.48E+01

Evaluation Time: 0.500000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.18E+00	2.16E-01	2.55E-05	2.34E-05	2.21E-04	9.18E-04	0.00E+00	2.40E+00
2	3.32E-01	1.63E+01	1.97E-03	1.75E-03	1.72E-02	8.81E-03	0.00E+00	1.66E+01
3	7.56E-02	3.76E+00	4.48E-04	4.06E-04	3.92E-03	6.57E-03	0.00E+00	3.85E+00
4	3.14E-02	1.72E+00	2.04E-04	1.86E-04	1.78E-03	5.29E-03	0.00E+00	1.76E+00
Total	2.62E+00	2.20E+01	2.65E-03	2.37E-03	2.31E-02	2.16E-02	0.00E+00	2.46E+01

Evaluation Time: 0.750000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.13E+00	2.22E-01	2.60E-05	2.34E-05	2.39E-04	9.52E-04	0.00E+00	2.36E+00
2	3.23E-01	1.65E+01	2.01E-03	1.74E-03	1.85E-02	9.13E-03	0.00E+00	1.69E+01
3	7.38E-02	3.84E+00	4.58E-04	4.05E-04	4.22E-03	6.82E-03	0.00E+00	3.93E+00
4	3.06E-02	1.77E+00	2.08E-04	1.86E-04	1.92E-03	5.48E-03	0.00E+00	1.81E+00
Total	2.56E+00	2.23E+01	2.70E-03	2.35E-03	2.49E-02	2.24E-02	0.00E+00	2.50E+01

Evaluation Time: 1.00000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.09E+00	2.20E-01	2.47E-05	2.26E-05	2.40E-04	9.23E-04	0.00E+00	2.31E+00
2	3.16E-01	1.65E+01	1.92E-03	1.70E-03	1.87E-02	8.86E-03	0.00E+00	1.68E+01
3	7.20E-02	3.82E+00	4.36E-04	3.93E-04	4.24E-03	6.61E-03	0.00E+00	3.90E+00
4	2.99E-02	1.75E+00	1.98E-04	1.80E-04	1.92E-03	5.32E-03	0.00E+00	1.79E+00
Total	2.50E+00	2.23E+01	2.58E-03	2.29E-03	2.51E-02	2.17E-02	0.00E+00	2.48E+01

Evaluation Time: 1.25000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.04E+00	2.25E-01	2.50E-05	2.26E-05	2.57E-04	9.48E-04	0.00E+00	2.27E+00
2	3.08E-01	1.67E+01	1.94E-03	1.68E-03	1.99E-02	9.09E-03	0.00E+00	1.71E+01
3	7.03E-02	3.89E+00	4.42E-04	3.91E-04	4.53E-03	6.79E-03	0.00E+00	3.97E+00
4	2.92E-02	1.79E+00	2.01E-04	1.80E-04	2.06E-03	5.46E-03	0.00E+00	1.83E+00
Total	2.45E+00	2.26E+01	2.61E-03	2.27E-03	2.67E-02	2.23E-02	0.00E+00	2.51E+01

Evaluation Time: 1.50000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.00E+00	2.24E-01	2.40E-05	2.19E-05	2.59E-04	9.26E-04	0.00E+00	2.22E+00
2	3.01E-01	1.67E+01	1.86E-03	1.64E-03	2.02E-02	8.89E-03	0.00E+00	1.71E+01
3	6.86E-02	3.88E+00	4.24E-04	3.81E-04	4.58E-03	6.63E-03	0.00E+00	3.96E+00
4	2.85E-02	1.78E+00	1.92E-04	1.75E-04	2.08E-03	5.33E-03	0.00E+00	1.82E+00
Total	2.40E+00	2.26E+01	2.50E-03	2.22E-03	2.71E-02	2.18E-02	0.00E+00	2.51E+01

- Choose to view "last risk report," or open the file "RESRADB_r.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway risks for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	1.65E-07	1.91E-11	1.87E-11	9.87E-11	8.65E-10	0.00E+00	1.99E-06
2	2.79E-07	1.27E-05	1.53E-09	1.44E-09	7.93E-09	8.59E-09	0.00E+00	1.30E-05
3	6.37E-08	2.90E-06	3.43E-10	3.30E-10	1.78E-09	6.25E-09	0.00E+00	2.97E-06
4	2.64E-08	1.32E-06	1.54E-10	1.50E-10	7.97E-10	5.00E-09	0.00E+00	1.35E-06
Total	2.20E-06	1.71E-05	2.05E-09	1.94E-09	1.06E-08	2.07E-08	0.00E+00	1.93E-05

Evaluation Time: 0.250000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.79E-06	1.76E-07	2.16E-11	1.96E-11	1.17E-10	9.66E-10	0.00E+00	1.97E-06
2	2.72E-07	1.31E-05	1.68E-09	1.45E-09	9.04E-09	9.50E-09	0.00E+00	1.34E-05
3	6.22E-08	3.05E-06	3.82E-10	3.38E-10	2.06E-09	6.95E-09	0.00E+00	3.12E-06
4	2.58E-08	1.40E-06	1.73E-10	1.56E-10	9.35E-10	5.57E-09	0.00E+00	1.43E-06
Total	2.15E-06	1.77E-05	2.25E-09	1.97E-09	1.21E-08	2.30E-08	0.00E+00	1.99E-05

Evaluation Time: 0.500000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.75E-06	1.74E-07	2.04E-11	1.89E-11	1.15E-10	9.27E-10	0.00E+00	1.92E-06
2	2.66E-07	1.30E-05	1.58E-09	1.41E-09	8.94E-09	9.12E-09	0.00E+00	1.33E-05
3	6.07E-08	3.02E-06	3.60E-10	3.27E-10	2.03E-09	6.67E-09	0.00E+00	3.09E-06
4	2.52E-08	1.38E-06	1.64E-10	1.50E-10	9.22E-10	5.34E-09	0.00E+00	1.41E-06
Total	2.10E-06	1.76E-05	2.12E-09	1.91E-09	1.20E-08	2.21E-08	0.00E+00	1.97E-05

Evaluation Time: 0.750000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.71E-06	1.78E-07	2.08E-11	1.89E-11	1.24E-10	9.61E-10	0.00E+00	1.89E-06
2	2.59E-07	1.32E-05	1.61E-09	1.40E-09	9.59E-09	9.45E-09	0.00E+00	1.35E-05
3	5.92E-08	3.08E-06	3.67E-10	3.26E-10	2.18E-09	6.92E-09	0.00E+00	3.15E-06
4	2.46E-08	1.42E-06	1.67E-10	1.50E-10	9.92E-10	5.54E-09	0.00E+00	1.45E-06
Total	2.05E-06	1.79E-05	2.17E-09	1.90E-09	1.29E-08	2.29E-08	0.00E+00	2.00E-05

Evaluation Time: 1.00000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.67E-06	1.76E-07	1.98E-11	1.82E-11	1.24E-10	9.32E-10	0.00E+00	1.85E-06
2	2.53E-07	1.32E-05	1.54E-09	1.37E-09	9.63E-09	9.17E-09	0.00E+00	1.35E-05
3	5.77E-08	3.06E-06	3.50E-10	3.17E-10	2.19E-09	6.71E-09	0.00E+00	3.13E-06
4	2.40E-08	1.41E-06	1.59E-10	1.45E-10	9.93E-10	5.37E-09	0.00E+00	1.44E-06
Total	2.01E-06	1.79E-05	2.07E-09	1.85E-09	1.29E-08	2.22E-08	0.00E+00	1.99E-05

Evaluation Time: 1.25000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.64E-06	1.81E-07	2.01E-11	1.82E-11	1.32E-10	9.57E-10	0.00E+00	1.82E-06
2	2.47E-07	1.34E-05	1.55E-09	1.36E-09	1.02E-08	9.41E-09	0.00E+00	1.37E-05
3	5.64E-08	3.12E-06	3.54E-10	3.15E-10	2.33E-09	6.89E-09	0.00E+00	3.19E-06
4	2.34E-08	1.44E-06	1.61E-10	1.45E-10	1.06E-09	5.52E-09	0.00E+00	1.47E-06
Total	1.96E-06	1.82E-05	2.09E-09	1.83E-09	1.38E-08	2.28E-08	0.00E+00	2.02E-05

Evaluation Time: 1.50000000 years

Pathway Detail of Risks

[Risk]

Source: 1

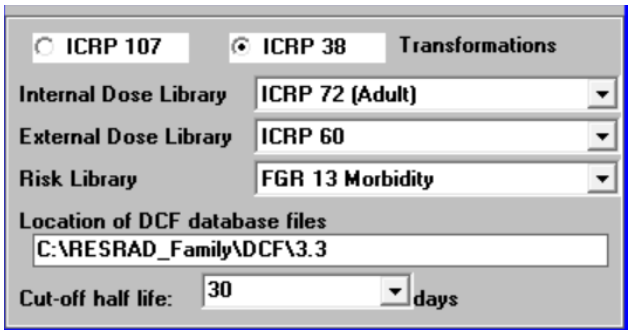
Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.60E-06	1.79E-07	1.92E-11	1.77E-11	1.33E-10	9.34E-10	0.00E+00	1.78E-06
2	2.41E-07	1.34E-05	1.49E-09	1.33E-09	1.04E-08	9.20E-09	0.00E+00	1.37E-05
3	5.50E-08	3.11E-06	3.40E-10	3.07E-10	2.35E-09	6.73E-09	0.00E+00	3.18E-06
4	2.28E-08	1.43E-06	1.54E-10	1.41E-10	1.07E-09	5.39E-09	0.00E+00	1.46E-06
Total	1.92E-06	1.82E-05	2.01E-09	1.79E-09	1.39E-08	2.23E-08	0.00E+00	2.01E-05

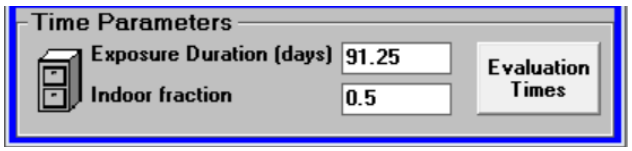
Required Data Input file "Volume 2_S=2_V=14_EXP.BLD" and the verification Excel file "Vol2_S=2_V=14.xlsx."

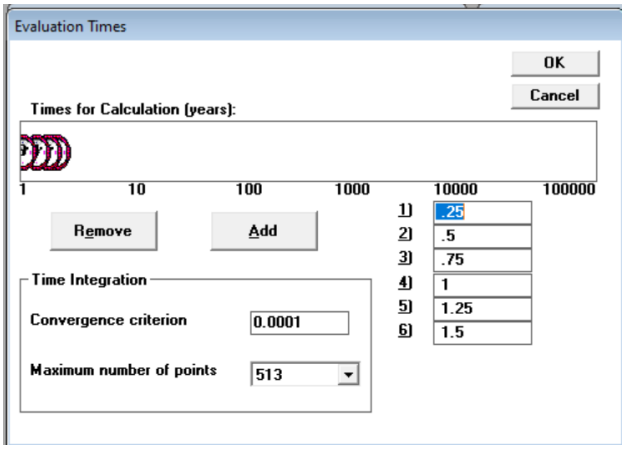
Expected Results The intermediate and final outputs should match those previously obtained (and verified) with the same input file or input selections/values.

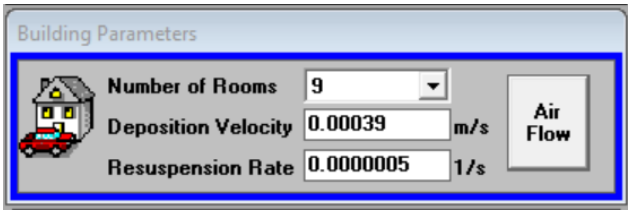
TEST CASE 008-4

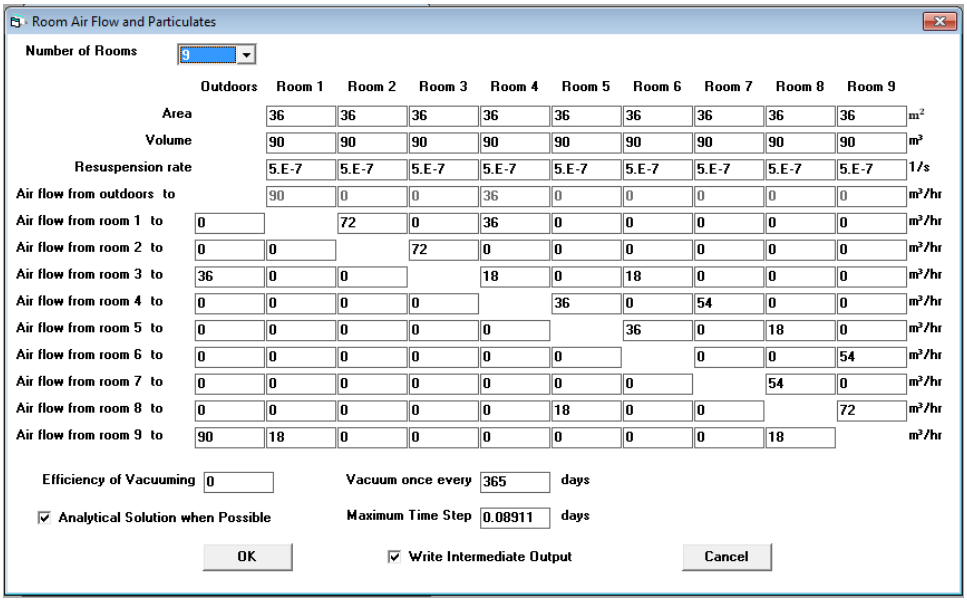
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-008-4
Requirements Tested	8, 11
Test Summary	Test the modeling of source release over multiple phases and transport of the released particles, resulting in radionuclide concentrations in air and on floors. With an area source (in Room 2) that is subjected to 7 release phases with different release rates, a 9-room building, and 4 receptors in different rooms, this test case tests and verifies the contaminant releases and air concentrations and the floor deposition concentrations in different rooms as functions of time.
Test Objective	Test and verify the modeling of the particulate releases to air, the air ventilation and transport, and the air and deposition concentrations of source particles and radionuclides, as required by the code requirements 8 and 11.
Procedure	Read in an input file that was used in a previous code verification effort (the verification results were documented in the Excel file "Area1_S=3.xlsx"), run the RESRAD-BUILD code to generate intermediate outputs and summary outputs, and then compare the results in these outputs with those previously obtained. The results obtained from the current run should match those that were obtained previously. Steps: • Read in the input file "Area 1_S=3_EXP.BLD." • Check to see the "new appearance" and "write intermediate output" features are selected and the number of receptors is 4. If not, change the input selections to match. • Check to see the inputs match the followings If not, change the inputs to match.

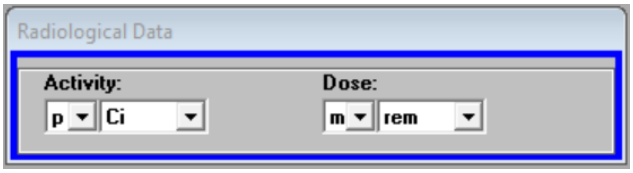


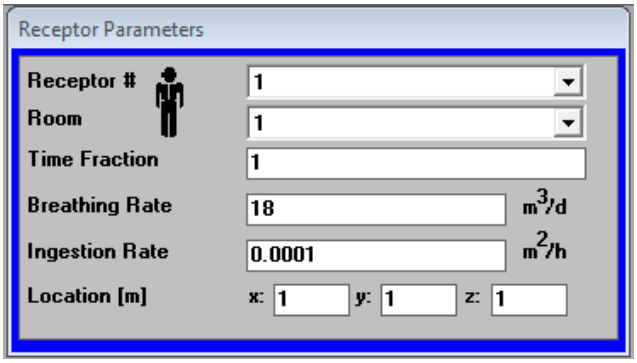


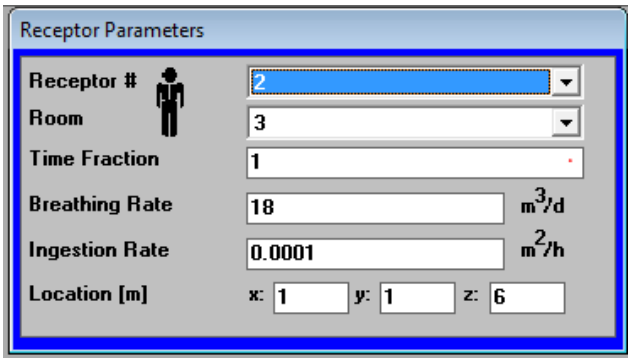

Evaluation Times
OK
Cancel
Times for Calculation (years):
1
10
100
1000
10000
100000
Remove
Add
1) .25
2) .5
3) .75
4) 1
5) 1.25
6) 1.5
Time Integration
Convergence criterion
0.0001
Maximum number of points
513

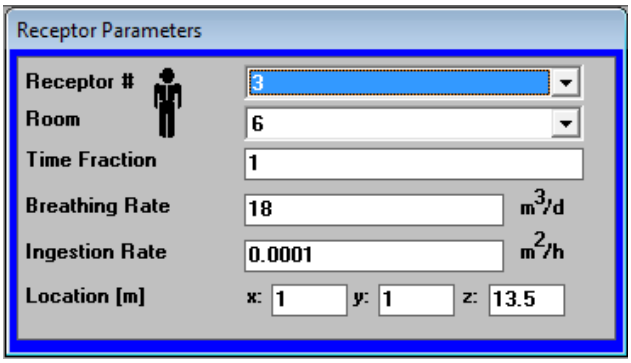

Building Parameters
Number of Rooms
9
Deposition Velocity
0.00039
m/s
Resuspension Rate
0.0000005
1/s
Air Flow

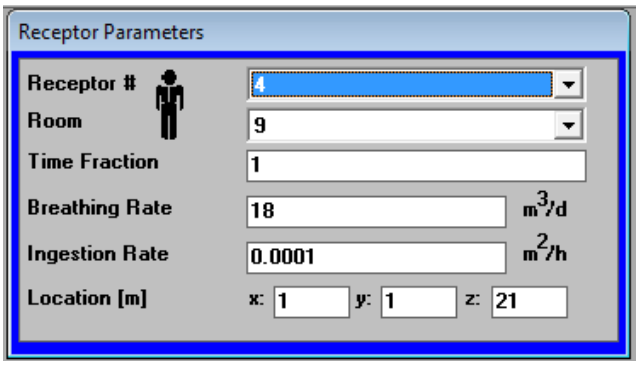

Room Air Flow and Particulates
Number of Rooms
9
Outdoors
Room 1
Room 2
Room 3
Room 4
Room 5
Room 6
Room 7
Room 8
Room 9
Area
Volume
Resuspension rate
Air flow from outdoors to
Air flow from room 1 to
Air flow from room 2 to
Air flow from room 3 to
Air flow from room 4 to
Air flow from room 5 to
Air flow from room 6 to
Air flow from room 7 to
Air flow from room 8 to
Air flow from room 9 to
Efficiency of Vacuuming
0
Vacuum once every
365
days
Analytical Solution when Possible
Maximum Time Step
0.08911
days
OK
Write Intermediate Output
Cancel

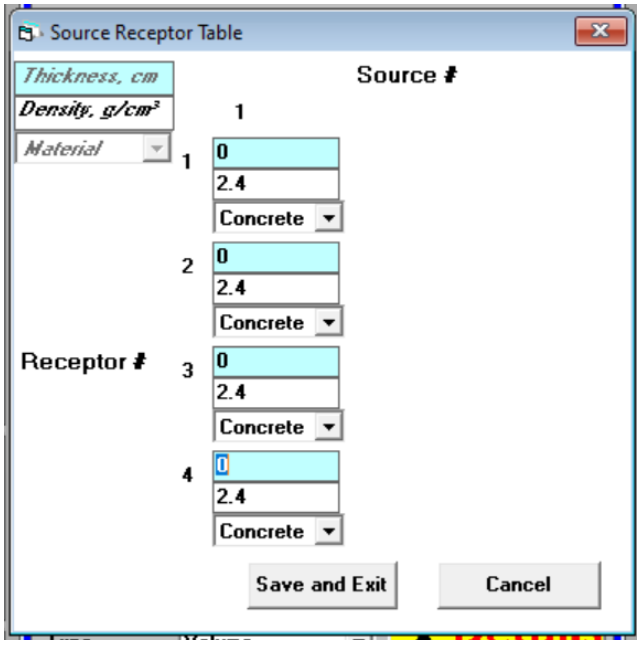

Radiological Data
Activity:
p
Ci
Dose:
m
rem

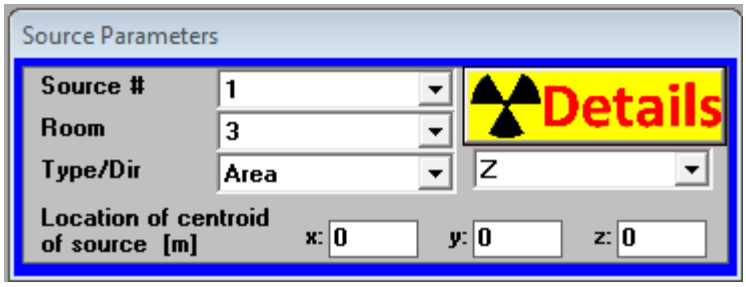

Receptor Parameters
Receptor #
1
Room
1
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 1

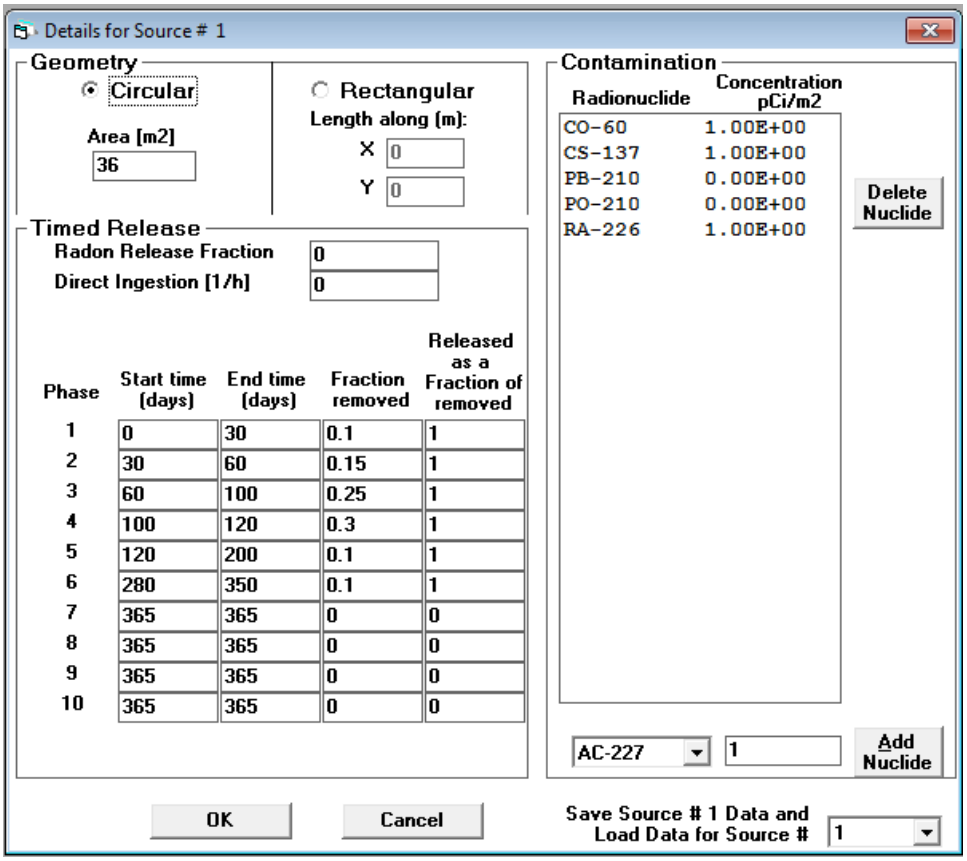

Receptor Parameters
Receptor #
2
Room
3
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 6


Receptor Parameters
Receptor #
3
Room
6
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 13.5


Receptor Parameters
Receptor #
4
Room
9
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 21


Source Receptor Table
Thickness, cm
Density, g/cm³
Material
Source #
1
Receptor #
1
0
2.4
Concrete
2
0
2.4
Concrete
3
0
2.4
Concrete
4
0
2.4
Concrete
Save and Exit
Cancel


Source Parameters
Source #
1
Room
3
Type/Dir
Area
Details
Z
Location of centroid of source [m]
x: 0
y: 0
z: 0



- Run the code.
- After the calculations are completed, open the file "AirRelRate1.out" in the directory where the code was installed to view. The intermediate outputs (for release rate of source material) should match those obtained from the code previously in the tab "RRB_AirRelrate1" in the "Area1_S=3.xlsx" Excel file.
- In the main interface of the code, choose the View -> "last intermediate output files" menu option. Then choose to view the "Time averaged concentrations of radionuclides on particulates suspended in air and deposited on floor" outputs for Source 1 or open the file "AirRelTimeIntegratedConcSource1.out" in the directory where the code was installed to view. The intermediate outputs (for time-averaged nuclide concentrations in the air and on the floor) should match those listed as "from RRB" in the tab "RRB_TimeIntegratedConcSource1" in the "Area1_S=3.xlsx" Excel file.
- Choose to view "last report," or open the file "RESRADB.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway doses for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.16E-05	5.98E-05	1.51E-08	6.74E-09	1.21E-07	2.38E-07	0.00E+00	7.19E-05
2	1.30E-06	2.47E-03	6.83E-07	2.78E-07	5.46E-06	1.16E-06	0.00E+00	2.48E-03
3	2.92E-07	7.62E-04	2.02E-07	8.59E-08	1.61E-06	1.45E-06	0.00E+00	7.66E-04
4	1.23E-07	4.23E-04	1.09E-07	4.76E-08	8.70E-07	1.30E-06	0.00E+00	4.25E-04
Total	1.34E-05	3.71E-03	1.01E-06	4.18E-07	8.06E-06	4.15E-06	0.00E+00	3.74E-03

Evaluation Time: 0.250000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	3.37E-06	1.65E-04	5.91E-08	1.82E-08	4.92E-07	6.84E-07	0.00E+00	1.69E-04
2	3.75E-07	3.28E-03	1.43E-06	3.63E-07	1.19E-05	2.70E-06	0.00E+00	3.29E-03
3	8.46E-08	1.51E-03	5.89E-07	1.67E-07	4.89E-06	3.90E-06	0.00E+00	1.52E-03
4	3.55E-08	1.03E-03	3.82E-07	1.14E-07	3.17E-06	3.65E-06	0.00E+00	1.04E-03
Total	3.86E-06	5.99E-03	2.46E-06	6.63E-07	2.04E-05	1.09E-05	0.00E+00	6.03E-03

Evaluation Time: 0.500000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.42E-06	9.88E-05	4.62E-08	1.07E-08	4.03E-07	3.63E-07	0.00E+00	1.01E-04
2	1.58E-07	5.40E-04	3.69E-07	5.85E-08	3.20E-06	9.70E-07	0.00E+00	5.45E-04
3	3.57E-08	5.96E-04	3.10E-07	6.45E-08	2.69E-06	1.83E-06	0.00E+00	6.01E-04
4	1.50E-08	5.38E-04	2.61E-07	5.81E-08	2.27E-06	1.84E-06	0.00E+00	5.42E-04
Total	1.63E-06	1.77E-03	9.85E-07	1.92E-07	8.56E-06	5.01E-06	0.00E+00	1.79E-03

Evaluation Time: 0.750000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	6.19E-07	5.39E-05	2.33E-08	5.68E-09	2.14E-07	1.89E-07	0.00E+00	5.49E-05
2	6.89E-08	6.93E-04	2.38E-07	7.30E-08	2.20E-06	5.76E-07	0.00E+00	6.96E-04
3	1.55E-08	3.83E-04	1.54E-07	4.04E-08	1.42E-06	9.79E-07	0.00E+00	3.86E-04
4	6.52E-09	3.03E-04	1.28E-07	3.19E-08	1.18E-06	9.65E-07	0.00E+00	3.05E-04
Total	7.10E-07	1.43E-03	5.44E-07	1.51E-07	5.02E-06	2.71E-06	0.00E+00	1.44E-03

Evaluation Time: 1.00000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	2.87E-05	1.33E-08	2.96E-09	1.29E-07	1.02E-07	0.00E+00	2.90E-05
2	0.00E+00	1.23E-04	9.36E-08	1.27E-08	9.03E-07	2.67E-07	0.00E+00	1.25E-04
3	0.00E+00	1.64E-04	8.37E-08	1.69E-08	8.10E-07	5.10E-07	0.00E+00	1.65E-04
4	0.00E+00	1.52E-04	7.27E-08	1.57E-08	7.04E-07	5.15E-07	0.00E+00	1.54E-04
Total	0.00E+00	4.68E-04	2.63E-07	4.83E-08	2.55E-06	1.39E-06	0.00E+00	4.73E-04

Evaluation Time: 1.25000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	1.05E-05	5.20E-09	1.06E-09	5.31E-08	3.37E-08	0.00E+00	1.06E-05
2	0.00E+00	2.54E-05	1.54E-08	2.55E-09	1.57E-07	7.05E-08	0.00E+00	2.56E-05
3	0.00E+00	5.14E-05	2.66E-08	5.18E-09	2.71E-07	1.57E-07	0.00E+00	5.19E-05
4	0.00E+00	5.27E-05	2.65E-08	5.30E-09	2.70E-07	1.64E-07	0.00E+00	5.31E-05
Total	0.00E+00	1.40E-04	7.36E-08	1.41E-08	7.51E-07	4.26E-07	0.00E+00	1.41E-04

Evaluation Time: 1.50000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	3.44E-06	1.72E-09	3.39E-10	1.85E-08	1.05E-08	0.00E+00	3.47E-06
2	0.00E+00	7.06E-06	3.72E-09	6.95E-10	4.00E-08	2.12E-08	0.00E+00	7.13E-06
3	0.00E+00	1.60E-05	8.10E-09	1.57E-09	8.72E-08	4.85E-08	0.00E+00	1.61E-05
4	0.00E+00	1.67E-05	8.44E-09	1.65E-09	9.08E-08	5.09E-08	0.00E+00	1.69E-05
Total	0.00E+00	4.32E-05	2.20E-08	4.25E-09	2.36E-07	1.31E-07	0.00E+00	4.36E-05

- Choose to view "last risk report," or open the file "RESRADB_r.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway risks for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	9.33E-12	4.80E-11	1.21E-14	5.44E-15	6.32E-14	2.41E-13	0.00E+00	5.76E-11
2	1.04E-12	1.98E-09	5.48E-13	2.24E-13	2.85E-12	1.23E-12	0.00E+00	1.98E-09
3	2.34E-13	6.11E-10	1.62E-13	6.93E-14	8.42E-13	1.49E-12	0.00E+00	6.14E-10
4	9.84E-14	3.39E-10	8.72E-14	3.84E-14	4.54E-13	1.33E-12	0.00E+00	3.41E-10
Total	1.07E-11	2.98E-09	8.09E-13	3.38E-13	4.21E-12	4.28E-12	0.00E+00	3.00E-09

Evaluation Time: 0.250000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.70E-12	1.32E-10	4.74E-14	1.47E-14	2.56E-13	6.95E-13	0.00E+00	1.36E-10
2	3.01E-13	2.63E-09	1.15E-12	2.93E-13	6.18E-12	2.86E-12	0.00E+00	2.64E-09
3	6.78E-14	1.21E-09	4.73E-13	1.35E-13	2.55E-12	3.99E-12	0.00E+00	1.22E-09
4	2.85E-14	8.29E-10	3.06E-13	9.22E-14	1.65E-12	3.72E-12	0.00E+00	8.35E-10
Total	3.10E-12	4.80E-09	1.98E-12	5.35E-13	1.06E-11	1.13E-11	0.00E+00	4.83E-09

Evaluation Time: 0.500000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.14E-12	7.93E-11	3.71E-14	8.61E-15	2.09E-13	3.71E-13	0.00E+00	8.10E-11
2	1.27E-13	4.33E-10	2.96E-13	4.72E-14	1.66E-12	1.01E-12	0.00E+00	4.36E-10
3	2.86E-14	4.78E-10	2.48E-13	5.20E-14	1.40E-12	1.88E-12	0.00E+00	4.82E-10
4	1.20E-14	4.31E-10	2.09E-13	4.69E-14	1.18E-12	1.89E-12	0.00E+00	4.35E-10
Total	1.31E-12	1.42E-09	7.90E-13	1.55E-13	4.45E-12	5.15E-12	0.00E+00	1.43E-09

Evaluation Time: 0.750000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	4.96E-13	4.32E-11	1.87E-14	4.58E-15	1.11E-13	1.93E-13	0.00E+00	4.40E-11
2	5.53E-14	5.56E-10	1.91E-13	5.89E-14	1.14E-12	6.05E-13	0.00E+00	5.58E-10
3	1.25E-14	3.07E-10	1.24E-13	3.26E-14	7.34E-13	1.00E-12	0.00E+00	3.09E-10
4	5.23E-15	2.43E-10	1.03E-13	2.57E-14	6.11E-13	9.87E-13	0.00E+00	2.44E-10
Total	5.69E-13	1.15E-09	4.36E-13	1.22E-13	2.60E-12	2.79E-12	0.00E+00	1.16E-09

Evaluation Time: 1.00000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	2.30E-11	1.07E-14	2.39E-15	6.67E-14	1.04E-13	0.00E+00	2.32E-11
2	0.00E+00	9.85E-11	7.51E-14	1.03E-14	4.66E-13	2.79E-13	0.00E+00	9.98E-11
3	0.00E+00	1.32E-10	6.71E-14	1.36E-14	4.18E-13	5.24E-13	0.00E+00	1.33E-10
4	0.00E+00	1.22E-10	5.83E-14	1.27E-14	3.64E-13	5.27E-13	0.00E+00	1.23E-10
Total	0.00E+00	3.76E-10	2.11E-13	3.89E-14	1.31E-12	1.43E-12	0.00E+00	3.79E-10

Evaluation Time: 1.25000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	8.45E-12	4.17E-15	8.55E-16	2.73E-14	3.45E-14	0.00E+00	8.52E-12
2	0.00E+00	2.03E-11	1.23E-14	2.06E-15	8.06E-14	7.26E-14	0.00E+00	2.05E-11
3	0.00E+00	4.13E-11	2.13E-14	4.18E-15	1.40E-13	1.62E-13	0.00E+00	4.16E-11
4	0.00E+00	4.23E-11	2.12E-14	4.28E-15	1.39E-13	1.69E-13	0.00E+00	4.26E-11
Total	0.00E+00	1.12E-10	5.90E-14	1.14E-14	3.87E-13	4.37E-13	0.00E+00	1.13E-10

Evaluation Time: 1.50000000 years

Pathway Detail of Risks

[Risk]

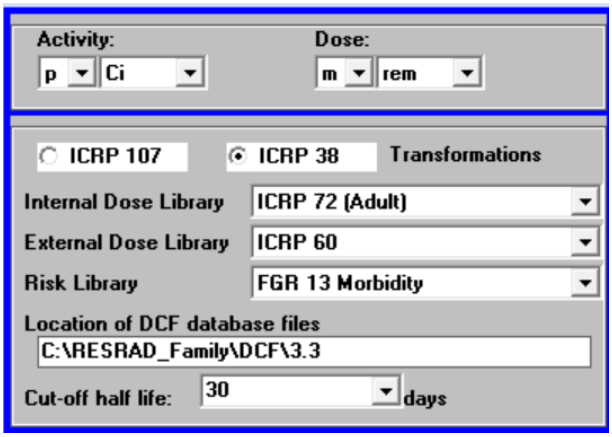
Source: 1

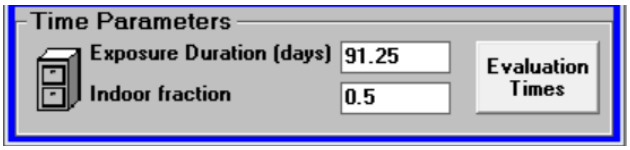
Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	0.00E+00	2.76E-12	1.38E-15	2.73E-16	9.50E-15	1.08E-14	0.00E+00	2.78E-12
2	0.00E+00	5.67E-12	2.98E-15	5.60E-16	2.06E-14	2.18E-14	0.00E+00	5.72E-12
3	0.00E+00	1.28E-11	6.50E-15	1.27E-15	4.48E-14	4.98E-14	0.00E+00	1.29E-11
4	0.00E+00	1.34E-11	6.76E-15	1.33E-15	4.66E-14	5.22E-14	0.00E+00	1.35E-11
Total	0.00E+00	3.47E-11	1.76E-14	3.43E-15	1.21E-13	1.35E-13	0.00E+00	3.50E-11

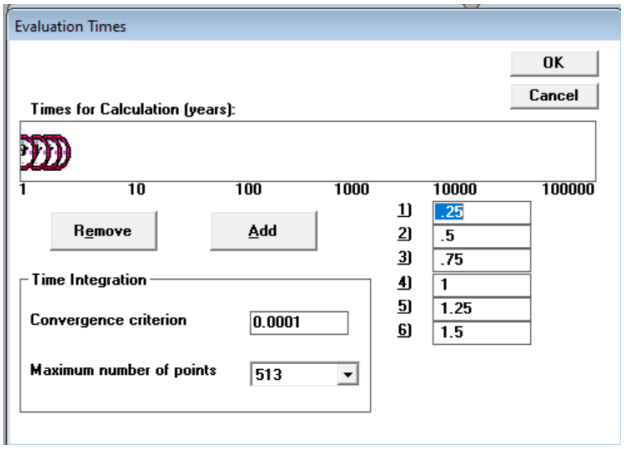
Required Data	Input file “Area 1_S=3_EXP.BLD” and the verification Excel file “Area1_S=3.xlsx.”
Expected Results	The intermediate and final outputs should match those previously obtained (and verified) with the same input file or input selections/values.

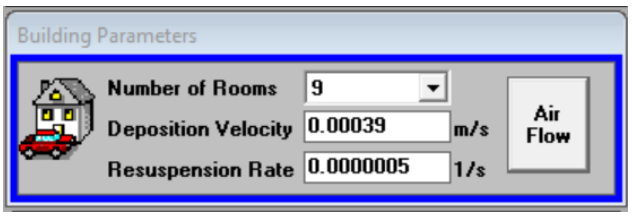
TEST CASE 008-5

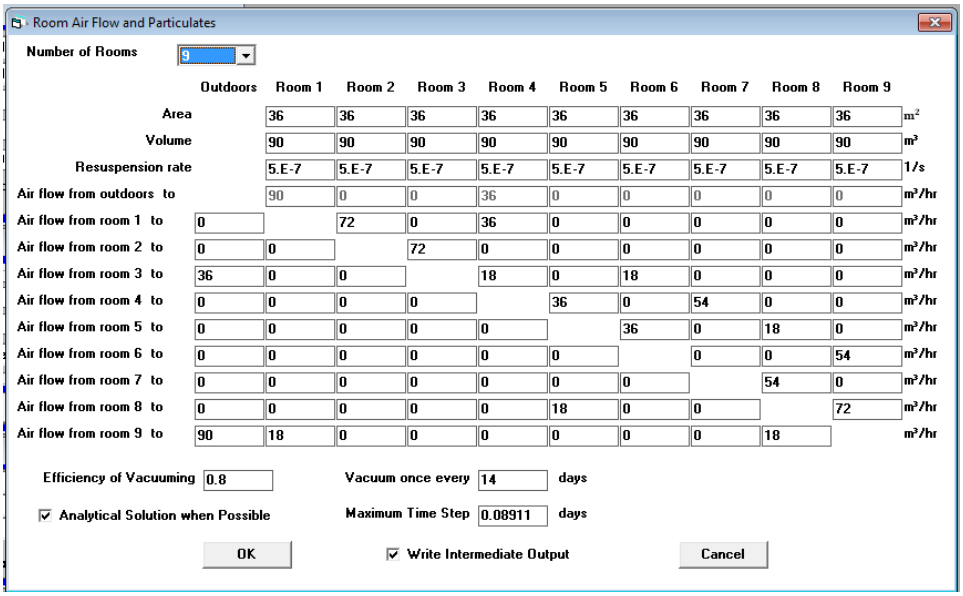
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-008-5
Requirements Tested	8, 11
Test Summary	Test the modeling of source release over multiple phases and transport of the released particles, resulting in radionuclide concentrations in air and on floors. With an area source (in Room 5) that is subjected to 7 release phases with different release rates, a 9-room building that is vacuumed every 14 days, and 4 receptors in different rooms, this test case tests and verifies the contaminant releases and air concentrations and the floor deposition concentrations in different rooms as functions of time.
Test Objective	Test and verify the modeling of the particulate releases to air, the air ventilation and transport, and the air and deposition concentrations of source particles and radionuclides, as required by the code requirements 8 and 11.
Procedure	Read in an input file that was used in a previous code verification effort (the verification results were documented in the Excel file "Area2_S=5_V=14.xlsx"), run the RESRAD-BUILD code to generate intermediate outputs and summary outputs, and then compare the results in these outputs with those previously obtained. The results obtained from the current run should match those that were obtained previously. Steps: • Read in the input file "Area 2_S=5_V=14_EXP.BLD." • Check to see the "new appearance" and "write intermediate output" features are selected and the number of receptors is 4. If not, change the input selections to match. • Check to see the inputs match the following. If not, change the inputs to match.

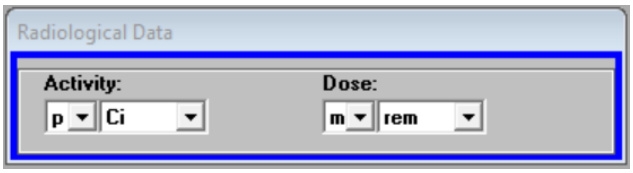


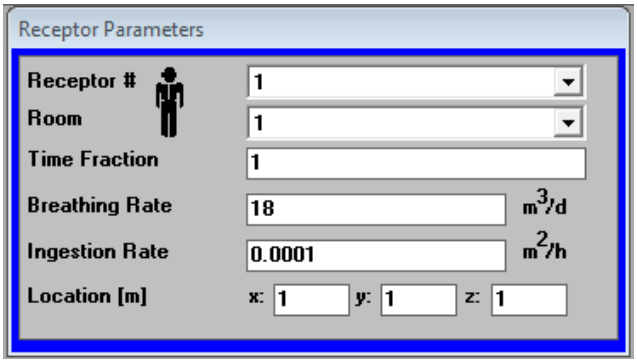


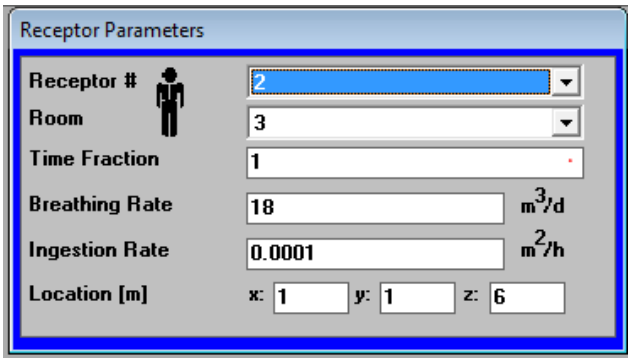

Evaluation Times
OK
Cancel
Times for Calculation (years):
1
10
100
1000
10000
100000
Remove
Add
1) .25
2) .5
3) .75
4) 1
5) 1.25
6) 1.5
Time Integration
Convergence criterion
0.0001
Maximum number of points
513

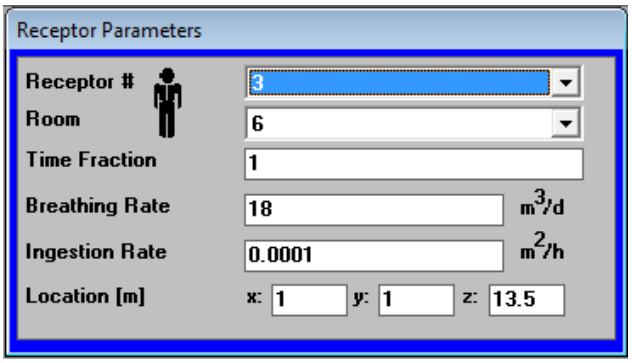

Building Parameters
Number of Rooms
9
Deposition Velocity
0.00039
m/s
Resuspension Rate
0.0000005
1/s
Air Flow

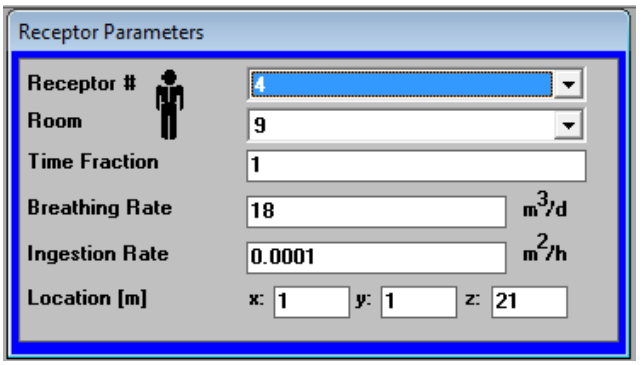

Room Air Flow and Particulates
Number of Rooms
9
Outdoors
Room 1
Room 2
Room 3
Room 4
Room 5
Room 6
Room 7
Room 8
Room 9
Area
Volume
Resuspension rate
Air flow from outdoors to
Air flow from room 1 to
Air flow from room 2 to
Air flow from room 3 to
Air flow from room 4 to
Air flow from room 5 to
Air flow from room 6 to
Air flow from room 7 to
Air flow from room 8 to
Air flow from room 9 to
Efficiency of Vacuuming
0.8
Vacuum once every
14
days
Analytical Solution when Possible
Maximum Time Step
0.08911
days
OK
Write Intermediate Output
Cancel

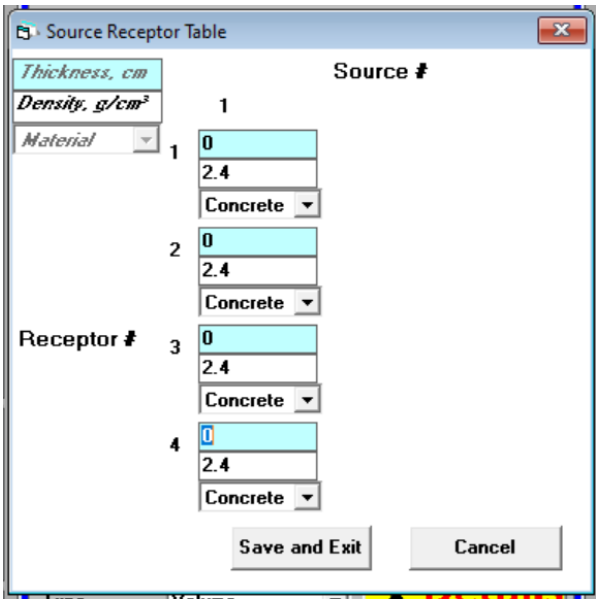

Radiological Data
Activity:
p
Ci
Dose:
m
rem

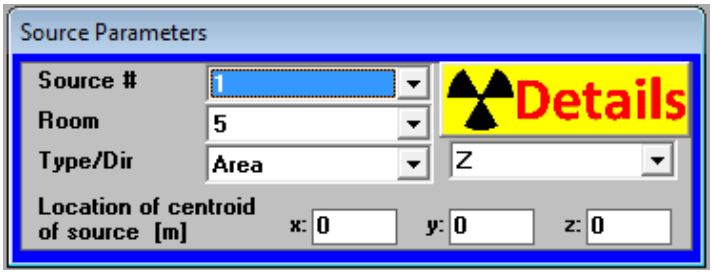

Receptor Parameters
Receptor #
1
Room
1
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 1

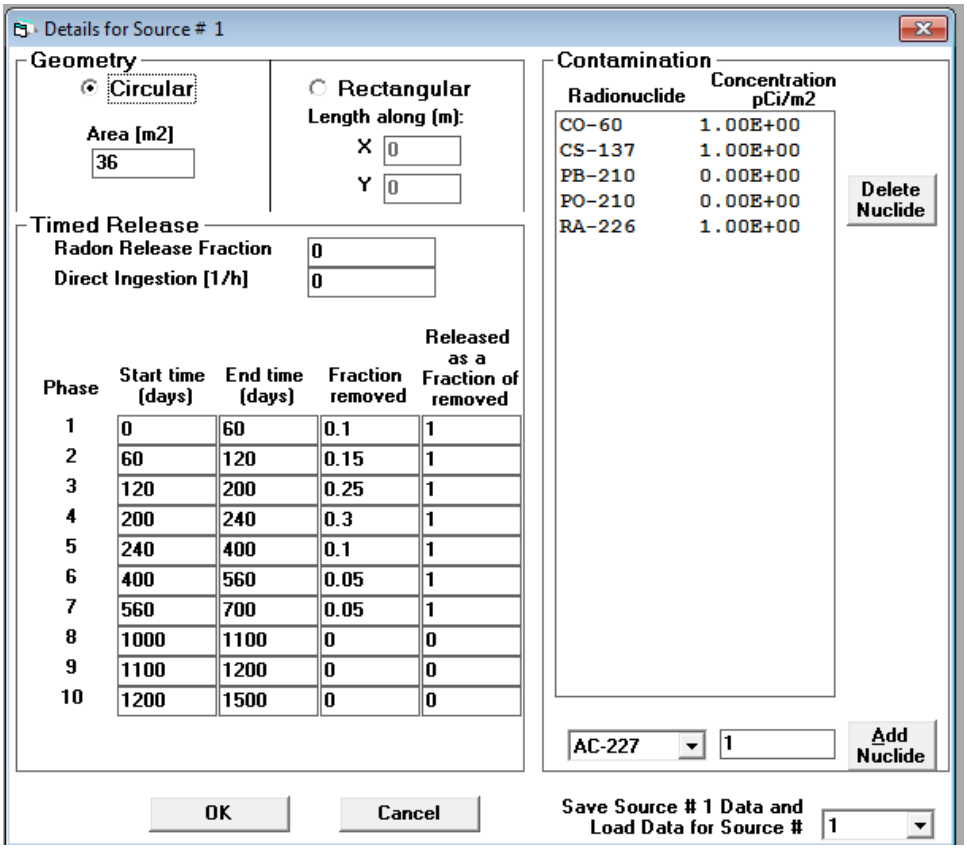

Receptor Parameters
Receptor #
2
Room
3
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 6


Receptor Parameters
Receptor #
3
Room
6
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 13.5


Receptor Parameters
Receptor #
4
Room
9
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 21


Source Receptor Table
Thickness, cm
Density, g/cm³
Material
Source #
1
Receptor #
1
0
2.4
Concrete
2
0
2.4
Concrete
3
0
2.4
Concrete
4
0
2.4
Concrete
Save and Exit
Cancel


Source Parameters
Source #
1
Room
5
Type/Dir
Area
Z
Details
Location of centroid of source [m]
x: 0
y: 0
z: 0



- Run the code.
- After the calculations are completed, open the file "AirRelRate1.out" in the directory where the code was installed to view. The intermediate outputs (for release rate of source material) should match those obtained from the code previously in the tab "RRB_AirRelrate1" in the "Area2_S=5_V=14.xlsx" Excel file.
- In the main interface of the code, choose the View -> "last intermediate output files" menu option. Then choose to view the "Time averaged concentrations of radionuclides on particulates suspended in air and deposited on floor" outputs for Source 1 or open the file "AirRelTimeIntegratedConcSource1.out" in the directory where the code was installed to view. The intermediate outputs (for time-averaged nuclide concentrations in the air and on the floor) should match those listed as "from RRB" in the tab "RRB_TimeIntegratedConcSource1" in the "Area2_S=5_V=14.xlsx" Excel file.
- Choose to view "last report," or open the file "RESRADB.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway doses for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.33E-05	2.61E-05	3.00E-09	2.95E-09	2.39E-08	5.02E-08	0.00E+00	3.95E-05
2	1.48E-06	1.15E-05	1.29E-09	1.30E-09	1.03E-08	5.72E-08	0.00E+00	1.30E-05
3	2.39E-07	5.39E-06	6.03E-10	6.08E-10	4.80E-09	3.49E-08	0.00E+00	5.67E-06
4	1.40E-07	2.10E-04	2.43E-08	2.37E-08	1.93E-07	2.75E-07	0.00E+00	2.10E-04
Total	1.51E-05	2.53E-04	2.92E-08	2.85E-08	2.32E-07	4.17E-07	0.00E+00	2.68E-04

Evaluation Time: 0.250000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	9.84E-06	4.15E-05	5.09E-09	4.58E-09	4.23E-08	8.48E-08	0.00E+00	5.15E-05
2	1.10E-06	1.87E-05	2.24E-09	2.06E-09	1.86E-08	9.70E-08	0.00E+00	1.99E-05
3	1.77E-07	8.83E-06	1.05E-09	9.74E-10	8.76E-09	5.92E-08	0.00E+00	9.07E-06
4	1.04E-07	3.30E-04	4.09E-08	3.64E-08	3.40E-07	4.63E-07	0.00E+00	3.31E-04
Total	1.12E-05	3.99E-04	4.93E-08	4.40E-08	4.09E-07	7.04E-07	0.00E+00	4.11E-04

Evaluation Time: 0.500000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	4.52E-06	5.96E-05	7.35E-09	6.44E-09	6.40E-08	1.23E-07	0.00E+00	6.43E-05
2	5.04E-07	2.71E-05	3.27E-09	2.92E-09	2.85E-08	1.41E-07	0.00E+00	2.77E-05
3	8.16E-08	1.28E-05	1.54E-09	1.38E-09	1.34E-08	8.61E-08	0.00E+00	1.30E-05
4	4.77E-08	4.72E-04	5.88E-08	5.10E-08	5.12E-07	6.71E-07	0.00E+00	4.73E-04
Total	5.16E-06	5.71E-04	7.09E-08	6.18E-08	6.18E-07	1.02E-06	0.00E+00	5.78E-04

Evaluation Time: 0.750000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.06E-06	9.13E-06	1.11E-09	9.61E-10	1.02E-08	1.87E-08	0.00E+00	1.12E-05
2	2.29E-07	4.16E-06	4.98E-10	4.38E-10	4.58E-09	2.15E-08	0.00E+00	4.42E-06
3	3.71E-08	1.97E-06	2.36E-10	2.08E-10	2.17E-09	1.31E-08	0.00E+00	2.02E-06
4	2.17E-08	7.22E-05	8.81E-09	7.61E-09	8.11E-08	1.02E-07	0.00E+00	7.25E-05
Total	2.35E-06	8.75E-05	1.06E-08	9.22E-09	9.80E-08	1.55E-07	0.00E+00	9.01E-05

Evaluation Time: 1.00000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.33E-06	6.40E-06	7.65E-10	6.59E-10	7.41E-09	1.32E-08	0.00E+00	7.75E-06
2	1.48E-07	2.92E-06	3.42E-10	3.01E-10	3.31E-09	1.51E-08	0.00E+00	3.08E-06
3	2.40E-08	1.38E-06	1.61E-10	1.42E-10	1.56E-09	9.24E-09	0.00E+00	1.42E-06
4	1.40E-08	5.06E-05	6.11E-09	5.22E-09	5.91E-08	7.20E-08	0.00E+00	5.08E-05
Total	1.52E-06	6.13E-05	7.38E-09	6.32E-09	7.14E-08	1.10E-07	0.00E+00	6.30E-05

Evaluation Time: 1.25000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	9.03E-07	4.58E-06	5.18E-10	4.60E-10	5.31E-09	9.17E-09	0.00E+00	5.50E-0
2	1.01E-07	2.07E-06	2.29E-10	2.08E-10	2.35E-09	1.05E-08	0.00E+00	2.18E-0
3	1.63E-08	9.78E-07	1.08E-10	9.83E-11	1.11E-09	6.41E-09	0.00E+00	1.00E-0
4	9.52E-09	3.64E-05	4.15E-09	3.65E-09	4.26E-08	5.01E-08	0.00E+00	3.65E-0
Total	1.03E-06	4.40E-05	5.01E-09	4.42E-09	5.14E-08	7.62E-08	0.00E+00	4.51E-0

Evaluation Time: 1.50000000 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	4.96E-07	5.11E-06	5.51E-10	5.01E-10	5.96E-09	9.97E-09	0.00E+00	5.62E-06
2	5.53E-08	2.29E-06	2.43E-10	2.25E-10	2.63E-09	1.14E-08	0.00E+00	2.36E-06
3	8.96E-09	1.08E-06	1.14E-10	1.06E-10	1.24E-09	6.96E-09	0.00E+00	1.10E-06
4	5.24E-09	4.07E-05	4.43E-09	3.99E-09	4.79E-08	5.45E-08	0.00E+00	4.08E-05
Total	5.66E-07	4.91E-05	5.33E-09	4.82E-09	5.77E-08	8.28E-08	0.00E+00	4.99E-05

- Choose to view "last risk report," or open the file "RESRADB_r.rpt" in the directory where the code was installed to view. The immersion, inhalation, and ingestion pathway risks for the 4 receptors at different time periods should match the values shown in the following tables.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.06E-11	2.09E-11	2.40E-15	2.38E-15	1.25E-14	5.09E-14	0.00E+00	3.16E-11
2	1.18E-12	9.20E-12	1.03E-15	1.04E-15	5.36E-15	5.77E-14	0.00E+00	1.05E-11
3	1.92E-13	4.32E-12	4.84E-16	4.91E-16	2.51E-15	3.52E-14	0.00E+00	4.55E-12
4	1.12E-13	1.68E-10	1.95E-14	1.91E-14	1.01E-13	2.80E-13	0.00E+00	1.69E-10
Total	1.21E-11	2.03E-10	2.34E-14	2.30E-14	1.21E-13	4.24E-13	0.00E+00	2.15E-10

Evaluation Time: 0.250000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	7.89E-12	3.33E-11	4.08E-15	3.70E-15	2.20E-14	8.60E-14	0.00E+00	4.13E-11
2	8.79E-13	1.50E-11	1.80E-15	1.66E-15	9.70E-15	9.79E-14	0.00E+00	1.60E-11
3	1.42E-13	7.08E-12	8.45E-16	7.86E-16	4.56E-15	5.97E-14	0.00E+00	7.29E-12
4	8.32E-14	2.65E-10	3.28E-14	2.94E-14	1.77E-13	4.71E-13	0.00E+00	2.65E-10
Total	9.00E-12	3.20E-10	3.95E-14	3.55E-14	2.13E-13	7.15E-13	0.00E+00	3.30E-10

Evaluation Time: 0.500000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	3.63E-12	4.78E-11	5.90E-15	5.19E-15	3.33E-14	1.25E-13	0.00E+00	5.16E-11
2	4.04E-13	2.17E-11	2.62E-15	2.36E-15	1.48E-14	1.42E-13	0.00E+00	2.23E-11
3	6.54E-14	1.03E-11	1.24E-15	1.12E-15	6.98E-15	8.68E-14	0.00E+00	1.04E-11
4	3.82E-14	3.78E-10	4.71E-14	4.12E-14	2.66E-13	6.84E-13	0.00E+00	3.80E-10
Total	4.13E-12	4.58E-10	5.69E-14	4.98E-14	3.21E-13	1.04E-12	0.00E+00	4.64E-10

Evaluation Time: 0.750000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.65E-12	7.32E-12	8.86E-16	7.75E-16	5.27E-15	1.90E-14	0.00E+00	9.00E-12
2	1.84E-13	3.34E-12	4.00E-16	3.54E-16	2.37E-15	2.17E-14	0.00E+00	3.55E-12
3	2.98E-14	1.58E-12	1.89E-16	1.67E-16	1.12E-15	1.32E-14	0.00E+00	1.63E-12
4	1.74E-14	5.79E-11	7.06E-15	6.14E-15	4.20E-14	1.04E-13	0.00E+00	5.81E-11
Total	1.88E-12	7.02E-11	8.54E-15	7.43E-15	5.07E-14	1.58E-13	0.00E+00	7.23E-11

Evaluation Time: 1.00000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.07E-12	5.13E-12	6.14E-16	5.32E-16	3.83E-15	1.34E-14	0.00E+00	6.22E-12
2	1.19E-13	2.34E-12	2.74E-16	2.42E-16	1.71E-15	1.53E-14	0.00E+00	2.48E-12
3	1.92E-14	1.11E-12	1.29E-16	1.15E-16	8.07E-16	9.31E-15	0.00E+00	1.14E-12
4	1.12E-14	4.06E-11	4.90E-15	4.21E-15	3.05E-14	7.33E-14	0.00E+00	4.07E-11
Total	1.22E-12	4.92E-11	5.92E-15	5.09E-15	3.69E-14	1.11E-13	0.00E+00	5.05E-11

Evaluation Time: 1.25000000 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	7.24E-13	3.68E-12	4.15E-16	3.71E-16	2.74E-15	9.30E-15	0.00E+00	4.41E-12
2	8.07E-14	1.66E-12	1.84E-16	1.68E-16	1.21E-15	1.06E-14	0.00E+00	1.75E-12
3	1.31E-14	7.85E-13	8.66E-17	7.93E-17	5.70E-16	6.46E-15	0.00E+00	8.05E-13
4	7.63E-15	2.92E-11	3.33E-15	2.95E-15	2.19E-14	5.10E-14	0.00E+00	2.93E-11
Total	8.25E-13	3.53E-11	4.01E-15	3.56E-15	2.64E-14	7.73E-14	0.00E+00	3.62E-11

Evaluation Time: 1.50000000 years

Pathway Detail of Risks

[Risk]

Source: 1

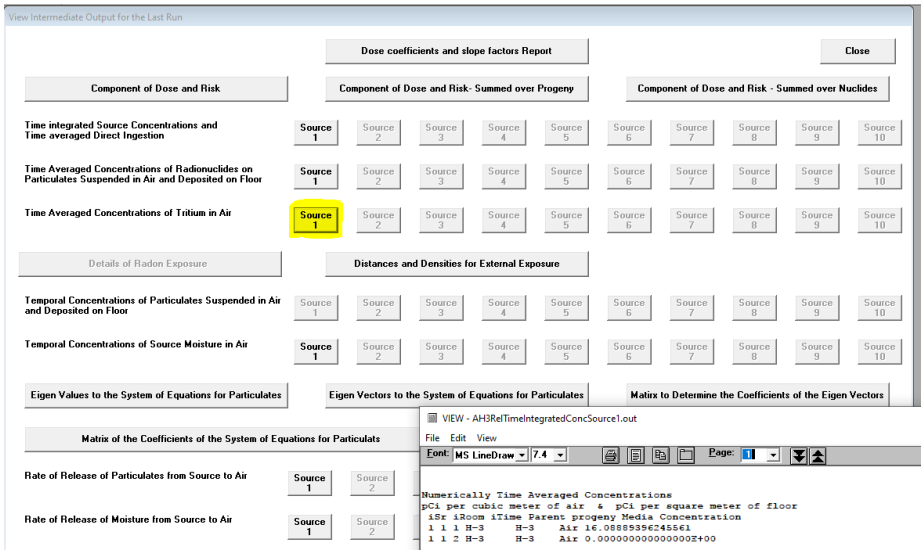
Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	3.98E-13	4.10E-12	4.42E-16	4.04E-16	3.06E-15	1.01E-14	0.00E+00	4.51E-12
2	4.43E-14	1.84E-12	1.95E-16	1.82E-16	1.35E-15	1.15E-14	0.00E+00	1.90E-12
3	7.18E-15	8.69E-13	9.16E-17	8.57E-17	6.35E-16	7.01E-15	0.00E+00	8.84E-13
4	4.20E-15	3.26E-11	3.55E-15	3.22E-15	2.46E-14	5.54E-14	0.00E+00	3.27E-11
Total	4.54E-13	3.94E-11	4.28E-15	3.89E-15	2.96E-14	8.40E-14	0.00E+00	4.00E-11

Required Data Input file "Area 2_S=5_V=14_EXP.BLD" and the verification Excel file "Area2_S=5_V=14.xlsx."

Expected Results The intermediate and final outputs should match those previously obtained (and verified) with the same input file or input selections/values.

TEST CASE 009

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-009
Requirements Tested	9
Test Summary	Test tritium concentrations from release of volume sources.
Test Objective	Test tritium concentration from volume source.
Procedure	1. Run file “Reqts_9_H3_Vol.bld.” 2. Compare with results in “View|Intermediate|Time Averaged Concentrations of Tritium in Air” below.



Required Data	NA
Expected Results	The expected results are shown below (as verified in “reqts_9_H3_vol.xlsx”).

VIEW - AH3RelTimeIntegratedConcSource1.out

File Edit View

Font: MS LineDraw 7.4 Page: 1

```
Numerically Time Averaged Concentrations
pCi per cubic meter of air  &  pCi per square meter of floor
 iSr iRoom iTime Parent progeny Media Concentration
 1 1 1 H-3      H-3     Air 16.08889396245561
 1 1 2 H-3      H-3     Air 0.0000000000000003E+00
```

TEST CASE 010

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-010
Requirements Tested	10, 14
Test Summary	Test modeling of radon release and radon dose.
Test Objective	Test radon release and radon dose.
Procedure	1. Run file Reqts_10_14_rn_pt.bld. 2. Generate "RadonAndProgeny.out" from "View|Intermediate" results. 3. Compare file with verified file "RadonAndProgeny_Verified.out."
Required Data	NA
Expected Results	The two files should be the same. The verification is in "radon dose.xlsx."

TEST CASE 012-1

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-012-1
Requirement Tested	12
Test Summary	Test the modeling of direct external dose and risk from different types of sources.
Test Objective	Test and verify the direct external pathway dose/risk from a point source at different receptor locations with and without shielding.
Procedure	Open the "point-source-verification.bld" RESRAD-BUILD input file that was used in the code verification effort (the verification results are in the EXCEL file "FGR12 Point Source Dose Calculations for few radionuclides-ver4.xlsx"). Run the RESRAD-BUILD code, open the "RESRADB.RPT" dose report and "RESRADB_R.RPT" risk report, and compare the results in these reports with those previously obtained. The verification details are in the "Verification of Point Source Dose Calculations.docx" file.
Required Data	Input file "point-source-verification.bld" and "Verification of Point Source Dose Calculations.docx."
Expected Results	The outputs in the RESRAD-BUILD dose report should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 1. The outputs in the RESRAD-BUILD risk report should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 2.

Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Doses

[mrem]

Source: 1

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Receptor 6	Receptor 7	Receptor 8	Receptor 9	Total
C-14	3.17E-11	4.04E-11	4.72E-11	3.36E-14	1.87E-11	7.13E-13	2.77E-31	1.01E-09	6.41E-12	1.15E-09
Co-60	1.31E-06	1.29E-06	1.22E-06	2.77E-07	1.26E-06	1.05E-06	1.39E-08	4.36E-05	2.44E-07	5.03E-05
Mn-54	3.36E-07	3.32E-07	3.18E-07	5.79E-08	3.26E-07	2.70E-07	1.46E-09	1.13E-05	6.28E-08	1.30E-05
Nb-94	9.28E-07	9.18E-07	8.81E-07	1.55E-07	9.01E-07	7.46E-07	3.57E-09	3.10E-05	1.73E-07	3.57E-05
Tc-99	1.01E-10	1.18E-10	1.66E-10	4.24E-12	1.12E-10	5.66E-11	3.96E-18	3.31E-09	1.97E-11	3.89E-09

Figure 1 Dose Results from RESRAD-BUILD Code for Different Receptors

Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Risks

[Risk]

Source: 1

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Receptor 6	Receptor 7	Receptor 8	Receptor 9	Total
C-14	1.85E-17	2.35E-17	2.75E-17	1.96E-20	1.09E-17	4.15E-19	1.61E-37	5.85E-16	3.73E-18	6.70E-16
Co-60	9.99E-13	9.85E-13	9.32E-13	2.11E-13	9.63E-13	8.01E-13	1.06E-14	3.34E-11	1.87E-13	3.85E-11
Mn-54	2.54E-13	2.51E-13	2.40E-13	4.37E-14	2.46E-13	2.04E-13	1.10E-15	8.49E-12	4.74E-14	9.77E-12
Nb-94	6.99E-13	6.91E-13	6.64E-13	1.17E-13	6.79E-13	5.62E-13	2.69E-15	2.34E-11	1.31E-13	2.69E-11
Tc-99	6.56E-17	7.64E-17	1.08E-16	2.75E-18	7.29E-17	3.67E-17	2.57E-24	2.15E-15	1.28E-17	2.52E-15

Figure 2 Risk Results from RESRAD-BUILD Code for Different Receptors

TEST CASE 012-2

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-012-2
Requirement Tested:	12
Test Summary	Test the modeling of direct external dose and risk from different types of sources.
Test Objective	Test and verify the direct external pathway dose/risk from a line source at different receptor locations with and without shielding.
Procedure	Open the "line-source-verification.bld" RESRAD-BUILD input file that was used in the code verification effort (the verification results are in the EXCEL file "FGR12 Line Source Dose Calculations for few radionuclides-ver4.xlsx"). Run the RESRAD-BUILD code, open the "RESRADB.RPT" dose report and "RESRADB_R.RPT" risk report, and compare the results in these reports with those previously obtained. The verification details are in the "Verification of Line Source Dose Calculations.docx" file.
Required Data	Input file "line-source-verification.bld" and "Verification of Line Source Dose Calculations.docx."
Expected Results	The outputs in the RESRAD-BUILD dose report should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 1. The outputs in thew RESRAD-BUILD risk report should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 2.

Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Doses

[mrem]

Source: 1

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Receptor 6	Receptor 7	Receptor 8	Receptor 9	Total
C-14	3.20E-11	4.07E-11	4.76E-11	3.39E-14	1.89E-11	7.18E-13	2.79E-31	6.20E-10	6.38E-12	7.67E-10
Co-60	1.32E-06	1.30E-06	1.23E-06	2.79E-07	1.27E-06	1.06E-06	1.40E-08	2.70E-05	2.43E-07	3.37E-05
Mn-54	3.39E-07	3.35E-07	3.20E-07	5.83E-08	3.28E-07	2.72E-07	1.47E-09	6.95E-06	6.25E-08	8.67E-06
Nb-94	9.35E-07	9.25E-07	8.88E-07	1.57E-07	9.08E-07	7.52E-07	3.60E-09	1.92E-05	1.73E-07	2.39E-05
Tc-99	1.02E-10	1.19E-10	1.67E-10	4.27E-12	1.13E-10	5.70E-11	3.99E-18	2.04E-09	1.96E-11	2.62E-09

Figure 1 Dose Results from RESRAD-BUILD Code for Different Receptors

Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Risks

[Risk]

Source: 1

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Receptor 6	Receptor 7	Receptor 8	Receptor 9	Total
C-14	1.86E-17	2.37E-17	2.77E-17	1.97E-20	1.10E-17	4.18E-19	1.62E-37	3.61E-16	3.71E-18	4.46E-16
Co-60	1.01E-12	9.93E-13	9.39E-13	2.13E-13	9.71E-13	8.07E-13	1.07E-14	2.06E-11	1.86E-13	2.57E-11
Mn-54	2.56E-13	2.53E-13	2.42E-13	4.40E-14	2.48E-13	2.05E-13	1.11E-15	5.24E-12	4.72E-14	6.54E-12
Nb-94	7.04E-13	6.97E-13	6.69E-13	1.18E-13	6.84E-13	5.66E-13	2.71E-15	1.44E-11	1.30E-13	1.80E-11
Tc-99	6.61E-17	7.69E-17	1.08E-16	2.77E-18	7.35E-17	3.70E-17	2.59E-24	1.32E-15	1.27E-17	1.70E-15

Figure 2 Risk Results from RESRAD-BUILD Code for Different Receptors

TEST CASE 012-3

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-012-3
Requirement Tested	12
Test Summary	Test the modeling of direct external dose and risk from different types of sources.
Test Objective	Test and verify the direct external pathway dose/risk from deposited source contamination.
Procedure	Open the "deposition-1.bld" RESRAD-BUILD input file that was used in the code verification effort (the verification results are in EXCEL files "FGR12 Deposition Dose Calculations for few radionuclides-ver4.xlsx" and "Deposition-Testing.xlsx"). Run the RESRAD-BUILD code, open the "RESRADB.RPT" dose report and "RESRADB_R.RPT" risk report, and compare the results in these reports with those previously obtained. The verification details are in the "Verification of External Exposure Dose and Risk from Deposition.docx" file.
Required Data	Input file "deposition-1.bld" and "Verification of External Exposure Dose and Risk from Deposition-ver4.docx."
Expected Results	The outputs in the RESRAD-BUILD dose report for deposition should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 1. The outputs in the RESRAD-BUILD risk report for deposition should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 2.

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	5.30E-06	1.37E-09	4.28E-13	2.62E-15	3.42E-09	0.00E+00	0.00E+00	5.30E-06
2	2.13E-08	2.75E-10	1.49E-13	5.24E-16	6.62E-10	0.00E+00	0.00E+00	2.22E-08
3	4.13E-09	1.76E-10	1.33E-13	3.35E-16	4.16E-10	0.00E+00	0.00E+00	4.72E-09
4	5.81E-11	2.73E-11	3.63E-14	5.20E-17	6.36E-11	0.00E+00	0.00E+00	1.49E-10
Total	5.32E-06	1.85E-09	7.45E-13	3.53E-15	4.56E-09	0.00E+00	0.00E+00	5.33E-06

Source: 2

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.09E-07	6.85E-09	3.60E-08	7.44E-10	6.93E-09	0.00E+00	0.00E+00	2.59E-07
2	6.77E-06	1.29E-09	1.15E-08	1.40E-10	1.26E-09	0.00E+00	0.00E+00	6.79E-06
3	4.76E-07	8.04E-10	9.80E-09	8.72E-11	7.74E-10	0.00E+00	0.00E+00	4.87E-07
4	9.49E-09	1.22E-10	2.41E-09	1.32E-11	1.16E-10	0.00E+00	0.00E+00	1.21E-08
Total	7.47E-06	9.07E-09	5.97E-08	9.84E-10	9.07E-09	0.00E+00	0.00E+00	7.55E-06

Source: 3

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	8.06E-08	6.85E-09	3.60E-08	7.44E-10	6.93E-09	0.00E+00	0.00E+00	1.31E-07
2	5.28E-07	1.29E-09	1.15E-08	1.40E-10	1.26E-09	0.00E+00	0.00E+00	5.42E-07
3	4.33E-06	8.04E-10	9.80E-09	8.72E-11	7.74E-10	0.00E+00	0.00E+00	4.34E-06
4	1.35E-08	1.22E-10	2.41E-09	1.32E-11	1.16E-10	0.00E+00	0.00E+00	1.62E-08
Total	4.95E-06	9.07E-09	5.97E-08	9.84E-10	9.07E-09	0.00E+00	0.00E+00	5.03E-06

Source: 4

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	3.30E-13	1.30E-09	4.29E-13	4.50E-15	5.69E-10	0.00E+00	0.00E+00	1.87E-09
2	4.67E-13	2.60E-10	1.48E-13	9.01E-16	1.10E-10	0.00E+00	0.00E+00	3.71E-10
3	6.08E-13	1.66E-10	1.30E-13	5.76E-16	6.92E-11	0.00E+00	0.00E+00	2.36E-10
4	4.50E-10	2.58E-11	3.46E-14	8.94E-17	1.06E-11	0.00E+00	0.00E+00	4.87E-10

Figure 1 Dose Results from RESRAD-BUILD Code for Different Receptors

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	3.08E-12	1.11E-14	2.49E-19	4.28E-21	3.27E-15	0.00E+00	0.00E+00	3.10E-12
2	1.24E-14	2.22E-15	8.65E-20	8.56E-22	6.33E-16	0.00E+00	0.00E+00	1.52E-14
3	2.40E-15	1.42E-15	7.72E-20	5.47E-22	3.99E-16	0.00E+00	0.00E+00	4.22E-15
4	3.38E-17	2.20E-16	2.11E-20	8.50E-23	6.08E-17	0.00E+00	0.00E+00	3.15E-16
Total	3.10E-12	1.50E-14	4.34E-19	5.77E-21	4.37E-15	0.00E+00	0.00E+00	3.12E-12

Source: 2

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.58E-13	1.24E-14	2.72E-14	5.60E-16	7.78E-15	0.00E+00	0.00E+00	2.06E-13
2	5.11E-12	2.33E-15	8.69E-15	1.05E-16	1.41E-15	0.00E+00	0.00E+00	5.12E-12
3	3.59E-13	1.45E-15	7.39E-15	6.57E-17	8.69E-16	0.00E+00	0.00E+00	3.69E-13
4	7.16E-15	2.20E-16	1.82E-15	9.98E-18	1.30E-16	0.00E+00	0.00E+00	9.34E-15
Total	5.63E-12	1.64E-14	4.51E-14	7.42E-16	1.02E-14	0.00E+00	0.00E+00	5.71E-12

Source: 3

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	6.08E-14	1.24E-14	2.72E-14	5.60E-16	7.78E-15	0.00E+00	0.00E+00	1.09E-13
2	3.98E-13	2.33E-15	8.69E-15	1.05E-16	1.41E-15	0.00E+00	0.00E+00	4.11E-13
3	3.26E-12	1.45E-15	7.39E-15	6.57E-17	8.69E-16	0.00E+00	0.00E+00	3.27E-12
4	1.02E-14	2.20E-16	1.82E-15	9.98E-18	1.30E-16	0.00E+00	0.00E+00	1.24E-14
Total	3.73E-12	1.64E-14	4.51E-14	7.42E-16	1.02E-14	0.00E+00	0.00E+00	3.81E-12

Source: 4

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.14E-19	5.94E-15	2.79E-19	1.03E-20	1.56E-15	0.00E+00	0.00E+00	7.50E-15
2	3.03E-19	1.19E-15	9.58E-20	2.07E-21	3.01E-16	0.00E+00	0.00E+00	1.49E-15
3	3.94E-19	7.62E-16	8.44E-20	1.32E-21	1.90E-16	0.00E+00	0.00E+00	9.52E-16
4	2.92E-16	1.18E-16	2.25E-20	2.05E-22	2.89E-17	0.00E+00	0.00E+00	4.39E-16

Figure 2 Risk Results from RESRAD-BUILD Code for Different Receptors

TEST CASE 012-4

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-012-4
Requirement Tested	12
Test Summary	Test the modeling of direct external dose and risk from different types of sources.
Test Objective	Test and verify the direct external pathway dose/risk from circular area source contamination.
Procedure	Open the "area-source-verification.bld" RESRAD-BUILD input file that was used in the code verification effort (the verification results are in EXCEL file "FGR12 Area Source Dose Calculations for few radionuclides-ver4.xlsx"). Run the RESRAD-BUILD code, open the "RESRADB.RPT" dose report and "RESRADB_R.RPT" risk report, and compare the results in these reports with those previously obtained. The verification details are in the "Verification of Area Source Dose Calculations.docx" file.
Required Data	Input file "area-source-verification.bld" and "Verification of Area Source Dose Calculations.docx."
Expected Results	The outputs in the RESRAD-BUILD dose report for circular area sources should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 1. The outputs in the RESRAD-BUILD risk report for circular area sources should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 2.

Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Doses

[mrem]

Source: 1

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	1.58E-09	2.81E-12	8.54E-11	1.96E-09	1.13E-09	4.76E-09
Mn-54	4.80E-05	9.87E-06	2.49E-05	6.25E-05	3.13E-05	1.77E-04
Tc-99	6.50E-09	1.23E-10	1.10E-09	8.12E-09	4.61E-09	2.05E-08

Source: 2

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	5.83E-10	2.81E-12	8.53E-11	9.52E-10	1.98E-10	1.82E-09
Mn-54	2.10E-05	9.75E-06	1.76E-05	3.55E-05	6.58E-06	9.04E-05
Tc-99	2.41E-09	1.23E-10	9.97E-10	3.99E-09	7.88E-10	8.31E-09

Source: 3

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	4.11E-10	2.81E-12	8.17E-11	7.72E-10	9.56E-11	1.36E-09
Mn-54	1.52E-05	8.82E-06	1.32E-05	2.94E-05	3.25E-06	6.98E-05
Tc-99	1.72E-09	1.23E-10	8.08E-10	3.27E-09	3.84E-10	6.30E-09

Source: 4

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	1.04E-09	2.81E-12	8.54E-11	1.42E-09	6.00E-10	3.15E-09
Mn-54	3.46E-05	9.87E-06	2.42E-05	4.92E-05	1.82E-05	1.36E-04
Tc-99	4.19E-09	1.23E-10	1.10E-09	5.80E-09	2.34E-09	1.36E-08

Source: 5

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	2.29E-10	2.81E-12	6.35E-11	5.62E-10	3.17E-11	8.89E-10
Mn-54	8.65E-06	6.11E-06	7.65E-06	2.17E-05	1.09E-06	4.52E-05
Tc-99	9.66E-10	1.10E-10	4.91E-10	2.41E-09	1.28E-10	4.10E-09

Source: 6

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	1.30E-10	2.63E-12	4.23E-11	4.22E-10	1.34E-11	6.11E-10
Mn-54	4.97E-06	3.80E-06	4.43E-06	1.65E-05	4.61E-07	3.01E-05
Tc-99	5.53E-10	8.25E-11	2.87E-10	1.81E-09	5.39E-11	2.79E-09

Figure 1 Dose Results from RESRAD-BUILD Code for Different Receptors

Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Risks

[Risk]

Source: 1

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	9.22E-16	1.64E-18	4.97E-17	1.14E-15	6.57E-16	2.77E-15
Mn-54	3.62E-11	7.44E-12	1.88E-11	4.72E-11	2.36E-11	1.33E-10
Tc-99	4.22E-15	7.95E-17	7.12E-16	5.27E-15	2.99E-15	1.33E-14

Source: 2

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	3.39E-16	1.64E-18	4.97E-17	5.54E-16	1.15E-16	1.06E-15
Mn-54	1.59E-11	7.35E-12	1.33E-11	2.68E-11	4.96E-12	6.82E-11
Tc-99	1.56E-15	7.95E-17	6.46E-16	2.59E-15	5.11E-16	5.39E-15

Source: 3

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	2.39E-16	1.64E-18	4.76E-17	4.49E-16	5.57E-17	7.94E-16
Mn-54	1.15E-11	6.65E-12	9.94E-12	2.21E-11	2.45E-12	5.27E-11
Tc-99	1.11E-15	7.95E-17	5.24E-16	2.12E-15	2.49E-16	4.09E-15

Source: 4

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	6.08E-16	1.64E-18	4.97E-17	8.26E-16	3.49E-16	1.84E-15
Mn-54	2.61E-11	7.44E-12	1.82E-11	3.71E-11	1.37E-11	1.03E-10
Tc-99	2.72E-15	7.95E-17	7.12E-16	3.76E-15	1.52E-15	8.79E-15

Source: 5

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	1.33E-16	1.64E-18	3.69E-17	3.27E-16	1.85E-17	5.18E-16
Mn-54	6.52E-12	4.61E-12	5.77E-12	1.64E-11	8.23E-13	3.41E-11
Tc-99	6.27E-16	7.16E-17	3.19E-16	1.56E-15	8.30E-17	2.66E-15

Source: 6

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	7.59E-17	1.53E-18	2.46E-17	2.46E-16	7.77E-18	3.55E-16
Mn-54	3.75E-12	2.86E-12	3.34E-12	1.24E-11	3.47E-13	2.27E-11
Tc-99	3.58E-16	5.35E-17	1.86E-16	1.18E-15	3.50E-17	1.81E-15

Figure 2 Risk Results from RESRAD-BUILD Code for Different Receptors

TEST CASE 012-5

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-012-5
Requirement Tested	12
Test Summary	Test the modeling of direct external dose and risk from different types of sources.
Test Objective	Test and verify the direct external pathway dose/risk from rectangular area source contamination.
Procedure	Open the "rectangle-area-source-verification.bld" RESRAD-BUILD input file that was used in the code verification effort (the verification results are in EXCEL file "FGR12 Rectangular Area Source Dose Calculations for few radionuclides.xlsx"). Run the RESRAD-BUILD code, open the "RESRADB.RPT" dose report and compare the results in this report with those previously obtained. The verification details are in the "Verification of Area Source Dose Calculations.docx" file.
Required Data	Input file "rectangle-area-source-verification.bld" and "Verification of Area Source Dose Calculations.docx."
Expected Results	The outputs in the RESRAD-BUILD dose report should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 1.

Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Doses

[mrem]

Source: 1

Nuclide	Receptor 1	Total
C-14	2.88E-10	2.88E-10

Source: 2

Nuclide	Receptor 1	Total
C-14	2.46E-10	2.46E-10

Source: 3

Nuclide	Receptor 1	Total
C-14	1.89E-10	1.89E-10

Source: 4

Nuclide	Receptor 1	Total
C-14	1.29E-10	1.29E-10

Source: 5

Nuclide	Receptor 1	Total
C-14	4.09E-10	4.09E-10

Source: 6

Nuclide	Receptor 1	Total
C-14	5.79E-10	5.79E-10

Figure 1 Dose Results from RESRAD-BUILD Code for Different Receptors

TEST CASE 012-6

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-012-6
Requirement Tested	12
Test Summary	Test the modeling of direct external dose and risk from different types of sources.
Test Objective	Test and verify the direct external pathway dose/risk from volume sources.
Procedure	Open the "volume-source-verification.bld" RESRAD-BUILD input file that was used in the code verification effort. Run the RESRAD-BUILD code, open the "RESRADB.RPT" dose report and compare the results in this report with those previously obtained. The verification details are in the "Verification of Volume Source Dose Calculations.docx" file.
Required Data	Input file "volume-source-verification.bld" and "Verification of Volume Source Dose Calculations.docx."
Expected Results	The outputs in the RESRAD-BUILD dose report should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 1. The outputs in the RESRAD-BUILD risk report should match those previously obtained by either comparing with the verified input file or with the results shown in Figure 2. The input file has two sources (one with Co-60 volumetric contamination and other with Mn-54 volumetric contamination) and 9 receptors at different locations with and without concrete shielding.

RESRAD-BUILD Dose Tables

Source Contributions to Receptor Doses

[mrem]

	Source 1	Source 2	Total
Receptor 1	1.17E+10	2.84E+09	1.46E+10
Receptor 2	9.88E+09	2.29E+09	1.22E+10
Receptor 3	4.72E+09	9.96E+08	5.72E+09
Receptor 4	8.49E+09	2.09E+09	1.06E+10
Receptor 5	7.66E+09	1.83E+09	9.49E+09
Receptor 6	4.41E+09	9.47E+08	5.35E+09
Receptor 7	2.25E+09	5.65E+08	2.82E+09
Receptor 8	2.14E+09	5.25E+08	2.66E+09
Receptor 9	1.53E+09	3.50E+08	1.88E+09
Total	5.28E+10	1.24E+10	6.52E+10

Figure 1 Dose Results from RESRAD-BUILD Code for Different Receptors

RESRAD-BUILD Risk Tables

Source Contributions to Receptor Risks

[Risk]

		Source 1	Source 2	Total
Receptor	1	8.97E+03	2.14E+03	1.11E+04
Receptor	2	7.55E+03	1.73E+03	9.28E+03
Receptor	3	3.61E+03	7.51E+02	4.36E+03
Receptor	4	6.49E+03	1.58E+03	8.07E+03
Receptor	5	5.85E+03	1.38E+03	7.23E+03
Receptor	6	3.37E+03	7.15E+02	4.08E+03
Receptor	7	1.72E+03	4.26E+02	2.15E+03
Receptor	8	1.63E+03	3.96E+02	2.03E+03
Receptor	9	1.17E+03	2.64E+02	1.44E+03
Total		4.04E+04	9.38E+03	4.98E+04

Figure 2 Risk Results from RESRAD-BUILD Code for Different Receptors

TEST CASE 017

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-017
Requirements Tested	17
Test Summary	Test selecting, viewing, printing, and saving text reports.
Test Objective	To test the result reporting functions as designed.
Procedure	1. Launch the code, choose the Advanced – Traditional Appearance menu option and set up the analysis with the following input information: a. Source 1, point source in Room 1; Receptor 1 in Room 1. b. Source 2, line source in Room 2; Receptor 2 in Room 2. c. Source 3, area source in Room 3; Receptor 3 in Room 3. d. Source 4, volume source in Room 1; Receptor 4 in Room 1. 2. Save the inputs to the file "Input 017.bld" and run the code. 3. Check whether the summary report pops up upon the end of calculation. If so, close the summary report, and open it by clicking menu View -> Last Report. 4. Test the function of each menu available in the Report Viewer. 5. Check the content of the report, including input echo and calculated results, referring to User's Guide Section 6.2. 6. Open the risk report by clicking menu View -> Last Risk Report, and check the content, referring to User's Guide Section 6.2. 7. Open each of the intermediate reports by clicking menu View -> Last Intermediate Output Files and check the content. 8. Switch to New Appearance by clicking menu Advanced -> New Appearance, change the location of Source 4 to Room 4, and save the input changes to the file "Input 017-1.bld." 9. Run the code and repeat Steps 5–7.
Required Data	The following files can be used as optional input and output for comparison: "Input 017.bld," "Test017.rpt," "Test017_r.rpt," and the files with ".out" as the extension in the V&V subfolder "Requirement 17\Tradition"; "Input 017-1.bld," "Test017-1.rpt," "Test017-1_r.rpt," and the files with ".out" as the extension in the V&V subfolder "Requirement 17\New."
Expected Results	The Viewer for viewing text reports should function correctly, including the menu functions. The report should echo the input information correctly and display the results correctly.

TEST CASE 018

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-018
Requirements Tested	18
Test Summary	Test selecting, viewing, printing, and saving graphic results.
Test Objective	To test the result graphics functions as designed.
Procedure	1. Launch the code and set up the model with the following information: a. Source 1, point source in Room 1. b. Source 2, line source in Room 2. c. Source 3, area source in Room 3. d. Source 4, volume source in Room 1. 2. Save the project as "Site018.bld" and run the code. 3. Open the deterministic graphics and check the plots of the output dose and risk results for the following options by referring to Section 6.3 of the User's Guide. Dose: a. Line Chart with different combinations of primary/secondary axis and data groupings. b. Bar Chart with different combinations of primary/secondary axis and data groupings. c. Stacked Chart with different combinations of primary/secondary axis and data groupings. Risk: a. Line Chart with different combinations of primary/secondary axis and data groupings. b. Bar Chart with different combinations of primary/secondary axis and data groupings. c. Stacked Chart with different combinations of primary/secondary axis and data groupings.
Required Data	The following files can be used as optional input and output for comparison: "Input 018.bld," "Test018.ddb," "Test018_r.ddb, bld_g.fil," and "bld_g_r.fil" in the V&V subfolder "Requirement 18."
Expected Results	The deterministic graphics viewer should retrieve and plot dose/risk results correctly and clearly.

TEST CASE 019

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-019
Requirements Tested	19
Test Summary	Test the functions of the DCF Editor for viewing, creating, editing, copying, and renaming a dose/risk coefficient library.
Test Objective	To test the functionality of the DCF Editor.

Procedure

1. Launch DCF Editor by clicking DCF icon in the Toolbar from the main interface. The default DCF folder is in "c:\RESRAD_Family\DCF\3.3."
2. The DCF Editor version number and creation date should display correctly.
3. The default of the main window should be the following:
    a. Radionuclides library: the same as the one identified in the RESRAD-BUILD main interface.
    b. Library option: Create a new DCF library.
    c. Base External DCF: the same as the one identified in the RESRAD-BUILD main interface.
    d. Base internal DCF: the same as the one identified in the RESRAD-BUILD main interface.
    e. Base risk library: the same as the one identified in the RESRAD-BUILD main interface.
4. Test the functions of DCF Editor following User's Guide Sections 5.1 and 5.2.
    a. View a Default Library (Read Only).
    b. Create a New DCF Library.
    c. Edit an Existing DCF Library.
    d. Rename an Existing DCF Library.
    e. Import and Export a DCF Library.
5. Click Help -> General Help on the menu bar and check whether the Help window pops up and whether the right panel presents the correct help contents according to the clicked help topic in the list in the left panel.
6. Choose the View a Default Library (Read Only) library option and then click the Dose Factors Help button at the upper-right corner of the data window. Check whether the Help window pops up and works properly.
7. Click the <- Back button, and the code should close the data window and return to the main interface of the DCF Editor.
8. Click the F1 key on the keyboard when in the main DCF Editor interface and check whether the Help window pops up.

Required Data	None.
Expected Results	The functions described in User's Guide Sections 5.1 and 5.2 should work properly.

TEST CASE 020

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-020
Requirements Tested	20
Test Summary	Test the functions of performing sensitivity analysis and presenting the results.
Test Objective	To test the functionality of the sensitivity analysis tool.

Procedure

1. Launch the code and select one of the following 4 groups of parameters for sensitivity analysis sequentially in each run. To activate sensitivity analysis, put the cursor on each input parameter and select the menu option Modify|Sensitivity Analysis (or press F9 key).
    a. Exposure Duration, Indoor Time Fraction, Breath Rate, Room Exchange Rate, Area of Room, Height of Room, Volume of Room, Efficiency of Vacuuming, Day Between Vacuuming, Building Exchange Rate;
    b. Deposition velocity, Resuspension Rate, Time Fraction, Breathing Rate, Ingestion Rate, Receptor Location, Source Location, Source Area, Radon Release Fraction, Air Fraction;
    c. Removable Fraction, Source Lifetime, Direct Ingestion Rate, Volumetric Water Content, Total Porosity of Contaminated Material, Humidity, Water Fraction Available for Vaporization, Wet + Dry Zone Thickness, Dry Zone Thickness, Density of Material; and
    d. Source Length Along Y Axis, Region Density, Radon Porosity, Radon Diffusion, Region Thickness, Radon Emanation Fraction, Erosion Rate, Shielding Thickness, Shielding Density.
2. Follow User's Guide Section 7.1 to set up sensitivity analysis for these parameters.
3. Check the bottom-left corner of the main interface. The number of parameters for sensitivity analysis, the Fortran variable name of each parameter, and its multiplication/division factor should be listed.
4. Save the input file of each run as "test020-1.bld," "test020-2.bld," "test020-3.bld," and "test020-4.bld," respectively.
5. Use a text editor such as Notepad to open the input file and check the variable names included in "SENS_PARAM," their upper values in "HVAL_PARAM," and their lower values in "LVAL_PARAM." They should match the input values.
6. Run the code and check the graphics for sensitivity analysis in the deterministic graphics viewer.
7. Choose the five parameters in next group for sensitivity analysis and repeat Steps 2 to 6.

Required Data	None.
Expected Results	Sensitivity analysis can be properly set up for eligible input parameters through the interface; correct parameter values are specified for use in sensitivity analysis in the input file; and sensitivity analysis results are presented properly in the standard graphics viewer.

TEST CASE 021

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-021
Requirements Tested	21
Test Summary	Test the functions of performing probabilistic analysis and presenting the results.
Test Objective	To test the functionality of the probabilistic/uncertainty module.
Procedure	1. Follow User's Guide Section 7.2 to set up probabilistic/uncertainty analysis for one parameter, e.g., breathing rate. 2. Save the inputs to "Test021.bld" and run the code. Using a text editor such as Notepad, open the saved input file and check the variables, "NUM_SAMPS" and "NUMVAR"; they should match with the input selections. 3. Open the file "EXAMPLE1.UN6" and check to see whether the information in that file matches the input values. 4. Follow the User's Guide Section 7.2 to open the uncertainty graphics. Check the two tabs – Input Specifications and Parameter Statistics; the information displayed should match the input selection/values. Click the Results tab and its sub-tabs. The plots displayed should match the values in output file "Test021.BUO." 5. Follow the User's Guide Section 7.2 to make some changes to each input option for probabilistic analysis and run the code again. 6. Repeat Steps 2–4. 7. Set up a probabilistic (uncertainty) analysis for two parameters following the User's Guide. 8. Repeat Steps 2–4.
Required Data	None.
Expected Results	Probabilistic analysis can be properly set up for eligible input parameters through the interface; correct parameter distributions and values are specified for use in probabilistic analysis in the input file; and probabilistic analysis results are presented properly in the probabilistic graphics viewer.

TEST CASE 022-1

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-022-1
Requirements Tested	22
Test Summary	Test the interface display, menu bar options, and file menu options.
Test Objective	Confirm that the RESRAD-BUILD interface display, menu bar options, and file menu options function correctly.

Procedure

1. Launch RESRAD-BUILD.
    - The interface shown in the figure titled "the Main Interface of RESRAD-BUILD" in Chapter 3 of the RESRAD-BUILD User's Guide displays (values shown in input fields may be different).
2. In the Case section of the window, edit the Title to read "BUILD Test 022-001."
3. View the menu for each item on the menu bar (File, View, Modify, Advanced, Help).
    - For each menu, check that the options match those shown in the "Main Menu and Submenus" figure in Chapter 3 of the User's Guide.
4. Click File/Save As. Alternatively, click the Save File icon (see the "Toolbar" figure in Chapter 3 of the User's Guide) or press Ctrl+A.
    - The Save As window displays.
5. Navigate to the "UserFiles" subfolder of the installation directory, enter the name "Test-022-001," then click Save.
6. Click File/New. Alternatively, in the Toolbar, click the Reset to Default icon (see the "Toolbar" figure in Chapter 3 of the User's Guide).
    - In the Case section of the main window, the Title now shows Default Case for RESRAD-BUILD.
7. Click File/Open. Alternatively, in the Toolbar, click the Open a File icon (see the "Toolbar" figure in Chapter 3 of the User's Guide) or press Ctrl+O.
    - The Open window for selecting a file displays.
8. Navigate to the "UserFiles" subfolder of the installation directory, select the file named "Test-022-001," then open the file.
    - In the Case section of the main window, the Title now displays BUILD Test 022-001.
9. In the Case section of the window, revise the Title to "BUILD Test 022-001 step 9."
10. Click File/Save. Alternatively press Ctrl+S.
11. Click File/New.
    - In the Case section of the main window, the Title now shows Default Case for RESRAD-BUILD.

12. Click File/Open. Navigate to the "UserFiles" subfolder of the installation directory, select the file created in Step 5 that was revised in Step 10, and open the file.
    - In the Case section of the main window, the Title now displays "BUILD Test 022-001 step 9."
13. Click File/Run. Alternatively, in the Toolbar, click the Perform Calculations icon (see the "Toolbar" figure in Chapter 3 of the User's Guide) or press Ctrl+R.
    - The Doing Calculations window displays briefly. After the Doing Calculations window disappears, the report viewer opens and displays results. The second line of the report displays "BUILD Test 022-001 step 9."
14. Click the X in the upper-right corner of the report viewer.
    - The report viewer closes.
15. Click File/DCF Editor.
    - The DCF Editor opens.
16. Exit the DCF Editor.
17. In RESRAD-BUILD, click File/Exit. Alternatively, click the X in the upper-right corner.
    - RESRAD-BUILD closes.

Required Data NA

Expected Results The test procedure is successfully completed with all actions being completed as described.

TEST CASE 022-2

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-022-2
Requirements Tested	22
Test Summary	Test the menu bar options within the View, Modify, Advanced, and Help menus; hotkeys; and the Toolbar icon for launching the DCF Editor.
Test Objective	Confirm that the View, Modify, Advanced, and Help menus in the menu bar (including relevant hotkeys) function as described in the RESRAD-BUILD User's Guide and that the Toolbar icon for the DCF Editor launches the DCF Editor.

Procedure

1. Launch RESRAD-BUILD.
2. Click on the input field for a nonzero parameter that is eligible for uncertainty analysis (e.g., "Ingestion Rate"; see the "Inputs Eligible for Probabilistic Analysis" table in Chapter 7 of the RESRAD-BUILD User's Guide for the complete list) and press F8.
    - The Uncertainty Analysis Input Summary window opens.
3. In the Uncertainty Analysis Input Summary window, select a value for Distribution and enter the required additional inputs. Optionally, change the sample specifications to reduce execution time.
4. Perform calculations. After calculations have finished, close the report viewer.
5. Test each item in the View, Modify, Advanced, and Help menus by following the descriptions in RESRAD-BUILD User's Guide Chapter 3. Also test the indicated hotkey (where applicable) for the items in the View, Modify, Advanced, and Help menus. When testing Sensitivity Analysis, please note that some inputs are not eligible for sensitivity analysis and clicking Modify>Sensitivity Analysis or pressing F9 will have no effect (to view all eligible inputs, refer to the "Inputs Eligible for Sensitivity Analysis" table in Chapter 7 of the User's Guide). Also note that to test toggling between Traditional Appearance and New Appearance, it is necessary to open a form with differences both before and after toggling. For example, see the two "Evaluation Times" form figures in Chapter 4 of the User's Guide for the expected layout of the Evaluation Times form for the Traditional and New Appearance.
    - Each menu item performs the function described in the User's Guide.
6. Click the DCF Editor icon in the Toolbar (see the "Toolbar" figure in Chapter 3 of the User's Guide).
    - The DCF Editor opens.
7. Close the DCF Editor by clicking the Exit Program button or the X in the upper-right corner of the DCF Editor.
    - The DCF Editor closes.
8. Click File -> Exit. Alternatively, click the X in the upper-right corner of RESRAD-BUILD.
9. RESRAD-BUILD closes.

Required Data	NA
Expected Results	All actions occur as described in the procedure and referenced sections of the RESRAD-BUILD User's Guide.

TEST CASE 022-3

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-022-3
Requirements Tested	22, 23, 24
Test Summary	Test the button commands for navigation and the form-level tools as well as the control-level tools and properties for user entry of data.
Test Objective	Confirm that the button commands for navigation, form-level tools for user entry of data, and control-level tools and properties for user entry of data function as described in the RESRAD-BUILD User's Guide.

Procedure

1. Launch RESRAD-BUILD.
2. For each of the following forms, test various elements of the form based on the description in Chapter 4 of the RESRAD-BUILD User's Guide. Spot-check to ensure that buttons for launching another form work correctly — the tab key can be used to navigate the fields, Save/OK and Cancel buttons work as expected, field names and units are provided as appropriate, the F1 key launches context-specific help, an alert is given regarding invalid input, and sensitivity analysis and/or uncertainty analysis can be activated for applicable input fields (see tables in Chapter 7 of the User's Guide). Conduct testing using both Traditional Appearance and New Appearance.
    a. The Case form, including the Evaluation Times form.
    b. The Building Parameters form, including the Room Details form and the Room Air Flow and Particulates form.
    c. The Radiological Data form.
    d. The Receptor Parameters form.
    e. The Shielding Parameters form, including the Source Receptor Table and the Copy Shielding screen.
    f. The Source Parameters form, including the Details for Source form and Layer Region Parameters form.

Required Data	NA
Expected Results	The forms listed in Step 2 of the procedure perform the functionality described as appropriate based on the RESRAD-BUILD User's Guide.

TEST CASE 025

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-025
Requirements Tested	25
Test Summary	Test the 3-D display of the source and receptor locations.
Test Objective	To test the functionality of the 3-D display for the source and receptor locations.
Procedure	1. In the main interface of the code, choose the View−3D Display menu option. The 3-D display window will pop up. Check to see the receptor and source objects are displayed in the 3-D display window. 2. Move the locations of the source and receptor in the 3D display window following instructions in User's Guide Section 4.7. Check the location changes in the Receptor Parameters and Source Parameters input forms in the main interface. The changes should reflect the moves in the 3D display. 3. Change the x-, y-, or/and z-coordinate value in the Receptor Parameters and Source Parameters input forms, respectively, in the main interface. The locations of the source and receptor in the 3-D display window should change accordingly. 4. Save the inputs to "TEST025.bld." Use a text editor such as Notepad to open the input file and check the location parameter values in the file. They should match the input values specified in the interface. 5. Add additional sources and receptors to make a total of 3 for each in the interface and see corresponding objects appear in the 3-D display window. 6. Repeat Steps 2 and 3.
Required Data	None.
Expected Results	The 3-D display window should reflect the location of sources and receptors correctly. The correspondence between the 3-D display window and the receptor and source parameters input form should be maintained.

TEST CASE 026

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-026
Requirements Tested	26
Test Summary	Test the help functions, including accessing general help, context-specific help, User's Manual, and User's Guide.
Test Objective	Verify that the RESRAD-BUILD provides information to help users develop scenarios and understand results.

Procedure	1. Launch RESRAD-BUILD.
	2. Click Help->User's Manual.
	  o A PDF of the User's Manual for RESRAD-BUILD opens.
	3. Return to RESRAD-BUILD and click Help->User's Guide.
	  o A PDF of the User's Guide opens.
	4. Return to RESRAD-BUILD and press F2 or click Help->General Help.
	  o RESRAD-BUILD Help opens.
	5. Return to RESRAD-BUILD, click on an input field (e.g., shielding density), and press F1 or click Help->Context Help.
	  o RESRAD-BUILD Help relevant to the selected input field opens.
	6. Repeat Step 5 for a different input field.
	7. Return to RESRAD-BUILD and click Help->About.
	  o The RESRAD-BUILD About screen opens.

Required Data	NA
Expected Results	The actions will occur as described in the procedure.

TEST CASE 027-1

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-027-1
Requirements Tested	27
Test Summary	Verify correct dose coefficients are used for dose calculations, including direct external, air submersion, inhalation, and ingestion coefficients.
Test Objective	Tests DCFs based on ICRP26/ICRP30 methodology for ICRP38 transformation database.
Procedure	1. Spot check based on PM scope request. 2. Start RESRAD-BUILD code and choose ICRP38 transformation database. 3. Select FGR11 as the Internal Dose Library in the code. 4. Set cutoff half-life = 0 days. 5. Select suggested few radionuclides in the source. 6. Run the code. 7. Verify by comparing data in the "Dose and Slope Factors.RPT" file and "DCF Individual.LIB" file. 8. Select cutoff half-life = 30 days. 9. Run the code. 10. Verify by comparing data in the "Dose and Slope Factors.RPT" file, and RESRAD-BUILD Manual Table C-7 for external dose coefficients and Table A-3 DCFs for air submersion, inhalation, and ingestion dose coefficients. 11. Further verification details are in the "RESRAD-BUILD-DCFs-Data-Verfication.docx" file.
Required Data	Test-027-1.bld.
Expected Results	The DCFs for selected radionuclides and their associated progeny radionuclides in the "Dose and Slope Factors.RPT" file matches with the "DCF Individual.LIB" file when the cutoff half-life was 0 days. The DCFs for selected radionuclides and their associated progeny radionuclides in the "Dose and Slope Factors.RPT" file matches the values listed in RESRAD-BUILD Manual Table C-7 for external dose coefficients and Table A-3 DCFs for air submersion, inhalation, and ingestion dose coefficients. Table 1 below shows the DCFs and SFs from the "Dose and Slope Factors.RPT" file and "DCF Individual.LIB" file for the cutoff half-life = 0 days when Co-60, Cs-137, Sr-90, and U-238 were selected radionuclides. Table 1 Results from "DCF Individual.LIB" file and "Dose and Slope Factors.RPT" file.

Data from "DCF Individual.LIB" file

DCF Individual - Notepad

File Edit Format View Help

FGR 11 FGR 12 FGR 13 Morbidity
FGR 11 FGR 12 FGR 13 Morbidity

Nuclide	ExtVolDC	ExtImmDC	InhalaDC	IngestDC	ExtVolSF	ExtImmSF	InhalaSF	IngestSF
Units	(mrem/y) /(pCi/g)	(mrem/y) /(pCi/m3)	mrem /pCi	mrem /pCi	(1/yr) /(pCi/g)	(1/yr) /(pCi/m3)	1 /pCi	1 /pCi
U-238	1.031E-04	3.980E-07	1.180E-01	2.550E-04	4.990E-11	1.938E-13	2.360E-08	8.660E-11
Th-234	2.410E-02	3.945E-05	3.500E-05	1.370E-05	1.630E-08	2.604E-11	3.070E-11	3.400E-11
Pa-234m	8.967E-02	8.391E-05	-2.00E+00	-2.00E+00	6.870E-08	6.866E-11	-2.00E+00	-2.00E+00
Pa-234	1.155E+01	1.090E-02	8.140E-07	2.160E-06	8.710E-06	8.197E-09	1.460E-12	3.700E-12
U-234	4.017E-04	8.905E-07	1.320E-01	2.830E-04	2.520E-10	5.103E-13	2.780E-08	9.550E-11
Th-230	1.209E-03	2.031E-06	3.260E-01	5.480E-04	8.190E-10	1.308E-12	3.400E-08	1.190E-10
Ra-226	3.176E-02	3.676E-05	8.580E-03	1.320E-03	2.290E-08	2.604E-11	2.820E-08	5.140E-10
Rn-222	2.354E-03	2.229E-06	0.000E+00	0.000E+00	1.740E-09	1.658E-12	0.000E+00	0.000E+00
Po-218	5.642E-05	5.228E-08	0.000E+00	0.000E+00	4.260E-11	3.947E-14	0.000E+00	0.000E+00
At-218	5.847E-03	1.389E-05	0.000E+00	0.000E+00	3.570E-09	8.337E-12	0.000E+00	0.000E+00
Pb-214	1.341E+00	1.377E-03	7.810E-06	6.250E-07	9.820E-07	1.006E-09	4.000E-11	4.850E-13
Bi-214	9.808E+00	8.928E-03	6.590E-06	2.830E-07	7.480E-06	6.831E-09	3.100E-11	2.650E-13
Po-214	5.138E-04	4.762E-07	0.000E+00	0.000E+00	3.860E-10	3.585E-13	0.000E+00	0.000E+00
Tl-210	-1.00E+00	-1.00E+00	0.000E+00	0.000E+00	0.000E+00	-1.00E+00	0.000E+00	0.000E+00
Pb-210	2.447E-03	6.582E-06	1.360E-02	5.370E-03	1.410E-09	3.760E-12	1.580E-08	1.180E-09
Bi-210	3.606E-03	3.840E-06	1.960E-04	6.400E-06	2.760E-09	5.278E-12	4.550E-10	1.300E-11
Po-210	5.231E-05	4.855E-08	9.400E-03	1.900E-03	3.950E-11	3.655E-14	1.450E-08	2.250E-09
Cs-137	7.510E-04	9.033E-07	3.190E-05	5.000E-05	5.320E-10	1.600E-12	1.120E-10	3.740E-11
Ba-137m	3.606E+00	3.361E-03	-2.00E+00	-2.00E+00	2.690E-06	2.522E-09	-2.00E+00	-2.00E+00
Sr-90	7.043E-04	8.788E-07	1.300E-03	1.420E-04	4.820E-10	1.635E-12	4.250E-10	6.880E-11
Y-90	2.391E-02	2.217E-05	8.440E-06	1.080E-05	1.910E-08	2.289E-11	8.400E-12	2.650E-11
Co-60	1.622E+01	1.471E-02	2.190E-04	2.690E-05	1.240E-05	1.124E-08	1.010E-10	2.230E-11

Data from "Dose and Slope Factors.RPT" file.

Individual Radionuclide Dose and Slope Factors

External Dose Factors from FGR 12
Internal Dose Factors from FGR 11

Slope Factors from FGR 13 Morbidity

Isotope	External Volume (mrem/y) /(pCi/g)	External Air (mrem/y) /(pCi/m³)	Inhalation mrem/pCi	Ingestion mrem/pCi	External Volume risk/y /(pCi/g)	External Air risk/y /(pCi/m³)	Inhalation risk /pCi	Ingestion risk /pCi
U-238	1.03E-04	3.98E-07	1.18E-01	2.55E-04	4.99E-11	1.94E-13	2.36E-08	8.66E-11
Th-234	2.41E-02	3.94E-05	3.50E-05	1.37E-05	1.63E-08	2.60E-11	3.07E-11	3.40E-11
Pa-234m	8.97E-02	8.39E-05	********	********	6.87E-08	6.87E-11	********	********
Pa-234	1.16E+01	1.09E-02	8.14E-07	2.16E-06	8.71E-06	8.20E-09	1.46E-12	3.70E-12
U-234	4.02E-04	8.91E-07	1.32E-01	2.83E-04	2.52E-10	5.10E-13	2.78E-08	9.55E-11
Th-230	1.21E-03	2.03E-06	3.26E-01	5.48E-04	8.19E-10	1.31E-12	3.40E-08	1.19E-10
Ra-226	3.18E-02	3.68E-05	8.58E-03	1.32E-03	2.29E-08	2.60E-11	2.82E-08	5.14E-10
Rn-222	2.35E-03	2.23E-06	0.00E+00	0.00E+00	1.74E-09	1.66E-12	0.00E+00	0.00E+00
Po-218	5.64E-05	5.23E-08	0.00E+00	0.00E+00	4.26E-11	3.95E-14	0.00E+00	0.00E+00
At-218	5.85E-03	1.39E-05	0.00E+00	0.00E+00	3.57E-09	8.34E-12	0.00E+00	0.00E+00
Pb-214	1.34E+00	1.38E-03	7.81E-06	6.25E-07	9.82E-07	1.01E-09	4.00E-11	4.85E-13
Bi-214	9.81E+00	8.93E-03	6.59E-06	2.83E-07	7.48E-06	6.83E-09	3.10E-11	2.65E-13
Po-214	5.14E-04	4.76E-07	0.00E+00	0.00E+00	3.86E-10	3.59E-13	0.00E+00	0.00E+00
Tl-210	********	********	0.00E+00	0.00E+00	0.00E+00	********	0.00E+00	0.00E+00
Pb-210	2.45E-03	6.58E-06	1.36E-02	5.37E-03	1.41E-09	3.76E-12	1.58E-08	1.18E-09
Bi-210	3.61E-03	3.84E-06	1.96E-04	6.40E-06	2.76E-09	5.28E-12	4.55E-10	1.30E-11
Po-210	5.23E-05	4.85E-08	9.40E-03	1.90E-03	3.95E-11	3.66E-14	1.45E-08	2.25E-09
Cs-137	7.51E-04	9.03E-07	3.19E-05	5.00E-05	5.32E-10	1.60E-12	1.12E-10	3.74E-11
Ba-137m	3.61E+00	3.36E-03	********	********	2.69E-06	2.52E-09	********	********
Sr-90	7.04E-04	8.79E-07	1.30E-03	1.42E-04	4.82E-10	1.63E-12	4.25E-10	6.88E-11
Y-90	2.39E-02	2.22E-05	8.44E-06	1.08E-05	1.91E-08	2.29E-11	8.40E-12	2.65E-11
Co-60	1.62E+01	1.47E-02	2.19E-04	2.69E-05	1.24E-05	1.12E-08	1.01E-10	2.23E-11

1. The external dose factors for volume sources are used to compute the direct external dose from volume sources, from area sources and from deposited radionuclides.

2. The ratio between the external dose factor for volume sources and the external slope factors for volume sources are used to compute the exteral risk from all sources types and from deposited material.

3. The other dose and slope factors are used to compute the associated progeny integrated factors in the next table.

3.a. ******** indicates that the specified database file does not contain a value for this factor. A value of 0.0 is used to compute the integrated factors.

TEST CASE 027-2

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-027-2
Requirements Tested	27
Test Summary	Verify correct dose coefficients are used for dose calculations, including direct external, air submersion, inhalation, and ingestion coefficients.
Test Objective	Tests DCFs based on ICRP60 methodology for ICRP38 transformation database.
Procedure	1. Spot check based on PM scope request. 2. Start RESRAD-BUILD code and choose ICRP38 transformation database. 3. Select ICRP72 Adult as the Internal Dose Library in the code. 4. Set cutoff half-life = 0 days. 5. Select suggested few radionuclides in the source. 6. Run the code. 7. Verify by comparing data in the "Dose and Slope Factors.RPT" file and "DCF Individual.LIB" file. 8. Select cutoff half-life = 30 days. 9. Run the code. 10. Verify by comparing data in the "Dose and Slope Factors.RPT" file and RESRAD-BUILD Manual Table C-8 for external dose coefficients and Table A-4 DCFs for air submersion, inhalation, and ingestion dose coefficients. 11. Further verification details are in the "RESRAD-BUILD-DCFs-Data-Verfication.docx" file.
Required Data	Test-027-2.bld.
Expected Results	The DCFs for selected radionuclides and their associated progeny radionuclides in the "Dose and Slope Factors.RPT" file matches with the "DCF Individual.LIB" file when the cutoff half-life was 0 days. The DCFs for selected radionuclides and their associated progeny radionuclides in the "Dose and Slope Factors.RPT" file matches with the values listed in RESRAD-BUILD Manual Table C-8 for external dose coefficients and Table A-4 DCFs for air submersion, inhalation, and ingestion dose coefficients. Table 1 below shows the DCFs and SFs from the "Dose and Slope Factors.RPT" file and "DCF Individual.LIB" file for the cutoff half-life = 0 days when Co-58, Pu-239, Ra-226, and Tc-99 were selected radionuclides.

Table 1 Results from "DCF Individual.LIB" file and "Dose and Slope Factors.RPT" file

DCF Individual - Notepad

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ICRP 72 (Adult)	ICRP 60	FGR 13 Morbidity						
ICRP 72 (Adult)	ICRP 60	FGR 13 Morbidity						
Nuclide	ExtVolDC	ExtImmDC	InhalaDC	IngestDC	ExtVolSF	ExtImmSF	InhalaSF	IngestSF
Units	(mrem/y) /(pCi/g)	(mrem/y) /(pCi/m3)	mrem /pCi	mrem /pCi	(1/yr) /(pCi/g)	(1/yr) /(pCi/m3)	1 /pCi	1 /pCi
Pu-239	2.635E-04	4.063E-07	4.440E-01	9.250E-04	2.000E-10	2.989E-13	5.510E-08	1.740E-10
U-235	6.597E-01	7.543E-04	3.145E-02	1.739E-04	5.180E-07	5.943E-10	2.500E-08	9.440E-11
Th-231	3.214E-02	5.348E-05	1.221E-06	1.258E-06	2.450E-08	3.923E-11	1.520E-12	3.240E-12
Pa-231	1.762E-01	1.833E-04	5.180E-01	2.627E-03	1.390E-07	1.448E-10	7.620E-08	2.260E-10
Ac-227	4.485E-04	5.978E-07	2.035E+00	4.070E-03	3.480E-10	4.624E-13	1.490E-07	2.450E-10
Th-227	4.803E-01	5.173E-04	3.700E-02	3.256E-05	3.780E-07	4.087E-10	3.510E-08	6.920E-11
Ra-226	2.915E-02	3.316E-05	3.515E-02	1.036E-03	2.290E-08	2.604E-11	2.820E-08	5.140E-10
Fr-223	1.813E-01	2.569E-04	3.293E-06	8.880E-06	1.400E-07	1.833E-10	4.030E-11	1.000E-11
Ra-223	5.532E-01	6.387E-04	3.219E-02	3.700E-04	4.340E-07	5.021E-10	2.920E-08	3.390E-10
Rn-222	2.186E-03	2.067E-06	0.000E+00	0.000E+00	1.740E-09	1.658E-12	0.000E+00	0.000E+00
Rn-219	2.859E-01	2.872E-04	0.000E+00	0.000E+00	2.250E-07	2.289E-10	0.000E+00	0.000E+00
Po-218	5.326E-05	4.916E-08	0.000E+00	0.000E+00	4.260E-11	3.947E-14	0.000E+00	0.000E+00
At-218	4.878E-03	1.134E-05	0.000E+00	0.000E+00	3.570E-09	8.337E-12	0.000E+00	0.000E+00
Po-215	9.456E-04	9.096E-07	0.000E+00	0.000E+00	7.480E-10	7.286E-13	0.000E+00	0.000E+00
Pb-214	1.243E+00	1.273E-03	5.550E-05	5.180E-07	9.820E-07	1.006E-09	4.000E-11	4.850E-13
Bi-214	9.325E+00	8.465E-03	5.180E-05	4.070E-07	7.480E-06	6.831E-09	3.100E-11	2.650E-13
Po-214	4.840E-04	4.449E-07	0.000E+00	0.000E+00	3.860E-10	3.585E-13	0.000E+00	0.000E+00
Pb-211	2.915E-01	3.024E-04	4.440E-05	6.660E-07	2.290E-07	2.207E-10	4.030E-11	5.810E-13
Bi-211	2.373E-01	2.382E-04	0.000E+00	0.000E+00	1.880E-07	1.892E-10	0.000E+00	0.000E+00
Po-211	4.485E-02	4.157E-05	0.000E+00	0.000E+00	3.580E-08	3.339E-11	0.000E+00	0.000E+00
Tl-210	1.661E+01	-1.00E+00	0.000E+00	0.000E+00	0.000E+00	-1.00E+00	0.000E+00	0.000E+00
Pb-210	1.981E-03	5.231E-06	2.072E-02	2.553E-03	1.410E-09	3.760E-12	1.580E-08	1.180E-09
Bi-210	5.476E-03	3.012E-05	3.441E-04	4.810E-06	2.760E-09	5.278E-12	4.550E-10	1.300E-11
Po-210	4.934E-05	4.542E-08	1.591E-02	4.440E-03	3.950E-11	3.655E-14	1.450E-08	2.250E-09
Tl-207	2.299E-02	5.289E-05	0.000E+00	0.000E+00	1.520E-08	1.740E-11	0.000E+00	0.000E+00
Tc-99	1.086E-04	3.351E-06	4.810E-05	2.368E-06	8.140E-11	4.344E-13	3.810E-11	4.000E-12
Co-58	5.606E+00	5.184E-03	7.770E-06	2.738E-06	4.480E-06	4.180E-09	7.960E-12	4.180E-12

Data from "Dose and Slope Factors.RPT" File

Individual Radionuclide Dose and Slope Factors

External Dose Factors from ICRP 60

Internal Dose Factors from ICRP 72 (Adult)

Slope Factors from FGR 13 Morbidity

Isotope	External Volume (mrem/y) /(pCi/g)	External Air (mrem/y) /(pCi/m³)	Inhalation mrem/pCi	Ingestion mrem/pCi	External Volume risk/y /(pCi/g)	External Air risk/y /(pCi/m³)	Inhalation risk /pCi	Ingestion risk /pCi
Pu-239	2.63E-04	4.06E-07	4.44E-01	9.25E-04	2.00E-10	2.99E-13	5.51E-08	1.74E-10
U-235	6.60E-01	7.54E-04	3.14E-02	1.74E-04	5.18E-07	5.94E-10	2.50E-08	9.44E-11
Th-231	3.21E-02	5.35E-05	1.22E-06	1.26E-06	2.45E-08	3.92E-11	1.52E-12	3.24E-12
Pa-231	1.76E-01	1.83E-04	5.18E-01	2.63E-03	1.39E-07	1.45E-10	7.62E-08	2.26E-10
Ac-227	4.49E-04	5.98E-07	2.04E+00	4.07E-03	3.48E-10	4.62E-13	1.49E-07	2.45E-10
Th-227	4.80E-01	5.17E-04	3.70E-02	3.26E-05	3.78E-07	4.09E-10	3.51E-08	6.92E-11
Ra-226	2.91E-02	3.32E-05	3.51E-02	1.04E-03	2.29E-08	2.60E-11	2.82E-08	5.14E-10
Fr-223	1.81E-01	2.57E-04	3.29E-06	8.88E-06	1.40E-07	1.83E-10	4.03E-11	1.00E-11
Ra-223	5.53E-01	6.39E-04	3.22E-02	3.70E-04	4.34E-07	5.02E-10	2.92E-08	3.39E-10
Rn-222	2.19E-03	2.07E-06	0.00E+00	0.00E+00	1.74E-09	1.66E-12	0.00E+00	0.00E+00
Rn-219	2.86E-01	2.87E-04	0.00E+00	0.00E+00	2.25E-07	2.29E-10	0.00E+00	0.00E+00
Po-218	5.33E-05	4.92E-08	0.00E+00	0.00E+00	4.26E-11	3.95E-14	0.00E+00	0.00E+00
At-218	4.88E-03	1.13E-05	0.00E+00	0.00E+00	3.57E-09	8.34E-12	0.00E+00	0.00E+00
Po-215	9.46E-04	9.10E-07	0.00E+00	0.00E+00	7.48E-10	7.29E-13	0.00E+00	0.00E+00
Pb-214	1.24E+00	1.27E-03	5.55E-05	5.18E-07	9.82E-07	1.01E-09	4.00E-11	4.85E-13
Bi-214	9.32E+00	8.47E-03	5.18E-05	4.07E-07	7.48E-06	6.83E-09	3.10E-11	2.65E-13
Po-214	4.84E-04	4.45E-07	0.00E+00	0.00E+00	3.86E-10	3.59E-13	0.00E+00	0.00E+00
Pb-211	2.92E-01	3.02E-04	4.44E-05	6.66E-07	2.29E-07	2.21E-10	4.03E-11	5.81E-13
Bi-211	2.37E-01	2.38E-04	0.00E+00	0.00E+00	1.88E-07	1.89E-10	0.00E+00	0.00E+00
Po-211	4.48E-02	4.16E-05	0.00E+00	0.00E+00	3.58E-08	3.34E-11	0.00E+00	0.00E+00
Tl-210	1.66E+01	********	0.00E+00	0.00E+00	0.00E+00	********	0.00E+00	0.00E+00
Pb-210	1.98E-03	5.23E-06	2.07E-02	2.55E-03	1.41E-09	3.76E-12	1.58E-08	1.18E-09
Bi-210	5.48E-03	3.01E-05	3.44E-04	4.81E-06	2.76E-09	5.28E-12	4.55E-10	1.30E-11
Po-210	4.93E-05	4.54E-08	1.59E-02	4.44E-03	3.95E-11	3.66E-14	1.45E-08	2.25E-09
Tl-207	2.30E-02	5.29E-05	0.00E+00	0.00E+00	1.52E-08	1.74E-11	0.00E+00	0.00E+00
Tc-99	1.09E-04	3.35E-06	4.81E-05	2.37E-06	8.14E-11	4.34E-13	3.81E-11	4.00E-12
Co-58	5.61E+00	5.18E-03	7.77E-06	2.74E-06	4.48E-06	4.18E-09	7.96E-12	4.18E-12

1. The external dose factors for volume sources are used to compute the direct external dose from volume sources, from area sources and from deposited radionuclides.
2. The ratio between the external dose factor for volume sources and the external slope factors for volume sources are used to compute the exteral risk from all sources types and from deposited material.
3. The other dose and slope factors are used to compute the associated progeny integrated factors in the next table.
3.a. ******** indicates that the specified database file does not contain a value for this factor. A value of 0.0 is used to compute the integrated factors.

TEST CASE 027-3

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-027-3
Requirements Tested	27
Test Summary	Verify correct dose coefficients are used for dose calculations, including direct external, air submersion, inhalation, and ingestion coefficients.
Test Objective	Tests DCFs based on ICRP60 methodology for ICRP107 transformation database
Procedure	1. Spot check based on PM scope request. 2. Start RESRAD-BUILD code and choose ICRP107 transformation database. 3. Select DCFPAK3.02 Adult as the Internal Dose Library in the code. 4. Set cutoff half-life = 0 days. 5. Select suggested few radionuclides in the source. 6. Run the code. 7. Verify by comparing data in the "Dose and Slope Factors.RPT" file and "DCF Individual.LIB" file. 8. Select cutoff half-life = 30 days. 9. Run the code. 10. Verify by comparing data in the "Dose and Slope Factors.RPT" file and RESRAD-BUILD Manual Table C-9 for external dose coefficients and Table A-5 DCFs for air submersion, inhalation, and ingestion dose coefficients. 11. Further verification details are in the "RESRAD-BUILD-DCFs-Data-Verfication.docx" file.
Required Data	Test-027-3.bld.
Expected Results	The DCFs for selected radionuclides and their associated progeny radionuclides in the "Dose and Slope Factors.RPT" file matches the "DCF Individual.LIB" file when the cutoff half-life was 0 days. The DCFs for selected radionuclides and their associated progeny radionuclides in the "Dose and Slope Factors.RPT" file matches the values listed in RESRAD-BUILD Manual Table C-9 for external dose coefficients and Table A-5 DCFs for air submersion, inhalation, and ingestion dose coefficients. Table 1 below shows the DCFs and SFs from the "Dose and Slope Factors.RPT" file and "DCF Individual.LIB" file for the cutoff half-life = 0 days when Am-241, C-14, Cf-252, and Th-232 were selected radionuclides.

Table 1 Results from "DCF Individual.LIB" File and "Dose and Slope Factors.RPT" File

Data from "DCF Individual.LIB" file -

DCF Individual - Notepad

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Nuclide	DCFPAK3.02 (Adult) ExtVolDC (mrem/y) /(pCi/g)	DCFPAK3.02 (Adult) ExtImmDC (mrem/y) /(pCi/m3)	DCFPAK3.02 Morbidity InhalaDC mrem /pCi	DCFPAK3.02 Morbidity IngestDC mrem /pCi	ExtVolSF (1/yr) /(pCi/g)	ExtImmSF (1/yr) /(pCi/m3)	InhalaSF 1 /pCi	IngestSF 1 /pCi
Units								
Cf-252	2.839E+00	2.604E-03	1.360E-01	3.349E-04	2.277E-06	2.090E-09	4.440E-08	1.824E-10
Cm-248	8.163E+00	7.485E-03	1.339E+00	2.868E-03	6.538E-06	6.025E-09	1.439E-07	5.956E-10
Pu-244	1.231E-01	1.133E-04	4.132E-01	8.806E-04	9.865E-08	9.096E-11	5.216E-08	1.879E-10
Am-241	3.717E-02	7.846E-05	3.566E-01	7.548E-04	2.767E-08	5.803E-11	3.774E-08	1.336E-10
U-240	1.494E-02	2.417E-05	2.067E-06	4.033E-06	1.155E-08	1.646E-11	3.089E-12	1.014E-11
Np-240m	1.834E+00	1.740E-03	-2.00E+00	-2.00E+00	1.459E-06	1.366E-09	-2.00E+00	-2.00E+00
Np-240	5.847E+00	5.523E-03	2.702E-07	2.683E-07	4.670E-06	4.425E-09	1.698E-13	2.723E-13
Pu-240	1.130E-04	3.842E-07	4.410E-01	9.287E-04	7.122E-11	2.522E-13	5.549E-08	1.743E-10
Np-237	6.706E-02	1.004E-04	1.839E-01	3.959E-04	5.172E-08	7.671E-11	2.867E-08	8.287E-11
U-236	1.758E-04	4.414E-07	3.211E-02	1.724E-04	1.238E-10	3.059E-13	2.568E-08	8.990E-11
Pa-233	1.018E+00	1.082E-03	1.532E-05	3.574E-06	8.032E-07	8.535E-10	1.528E-11	8.953E-12
U-233	9.191E-04	1.238E-06	3.549E-02	1.894E-04	7.110E-10	9.376E-13	2.830E-08	9.693E-11
Th-232	4.782E-04	9.224E-07	4.070E-01	8.547E-04	3.584E-10	6.807E-13	4.329E-08	1.332E-10
Th-229	2.877E-01	3.877E-04	8.831E-01	1.846E-03	2.242E-07	3.001E-10	1.746E-07	2.904E-10
Ra-228	6.575E-05	3.374E-07	5.938E-02	2.575E-03	3.432E-11	2.148E-13	4.366E-08	1.424E-09
Ac-228	5.044E+00	4.682E-03	5.416E-05	1.399E-06	4.040E-06	3.760E-09	4.920E-11	2.734E-12
Th-228	7.248E-03	9.633E-06	1.468E-01	2.664E-04	5.639E-09	7.449E-12	1.324E-07	1.480E-10
Ra-225	8.910E-03	2.884E-05	2.869E-02	3.685E-04	6.106E-09	1.845E-11	2.616E-08	1.535E-10
Ac-225	5.286E-02	6.609E-05	3.137E-02	1.428E-04	4.121E-08	5.149E-11	2.856E-08	2.716E-10
Ra-224	4.950E-02	5.266E-05	1.242E-02	2.390E-04	3.911E-08	4.168E-11	1.132E-08	2.383E-10
Fr-221	1.332E-01	1.460E-04	-2.00E+00	-2.00E+00	1.048E-07	1.152E-10	-2.00E+00	-2.00E+00
Rn-220	3.474E-03	3.281E-06	-2.00E+00	-2.00E+00	2.767E-09	2.627E-12	-2.00E+00	-2.00E+00
At-217	1.186E-03	1.238E-06	-2.00E+00	-2.00E+00	9.363E-10	9.761E-13	-2.00E+00	-2.00E+00
Po-216	8.873E-05	8.173E-08	-2.00E+00	-2.00E+00	7.098E-11	6.585E-14	-2.00E+00	-2.00E+00
Bi-213	6.874E-01	6.936E-04	1.183E-04	7.326E-07	5.429E-07	5.324E-10	7.399E-11	7.177E-13
Po-213	2.167E-04	1.997E-07	-2.00E+00	-2.00E+00	1.728E-10	1.611E-13	-2.00E+00	-2.00E+00
Pb-212	6.314E-01	7.134E-04	7.033E-04	2.220E-05	4.962E-07	5.570E-10	6.400E-10	3.566E-11
Bi-212	6.258E-01	6.037E-04	1.229E-04	9.657E-07	4.962E-07	4.612E-10	8.435E-11	1.010E-12
Po-212	0.000E+00	0.000E+00	-2.00E+00	-2.00E+00	0.000E+00	0.000E+00	-2.00E+00	-2.00E+00
Tl-209	1.287E+01	1.191E-02	-2.00E+00	-2.00E+00	1.032E-05	9.575E-09	-2.00E+00	-2.00E+00
Pb-209	7.528E-04	1.168E-05	2.255E-07	2.098E-07	5.371E-10	1.705E-12	2.079E-13	3.485E-13
Tl-208	2.167E+01	1.962E-02	-2.00E+00	-2.00E+00	1.751E-05	1.588E-08	-2.00E+00	-2.00E+00
C-14	1.106E-05	3.036E-07	2.120E-05	2.150E-06	7.857E-12	4.285E-14	1.694E-11	1.998E-12

Note: -2 and -1 indicate DCFs in the source are not available.

Data from "Dose and Slope Factors.RPT" File

Individual Radionuclide Dose and Slope Factors

External Dose Factors from DCFPAK3.02
Internal Dose Factors from DCFPAK3.02 (Adult)
Slope Factors from DCFPAK3.02 Morbidity

Isotope	External Volume (mrem/y) /(pCi/g)	External Air (mrem/y) /(pCi/m³)	Inhalation mrem/pCi	Ingestion mrem/pCi	External Volume risk/y /(pCi/g)	External Air risk/y /(pCi/m³)	Inhalation risk /pCi	Ingestion risk /pCi
Cf-252	2.84E+00	2.60E-03	1.36E-01	3.35E-04	2.28E-06	2.09E-09	4.44E-08	1.82E-10
Cm-248	8.16E+00	7.48E-03	1.34E+00	2.87E-03	6.54E-06	6.03E-09	1.44E-07	5.96E-10
Pu-244	1.23E-01	1.13E-04	4.13E-01	8.81E-04	9.86E-08	9.10E-11	5.22E-08	1.88E-10
Am-241	3.72E-02	7.85E-05	3.57E-01	7.55E-04	2.77E-08	5.80E-11	3.77E-08	1.34E-10
U-240	1.49E-02	2.42E-05	2.07E-06	4.03E-06	1.16E-08	1.65E-11	3.09E-12	1.01E-11
Np-240m	1.83E+00	1.74E-03	********	********	1.46E-06	1.37E-09	********	********
Np-240	5.85E+00	5.52E-03	2.70E-07	2.68E-07	4.67E-06	4.42E-09	1.70E-13	2.72E-13
Pu-240	1.13E-04	3.84E-07	4.41E-01	9.29E-04	7.12E-11	2.52E-13	5.55E-08	1.74E-10
Np-237	6.71E-02	1.00E-04	1.84E-01	3.96E-04	5.17E-08	7.67E-11	2.87E-08	8.29E-11
U-236	1.76E-04	4.41E-07	3.21E-02	1.72E-04	1.24E-10	3.06E-13	2.57E-08	8.99E-11
Pa-233	1.02E+00	1.08E-03	1.53E-05	3.57E-06	8.03E-07	8.53E-10	1.53E-11	8.95E-12
U-233	9.19E-04	1.24E-06	3.55E-02	1.89E-04	7.11E-10	9.38E-13	2.83E-08	9.69E-11
Th-232	4.78E-04	9.22E-07	4.07E-01	8.55E-04	3.58E-10	6.81E-13	4.33E-08	1.33E-10
Th-229	2.88E-01	3.88E-04	8.83E-01	1.85E-03	2.24E-07	3.00E-10	1.75E-07	2.90E-10
Ra-228	6.57E-05	3.37E-07	5.94E-02	2.58E-03	3.43E-11	2.15E-13	4.37E-08	1.42E-09
Ac-228	5.04E+00	4.68E-03	5.42E-05	1.40E-06	4.04E-06	3.76E-09	4.92E-11	2.73E-12
Th-228	7.25E-03	9.63E-06	1.47E-01	2.66E-04	5.64E-09	7.45E-12	1.32E-07	1.48E-10
Ra-225	8.91E-03	2.88E-05	2.87E-02	3.69E-04	6.11E-09	1.85E-11	2.62E-08	1.54E-10
Ac-225	5.29E-02	6.61E-05	3.14E-02	1.43E-04	4.12E-08	5.15E-11	2.86E-08	2.72E-10
Ra-224	4.95E-02	5.27E-05	1.24E-02	2.39E-04	3.91E-08	4.17E-11	1.13E-08	2.38E-10
Fr-221	1.33E-01	1.46E-04	********	********	1.05E-07	1.15E-10	********	********
Rn-220	3.47E-03	3.28E-06	********	********	2.77E-09	2.63E-12	********	********
At-217	1.19E-03	1.24E-06	********	********	9.36E-10	9.76E-13	********	********
Po-216	8.87E-05	8.17E-08	********	********	7.10E-11	6.59E-14	********	********
Bi-213	6.87E-01	6.94E-04	1.18E-04	7.33E-07	5.43E-07	5.32E-10	7.40E-11	7.18E-13
Po-213	2.17E-04	2.00E-07	********	********	1.73E-10	1.61E-13	********	********
Pb-212	6.31E-01	7.13E-04	7.03E-04	2.22E-05	4.96E-07	5.57E-10	6.40E-10	3.57E-11
Bi-212	6.26E-01	6.04E-04	1.23E-04	9.66E-07	4.96E-07	4.61E-10	8.43E-11	1.01E-12
Po-212	0.00E+00	0.00E+00	********	********	0.00E+00	0.00E+00	********	********
Tl-209	1.29E+01	1.19E-02	********	********	1.03E-05	9.58E-09	********	********
Pb-209	7.53E-04	1.17E-05	2.26E-07	2.10E-07	5.37E-10	1.70E-12	2.08E-13	3.49E-13
Tl-208	2.17E+01	1.96E-02	********	********	1.75E-05	1.59E-08	********	********
C-14	1.11E-05	3.04E-07	2.12E-05	2.15E-06	7.86E-12	4.29E-14	1.69E-11	2.00E-12

1. The external dose factors for volume sources are used to compute the direct external dose from volume sources, from area sources and from deposited radionuclides.
2. The ratio between the external dose factor for volume sources and the external slope factors for volume sources are used to compute the exteral risk from all sources types and from deposited material.
3. The other dose and slope factors are used to compute the associated progeny integrated factors in the next table.
3.a. ******** indicates that the specified database file does not contain a value for this factor. A value of 0.0 is used to compute the integrated factors.

TEST CASE 028

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-028
Requirements Tested	28
Test Summary	Verify risk coefficients in databases are the same as in referenced sources. By choosing FGR13 for ICRP38 nuclides or DCFPAK3.02 for ICRP107 nuclides, the default slope factor values in these DCF libraries are used in the cancer risk calculations for the selected nuclides and their progenies by the code. The slope factor values the code retrieves from the DCF Editor are listed in the dose and risk factors report, which is opened after the calculations are completed. These listed slope factors are compared with the values in the source document to see whether they agree with each other, to confirm the RESRAD-BUILD code meets the code requirement No. 28.
Test Objective	Test and verify the default slope factors in the FGR13 and DCFPAK3.02 libraries match the values in the source documents and are used in risk calculations by the code.
Procedure	Perform several RESRAD-BUILD runs and open the dose and risk factors report generated by the code. Compare the slope factor values listed in the report for each relevant nuclide in the current run with those listed in the source document. Steps: 1. Open the RESRAD-Build code. 2. Choose ICRP38 as the transformation database. Choose FGR13 morbidity factors to be used in cancer risk calculations. 3. Randomly select a few nuclides to be included in the source. 4. Open the DCF Editor to view the FGR13 morbidity slope factors of the relevant nuclides in the current run. Write down the default values for the external volume, external air, ingestion (of plant/meat), and inhalation pathways for each relevant nuclide. 5. Launch RESRAD-BUILD calculations. 6. In the directory where the code was installed, open the file “dose and slope factors.rpt.” There are two sets of dose and slope factors in the report; the first set has values for individual nuclides that are taken from the database of the DCF Editor. Write down the external volume, external air, ingestion, and inhalation slope factor values for comparison. 7. Compare the written-down slope factor values in Steps 4 and 6 with those in the source FGR13 report.

8. Note: The slope factors listed under “total” and age “0-110” in the FGR13 report should be used for this comparison. Choose “soil layer” and “submersion” factors for comparison with the “external volume” and “external air”/“air submersion” factors in the DCF Editor and in the “dose and slope factors.rpt.” For ingestion slope factors, the values listed under “dietary” in the FG13 report should be compared with the “ingestion plant/meat”/ “ingestion” factors in the DCF Editor and the “dose and slope factors.rpt.” For inhalation slope factors, the maximum among different absorption classes (F, M, S) and different forms (solid, vapor, or gas) should be compared with the maximum “inhalation” factor in the DCF Editor and the “inhalation” factor in the “dose and slope factors.rpt.”

Choose “FGR13 mortality”, then “DCFPAK 3.02 morbidity” and “DCFPAK3.02 mortality” with ICRP107 transformation data; repeat Steps 3–7.

Expected Results The slope factors listed in the DCF Editor, “dose and slope factors.rpt” and the source document should agree.

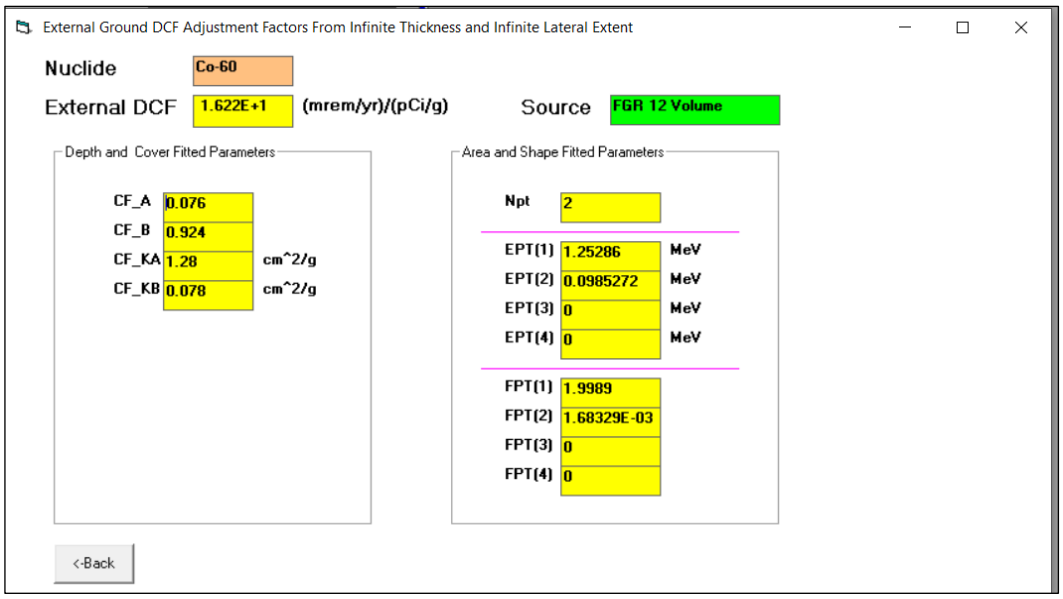
Note: In the source document, the external slope factors listed under “soil layer” have a unit of (risk/s per Bq/g) so they need to be multiplied by 3600 × 24 × 365 × 1000 to get values for (risk/yr per Bq/kg) for comparison. The external slope factors listed under “submersion” have a unit of (risk/s per Bq/m^3) so they need to be multiplied by 3600 x 24 x 365 to get values for (risk/yr per Bq/m^3) for comparison.

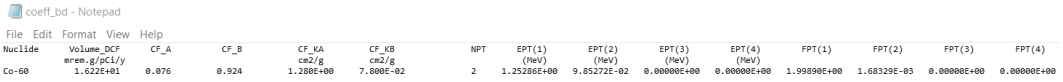
Required Data None.

TEST CASE 030-1

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-030-1
Requirements Tested	30
Test Summary	Check fitted parameters used with FGR12, FGR13, and DCFPAK 3.02 dose coefficients in external exposure modeling.
Test Objective	Test parameters used in external exposure model.
Procedure	1. Spot check based on PM scope request. 2. Start RESRAD-BUILD code and choose ICRP38 transformation database. 3. Select FGR11 as the Internal Dose Library in the code. 4. Set cutoff half-life = 0 days. 5. Select suggested few radionuclides in the source. 6. Run the code. 7. Verify by comparing data in DCF Editor with "coeff_bd.LIB" text files in the code's main directory. 8. Select cutoff half-life = 30 days. 9. Run the code. 10. Verify by comparing data for selected radionuclide in RESRAD-BUILD Manual Tables C.1 and C.4 with ""coeff_bd.LIB" files in the code's main directory for 30-day cutoff half-life radionuclides. 11. Further verification details are in the "RESRAD-BUILD-External-Model-Data-Verfication.docx" file.
Required Data	NA
Expected Results	The data in DCF editor for fitted parameters matches the data in the "coeff_bd.LIB" file when the cutoff half-life = 0 days. Table 1 shows the comparison for Co-60. Make sure the "coeff_bd.LIB" file for fitting parameters for 30-day cutoff half-life radionuclides matches the values listed in RESRAD-BUILD Tables C.1 and C.4.

Table 1 Comparison for Co-60





TEST CASE 030-2

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-030-2
Requirements Tested	30
Test Summary	Check fitted parameters used with FGR12, FGR13, and DCFPAK 3.02 dose coefficients in external exposure modeling.
Test Objective	Test parameters used in external exposure model.

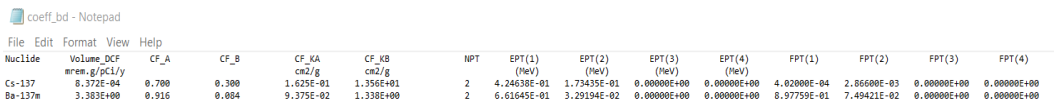
Procedure

1. Spot check based on PM scope request.
2. Start RESRAD-BUILD code and choose ICRP38 transformation database.
3. Select ICRP 72 (Adult) as the Internal Dose Library in the code.
4. Set cutoff half-life = 0 days.
5. Select suggested few radionuclides in the source.
6. Run the code.
7. Verify by comparing data in the DCF Editor with the "coeff_bd.LIB" file in the code's main directory.
8. Select cutoff half-life = 30 days.
9. Run the code.
10. Verify by comparing data for selected radionuclides in RESRAD-BUILD Manual Tables C.2 and C.4 with the "coeff_bd.LIB" file in the code's main directory for 30-day cutoff half-life radionuclides.
11. Further verification details are in the "RESRAD-BUILD-External-Model-Data-Verfication.docx" file.

Required Data	NA
Expected Results	The data in the DCF Editor for fitted parameters matches with the data in the "coeff_bd.LIB" file when the cutoff half-life = 0 days.

Make sure the "coeff_bd.LIB" file for the fitting parameters for 30-day cutoff half-life radionuclides matches the values listed in RESRAD-BUILD Tables C.2 and C.4. Table 1 compares the values for Cs-137 in the "coeff_bd.LIB" file with values in Table C.2.

Table 1 Comparison for Cs-137



coeff_bd - Notepad

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Nuclide	Volume_DCF mrem.g/pCi/y	CF_A	CF_B	CF_KA cm2/g	CF_KB cm2/g	NPT	EPT(1) (MeV)	EPT(2) (MeV)	EPT(3) (MeV)	EPT(4) (MeV)	FPT(1)	FPT(2)	FPT(3)	FPT(4)
Cs-137	8.372E-04	0.700	0.300	1.625E-01	1.356E+01	2	4.24638E-01	1.73435E-01	0.00000E+00	0.00000E+00	4.02000E-04	2.86600E-03	0.00000E+00	0.00000E+00
Ba-137m	3.383E+00	0.916	0.084	9.375E-02	1.338E+00	2	6.61645E-01	3.29194E-02	0.00000E+00	0.00000E+00	8.97759E-01	7.49421E-02	0.00000E+00	0.00000E+00

TABLE C-2: Fitted Parameters A, B, K_A, and K_B for at least 30 Day Cutoff Half-life Radionuclides and Their Associated Progeny Determined with the Dose Coefficients from FGR-13

	Fitted Parameters[a]			
Radionuclide	A	B	K_A (cm^2/g)	K_B (cm^2/g)
Ba-137m	9.16E-01	8.40E-02	9.38E-02	1.34E+00
Cs-137	7.00E-01	3.00E-01	1.63E-01	1.36E+01

TEST CASE 030-3

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-030-3
Requirements Tested	30
Test Summary	Check fitted parameters used with FGR12, FGR13, and DCFPAK 3.02 dose coefficients in external exposure modeling.
Test Objective	Test parameters used in external exposure model.

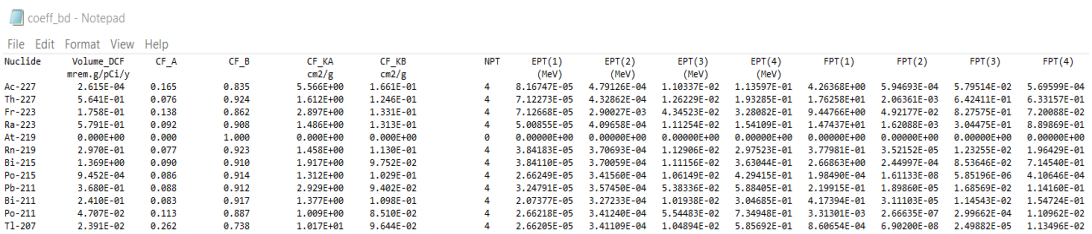
Procedure

1. Spot check based on PM scope request.
2. Start RESRAD-BUILD code and choose ICRP107 transformation database.
3. Select DCFPAK3.02 (Adult) as the Internal Dose Library in the code.
4. Set cutoff half-life = 0 days.
5. Select suggested few radionuclides in the source.
6. Run the code.
7. Verify by comparing data in the DCF Editor with the "coeff_bd.LIB" file in the code's main directory.
8. Select cutoff half-life = 30 days.
9. Run the code.
10. Verify by comparing data for selected radionuclides in RESRAD-BUILD Manual Tables C.3 and C.5 with the "coeff_bd.LIB" file in the code's main directory for 30-day cutoff half-life radionuclides.
11. Further verification details are in the"RESRAD-BUILD-External-Model-Data-Verfication.docx" file.

Required Data	NA
Expected Results	The data in DCF editor for fitted parameters matches with the data in the "coeff_bd.LIB" file when the cutoff half-life = 0 days.

Make sure the "coeff_bd.LIB" file for the fitting parameters for 30-day cutoff half-life radionuclides matches the values listed in RESRAD-BUILD User's Manual Tables C.2 and C.4. Table 1 compares the values for Ac-227 in the "coeff_bd.LIB" file with values in Table C.3.

Table 1 Comparison for Ac-227



coeff_bd - Notepad

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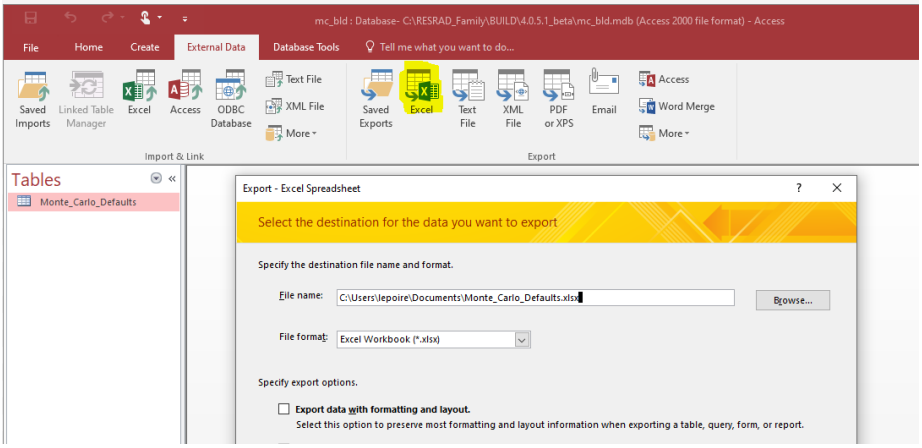
Nuclide	Volume_DCF	CF_A	CF_B	CF_KA	CF_KB	NPT	EPT(1)	EPT(2)	EPT(3)	EPT(4)	FPT(1)	FPT(2)	FPT(3)	FPT(4)
	mrem.g/pCi/y			cm2/g	cm2/g		(MeV)	(MeV)	(MeV)	(MeV)				
Ac-227	2.615E-04	0.165	0.835	5.566E+00	1.661E-01	4	8.16747E-05	4.79126E-04	1.10337E-02	1.13597E-01	4.26368E+00	5.94693E-04	5.79514E-02	5.69599E-04
Th-227	5.641E-01	0.076	0.924	1.612E+00	1.246E-01	4	7.12273E-05	4.32862E-04	1.26229E-02	1.93285E-01	1.76258E+01	2.06361E-03	6.42411E-01	6.33157E-01
Fr-223	1.758E-01	0.138	0.862	2.897E+00	1.331E-01	4	7.12668E-05	2.90027E-03	4.34523E-02	3.28082E-01	9.44766E+00	4.92177E-02	8.27575E-01	7.20088E-02
Ra-223	5.791E-01	0.092	0.908	1.486E+00	1.313E-01	4	5.00855E-05	4.09658E-04	1.11254E-02	1.54109E-01	1.47437E+01	1.62088E-03	3.04475E-01	8.89869E-01
At-219	0.000E+00	0.000	1.000	0.000E+00	0.000E+00	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
Rn-219	2.970E-01	0.077	0.923	1.458E+00	1.130E-01	4	3.84183E-05	3.70693E-04	1.12906E-02	2.97523E-01	3.77981E-01	3.52152E-05	1.23255E-02	1.96429E-01
Bi-215	1.369E+00	0.090	0.910	1.917E+00	9.752E-02	4	3.84110E-05	3.70059E-04	1.11156E-02	3.63044E-01	2.66863E+00	2.44997E-04	8.53646E-02	7.14540E-01
Po-215	9.452E-04	0.086	0.914	1.312E+00	1.029E-01	4	2.66249E-05	3.41560E-04	1.06149E-02	4.29415E-01	1.98490E-04	1.61133E-08	5.85196E-06	4.10646E-04
Pb-211	3.680E-01	0.088	0.912	2.929E+00	9.402E-02	4	3.24791E-05	3.57450E-04	5.38336E-02	5.88405E-01	2.19915E-01	1.89860E-05	1.68569E-02	1.14160E-01
Bi-211	2.410E-01	0.083	0.917	1.377E+00	1.098E-01	4	2.07377E-05	3.27233E-04	1.01938E-02	3.04685E-01	4.17394E-01	3.11103E-05	1.14543E-02	1.54724E-01
Po-211	4.707E-02	0.113	0.887	1.009E+00	8.510E-02	4	2.66218E-05	3.41240E-04	5.54483E-02	7.34948E-01	3.31301E-03	2.66635E-07	2.99662E-04	1.10962E-02
Tl-207	2.391E-02	0.262	0.738	1.017E+01	9.644E-02	4	2.66205E-05	3.41109E-04	1.04894E-02	5.85692E-01	8.60654E-04	6.90200E-08	2.49882E-05	1.13496E-02

TABLE C-3 Fitted Parameters A, B, KA, and KB for at least 30 Day Cutoff Half-life Radionuclides and Their Associated Progeny Determined with the Dose Coefficients from DCFPAK3.02

Radionuclide	Fitted Parameters			
	A	B	KA (cm2/g)	KB (cm2/g)
Ac-227	1.65E-01	8.35E-01	5.57E+00	1.66E-01
At-219	0.00E+00	1.00E+00	0.00E+00	0.00E+00
Bi-211	8.30E-02	9.17E-01	1.38E+00	1.10E-01
Bi-215	9.00E-02	9.10E-01	1.92E+00	9.75E-02
Fr-223	1.38E-01	8.62E-01	2.90E+00	1.33E-01
Pb-211	8.80E-02	9.12E-01	2.93E+00	9.40E-02
Po-211	1.13E-01	8.87E-01	1.01E+00	8.51E-02
Po-215	8.60E-02	9.14E-01	1.31E+00	1.03E-01
Ra-223	9.20E-02	9.08E-01	1.49E+00	1.31E-01
Rn-219	7.70E-02	9.23E-01	1.46E+00	1.13E-01
Th-227	7.60E-02	9.24E-01	1.61E+00	1.25E-01
Tl-207	2.62E-01	7.38E-01	1.02E+01	9.64E-02

TEST CASE 031

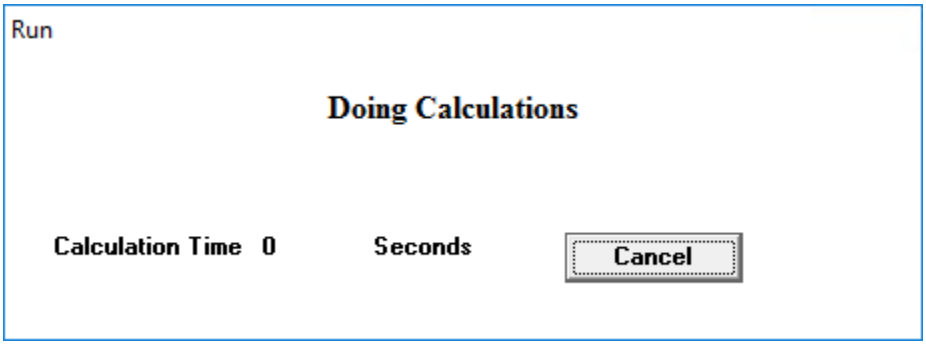
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-031
Requirements Tested	31
Test Summary	Check uncertainty analysis defaults for eligible input parameters.
Test Objective	Test uncertainty defaults.
Procedure	• Extract the uncertainty defaults from the installed mc_bld.mdb file as shown below. • Compare this file with the file "BUILD Uncertainty Defaults.csv" in the BOX test folder.



Required Data	NA
Expected Results	The two files should be the same (as verified in "BUILD Uncertainty Defaults.csv").

TEST CASE 032

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-032
Requirements Tested	32
Test Summary	Verify running time with the default case is under 30 seconds.
Test Objective	Ensure that code runs default case in under 30 seconds.
Procedure	1. Launch RESRAD-BUILD. 2. Click File->New to generate the default case with Co-60 contamination. 3. Click File->Run to execute the calculations. 4. Verify that RESRAD-BUILD finishes the calculation before the Calculation Time on the Doing Calculations window (shown below) reaches 30 seconds.



Required Data	NA
Expected Results	The Doing Calculations window disappears before the Calculation Time reaches 30, and "RESRADB.RPT" displays.

TEST CASE 033

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-033
Requirements Tested	33
Test Summary	Test validation of user's email for download.
Test Objective	Tests validation of user's email for download.
Procedure	1. Submit the Download form on the RESRAD website (https://resrad.evs.anl.gov/download/). 2. Verify receipt of email for access to download. 3. Verify email link allows access. 4. Verify download is successful.
Required Data	NA
Expected Results	The RESRAD-BUILD installer is downloaded successfully.

TEST CASE 034

Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-034
Requirements Tested	34
Test Summary	Test the setting and function of calculating instantaneous external dose for IND nuclides. This test involves retrieving the 10 template files as input to the RESRAD-BUILD code, then verifying that all IND radionuclides are included in the area source, the special settings to calculate instantaneous external dose rates are implemented, the input parameter values can be revised and saved to a new input file, and dose calculations are completed without any issues.
Test Objective	Test and verify the code has a special setup to calculate instantaneous external dose rates for the scenarios in the RESRAD-IND code.
Procedure	Copy the file "ind96dcf.key" that contains the special key needed to set up the RESRAD-BUILD code for IND analysis to the directory where the RESRAD-BUILD code was installed. Test the RESRAD-BUILD code with the following procedure: 1. Check to see the menu option INitial external Dose rate is available under View. 2. Retrieve the first template input file. 3. Check the following settings are in place: a. Only the evaluation time of 0 year can be specified. b. Exposure duration = 1 year; indoor time fraction = 1. c. Cut-off half-life = 0 day. d. There are 96 initially existing nuclides in each radiation source. e. All sources are area sources. 4. Without making any changes, launch calculations (with the File\Run menu option or the Perform Calculations tool button). Verify that calculations are completed without any issue and the template file is used for the calculations (check the header section of the summary report). Record the direct external dose at t =0 for each parent nuclide. 5. In subsequent runs, keep a couple of radionuclides, keep one source and make sure the source concentration is 1, change the exposure duration to 365/2 (then to 365/10, 365/50, 365/250, 365/1250, and 365/6250 day), save the inputs to a different file, and then launch calculations. Record the direct external dose at t=0 for each parent nuclide after each run is completed from "Dose and Risk Components.rpt." 6. Normalize the calculated direct external dose in Step 5 to get annual dose, by multiplying with a factor of 2, 10, 50, 250, 1250, and 6250, respectively.

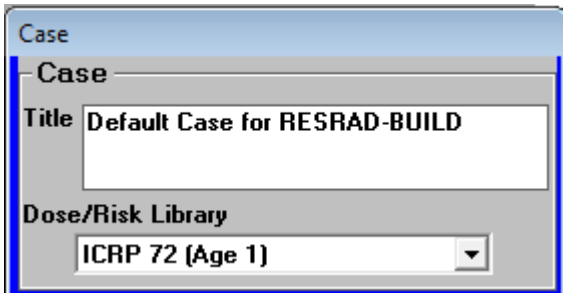
7. Retrieve the template input file with an exposure duration of 365 days. Launch calculations by selecting the "Initial external dose rate" option under the View menu. Confirm two messages appear that inform: (i) File will be saved with extension "iie", and (ii) Instantaneous exposure from source based on unit concentration for selected radionuclides will be calculated.
8. View the report brought up after calculations are completed. Confirm that only radiation dose for the direct external pathway is calculated. Dose results for other pathways are 0s.
9. Compare the direct external dose with the normalized annual doses for selected radionuclides in Step 6. The annual doses would display a trend of getting closer to the direct external dose (obtained with the input file with the "iie" extension).
10. Repeat Steps 3–9 with a different template file.z.

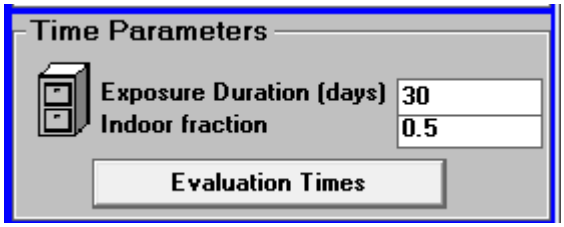
Required Data The special key file named "ind96dcf.key" for enabling this feature and the 10 template input files, including (1) "Bridge.tem," (2) "Monument.tem," (3) "RailCar.tem," (4) "RuralHouse.tem," (5) "Store.tem," (6) "Street.tem," (7) "SubHouse.tem," (8) "substation.tem," (9) "UrbanApt.tem," and (10) "Warehouse.tem."

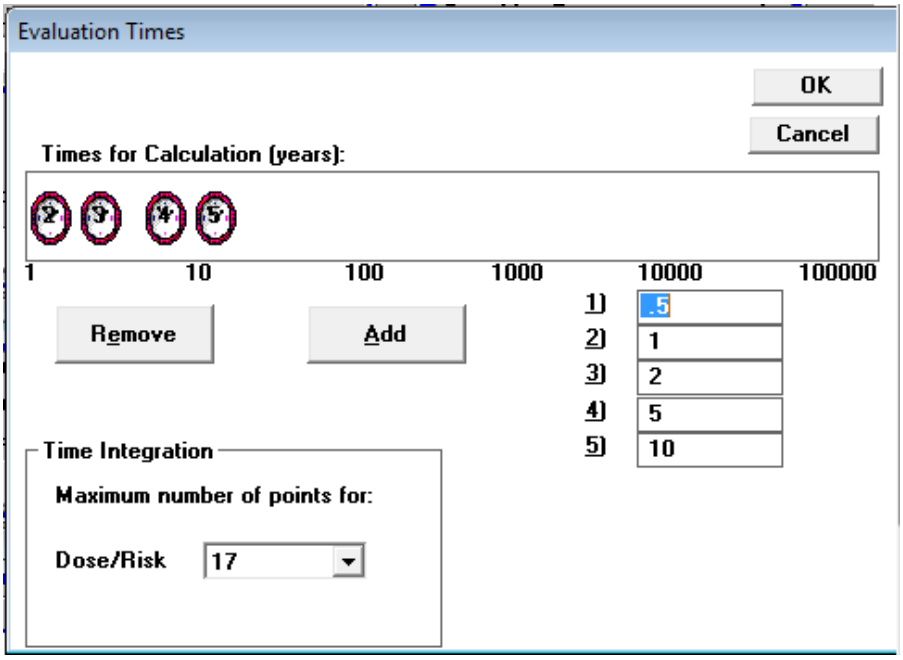
Expected Results The code performs as described in the procedure.

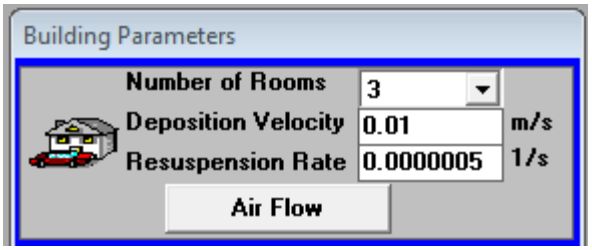
TEST CASE 036

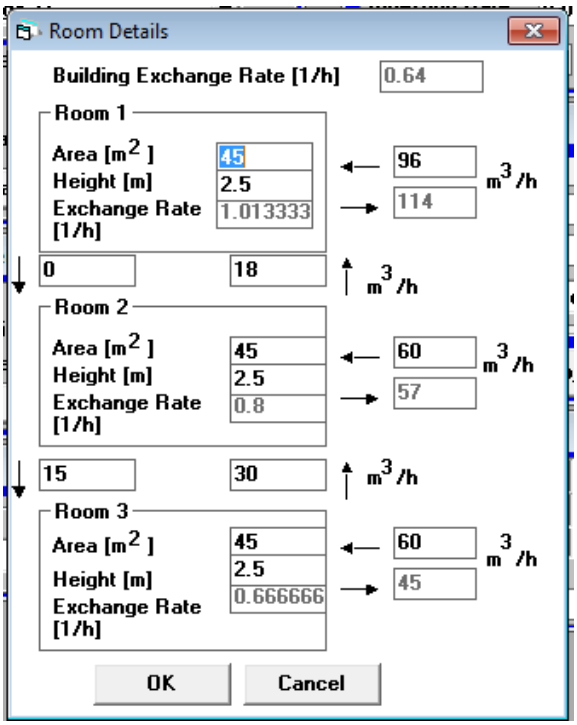
Project	**RESRAD-BUILD**
Test Case ID	RESBLD-TEST-036
Requirements Tested	36
Test Summary	Test compatibility with input files generated with previous version of the code. With two input files generated by using Version 3.5, this test case tests whether Version 4.0 can read in old input files without any issue and preserve the input values for most of the input parameters, except for those that are used previously but not in Version 4.0 or vice versa. For the exceptions, proper input values should be assigned to related input parameters. The code is then tested to save the input file and perform calculations.
Test Objective	Test and verify that Version 4.0 of RESRAD-BUILD can read in old input files created with previous version(s) of the code, as required by the code requirement 36.
Procedure	• Read in the input file "Test 36-1.BLD," which was generated using Version 3.5 of the code. The following are the input values/selections:

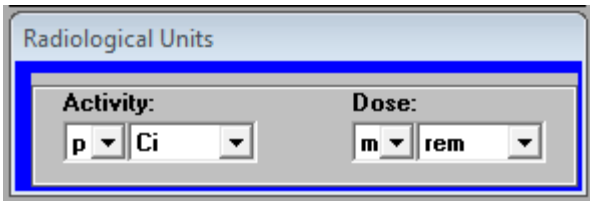


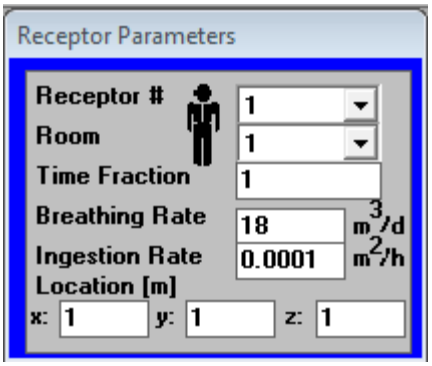


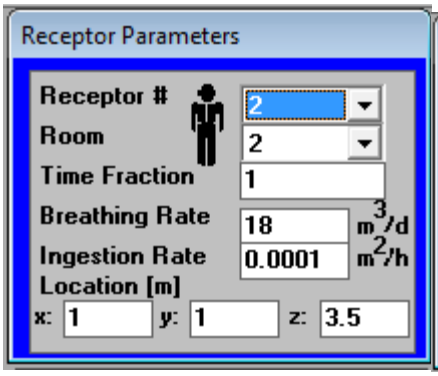

Evaluation Times
OK
Cancel
Times for Calculation (years):
1
10
100
1000
10000
100000
Remove
Add
1) .5
2) 1
3) 2
4) 5
5) 10
Time Integration
Maximum number of points for:
Dose/Risk
17

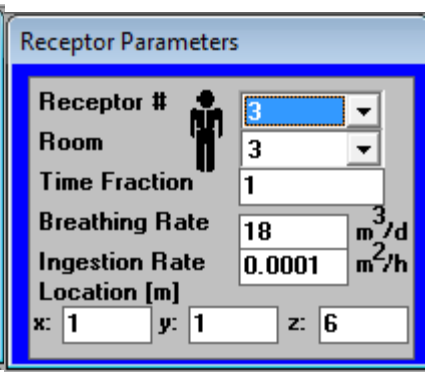

Building Parameters
Number of Rooms
3
Deposition Velocity
0.01
m/s
Resuspension Rate
0.0000005
1/s
Air Flow

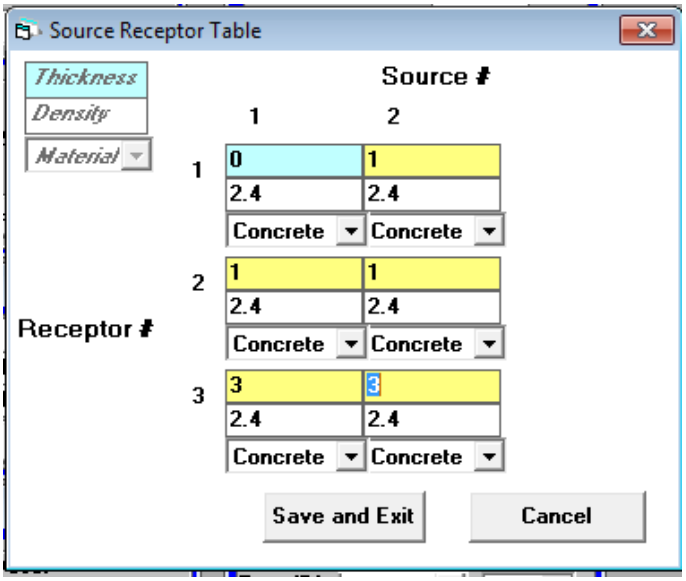

Room Details
Building Exchange Rate [1/h]
0.64
Room 1
Area [m2]
45
Height [m]
2.5
Exchange Rate [1/h]
1.013333
96
114
m3/h
0
18
m3/h
Room 2
Area [m2]
45
Height [m]
2.5
Exchange Rate [1/h]
0.8
60
57
m3/h
15
30
m3/h
Room 3
Area [m2]
45
Height [m]
2.5
Exchange Rate [1/h]
0.666666
60
45
m3/h
OK
Cancel

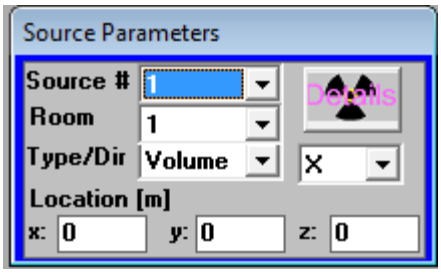

Radiological Units
Activity:
p
Ci
Dose:
m
rem

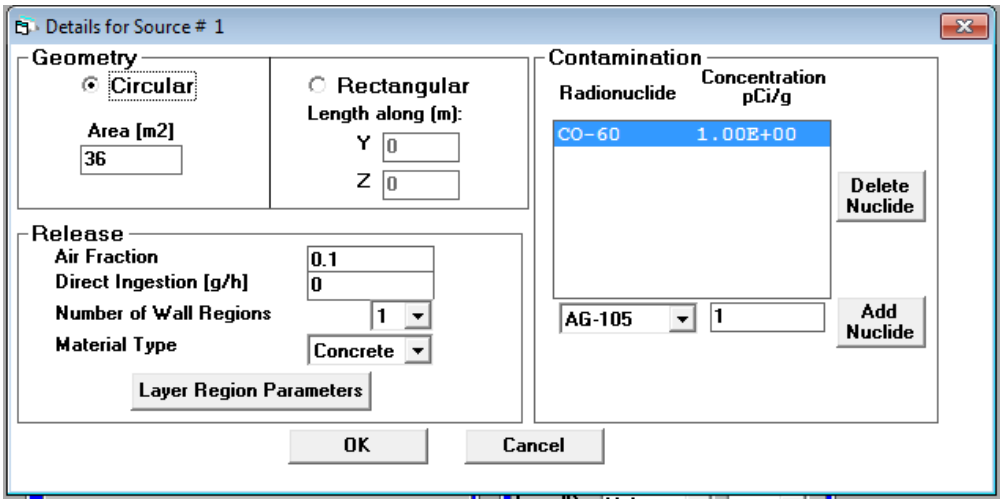

Receptor Parameters
Receptor #
Room
Time Fraction
Breathing Rate
Ingestion Rate
Location [m]
1
1
1
18
0.0001
m3/d
m2/h
x: 1
y: 1
z: 1

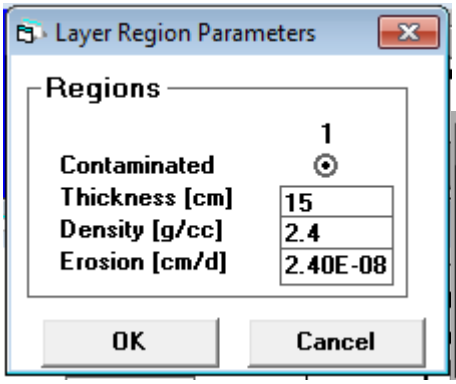

Receptor Parameters
Receptor #
Room
Time Fraction
Breathing Rate
Ingestion Rate
Location [m]
2
2
1
18
0.0001
m3/d
m2/h
x: 1
y: 1
z: 3.5

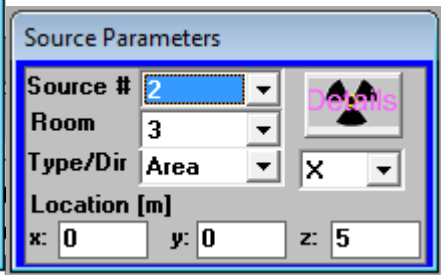

Receptor Parameters
Receptor #
Room
Time Fraction
Breathing Rate
Ingestion Rate
Location [m]
3
3
1
18
0.0001
m3/d
m2/h
x: 1
y: 1
z: 6

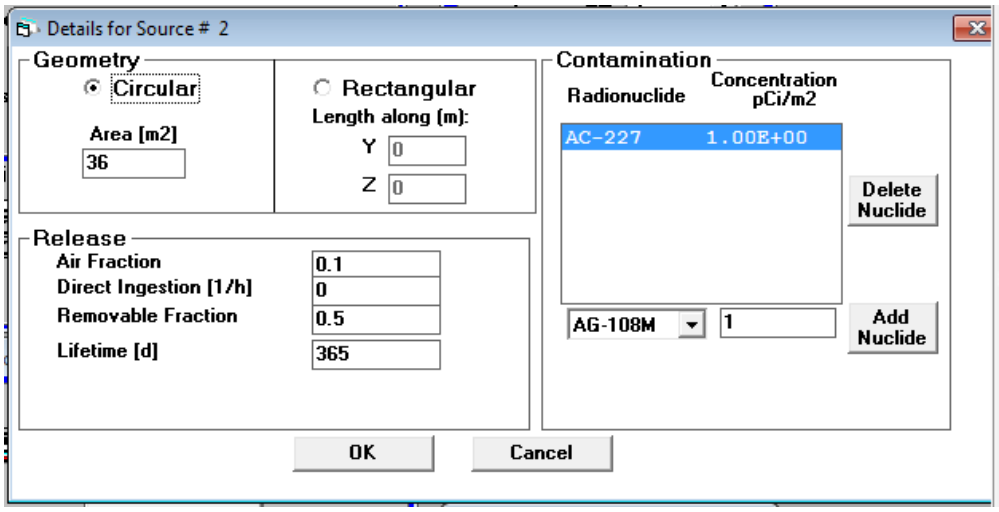

Source Receptor Table
Thickness
Density
Material
Source #
1
2
Receptor #
1
2
3
0
1
2.4
2.4
Concrete
Concrete
1
1
2.4
2.4
Concrete
Concrete
3
3
2.4
2.4
Concrete
Concrete
Save and Exit
Cancel


Source Parameters
Source #
1
Details
Room
1
Type/Dir
Volume
X
Location [m]
x:
0
y:
0
z:
0

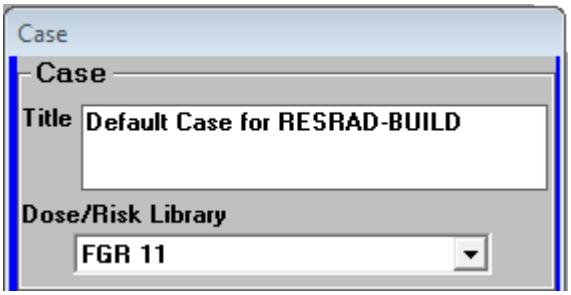

Details for Source # 1
Geometry
Circular
Area [m2]
36
Rectangular
Length along (m):
Y
0
Z
0
Release
Air Fraction
0.1
Direct Ingestion [g/h]
0
Number of Wall Regions
1
Material Type
Concrete
Layer Region Parameters
Contamination
Radionuclide
Concentration pCi/g
CO-60
1.00E+00
Delete Nuclide
AG-105
1
Add Nuclide
OK
Cancel

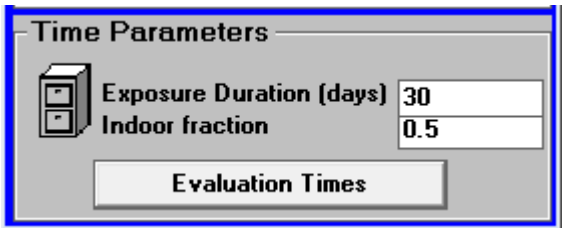

Layer Region Parameters
Regions
1
Contaminated
Thickness [cm]
15
Density [g/cc]
2.4
Erosion [cm/d]
2.40E-08
OK
Cancel

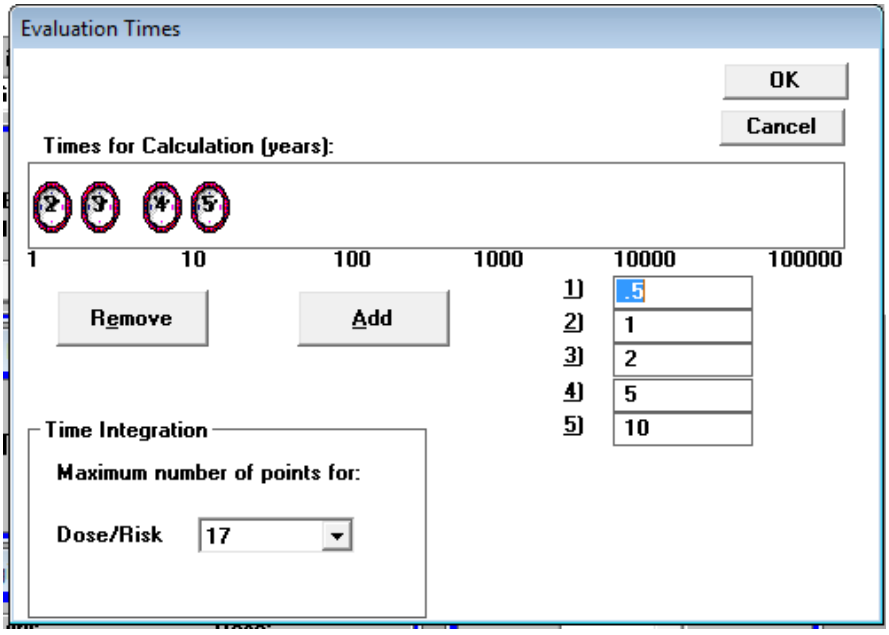

Source Parameters
Source #
2
Details
Room
3
Type/Dir
Area
X
Location [m]
x:
0
y:
0
z:
5

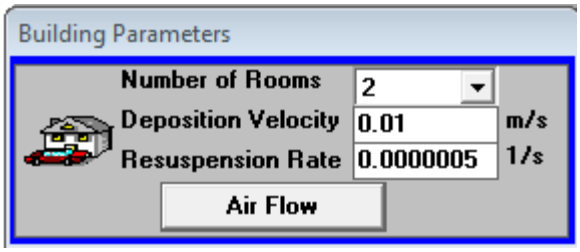


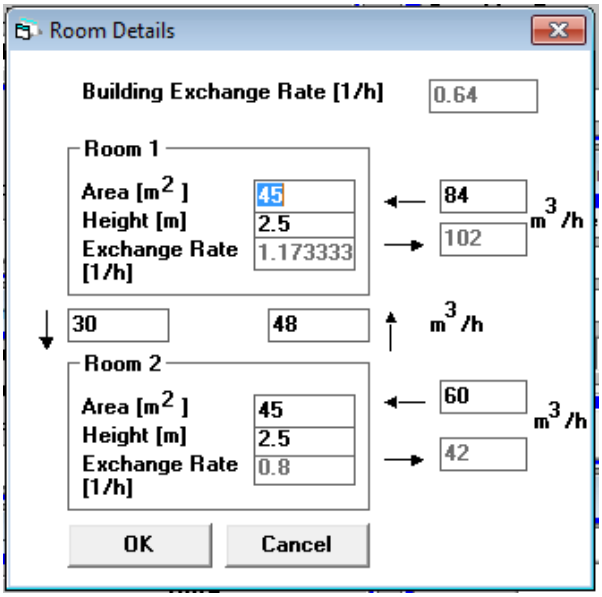
- Check to see whether Traditional Appearance and Write intermediate output are the selected Advanced features. The internal dose library is set to ICRP72 (Age 1), the external dose library to ICRP60, and the risk library to FGR13 morbidity.
- Check to see whether all the other input parameter values/selections are preserved.
- Check to see whether the values of randomly selected input parameters can be changed. Revert the changes.
- Save the inputs to a new file under the directory of the current version.
- Run the code to see whether calculations are performed and summary reports and intermediate outputs are generated without any issue.
- Read in the input file "Test 36-2.BLD," which was also generated using Version 3.5 of the code. Repeat the above steps to check the advanced setting, check the input values, change input values and revert the changes, save the inputs to a file under the current version, and run the code to generate summary reports and intermediate outputs.
- The following are the input values/settings of "Test 36-2.BLD":

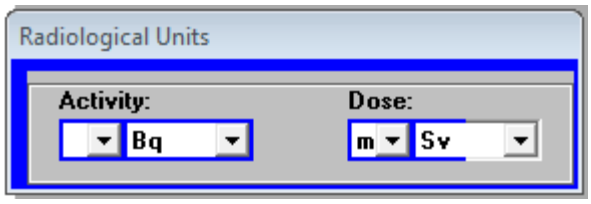


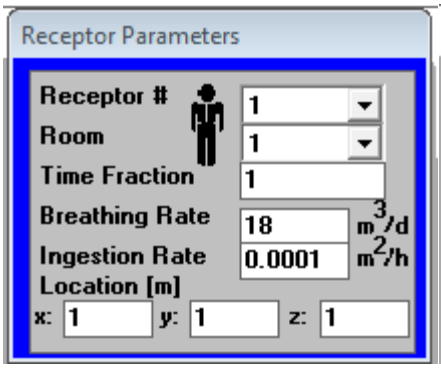


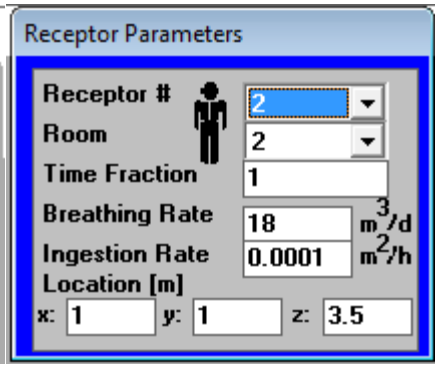

Evaluation Times
OK
Cancel
Times for Calculation (years):
1
10
100
1000
10000
100000
Remove
Add
1) .5
2) 1
3) 2
4) 5
5) 10
Time Integration
Maximum number of points for:
Dose/Risk
17

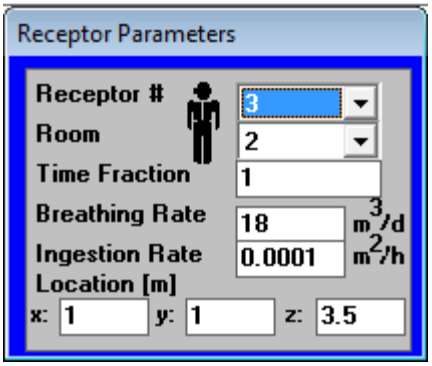

Building Parameters
Number of Rooms
2
Deposition Velocity
0.01
m/s
Resuspension Rate
0.0000005
1/s
Air Flow

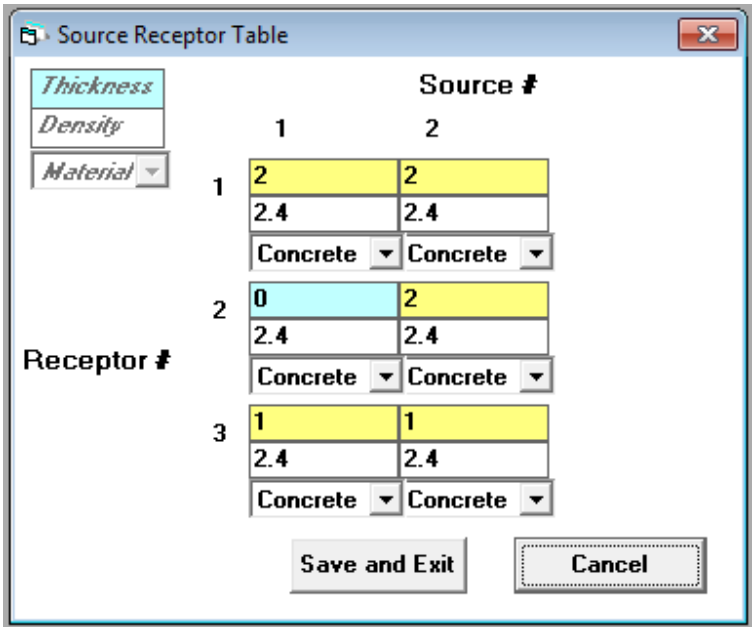

Room Details
Building Exchange Rate [1/h]
0.64
Room 1
Area [m2]
45
Height [m]
2.5
Exchange Rate [1/h]
1.173333
84
102
m3/h
30
48
m3/h
Room 2
Area [m2]
45
Height [m]
2.5
Exchange Rate [1/h]
0.8
60
42
m3/h
OK
Cancel

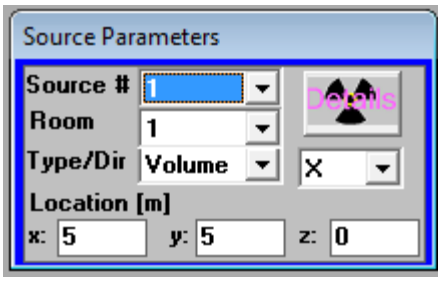

Radiological Units
Activity:
Bq
Dose:
m
Sv

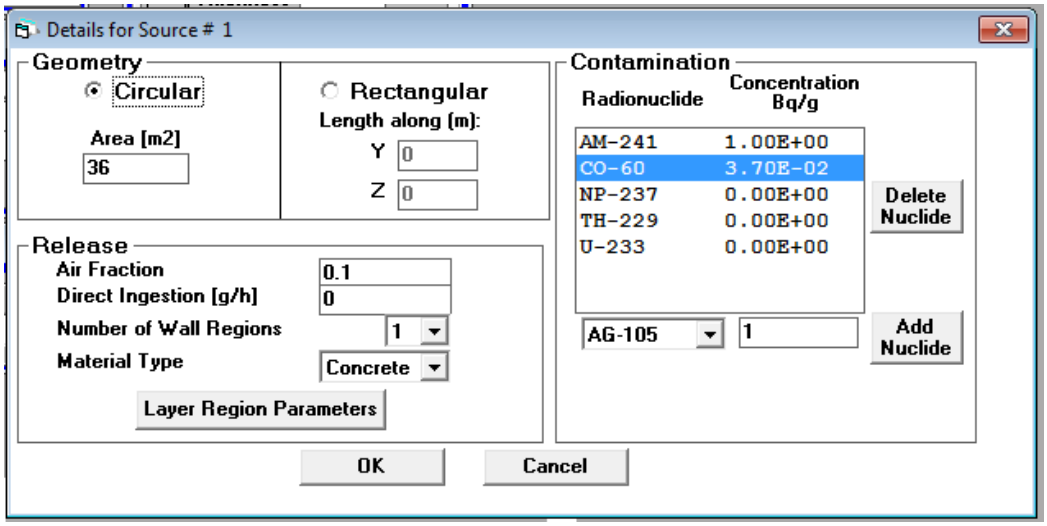

Receptor Parameters
Receptor #
1
Room
1
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 1

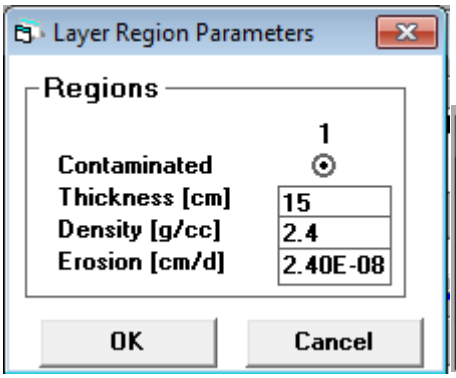

Receptor Parameters
Receptor #
2
Room
2
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 3.5

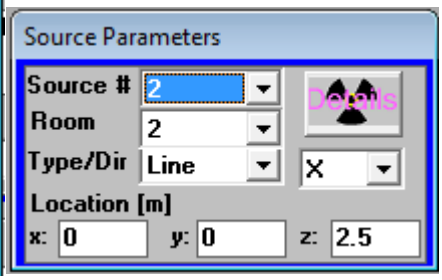

Receptor Parameters
Receptor #
3
Room
2
Time Fraction
1
Breathing Rate
18
m3/d
Ingestion Rate
0.0001
m2/h
Location [m]
x: 1
y: 1
z: 3.5

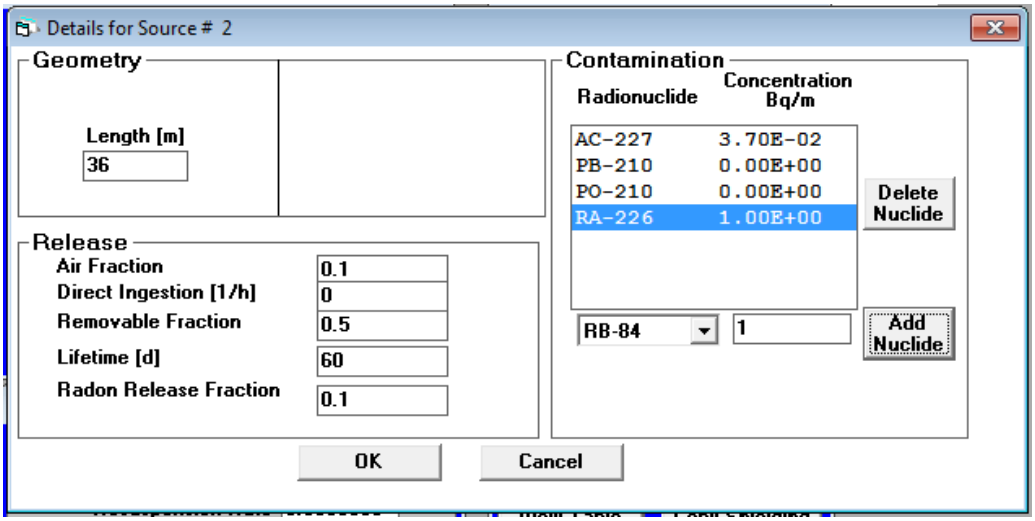

Source Receptor Table
Thickness
Density
Material
Source #
1
2
Receptor #
1
2
2
2.4
Concrete
2
0
2
2.4
Concrete
3
1
1
2.4
Concrete
Save and Exit
Cancel


Source Parameters
Source # 1
Room 1
Type/Dir Volume
X
Details
Location [m]
x: 5
y: 5
z: 0


Details for Source # 1
Geometry
Circular
Area [m2]
36
Rectangular
Length along (m):
Y 0
Z 0
Release
Air Fraction 0.1
Direct Ingestion [g/h] 0
Number of Wall Regions 1
Material Type Concrete
Layer Region Parameters
Contamination
Radionuclide
Concentration Bq/g
AM-241 1.00E+00
CO-60 3.70E-02
NP-237 0.00E+00
TH-229 0.00E+00
U-233 0.00E+00
Delete Nuclide
AG-105 1
Add Nuclide
OK
Cancel


Layer Region Parameters
Regions
1
Contaminated
Thickness [cm] 15
Density [g/cc] 2.4
Erosion [cm/d] 2.40E-08
OK
Cancel


Source Parameters
Source # 2
Room 2
Type/Dir Line
X
Details
Location [m]
x: 0
y: 0
z: 2.5



Required Data Input files "Test 36-1.BLD" and "Test 36-2.BLD" that were generated with Version 3.5 of the code.

Expected Results Version 4.0 (the version tested) should be able to read in the old input files generated with previous version of the code and continue the normal operations.

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APPENDIX B. RESRAD-BUILD Version 4.0 Release Testing Report

This appendix is a compilation of the separate test reports prepared by various testers who conducted the RESRAD-BUILD Version 4.0 release testing. The release testing was conducted December 15-19, 2022, using the candidate beta version, 4.0.19.0, and with the test cases designed by the RESRAD team (see Appendix A). The beta version successfully passed the release testing and was officially released as Version 4.0 on December 22, 2022.

The test cases were designed to verify that the RESRAD-BUILD code meets each of the software requirements, which include but are not limited to (1) proper functioning of the interface to accept input data, access the nuclide databases, launch calculations, and display calculation results; (2) perform calculations that implement the methodology and models as described in the User's Manual; and (3) ensure compatibility with the Windows® operating system and with the input files generated by the previously released Version 3.5.

In general, the RESRAD-BUILD code is considered to pass the testing with a test case when it performs as expected or produces expected calculation results. In many cases, the expected calculation results are those that were verified by spreadsheets that implement the same methodology or model for specific building and exposure conditions and calculate radiation doses associated with external radiation, inhalation, and ingestion exposures of selected receptors to selected radionuclides. Chapters 2 and 3 of this report detail the comparisons of results calculated by the RESRAD-BUILD code Version 4.0 and the verification spreadsheets.

Some of the release testing was documented as video recordings, showing maneuvering in the interface to verify the functioning of the various features and input and output options provided by the interface. These recordings were saved in a designated folder in the RESRAD program central storage location and are not included in this appendix. The test reports included in this appendix are ordered by each test case's identification number.

1. TEST CASE 001

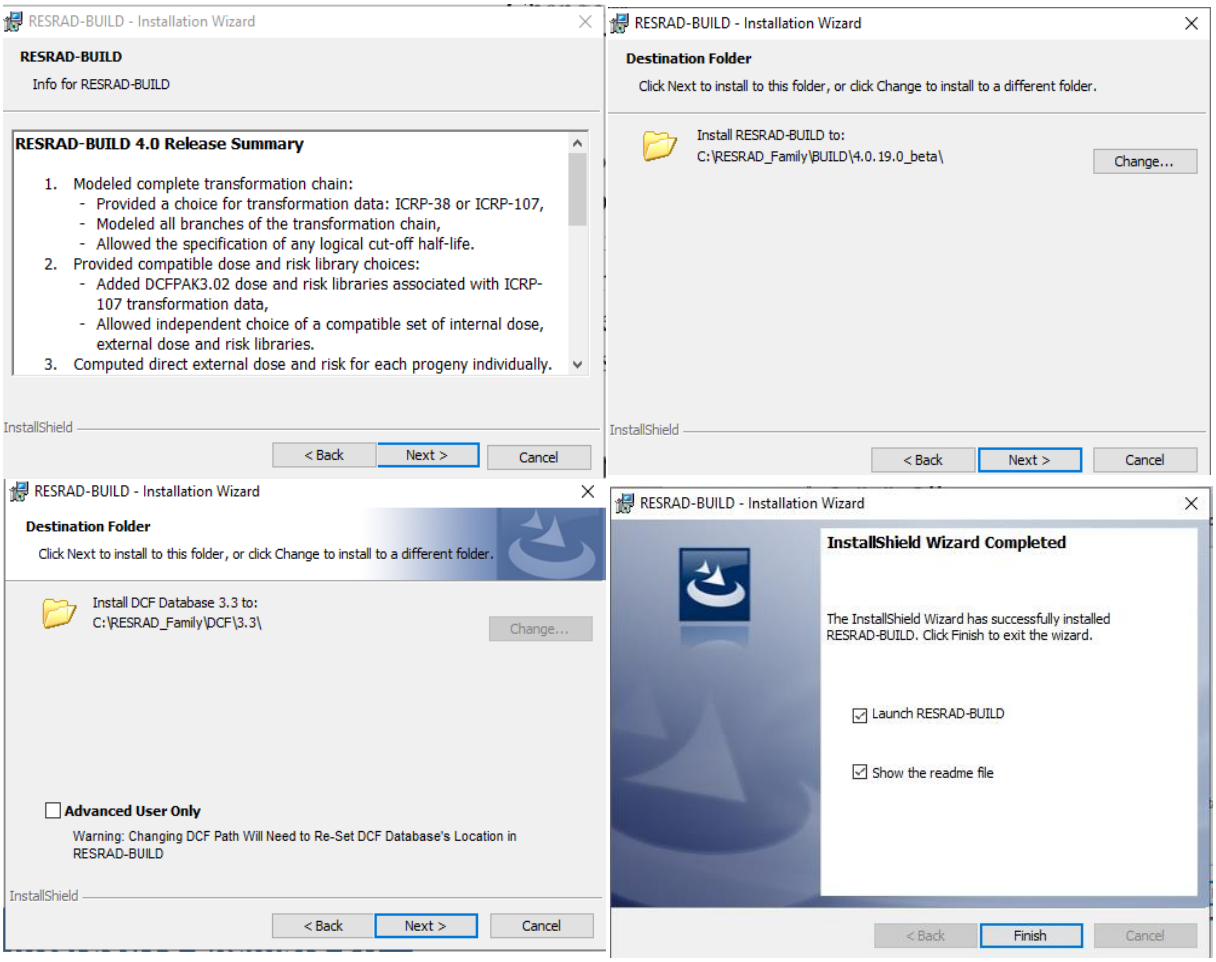
Test objectives/descriptions:

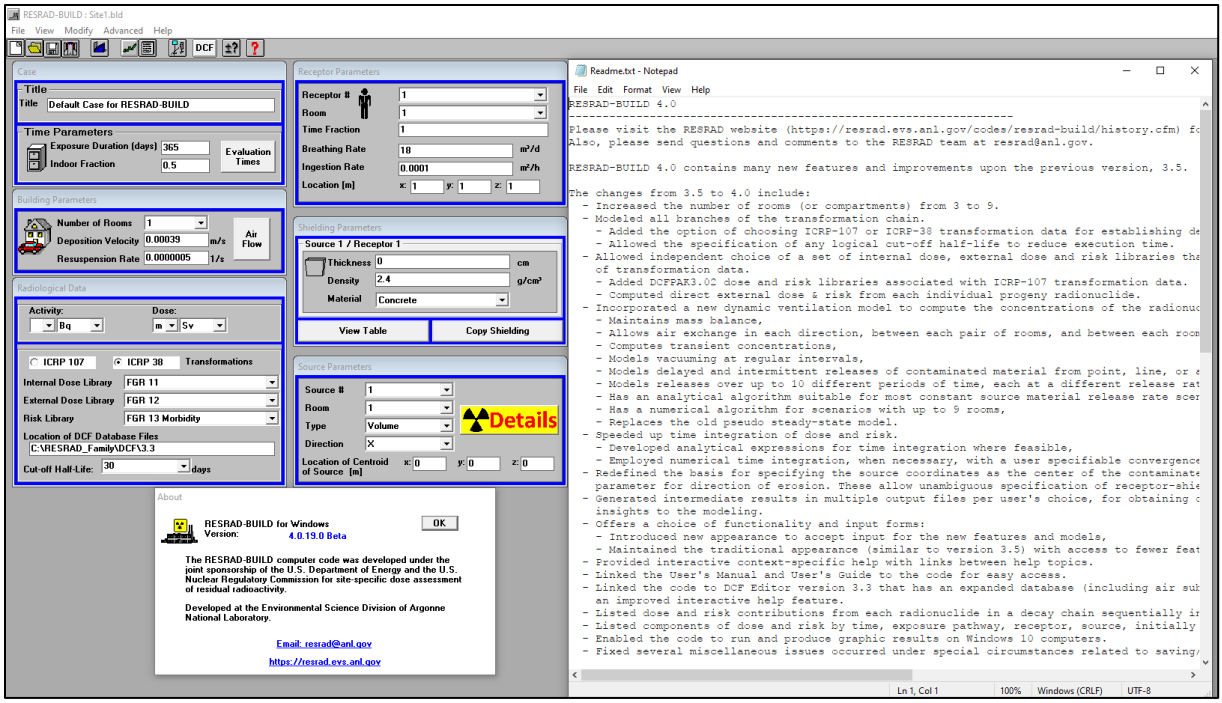
To test installation and operation with the Windows operating system.

Test result (Pass/Fail): Pass

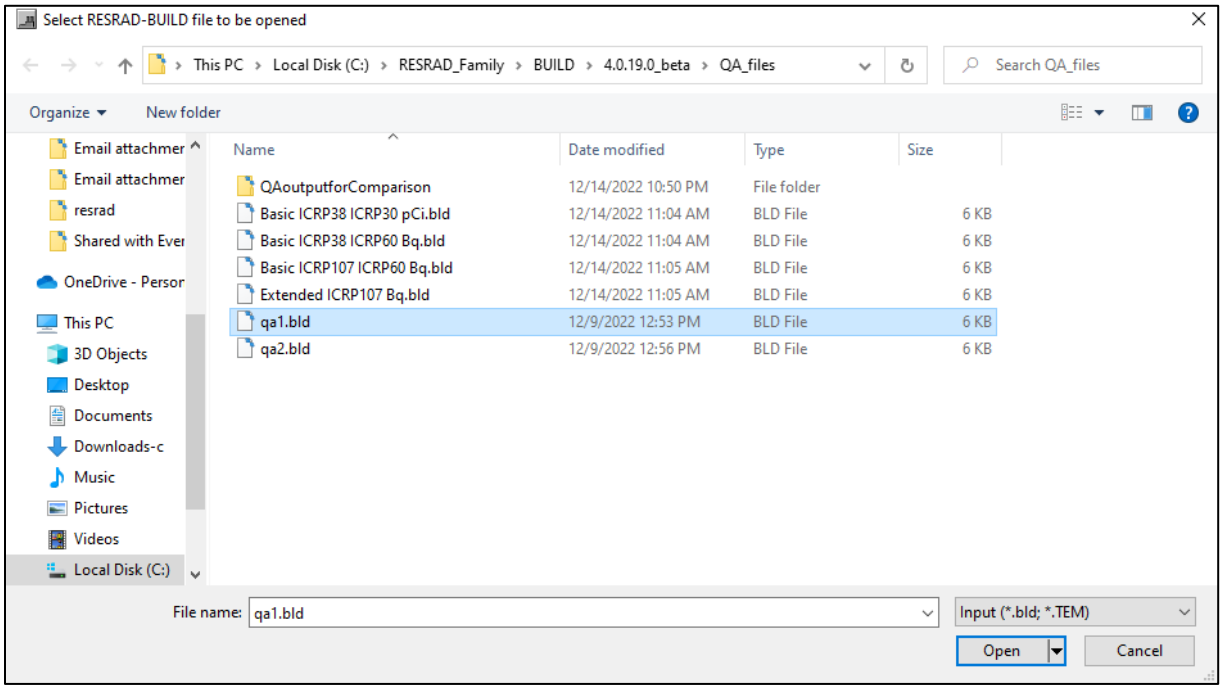
Test details:

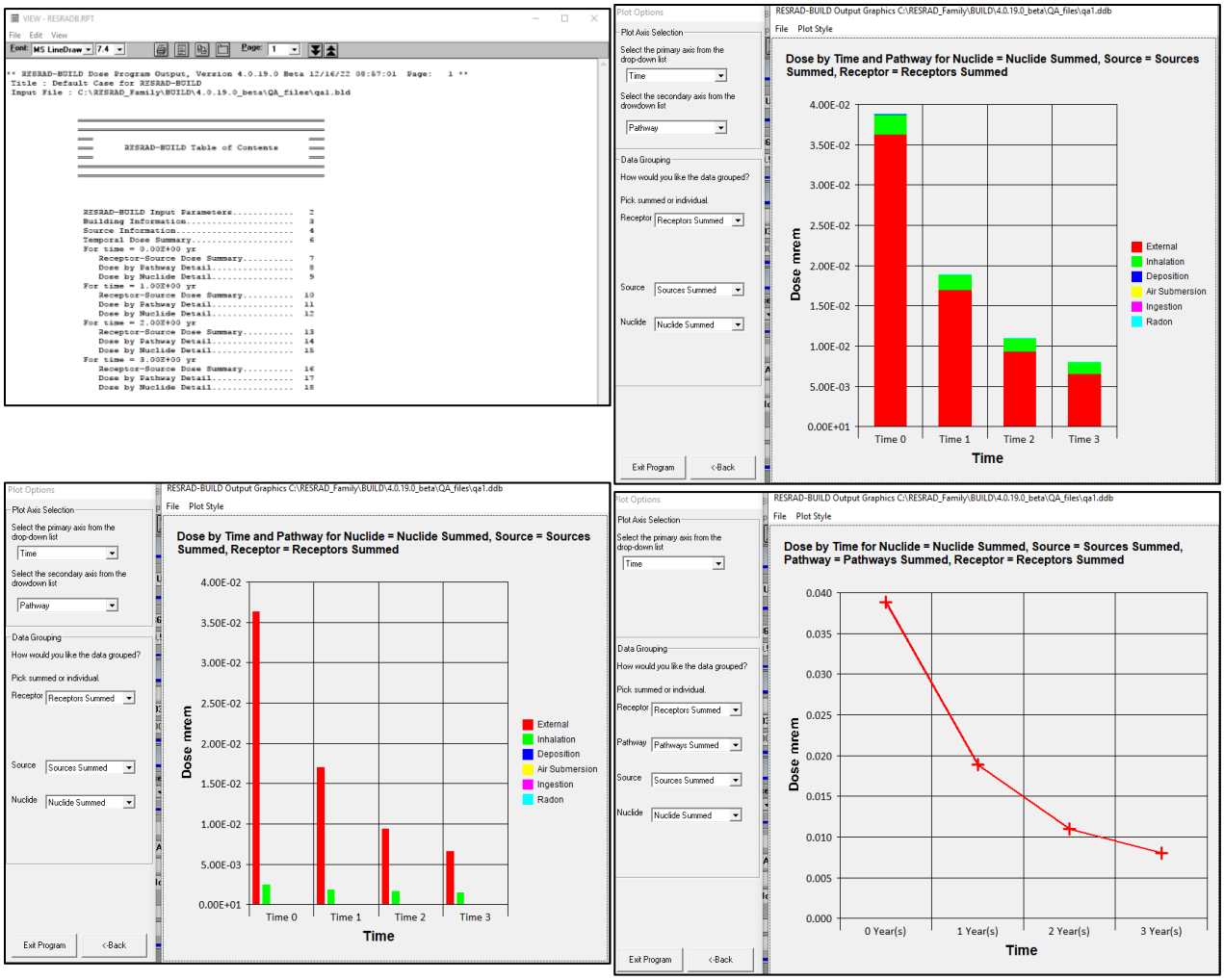
(1) Installed the code to the default location by double-clicking the installation and using all the default settings. Checked whether the functionality of opening the Readme file and launching the code works at the end of installation. It worked as expected.





(2) Opened "qa1.bld" in QA_files, the subfolder of where the RESRAD-BUILD code was installed and ran it. Compared the dose report file with the file "QA_files\QAoutputforComparison\qa1.RPT" and saved the comparison result to file "difference_qa1.gra." Differences were only in reporting time and code version number. Checked the display of graphics and report, especially the font and special characters. All looked properly displayed. Therefore, the code performed as expected.





(3) Repeated Step 2 using the "qa2.bld" file in the same subfolder and saved the comparison result to the file "difference_qa2.gra." The code performed as expected.

2. TEST CASE 002

Test objectives/descriptions:

The objective of the test was to verify that conceptual models involving multiple rooms, sources, and receptors could be constructed and analyzed by the code.

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, the RESRAD-BUILD Test Cases report. Eight input files were generated, and calculations were launched with each input file. The RESRAD-BUILD code allowed for the specifications of different numbers of rooms, receptors, sources, and their characteristics without any issues. Calculations were completed with each input file.

Test result (Pass/Fail): Pass

Test details:

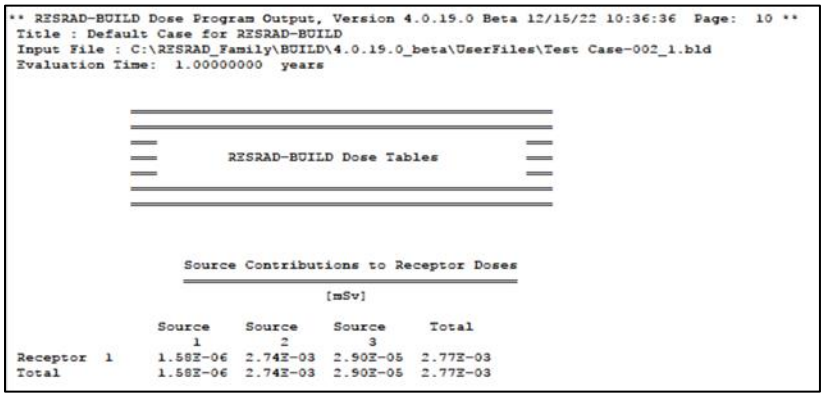
Input specifications from RESBLD-Test-001, Rev. 2:

Table. Input Specifications

Test No.	Form Appearance	No. of Rooms in Building	No. of Receptors	Receptor Room No.	No. of Sources	Source Room No.	Source Type	No. of Release Phases of Each Source
1	Traditional	1	1	1	3	1, 1, 1	A, V, L	1, 1, 1
2	Traditional	2	3	1, 2, 1	2	1, 2	A, V	1, 1
3	Traditional	3	5	1, 2, 3, 2, 1	5	3, 2, 1, 2, 3	A, L, P, A, V	1, 1, 1, 1, 1
4	New	2	6	1, 1, 1, 2, 2, 2	1	2	V	1
5	New	4	8	1, 2, 3, 4, 4, 3, 2, 1	4	4, 3, 2, 1	V, V, A, L	1, 1, 2, 3
6	New	6	10	1, 2, 3, 4, 5, 6, 1, 2, 4, 6	5	2, 4, 6, 5, 3	A, A, V, V, L	5, 7, 1, 1, 4
7	New	8	5	2, 4, 6, 8, 1	7	1, 2, 3, 4, 5, 6, 7	A, V, A, V, L, P, V	5, 1, 4, 1, 6, 9, 1
8	New	9	3	3, 6, 9	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 9	V, V, V, V, A, A, A, A, L, P	1, 1, 1, 1, 3, 6, 9, 10, 5, 3

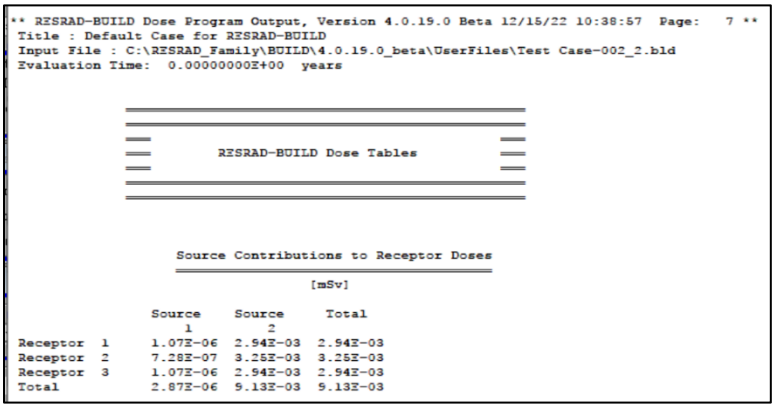
Source Type —A: Area, L: Line, P: Point, V: Volume.

(1) Test No. 1 results – Input file generated, "Test-002_1.bld." The input echo of the summary report reflected the input specifications. Dose results to each receptor from different sources were successfully calculated.



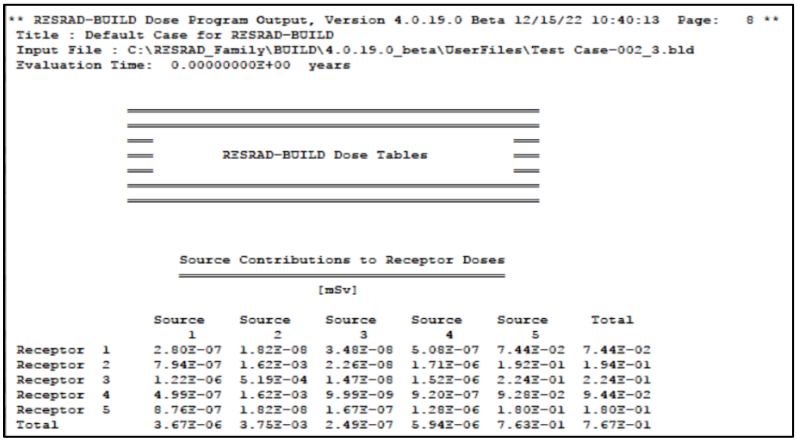
```
** RESRAD-BUILD Dose Program Output, Version 4.0.15.0 Beta 12/15/22 10:36:36  Page:  10 **
Title : Default Case for RESRAD-BUILD
Input File : C:\RESRAD_Family\BUILD\4.0.15.0_beta\UserFiles\Test Case-002_1.bld
Evaluation Time:  1.00000000  years

                    RESRAD-BUILD Dose Tables


                Source Contributions to Receptor Doses
                              [mSv]

                 Source     Source     Source      Total
                    1          2          3
Receptor  1   1.58E-06   2.74E-03   2.90E-05   2.77E-03
Total         1.58E-06   2.74E-03   2.90E-05   2.77E-03
```

(2) Test No. 2 results – Input file generated, "Test-002_2.bld." Input echo of the summary report reflected the input specifications. Dose results to each receptor from different sources were successfully calculated.



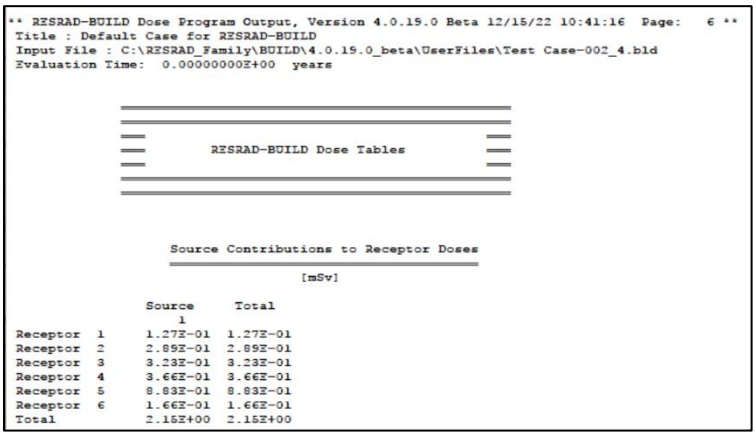
```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/15/22 10:38:57  Page:   7 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Test Case-002_2.bld
 Evaluation Time:  0.00000000E+00  years

                    RESRAD-BUILD Dose Tables


                 Source Contributions to Receptor Doses
                                 [mSv]

                  Source     Source      Total
                      1          2
Receptor  1     1.07E-06  2.94E-03  2.94E-03
Receptor  2     7.28E-07  3.25E-03  3.25E-03
Receptor  3     1.07E-06  2.94E-03  2.94E-03
Total           2.87E-06  9.13E-03  9.13E-03
```

(3) Test No. 3 results – Input file generated, Test-002_3.bld. The input echo of the summary report reflected the input specifications. Dose results to each receptor from different sources were successfully calculated.



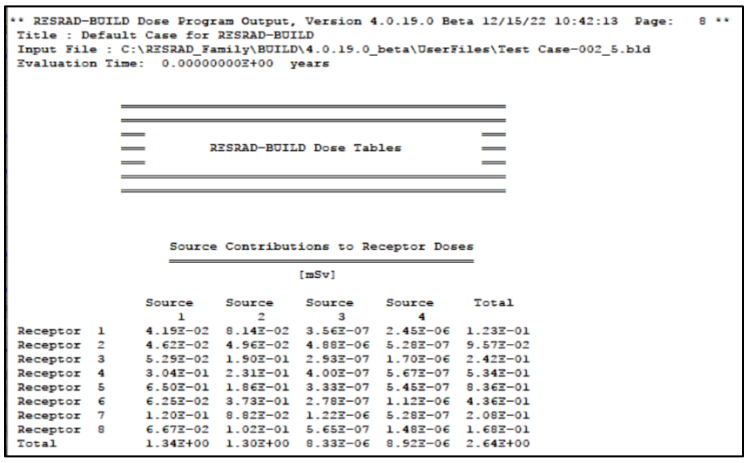
```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/15/22 10:40:13  Page:   8 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Test Case-002_3.bld
 Evaluation Time:  0.00000000E+00  years

                    RESRAD-BUILD Dose Tables


                 Source Contributions to Receptor Doses
                                 [mSv]

                  Source     Source     Source     Source     Source      Total
                      1          2          3          4          5
Receptor  1     2.80E-07  1.82E-08  3.48E-08  5.08E-07  7.44E-02  7.44E-02
Receptor  2     7.94E-07  1.62E-03  2.26E-08  1.71E-06  1.92E-01  1.94E-01
Receptor  3     1.22E-06  5.19E-04  1.47E-08  1.52E-06  2.24E-01  2.24E-01
Receptor  4     4.99E-07  1.62E-03  9.99E-09  9.20E-07  9.28E-02  9.44E-02
Receptor  5     8.76E-07  1.82E-08  1.67E-07  1.28E-06  1.80E-01  1.80E-01
Total           3.67E-06  3.75E-03  2.49E-07  5.94E-06  7.63E-01  7.67E-01
```

(4) Test No. 4 results – Input file generated, "Test-002_4.bld." The input echo of the summary report reflected the input specifications. Dose results to each receptor from different sources were successfully calculated.



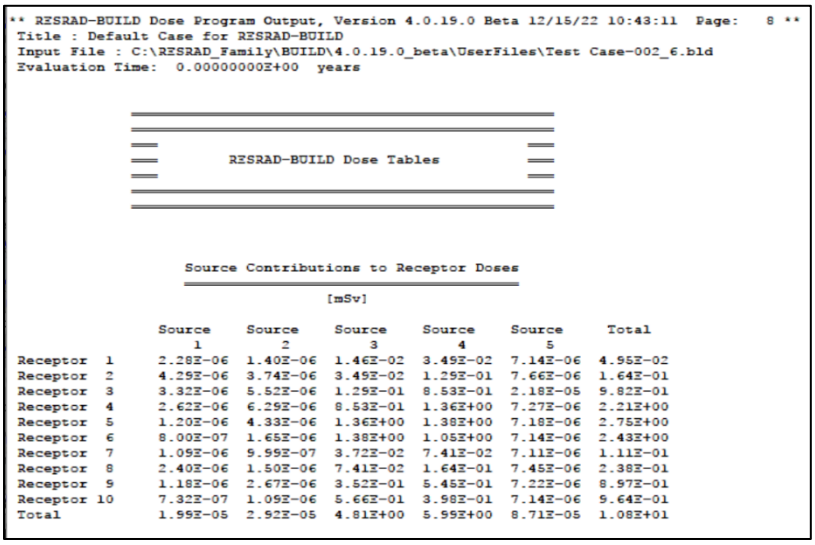
```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/15/22 10:41:16  Page:   6 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Test Case-002_4.bld
 Evaluation Time:  0.00000000E+00  years

                    RESRAD-BUILD Dose Tables


                 Source Contributions to Receptor Doses
                                 [mSv]

                  Source      Total
                      1
Receptor  1     1.27E-01  1.27E-01
Receptor  2     2.89E-01  2.89E-01
Receptor  3     3.23E-01  3.23E-01
Receptor  4     3.66E-01  3.66E-01
Receptor  5     8.83E-01  8.83E-01
Receptor  6     1.66E-01  1.66E-01
Total           2.15E+00  2.15E+00
```

(5) Test No. 5 results – Input file generated, "Test-002_5.bld." The input echo of the summary report reflected the input specifications. Dose results to each receptor from different sources were successfully calculated.



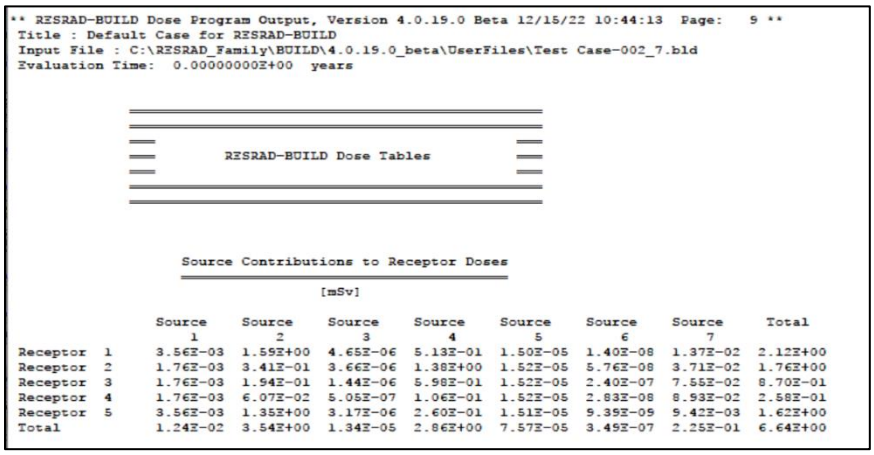
```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/15/22 10:42:13  Page:   8 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Test Case-002_5.bld
 Evaluation Time:  0.00000000E+00  years

                    RESRAD-BUILD Dose Tables

                  Source Contributions to Receptor Doses
                                  [mSv]

                  Source     Source     Source     Source     Total
                     1          2          3          4
Receptor  1     4.19E-02   8.14E-02   3.56E-07   2.45E-06   1.23E-01
Receptor  2     4.62E-02   4.96E-02   4.88E-06   5.28E-07   9.57E-02
Receptor  3     5.29E-02   1.90E-01   2.93E-07   1.70E-06   2.42E-01
Receptor  4     3.04E-01   2.31E-01   4.00E-07   5.67E-07   5.34E-01
Receptor  5     6.50E-01   1.86E-01   3.33E-07   5.45E-07   8.36E-01
Receptor  6     6.25E-02   3.73E-01   2.78E-07   1.12E-06   4.36E-01
Receptor  7     1.20E-01   8.82E-02   1.22E-06   5.28E-07   2.08E-01
Receptor  8     6.67E-02   1.02E-01   5.65E-07   1.48E-06   1.68E-01
Total           1.34E+00   1.30E+00   8.33E-06   8.92E-06   2.64E+00
```

(6) Test No. 6 results – Input file generated, "Test-002_6.bld." The input echo of the summary report reflected the input specifications. Dose results to each receptor from different sources were successfully calculated.



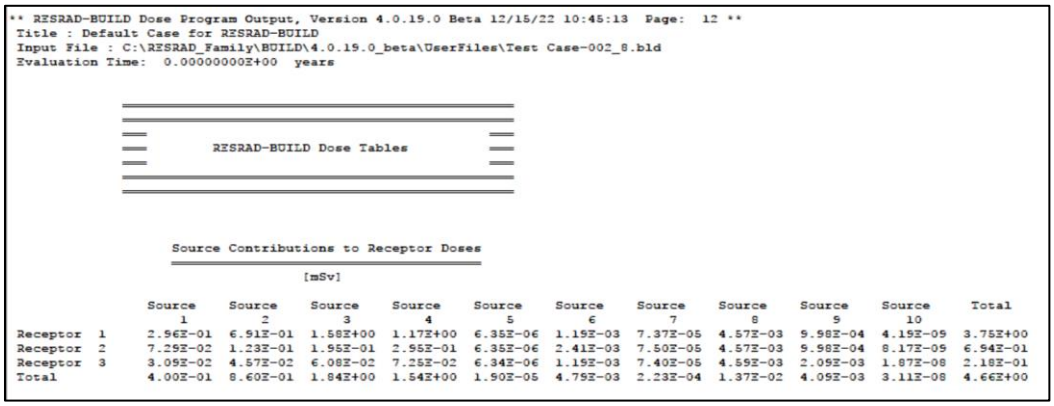
```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/15/22 10:43:11  Page:   8 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Test Case-002_6.bld
 Evaluation Time:  0.00000000E+00  years

                    RESRAD-BUILD Dose Tables

                  Source Contributions to Receptor Doses
                                  [mSv]

                  Source     Source     Source     Source     Source     Total
                     1          2          3          4          5
Receptor  1     2.28E-06   1.40E-06   1.46E-02   3.49E-02   7.14E-06   4.95E-02
Receptor  2     4.29E-06   3.74E-06   3.49E-02   1.29E-01   7.66E-06   1.64E-01
Receptor  3     3.32E-06   5.52E-06   1.29E-01   8.53E-01   2.18E-05   9.82E-01
Receptor  4     2.62E-06   6.29E-06   8.53E-01   1.36E+00   7.27E-06   2.21E+00
Receptor  5     1.20E-06   4.33E-06   1.36E+00   1.38E+00   7.18E-06   2.75E+00
Receptor  6     8.00E-07   1.65E-06   1.38E+00   1.05E+00   7.14E-06   2.43E+00
Receptor  7     1.09E-06   9.99E-07   3.72E-02   7.41E-02   7.11E-06   1.11E-01
Receptor  8     2.40E-06   1.50E-06   7.41E-02   1.64E-01   7.45E-06   2.38E-01
Receptor  9     1.18E-06   2.67E-06   3.52E-01   5.45E-01   7.22E-06   8.97E-01
Receptor 10     7.32E-07   1.09E-06   5.66E-01   3.98E-01   7.14E-06   9.64E-01
Total           1.99E-05   2.92E-05   4.81E+00   5.99E+00   8.71E-05   1.08E+01
```

(7) Test No. 7 results – Input file generated, "Test-002_7.bld." The input echo of the summary report reflected the input specifications. Dose results to each receptor from different sources were successfully calculated.



```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/15/22 10:44:13  Page:   9 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Test Case-002_7.bld
 Evaluation Time:  0.00000000E+00  years

                    RESRAD-BUILD Dose Tables

                  Source Contributions to Receptor Doses
                                  [mSv]

                 Source     Source     Source     Source     Source     Source     Source      Total
                    1          2          3          4          5          6          7
Receptor  1    3.56E-03   1.59E+00   4.65E-06   5.13E-01   1.50E-05   1.40E-08   1.37E-02   2.12E+00
Receptor  2    1.76E-03   3.41E-01   3.66E-06   1.38E+00   1.52E-05   5.76E-08   3.71E-02   1.76E+00
Receptor  3    1.76E-03   1.94E-01   1.44E-06   5.98E-01   1.52E-05   2.40E-07   7.55E-02   8.70E-01
Receptor  4    1.76E-03   6.07E-02   5.05E-07   1.06E-01   1.52E-05   2.83E-08   8.93E-02   2.58E-01
Receptor  5    3.56E-03   1.35E+00   3.17E-06   2.60E-01   1.51E-05   9.39E-09   9.42E-03   1.62E+00
Total          1.24E-02   3.54E+00   1.34E-05   2.86E+00   7.57E-05   3.45E-07   2.25E-01   6.64E+00
```

(8) Test No. 8 results – Input file generated, "Test-002_8.bld." The input echo of the summary report reflected the input specifications. Dose results to each receptor from different sources were successfully calculated.



```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/15/22 10:45:13  Page:  12 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Test Case-002_8.bld
 Evaluation Time:  0.00000000E+00  years

                    RESRAD-BUILD Dose Tables

                  Source Contributions to Receptor Doses
                                  [mSv]

                 Source     Source     Source     Source     Source     Source     Source     Source     Source     Source      Total
                    1          2          3          4          5          6          7          8          9          10
Receptor  1    2.96E-01   6.91E-01   1.58E+00   1.17E+00   6.35E-06   1.15E-03   7.37E-05   4.57E-03   9.98E-04   4.19E-09   3.75E+00
Receptor  2    7.29E-02   1.23E-01   1.95E-01   2.95E-01   6.35E-06   2.41E-03   7.50E-05   4.57E-03   9.98E-04   8.17E-09   6.94E-01
Receptor  3    3.09E-02   4.57E-02   6.08E-02   7.25E-02   6.34E-06   1.15E-03   7.40E-05   4.59E-03   2.09E-03   1.87E-08   2.18E-01
Total          4.00E-01   8.60E-01   1.84E+00   1.54E+00   1.90E-05   4.79E-03   2.23E-04   1.37E-02   4.09E-03   3.11E-08   4.66E+00
```

3. TEST CASE 005

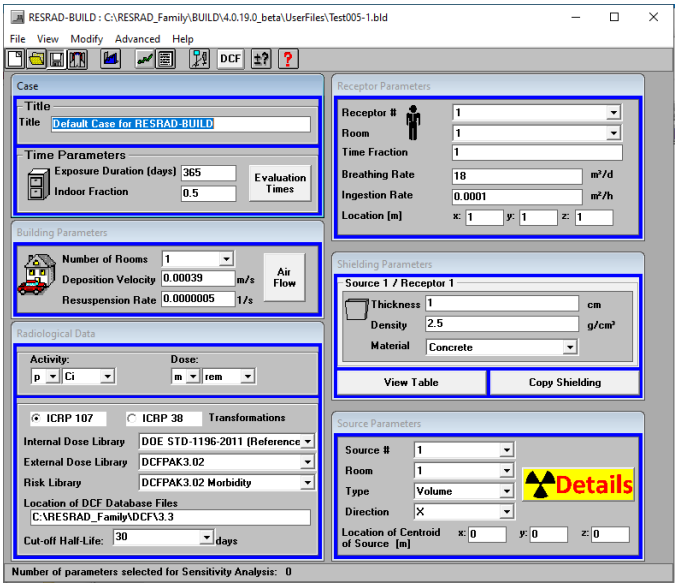
Test objectives/descriptions:

To test the specification of shielding between radiation sources and receptors.

Test result (Pass/Fail): Pass

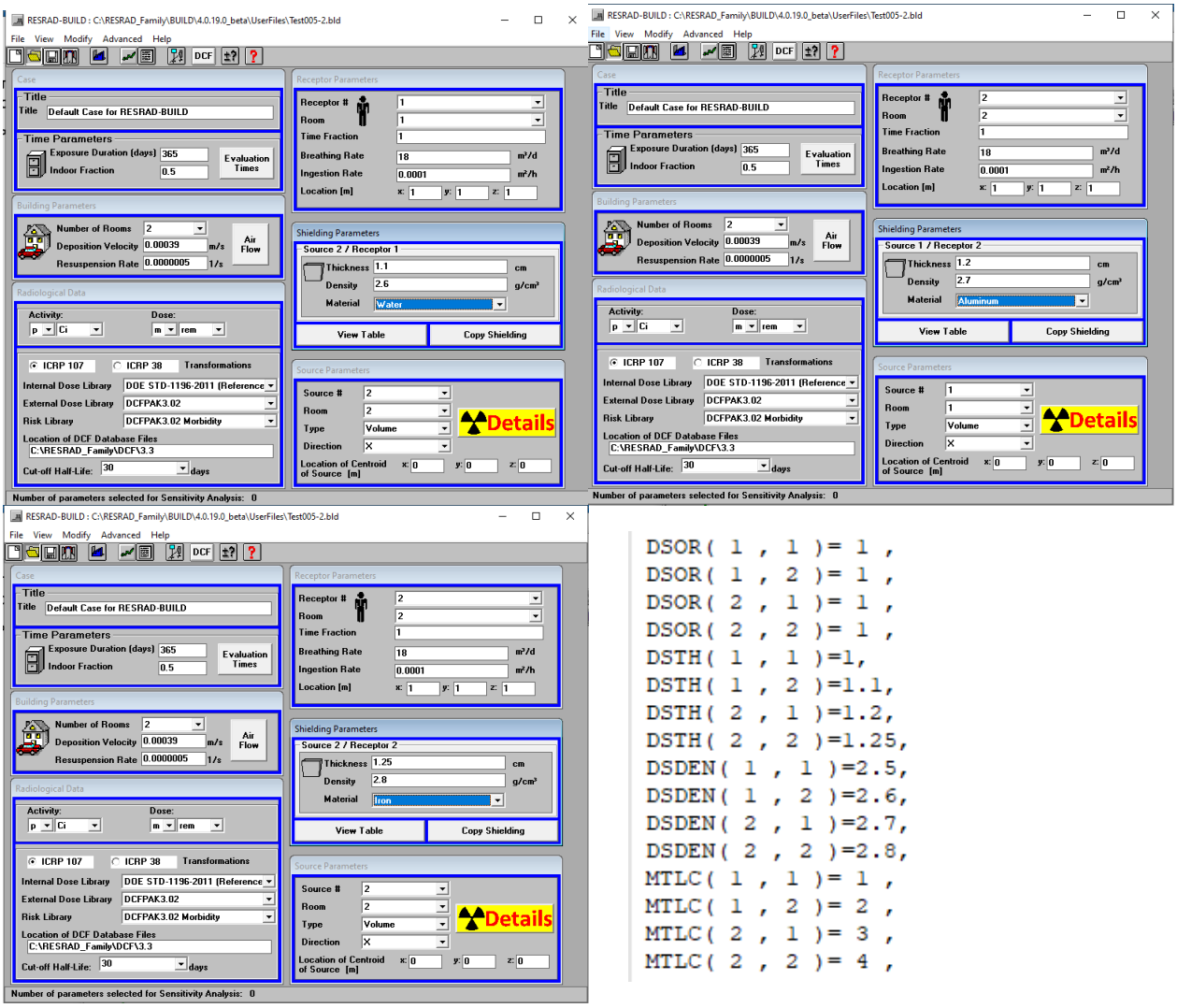
Test details:

(1) Launched the code and specified values to Thickness, Density, and Material in the Shielding Parameter window. Saved the file as "Test005-1.bld." The values for the shielding parameters in the input file matched those specified in the interface. The code performed as expected.



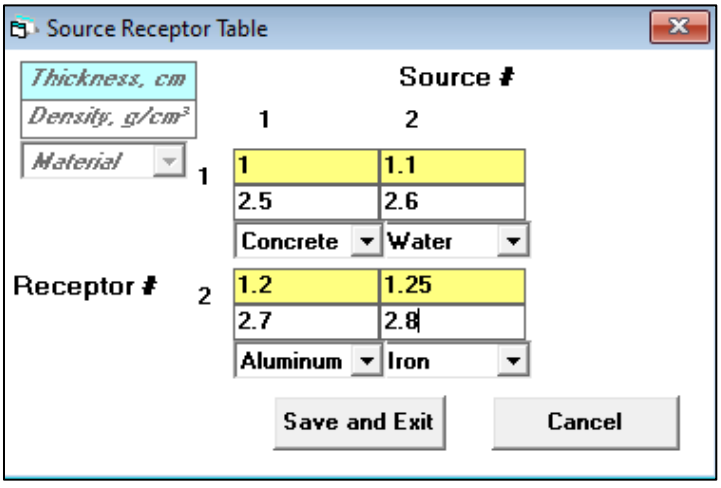

```
DSOR( 1 , 1 )= 1 ,
DSTH( 1 , 1 )=1,
DSDEN( 1 , 1 )=2.5,
MTLC( 1 , 1 )= 1 ,
```

(2) Opened "Test005-1.bld" and added a source and receptor in Room 2. Specified the Thickness, Density, and Material for shielding between Source 2 and Receptor 2 in the Shielding Parameter window and saved the inputs to "Test005-2.bld." Opened the generated input file and compared the values for the shielding parameters. They were identical to those input in the interface. The code performed as expected.

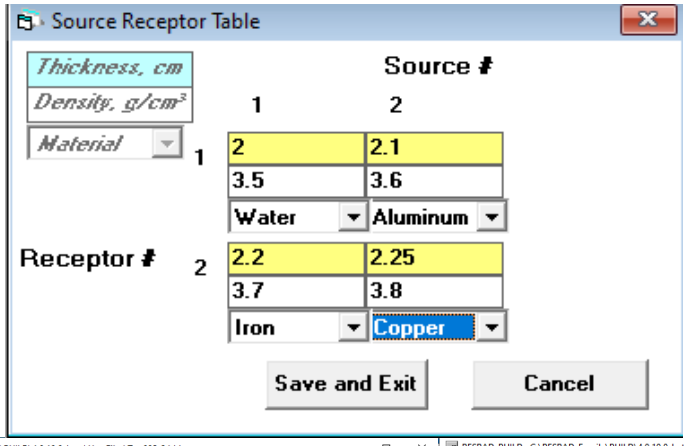


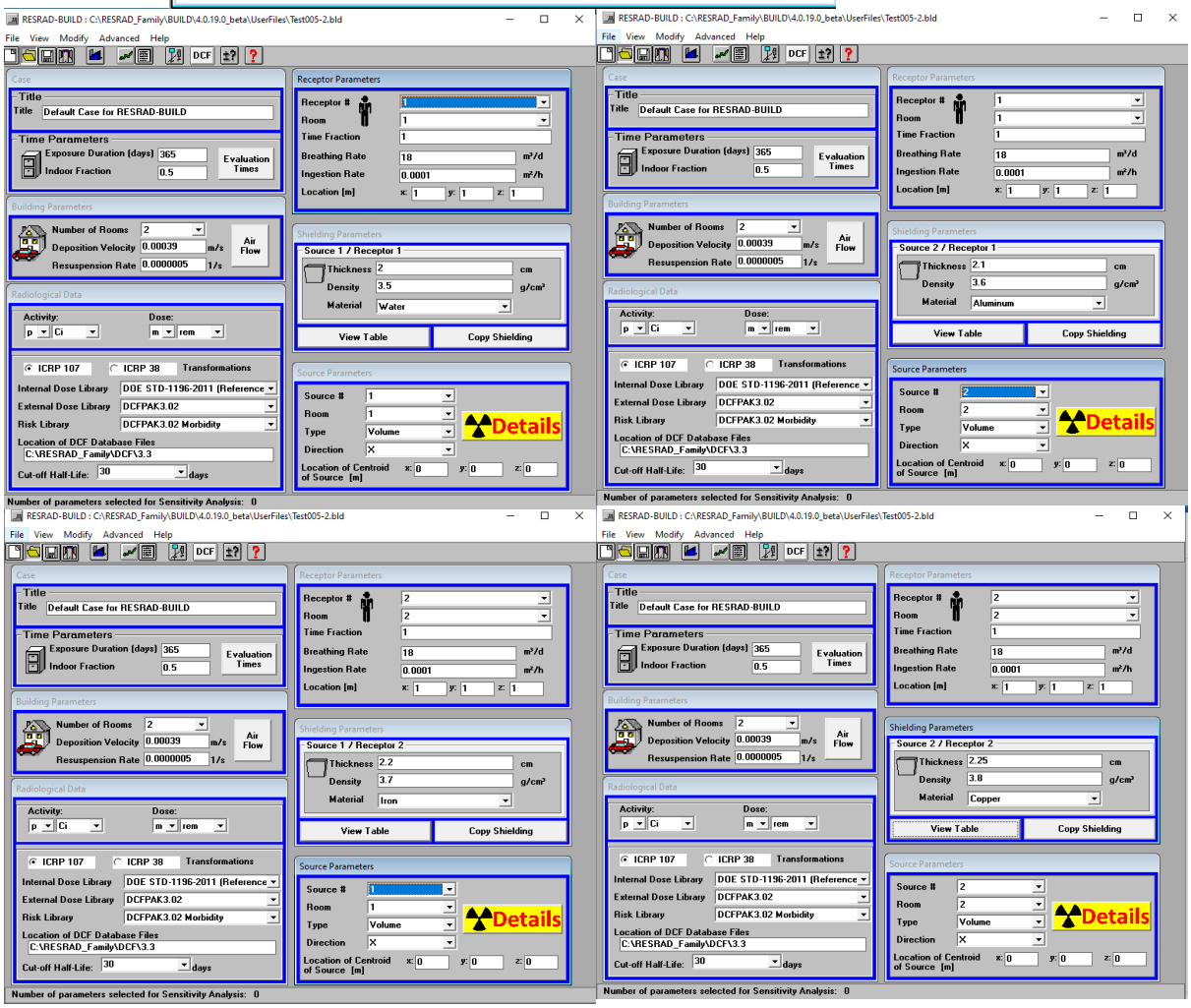

```
DSOR( 1 , 1 )= 1 ,
DSOR( 1 , 2 )= 1 ,
DSOR( 2 , 1 )= 1 ,
DSOR( 2 , 2 )= 1 ,
DSTH( 1 , 1 )=1,
DSTH( 1 , 2 )=1.1,
DSTH( 2 , 1 )=1.2,
DSTH( 2 , 2 )=1.25,
DSDEN( 1 , 1 )=2.5,
DSDEN( 1 , 2 )=2.6,
DSDEN( 2 , 1 )=2.7,
DSDEN( 2 , 2 )=2.8,
MTLC( 1 , 1 )= 1 ,
MTLC( 1 , 2 )= 2 ,
MTLC( 2 , 1 )= 3 ,
MTLC( 2 , 2 )= 4 ,
```

(3) Opened "Test005-2.bld." Clicked the View Table button in the Shielding Parameters window to check whether the values shown in the pop-up window matched those shown in the main interface. The code worked as expected.

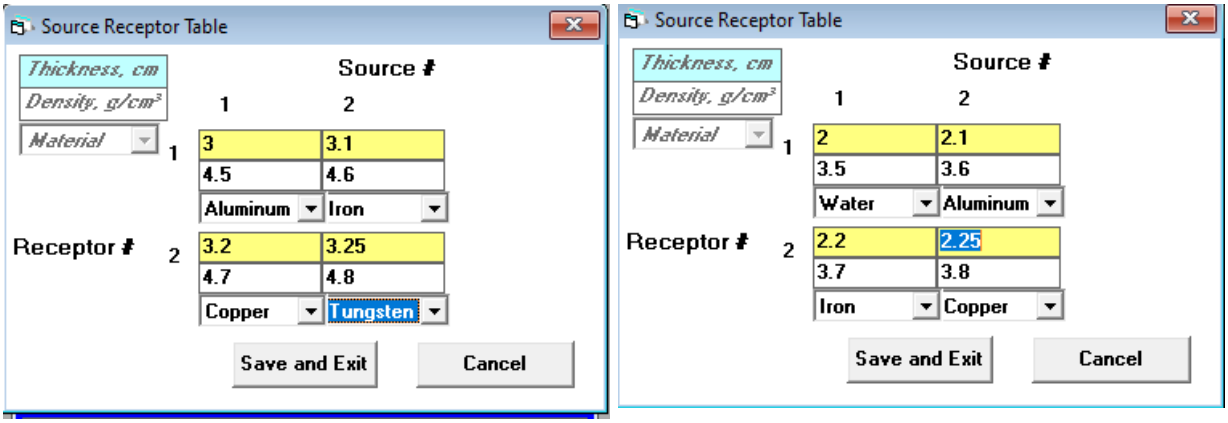


(4) Opened “Test005-2.bld,” then clicked the View Table button in the Shielding Parameter window, made changes to the values, and then clicked the Save and Exit button in the Source Receptor Table. Checked the values in the main interface. The values matched those modified in the Source Receptor Table window.

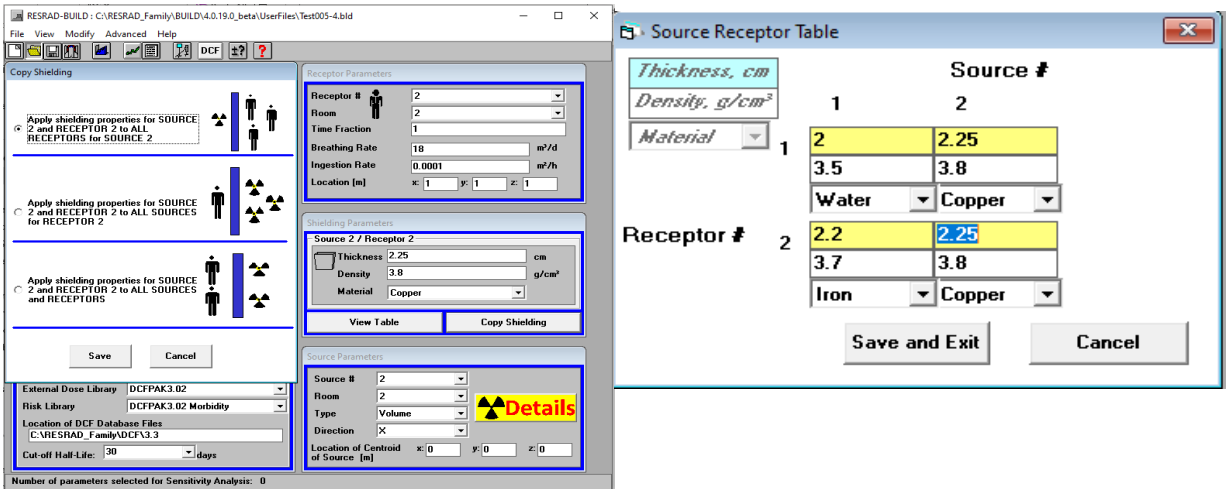




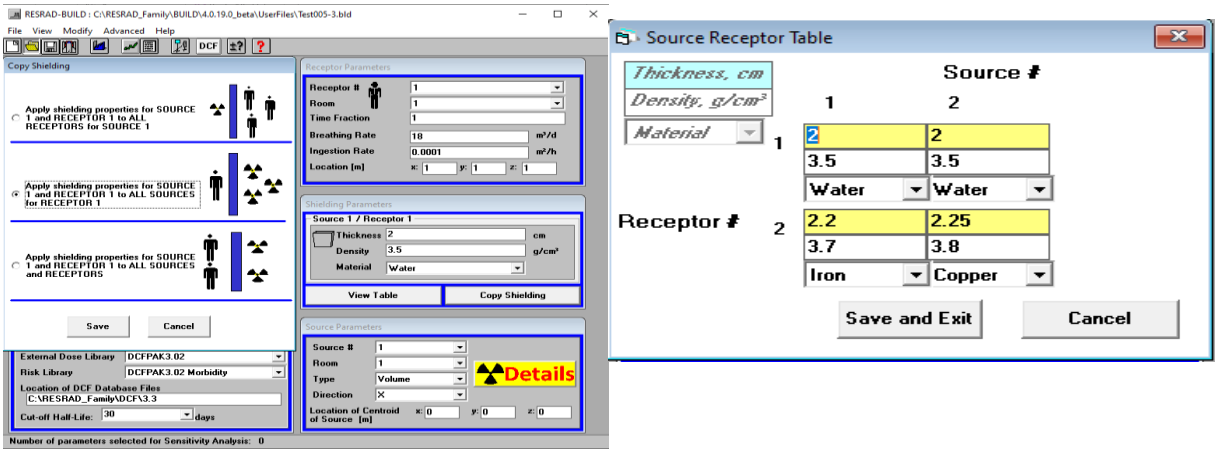
(5) Saved the inputs to "Test005-3.bld." Repeated Step 4 (as shown in the left panel of the figure below) but clicked the Cancel button this time rather than the Save and Exit button. Checked the values in the main interface, which remained the same as prior to the change, as shown in the right panel of the figure below.



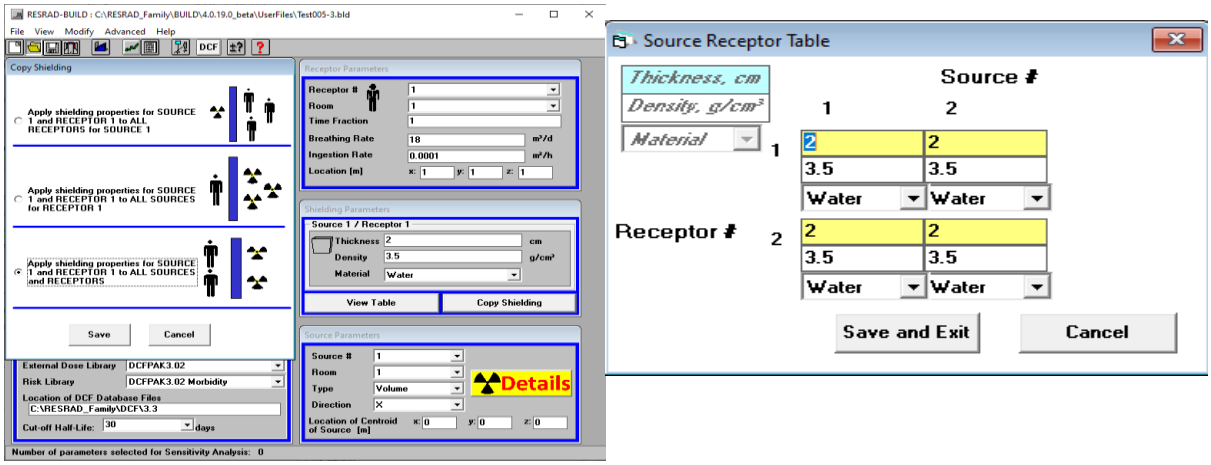
(6) Opened "Test005-3.bld" with Receptor 2 and Source 2 shown in the main interface and then clicked the Copy Shielding button in the Shielding Parameters window. The Copy Shielding window popped up. Selected the first option and then saved the change. Checked whether the shielding parameters for Source 2 and Receptor 2 were applied to Receptor 1/Source 2. Saved the inputs to "Test005-4.bld." The code performed as expected.



(7) Opened “Test005-3.bld” and made sure the Shielding Parameters window was showing for Source 1/Receptor 1. Clicked Copy Shielding, selected the second option, and saved the changes. Checked whether the changes were shown in the main interface and saved the inputs to “Test005-4.bld.” The code worked as expected.



(8) Repeated Step 7 but selected the third option. The code performed as expected.



4. TEST CASE 006

Test objectives/descriptions:

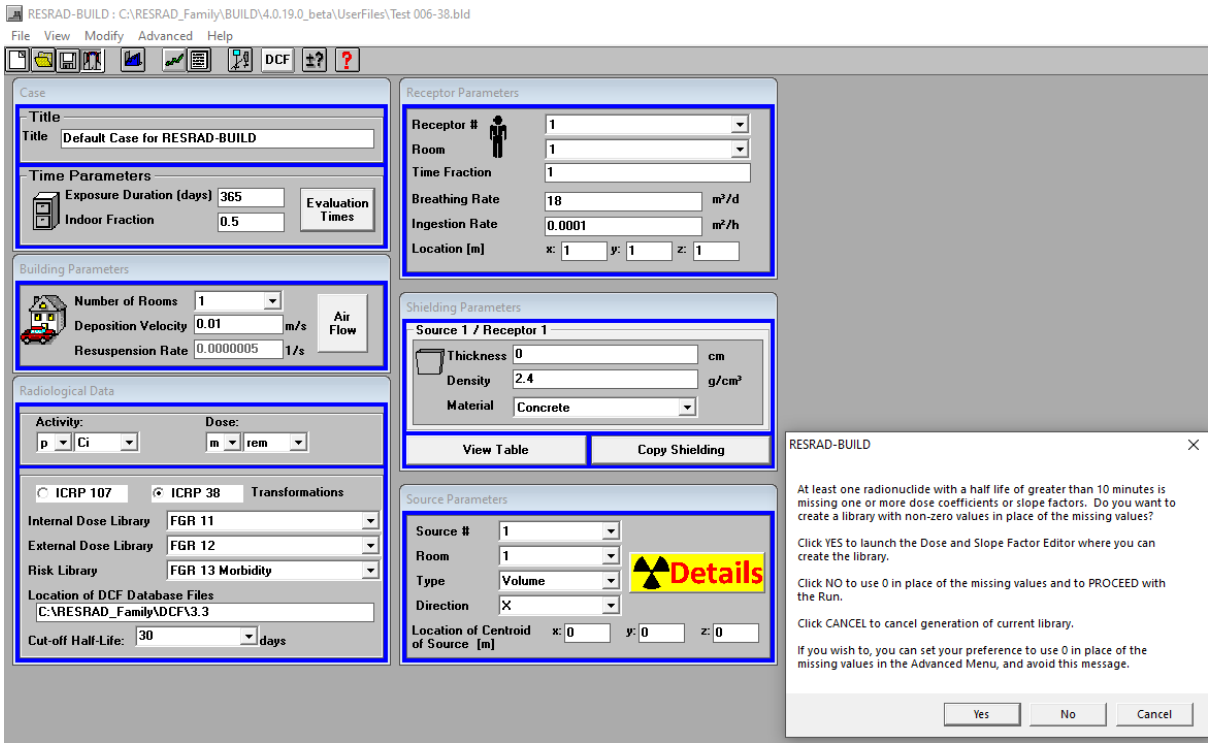
To test the assembly of decay chains based on a specified transformation database and input cutoff half-life.

Test result (Pass/Fail): Pass

Test details:

(1) Copied the files "Test 006-38.bld" and "Input 006-107.bld" that are associated with this test case to the subfolder, UserFiles, of the RESRAD-BUILD code installation directory.

(2) Ran "Test 006-38.bld" with "No" selected in the pop-up warning message window and saved the results to "test006-1.rpt." Compared the results with the provided result file "test 006-38.RPT" and saved the comparison to "test006-38.dif," which showed only differences in the directory path, running time, and code version number. The code performed as expected.



(3) Repeated Step 2 using the provided "Input 006-107.bld" file and saved the comparison to "test006-107.dif." The code performed as expected.

5. TEST CASE 007

5.1 TEST CASE 007-1

Test objectives/descriptions:

The objective of the test was to verify the modeling of concentrations in the source, the modeling of the releases and ventilation, and the subsequent dose and risk calculations, with the intermediate outputs of time-averaged activity in the source, time-integrated direct ingestion, air release rate, time-averaged radionuclide concentration in the air and on the floor, dose and risk components, as well as the summary results of the inhalation (of particulates), ingestion, and air submersion pathway dose and risk to each receptor.

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. It involved retrieving the same input file previously used for verification, launching calculations, and comparing the results and outputs with those obtained previously, which were shown to agree with the calculation results from the verification spreadsheet.

The input file "Volume 1_S=1_EXP.BLD" associated with Test Case 007-1 was used to run the code. It considered a building with 9 rooms, 4 receptors in different rooms, and a volume source in Room 1 that released radioactivity into the air; no vacuuming of floor deposition was involved. The dose and risk coefficients used in calculations matched those provided in RESBLD-Test-001, Rev. 2; the intermediate outputs matched those in the verification spreadsheet file "Vol1_S=1.xlsx," and the pathway dose/risk results to each receptor matched those provided in RESBLD-Test-001, Rev. 2.

Test result (Pass/Fail): Pass

Test details:

(1) The aggregated dose and slope factors (including those of short-live progeny) from the run matched those provided in RESBLD-Test-001, Rev. 2.

(2) Time-averaged activity in the source and time-integrated direct ingestion of activity from the run matched those in "Vol1_S=1.xlsx":

Results from “Vol1_S=1.xlsx”

Time averaged activity from RRB E

iSrc	iTime	Parent	Porgeny	pCi	p
1	1	RA-226	RA-226	12864698.58	
1	1	RA-226	PB-210	49699.58387	
1	1	RA-226	PO-210	6776.713027	
1	2	RA-226	RA-226	12673990.75	
1	2	RA-226	PB-210	146696.8331	
1	2	RA-226	PO-210	41522.64202	
1	3	RA-226	RA-226	12483323.35	
1	3	RA-226	PB-210	240018.8003	
1	3	RA-226	PO-210	97815.28964	
1	4	RA-226	RA-226	12292697.44	
1	4	RA-226	PB-210	329705.631	
1	4	RA-226	PO-210	166189.72	
1	5	RA-226	RA-226	12102113.04	
1	5	RA-226	PB-210	415797.0256	
1	5	RA-226	PO-210	240752.0488	
1	6	RA-226	RA-226	11911569.06	
1	6	RA-226	PB-210	498332.3857	
1	6	RA-226	PO-210	317838.3615	
1	7	RA-226	RA-226	11721067.65	
1	7	RA-226	PB-210	577350.6139	
1	7	RA-226	PO-210	395176.8597	

Time Integrated direct ingestion (full occupancy), pC from RRB

iSrc	iTime	Parent	Porgeny	pCi
1	1	RA-226	RA-226	21.898819
1	1	RA-226	PB-210	0.084808298
1	1	RA-226	PO-210	0.011577215
1	2	RA-226	RA-226	21.8964481
1	2	RA-226	PB-210	0.253652513
1	2	RA-226	PO-210	0.071841106
1	3	RA-226	RA-226	21.8940773
1	3	RA-226	PB-210	0.421171427
1	3	RA-226	PO-210	0.171699181
1	4	RA-226	RA-226	21.8917065
1	4	RA-226	PB-210	0.587375283
1	4	RA-226	PO-210	0.29613328
1	5	RA-226	RA-226	21.8893356
1	5	RA-226	PB-210	0.752274275
1	5	RA-226	PO-210	0.435641676
1	6	RA-226	RA-226	21.8869648
1	6	RA-226	PB-210	0.915878534
1	6	RA-226	PO-210	0.584214151
1	7	RA-226	RA-226	21.884594
1	7	RA-226	PB-210	1.07819796
1	7	RA-226	PO-210	0.738050222

Time averaged activity from RRB

iSrc	iTime	Parent	Porgeny	pCi
1	1	CS-137	CS-137	12828423.49
1	2	CS-137	CS-137	12566824.26
1	3	CS-137	CS-137	12307813.75
1	4	CS-137	CS-137	12051368.56
1	5	CS-137	CS-137	11797470.59
1	6	CS-137	CS-137	11546096.44
1	7	CS-137	CS-137	11297226.95

Time Integrated direct ingestion (full occupancy), pC from RRB

iSrc	iTime	Parent	Porgeny	pCi
1	1	CS-137	CS-137	21.8369198
1	2	CS-137	CS-137	21.7111492
1	3	CS-137	CS-137	21.5861015
1	4	CS-137	CS-137	21.4617748
1	5	CS-137	CS-137	21.3381634
1	6	CS-137	CS-137	21.2152653
1	7	CS-137	CS-137	21.0930748

Results from the run

```
Time averaged activity
 iSrc iTime Parent Progeny pCi
 1 1 Ra-226  Ra-226  12864698.57893049
 1 1 Ra-226  Pb-210  49699.58387011669
 1 1 Ra-226  Po-210  6776.713026889904
 1 2 Ra-226  Ra-226  12673990.74743785
 1 2 Ra-226  Pb-210  146696.8331040081
 1 2 Ra-226  Po-210  41522.64202130898
 1 3 Ra-226  Ra-226  12483323.34809944
 1 3 Ra-226  Pb-210  240018.8003490614
 1 3 Ra-226  Po-210  97815.28963571791
 1 4 Ra-226  Ra-226  12292697.44491933
 1 4 Ra-226  Pb-210  329705.6309771690
 1 4 Ra-226  Po-210  166189.7199634703
 1 5 Ra-226  Ra-226  12102113.03789751
 1 5 Ra-226  Pb-210  415797.0256397768
 1 5 Ra-226  Po-210  240752.0487711821
 1 6 Ra-226  Ra-226  11911569.06302993
 1 6 Ra-226  Pb-210  498332.3857371892
 1 6 Ra-226  Po-210  317838.3614571284
 1 7 Ra-226  Ra-226  11721067.64832471
 1 7 Ra-226  Pb-210  577350.6139178082
 1 7 Ra-226  Po-210  395176.8597300862
```

```
Time Integrated direct ingestion, pCi
 iSrc iTime Parent Progeny Full occupancy ingestion
 1 1 Ra-226  Ra-226  21.8988190
 1 1 Ra-226  Pb-210  8.48082975E-02
 1 1 Ra-226  Po-210  1.15772150E-02
 1 2 Ra-226  Ra-226  21.8964481
 1 2 Ra-226  Pb-210  0.253652513
 1 2 Ra-226  Po-210  7.18411058E-02
 1 3 Ra-226  Ra-226  21.8940773
 1 3 Ra-226  Pb-210  0.421171427
 1 3 Ra-226  Po-210  0.171699181
 1 4 Ra-226  Ra-226  21.8917065
 1 4 Ra-226  Pb-210  0.587375283
 1 4 Ra-226  Po-210  0.296133280
 1 5 Ra-226  Ra-226  21.8893356
 1 5 Ra-226  Pb-210  0.752274275
 1 5 Ra-226  Po-210  0.435641676
 1 6 Ra-226  Ra-226  21.8869648
 1 6 Ra-226  Pb-210  0.915878534
 1 6 Ra-226  Po-210  0.584214151
 1 7 Ra-226  Ra-226  21.8845940
 1 7 Ra-226  Pb-210  1.07819796
 1 7 Ra-226  Po-210  0.738050222
```

```
Time averaged activity
 iSrc iTime Parent Progeny pCi
 1 1 Cs-137  Cs-137  12828423.48855200
 1 2 Cs-137  Cs-137  12566824.25863014
 1 3 Cs-137  Cs-137  12307813.75058346
 1 4 Cs-137  Cs-137  12051368.55632268
 1 5 Cs-137  Cs-137  11797470.58777879
 1 6 Cs-137  Cs-137  11546096.43686251
 1 7 Cs-137  Cs-137  11297226.95150076
```

```
Time Integrated direct ingestion, pCi
 iSrc iTime Parent Progeny Full occupancy ingestion
 1 1 Cs-137  Cs-137  21.8369198
 1 2 Cs-137  Cs-137  21.7111492
 1 3 Cs-137  Cs-137  21.5861015
 1 4 Cs-137  Cs-137  21.4617748
 1 5 Cs-137  Cs-137  21.3381634
 1 6 Cs-137  Cs-137  21.2152653
 1 7 Cs-137  Cs-137  21.0930748
```

Time averaged activity					from RRB
	iSrc	iTime	Parent	Porgeny	pCi
	1	1	CO-60	CO-60	12656864.54
	1	2	CO-60	CO-60	12067283.93
	1	3	CO-60	CO-60	11502601.01
	1	4	CO-60	CO-60	10961819.89
	1	5	CO-60	CO-60	10443987.2
	1	6	CO-60	CO-60	9948183.653
	1	7	CO-60	CO-60	9473526.123

```
Time averaged activity
 iSrc iTime Parent Progeny pCi
 1 1 Co-60   Co-60   12656864.53810654
 1 2 Co-60   Co-60   12067283.92903501
 1 3 Co-60   Co-60   11502601.01494064
 1 4 Co-60   Co-60   10961819.88802435
 1 5 Co-60   Co-60   10443987.20064942
 1 6 Co-60   Co-60   9948183.653308980
 1 7 Co-60   Co-60   9473526.122634195
```

Time Integrated direct ingestion (full occupancy), pCi					from RRB
	iSrc	iTime	Parent	Porgeny	pCi
	1	1	CO-60	CO-60	21.5441723
	1	2	CO-60	CO-60	20.8474121
	1	3	CO-60	CO-60	20.1731853
	1	4	CO-60	CO-60	19.5207653
	1	5	CO-60	CO-60	18.8894444
	1	6	CO-60	CO-60	18.2785416
	1	7	CO-60	CO-60	17.6873951

```
Time Integrated direct ingestion, pCi
 iSrc iTime Parent Progeny Full occupancy ingestion
 1 1 Co-60   Co-60   21.5441723
 1 2 Co-60   Co-60   20.8474121
 1 3 Co-60   Co-60   20.1731853
 1 4 Co-60   Co-60   19.5207653
 1 5 Co-60   Co-60   18.8894444
 1 6 Co-60   Co-60   18.2785416
 1 7 Co-60   Co-60   17.6873951
```

(3) The calculated air release rates from the run matched those in "Vol1_S=1.xlsx":

Results from "Vol1_S=1.xlsx" Results from the run

Rate of release of source material to air						
fraction of source per second per volume (m3) of the room of release						
2.06E-12	from	time	0.00E+00	to	time	5.4E+08 seconds
8.64E+00	from	time	0.00E+00	to	time	150000 hrs

```
Rate of release of source material to air
fraction of source per second per volume (cubic meter) of the room of release
2.05761471E-12  from time  0.00000000E+00  to time  540000000.  seconds
```

(4) Time-averaged concentrations of radionuclide in the air and depositing on the floor from the run matched those in "Vol1_S=1.xlsx":

Results from "Vol1_S=1.xlsx" Results from the run

RESRAD-BUILD input file "Volume1_S=1_Exp.BLD"						from RRB
iSr	iRoom	iTime	Parent	progeny	Media	Concentration
1	1	1	RA-226	RA-226	Air	2.17E-02
1	1	1	RA-226	RA-226	Floor	12.46466159
1	1	1	RA-226	PB-210	Air	8.72E-05
1	1	1	RA-226	PB-210	Floor	5.82E-02
1	1	1	RA-226	PO-210	Air	1.21E-05
1	1	1	RA-226	PO-210	Floor	8.41E-03
1	1	2	RA-226	RA-226	Air	2.38E-02
1	1	2	RA-226	RA-226	Floor	18.26215525
1	1	2	RA-226	PB-210	Air	2.76E-04
1	1	2	RA-226	PB-210	Floor	0.21220567
1	1	2	RA-226	PO-210	Air	7.81E-05
1	1	2	RA-226	PO-210	Floor	6.02E-02
1	1	3	RA-226	RA-226	Air	2.40E-02
1	1	3	RA-226	RA-226	Floor	18.67414307
1	1	3	RA-226	PB-210	Air	4.61E-04
1	1	3	RA-226	PB-210	Floor	0.359286625
1	1	3	RA-226	PO-210	Air	1.88E-04
1	1	3	RA-226	PO-210	Floor	0.14644909
1	1	4	RA-226	RA-226	Air	2.40E-02
1	1	4	RA-226	RA-226	Floor	18.70897818
1	1	4	RA-226	PB-210	Air	6.44E-04
1	1	4	RA-226	PB-210	Floor	0.501985826
1	1	4	RA-226	PO-210	Air	3.24E-04
1	1	4	RA-226	PO-210	Floor	0.253029538
1	1	5	RA-226	RA-226	Air	2.40E-02
1	1	5	RA-226	RA-226	Floor	18.71052055
1	1	5	RA-226	PB-210	Air	8.24E-04
1	1	5	RA-226	PB-210	Floor	0.643027968
1	1	5	RA-226	PO-210	Air	4.77E-04
1	1	5	RA-226	PO-210	Floor	0.372306982

```
Numerically Time Averaged Concentrations
pCi per cubic meter of air  &  pCi per square meter of floor
 iSr iRoom iTime Parent progeny Media Concentration
 1 1 1 Ra-226  Ra-226  Air 2.165754613774734E-02
 1 1 1 Ra-226  Ra-226  Floor 12.46466159309995
 1 1 1 Ra-226  Pb-210  Air 8.723064947104102E-05
 1 1 1 Ra-226  Pb-210  Floor 5.817570395738204E-02
 1 1 1 Ra-226  Po-210  Air 1.207151659728511E-05
 1 1 1 Ra-226  Po-210  Floor 8.407825580289192E-03
 1 1 2 Ra-226  Ra-226  Air 2.378002322742263E-02
 1 1 2 Ra-226  Ra-226  Floor 18.26215525114155
 1 1 2 Ra-226  Pb-210  Air 2.757701206062119E-04
 1 1 2 Ra-226  Pb-210  Floor 0.2122057172754947
 1 1 2 Ra-226  Po-210  Air 7.816603847834617E-05
 1 1 2 Ra-226  Po-210  Floor 6.023505279680366E-02
 1 1 3 Ra-226  Ra-226  Air 2.397255715690005E-02
 1 1 3 Ra-226  Ra-226  Floor 18.67414307458143
 1 1 3 Ra-226  Pb-210  Air 4.611833437876553E-04
 1 1 3 Ra-226  Pb-210  Floor 0.3592867195391172
 1 1 3 Ra-226  Po-210  Air 1.880187368949375E-04
 1 1 3 Ra-226  Po-210  Floor 0.1464859684170472
 1 1 4 Ra-226  Ra-226  Air 2.398886589928970E-02
 1 1 4 Ra-226  Ra-226  Floor 18.70897818366311
 1 1 4 Ra-226  Pb-210  Air 6.436473395484525E-04
 1 1 4 Ra-226  Pb-210  Floor 0.5019855208523592
 1 1 4 Ra-226  Po-210  Air 3.245044787603849E-04
 1 1 4 Ra-226  Po-210  Floor 0.2530846968543886
 1 1 5 Ra-226  Ra-226  Air 2.398814053779807E-02
 1 1 5 Ra-226  Ra-226  Floor 18.71052054794520
 1 1 5 Ra-226  Pb-210  Air 8.244045495624048E-04
 1 1 5 Ra-226  Pb-210  Floor 0.6430280948756976
 1 1 5 Ra-226  Po-210  Air 4.774124400982211E-04
 1 1 5 Ra-226  Po-210  Floor 0.3723774733637747
```

(5) The dose and risk component results from the run matched those in "Vol1_S=1.xlsx."

(6) The total pathway dose results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	6.33E-01	1.90E-04	7.16E-05	0.00E+00	1.30E-04	1.21E-02	2.92E+00
2	1.74E-01	1.60E-01	4.27E-05	1.63E-05	3.40E-04	6.25E-05	0.00E+00	3.35E-01
3	2.38E-02	1.20E-01	2.56E-05	9.78E-06	4.08E-04	3.75E-05	0.00E+00	1.45E-01
4	3.25E-02	2.41E-01	8.53E-05	3.26E-05	1.02E-03	1.26E-04	0.00E+00	2.75E-01
Total	2.51E+00	1.15E+00	3.44E-04	1.30E-04	1.77E-03	3.56E-04	1.21E-02	3.68E+00

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	6.33E-01	1.90E-04	7.16E-05	0.00E+00	1.30E-04	1.21E-02	2.92E+00
2	1.74E-01	1.60E-01	4.27E-05	1.63E-05	3.40E-04	6.25E-05	0.00E+00	3.35E-01
3	2.38E-02	1.20E-01	2.56E-05	9.78E-06	4.08E-04	3.75E-05	0.00E+00	1.45E-01
4	3.25E-02	2.41E-01	8.53E-05	3.26E-05	1.02E-03	1.26E-04	0.00E+00	2.75E-01
Total	2.51E+00	1.15E+00	3.44E-04	1.30E-04	1.77E-03	3.56E-04	1.21E-02	3.68E+00

(7) The total pathway risk results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	5.08E-07	1.53E-10	5.77E-11	0.00E+00	1.43E-10	6.35E-09	2.34E-06
2	1.40E-07	1.29E-07	3.42E-11	1.32E-11	1.78E-10	7.54E-11	0.00E+00	2.68E-07
3	1.91E-08	9.65E-08	2.05E-11	7.85E-12	2.13E-10	5.65E-11	0.00E+00	1.16E-07
4	2.64E-08	1.93E-07	6.84E-11	2.63E-11	5.33E-10	1.13E-10	0.00E+00	2.20E-07
Total	2.01E-06	9.26E-07	2.76E-10	1.05E-10	9.24E-10	3.88E-10	6.35E-09	2.95E-06

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	5.08E-07	1.53E-10	5.77E-11	0.00E+00	1.43E-10	6.35E-09	2.34E-06
2	1.40E-07	1.29E-07	3.42E-11	1.32E-11	1.78E-10	7.54E-11	0.00E+00	2.68E-07
3	1.91E-08	9.65E-08	2.05E-11	7.85E-12	2.13E-10	5.65E-11	0.00E+00	1.16E-07
4	2.64E-08	1.93E-07	6.84E-11	2.63E-11	5.33E-10	1.13E-10	0.00E+00	2.20E-07
Total	2.01E-06	9.26E-07	2.76E-10	1.05E-10	9.24E-10	3.88E-10	6.35E-09	2.95E-06

5.2 TEST CASE 007-2

Test objectives/descriptions:

The objective of the test was to verify the modeling of concentrations in the source, the modeling of the releases and ventilation, and the subsequent dose and risk calculations, with the intermediate outputs of time-averaged activity in the source, time-integrated direct ingestion, air release rate, time-averaged radionuclide concentration in the air and on the floor, the dose and risk components, as well as the summary results of the inhalation (of particulates), ingestion, and air submersion pathway dose and risk to each receptor.

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. It involved retrieving the same input file previously used for verification, launching calculations, and comparing the results and outputs with those obtained previously, which were shown to agree with the calculation results from the verification spreadsheet.

The input file "Area 1_S=3_V=14_exp.BLD" associated with Test Case 007-2 was used to run the code. It considered a building with 9 rooms, 4 receptors in different rooms, and an area source in Room 3 that released radioactivity into the air; floor vacuuming was considered every 14 days with an efficiency of 80%. The dose and risk coefficients used in the calculations matched those provided in RESBLD-Test-001, Rev. 2; the intermediate outputs matched those in the verification file "Area 1_S=3_V=14.xlsx," and the pathway dose/risk results to each receptor matched those provided in RESBLD-Test-001, Rev. 2.

Test result (Pass/Fail): Pass

Test details:

(1) The aggregated dose and slope factors (including those of short-live progeny) from the run matched those provided in RESBLD-Test-001, Rev. 2.

(2) Time-averaged activity and time-integrated direct ingestion results from the run matched those in "Area 1_S=3_V=14.xlsx":

Results from "Area 1_S=3_V=14.xlsx"

Time averaged activity				from RRB
iSrc	iTime	Parent	Porgeny	pCi
1	1	RA-226	RA-226	29.0493861
1	1	RA-226	PB-210	0.102088906
1	1	RA-226	PO-210	1.32E-02
1	2	RA-226	RA-226	8.538455226
1	2	RA-226	PB-210	9.00E-02
1	2	RA-226	PO-210	2.37E-02
1	3	RA-226	RA-226	3.673446918
1	3	RA-226	PB-210	7.04E-02
1	3	RA-226	PO-210	2.86E-02
1	4	RA-226	RA-226	1.619424562
1	4	RA-226	PB-210	4.08E-02
1	4	RA-226	PO-210	1.97E-02
1	5	RA-226	RA-226	0.00E+00
1	5	RA-226	PB-210	0.00E+00
1	5	RA-226	PO-210	0.00E+00
1	6	RA-226	RA-226	0.00E+00
1	6	RA-226	PB-210	0.00E+00
1	6	RA-226	PO-210	0.00E+00
1	7	RA-226	RA-226	0.00E+00
1	7	RA-226	PB-210	0.00E+00
1	7	RA-226	PO-210	0.00E+00

Time Integrated direct ingestion (full occupancy), pCi				from RRB
iSrc	iTime	Parent	Porgeny	pCi
1	1	RA-226	RA-226	7.88E-04
1	1	RA-226	PB-210	3.05E-06
1	1	RA-226	PO-210	4.17E-07
1	2	RA-226	RA-226	7.88E-04
1	2	RA-226	PB-210	9.13E-06
1	2	RA-226	PO-210	2.59E-06
1	3	RA-226	RA-226	1.50E-04
1	3	RA-226	PB-210	2.42E-06
1	3	RA-226	PO-210	8.67E-07
1	4	RA-226	RA-226	6.05E-04
1	4	RA-226	PB-210	1.60E-05
1	4	RA-226	PO-210	7.99E-06
1	5	RA-226	RA-226	0.00E+00
1	5	RA-226	PB-210	0.00E+00
1	5	RA-226	PO-210	0.00E+00
1	6	RA-226	RA-226	0.00E+00
1	6	RA-226	PB-210	0.00E+00
1	6	RA-226	PO-210	0.00E+00
1	7	RA-226	RA-226	0.00E+00
1	7	RA-226	PB-210	0.00E+00
1	7	RA-226	PO-210	0.00E+00

Results from the run

```
Time averaged activity
 iSrc iTime Parent Progeny pCi
 1 1 Ra-226  Ra-226  29.04938609842720
 1 1 Ra-226  Pb-210  0.1020889291206875
 1 1 Ra-226  Po-210  1.321440792615979E-02
 1 2 Ra-226  Ra-226  8.538455225773719
 1 2 Ra-226  Pb-210  8.997705796549975E-02
 1 2 Ra-226  Po-210  2.372384611039764E-02
 1 3 Ra-226  Ra-226  3.673446917808219
 1 3 Ra-226  Pb-210  7.041755255898022E-02
 1 3 Ra-226  Po-210  2.864322916666667E-02
 1 4 Ra-226  Ra-226  1.619424562404871
 1 4 Ra-226  Pb-210  4.075092453862252E-02
 1 4 Ra-226  Po-210  1.973424320617707E-02
 1 5 Ra-226  Ra-226  0.000000000000000E+00
 1 5 Ra-226  Pb-210  0.000000000000000E+00
 1 5 Ra-226  Po-210  0.000000000000000E+00
 1 6 Ra-226  Ra-226  0.000000000000000E+00
 1 6 Ra-226  Pb-210  0.000000000000000E+00
 1 6 Ra-226  Po-210  0.000000000000000E+00
 1 7 Ra-226  Ra-226  0.000000000000000E+00
 1 7 Ra-226  Pb-210  0.000000000000000E+00
 1 7 Ra-226  Po-210  0.000000000000000E+00
```

```
Time Integrated direct ingestion, pCi
 iSrc iTime Parent Progeny Full occupancy ingestion
 1 1 Ra-226  Ra-226  7.88357342E-04
 1 1 Ra-226  Pb-210  3.05309823E-06
 1 1 Ra-226  Po-210  4.16779642E-07
 1 2 Ra-226  Ra-226  7.88271951E-04
 1 2 Ra-226  Pb-210  9.13148870E-06
 1 2 Ra-226  Po-210  2.58627915E-06
 1 3 Ra-226  Ra-226  1.50085936E-04
 1 3 Ra-226  Pb-210  2.42398482E-06
 1 3 Ra-226  Po-210  8.67010101E-07
 1 4 Ra-226  Ra-226  6.04574103E-04
 1 4 Ra-226  Pb-210  1.59933443E-05
 1 4 Ra-226  Po-210  7.98770907E-06
 1 5 Ra-226  Ra-226  0.00000000E+00
 1 5 Ra-226  Pb-210  0.00000000E+00
 1 5 Ra-226  Po-210  0.00000000E+00
 1 6 Ra-226  Ra-226  0.00000000E+00
 1 6 Ra-226  Pb-210  0.00000000E+00
 1 6 Ra-226  Po-210  0.00000000E+00
 1 7 Ra-226  Ra-226  0.00000000E+00
 1 7 Ra-226  Pb-210  0.00000000E+00
 1 7 Ra-226  Po-210  0.00000000E+00
```

Time averaged activity					from RRB
	iSrc	iTime	Parent	Porgeny	pCi
	1	1	CS-137	CS-137	28.9748762
	1	2	CS-137	CS-137	8.472733257
	1	3	CS-137	CS-137	3.621955733
	1	4	CS-137	CS-137	1.589603564
	1	5	CS-137	CS-137	0.00E+00
	1	6	CS-137	CS-137	0.00E+00
	1	7	CS-137	CS-137	0.00E+00

```
Time averaged activity
 iSrc iTime Parent Progeny pCi
 1 1 Cs-137  Cs-137  28.97487620497209
 1 2 Cs-137  Cs-137  8.472733257229832
 1 3 Cs-137  Cs-137  3.621955733130390
 1 4 Cs-137  Cs-137  1.589603564180619
 1 5 Cs-137  Cs-137  0.000000000000000E+00
 1 6 Cs-137  Cs-137  0.000000000000000E+00
 1 7 Cs-137  Cs-137  0.000000000000000E+00
```

Time Integrated direct ingestion (full occupancy), pCi					from RRB
	iSrc	iTime	Parent	Porgeny	pCi
	1	1	CS-137	CS-137	7.86E-04
	1	2	CS-137	CS-137	7.82E-04
	1	3	CS-137	CS-137	1.48E-04
	1	4	CS-137	CS-137	5.93E-04
	1	5	CS-137	CS-137	0.00E+00
	1	6	CS-137	CS-137	0.00E+00
	1	7	CS-137	CS-137	0.00E+00

```
Time Integrated direct ingestion, pCi
 iSrc iTime Parent Progeny Full occupancy ingestion
 1 1 Cs-137  Cs-137  7.86128920E-04
 1 2 Cs-137  Cs-137  7.81601178E-04
 1 3 Cs-137  Cs-137  1.48314211E-04
 1 4 Cs-137  Cs-137  5.92868368E-04
 1 5 Cs-137  Cs-137  0.00000000E+00
 1 6 Cs-137  Cs-137  0.00000000E+00
 1 7 Cs-137  Cs-137  0.00000000E+00
```

Time averaged activity					from RRB
	iSrc	iTime	Parent	Porgeny	pCi
	1	1	CO-60	CO-60	28.62219685
	1	2	CO-60	CO-60	8.165660578
	1	3	CO-60	CO-60	3.385642948
	1	4	CO-60	CO-60	1.454435312
	1	5	CO-60	CO-60	0.00E+00
	1	6	CO-60	CO-60	0.00E+00
	1	7	CO-60	CO-60	0.00E+00

```
Time averaged activity
 iSrc iTime Parent Progeny pCi
 1 1 Co-60   Co-60   28.62227650938610
 1 2 Co-60   Co-60   8.165729578893963
 1 3 Co-60   Co-60   3.385695585996956
 1 4 Co-60   Co-60   1.454465024099442
 1 5 Co-60   Co-60   0.000000000000000E+00
 1 6 Co-60   Co-60   0.000000000000000E+00
 1 7 Co-60   Co-60   0.000000000000000E+00
```

Time Integrated direct ingestion (full occupancy), pCi					from RRB
	iSrc	iTime	Parent	Porgeny	pCi
	1	1	CO-60	CO-60	7.76E-04
	1	2	CO-60	CO-60	7.50E-04
	1	3	CO-60	CO-60	1.40E-04
	1	4	CO-60	CO-60	5.40E-04
	1	5	CO-60	CO-60	0.00E+00
	1	6	CO-60	CO-60	0.00E+00
	1	7	CO-60	CO-60	0.00E+00

```
Time Integrated direct ingestion, pCi
 iSrc iTime Parent Progeny Full occupancy ingestion
 1 1 Co-60   Co-60   7.75590015E-04
 1 2 Co-60   Co-60   7.50506704E-04
 1 3 Co-60   Co-60   1.40128206E-04
 1 4 Co-60   Co-60   5.39970177E-04
 1 5 Co-60   Co-60   0.00000000E+00
 1 6 Co-60   Co-60   0.00000000E+00
 1 7 Co-60   Co-60   0.00000000E+00
```

(3) The air release rate results from the run matched those in "Area 1_S=3_V=14.xlsx":

Results from "Area 1_S=3_V=14.xlsx"

Rate of release of source material to air				
fraction of source per second per volume (m3) of the room of release				
2.14E-10 from	time	0 to	time	2592000 seconds
3.22E-10 from	time	2592000 to	time	5184000 seconds
4.02E-10 from	time	5184000 to	time	8640000 seconds
9.65E-10 from	time	8640000 to	time	10368000 seconds
8.04E-11 from	time	10368000 to	time	17280000 seconds
9.19E-11 from	time	24192000 to	time	30240000 seconds

Results from the run

```
Rate of release of source material to air
fraction of source per second per volume (cubic meter) of the room of release
2.14411697E-10  from time  0.00000000E+00  to time  2592000.00  seconds
3.21617566E-10  from time  2592000.00  to time  5184000.00  seconds
4.01919387E-10  from time  5184000.00  to time  8640000.00  seconds
9.65345137E-10  from time  8640000.00  to time  10368000.0  seconds
8.03838801E-11  from time  10368000.0  to time  17280000.0  seconds
9.18773321E-11  from time  24192000.0  to time  30240000.0  seconds
```

(4) Time-averaged concentrations of radionuclide in the air and depositing on the floor from the run matched those in "Area 1_S=3_V=14.xlsx":

Results from "Area 1_S=3_V=14.xlsx"

RESRAD-BUILD input file "Area1_S=3_V=14_Exp.BLD"						from RRB	E
iSr	iRoom	iTime	Parent	progeny	Media	Concentration (pCi/m3 or pCi/m2)	C ((b ir c
1	1	1	RA-226	RA-226	Air	4.40E-07	
1	1	1	RA-226	RA-226	Floor	9.58E-05	
1	1	1	RA-226	PB-210	Air	1.97E-09	
1	1	1	RA-226	PB-210	Floor	4.43E-07	
1	1	1	RA-226	PO-210	Air	2.83E-10	
1	1	1	RA-226	PO-210	Floor	6.40E-08	
1	1	2	RA-226	RA-226	Air	4.85E-07	
1	1	2	RA-226	RA-226	Floor	1.26E-04	
1	1	2	RA-226	PB-210	Air	4.84E-09	
1	1	2	RA-226	PB-210	Floor	1.29E-06	
1	1	2	RA-226	PO-210	Air	1.21E-09	
1	1	2	RA-226	PO-210	Floor	3.28E-07	
1	1	3	RA-226	RA-226	Air	2.78E-08	
1	1	3	RA-226	RA-226	Floor	8.43E-06	
1	1	3	RA-226	PB-210	Air	4.58E-10	
1	1	3	RA-226	PB-210	Floor	1.42E-07	
1	1	3	RA-226	PO-210	Air	1.66E-10	
1	1	3	RA-226	PO-210	Floor	5.22E-08	
1	1	4	RA-226	RA-226	Air	1.04E-07	
1	1	4	RA-226	RA-226	Floor	2.45E-05	
1	1	4	RA-226	PB-210	Air	2.78E-09	
1	1	4	RA-226	PB-210	Floor	6.65E-07	
1	1	4	RA-226	PO-210	Air	1.40E-09	
1	1	4	RA-226	PO-210	Floor	3.37E-07	
1	1	5	RA-226	RA-226	Air	7.48E-10	
1	1	5	RA-226	RA-226	Floor	5.35E-07	
1	1	5	RA-226	PB-210	Air	2.35E-11	
1	1	5	RA-226	PB-210	Floor	1.68E-08	
1	1	5	RA-226	PO-210	Air	1.29E-11	
1	1	5	RA-226	PO-210	Floor	9.28E-09	

Results from the run

```
Numerically Time Averaged Concentrations
pCi per cubic meter of air  &  pCi per square meter of floor
 iSr iRoom iTime Parent progeny Media Concentration
 1 1 1 Ra-226  Ra-226  Air 4.396054540292555E-07
 1 1 1 Ra-226  Ra-226  Floor 9.582810617231101E-05
 1 1 1 Ra-226  Pb-210  Air 1.966785299315300E-09
 1 1 1 Ra-226  Pb-210  Floor 4.425644572164612E-07
 1 1 1 Ra-226  Po-210  Air 2.832362040374589E-10
 1 1 1 Ra-226  Po-210  Floor 6.407039652978751E-08
 1 1 2 Ra-226  Ra-226  Air 4.847176724554378E-07
 1 1 2 Ra-226  Ra-226  Floor 1.261211764927385E-04
 1 1 2 Ra-226  Pb-210  Air 4.838663047034991E-09
 1 1 2 Ra-226  Pb-210  Floor 1.289413399892311E-06
 1 1 2 Ra-226  Po-210  Air 1.207411521691347E-09
 1 1 2 Ra-226  Po-210  Floor 3.278468055570265E-07
 1 1 3 Ra-226  Ra-226  Air 2.780824498982674E-08
 1 1 3 Ra-226  Ra-226  Floor 8.429396158544500E-06
 1 1 3 Ra-226  Pb-210  Air 4.581249456518135E-10
 1 1 3 Ra-226  Pb-210  Floor 1.416333673691036E-07
 1 1 3 Ra-226  Po-210  Air 1.663871598300037E-10
 1 1 3 Ra-226  Po-210  Floor 5.220721996961542E-08
 1 1 4 Ra-226  Ra-226  Air 1.041041162641807E-07
 1 1 4 Ra-226  Ra-226  Floor 2.454541117814759E-05
 1 1 4 Ra-226  Pb-210  Air 2.780795014188835E-09
 1 1 4 Ra-226  Pb-210  Floor 6.647457149898504E-07
 1 1 4 Ra-226  Po-210  Air 1.397073403083994E-09
 1 1 4 Ra-226  Po-210  Floor 3.367386028767842E-07
 1 1 5 Ra-226  Ra-226  Air 7.475319591113179E-10
 1 1 5 Ra-226  Ra-226  Floor 5.349562532220740E-07
 1 1 5 Ra-226  Pb-210  Air 2.348345221173375E-11
 1 1 5 Ra-226  Pb-210  Floor 1.682454501838626E-08
 1 1 5 Ra-226  Po-210  Air 1.294442879464638E-11
 1 1 5 Ra-226  Po-210  Floor 9.279869183073910E-09
```

(5) The dose and risk component results from the run matched those in "Area 1_S=3_V=14.xlsx."

(6) The total pathway dose results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.16E-05	1.25E-05	1.46E-09	1.45E-09	0.00E+00	3.30E-08	0.00E+00	2.45E-05
2	6.48E-07	5.55E-04	5.95E-08	5.64E-08	4.74E-07	9.56E-08	2.15E-07	5.56E-04
3	8.77E-08	5.48E-05	7.56E-09	7.71E-09	1.27E-07	6.43E-08	0.00E+00	5.51E-05
4	1.23E-07	8.60E-05	1.15E-08	1.16E-08	1.42E-07	1.85E-07	0.00E+00	8.65E-05
Total	1.25E-05	7.49E-04	8.07E-08	7.72E-08	7.42E-07	3.78E-07	2.15E-07	7.63E-04

Results from the run

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.16E-05	1.25E-05	1.46E-09	1.45E-09	0.00E+00	3.30E-08	0.00E+00	2.45E-05
2	6.48E-07	5.55E-04	5.95E-08	5.64E-08	4.74E-07	9.56E-08	2.15E-07	5.56E-04
3	8.77E-08	5.48E-05	7.56E-09	7.71E-09	1.27E-07	6.43E-08	0.00E+00	5.51E-05
4	1.23E-07	8.60E-05	1.15E-08	1.16E-08	1.42E-07	1.85E-07	0.00E+00	8.65E-05
Total	1.25E-05	7.49E-04	8.07E-08	7.72E-08	7.42E-07	3.78E-07	2.15E-07	7.63E-04

(7) The total pathway risk results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	9.33E-12	1.03E-11	1.17E-15	1.17E-15	0.00E+00	3.34E-14	0.00E+00	1.97E-11
2	5.20E-13	4.45E-10	4.77E-14	4.55E-14	2.47E-13	1.13E-13	1.14E-13	4.46E-10
3	7.03E-14	7.60E-11	6.38E-15	6.21E-15	6.62E-14	9.12E-14	0.00E+00	7.63E-11
4	9.84E-14	6.90E-11	9.51E-15	9.40E-15	7.40E-14	1.56E-13	0.00E+00	6.93E-11
Total	1.00E-11	6.00E-10	6.46E-14	6.22E-14	3.86E-13	3.54E-13	1.14E-13	6.11E-10

Results from the run

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	9.33E-12	1.03E-11	1.17E-15	1.17E-15	0.00E+00	3.34E-14	0.00E+00	1.97E-11
2	5.20E-13	4.45E-10	4.77E-14	4.55E-14	2.47E-13	1.13E-13	1.14E-13	4.46E-10
3	7.03E-14	7.60E-11	6.38E-15	6.21E-15	6.62E-14	9.12E-14	0.00E+00	7.63E-11
4	9.84E-14	6.90E-11	9.51E-15	9.40E-15	7.40E-14	1.56E-13	0.00E+00	6.93E-11
Total	1.00E-11	6.00E-10	6.46E-14	6.22E-14	3.86E-13	3.54E-13	1.14E-13	6.11E-10

6. TEST CASE 008

6.1 TEST CASE 008-1

Test objectives/descriptions:

The objective of the test was to verify the release and ventilation modeling in the code and the subsequent radiation exposures associated with the releases, with the intermediate outputs of air release rate and time-averaged radionuclide concentration in the air and on the floor, as well as the resultant inhalation, ingestion, and air submersion pathway dose and risk to each receptor.

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. It involved retrieving the same input file previously used for verification, launching calculations, and comparing the results and outputs with those obtained previously, which were shown to agree with the calculation results from the verification spreadsheet.

The input file, "Volume 1_S=1_V=30_EXP.BLD," associated with Test Case 008-1 was used to run the code. It considered a building with 9 rooms, 4 receptors in different rooms, and a volume source in Room 1 that released radioactivity into the air; floor vacuuming was considered every 30 days with an efficiency of 90%. The intermediate outputs matched those in the verification spreadsheet file, "Vol1_S=1_V=30.xlsx." The resultant pathway dose/risk to each receptor matched those obtained previously and provided in RESBLD-Test-001, Rev. 2.

Test result (Pass/Fail): Pass

Test details:

(1) The air release rate results from the run matched those in "Vol1_S=1_V=30.xlsx":

Results from "Vol1_S=1_V=30.xlsx"

Rate of release of source material to air						
fraction of source per second per volume (m3) of the room of release						
2.06E-11	from	time	0.00E+00	to	time	5.4E+08 seconds
8.64E+01	from	time	0.00E+00	to	time	150000 hrs

Results from the run

```
Rate of release of source material to air
fraction of source per second per volume (cubic meter) of the room of release
2.05761467E-11  from time  0.00000000E+00  to time  540000000.  seconds
```

(2) Time-averaged concentrations of radionuclide in the air and depositing on the floor from the run matched those in "Vol1_S=1_V=30.xlsx":

Results from "Vol1_S=1_V=30.xlsx"

RESRAD-BUILD input file "Volume1_S=1_V=30_Exp.BLD"						from RRB
iSr	iRoom	iTime	Parent	progeny	Media	Concentration
1	1	1	RA-226	RA-226	Air	1.99E-01
1	1	1	RA-226	RA-226	Floor	7.03E+01
1	1	1	RA-226	PB-210	Air	7.78E-04
1	1	1	RA-226	PB-210	Floor	2.98E-01
1	1	1	RA-226	PO-210	Air	1.07E-04
1	1	1	RA-226	PO-210	Floor	4.18E-02
1	1	2	RA-226	RA-226	Air	2.00E-01
1	1	2	RA-226	RA-226	Floor	7.30E+01
1	1	2	RA-226	PB-210	Air	2.32E-03
1	1	2	RA-226	PB-210	Floor	8.58E-01
1	1	2	RA-226	PO-210	Air	6.57E-04
1	1	2	RA-226	PO-210	Floor	2.46E-01
1	1	3	RA-226	RA-226	Air	2.00E-01
1	1	3	RA-226	RA-226	Floor	7.31E+01
1	1	3	RA-226	PB-210	Air	3.84E-03
1	1	3	RA-226	PB-210	Floor	1.41E+00
1	1	3	RA-226	PO-210	Air	1.57E-03
1	1	3	RA-226	PO-210	Floor	5.78E-01
1	1	4	RA-226	RA-226	Air	2.00E-01
1	1	4	RA-226	RA-226	Floor	7.30E+01
1	1	4	RA-226	PB-210	Air	5.36E-03
1	1	4	RA-226	PB-210	Floor	1.96E+00
1	1	4	RA-226	PO-210	Air	2.70E-03
1	1	4	RA-226	PO-210	Floor	9.90E-01
1	1	5	RA-226	RA-226	Air	2.00E-01
1	1	5	RA-226	RA-226	Floor	7.33E+01
1	1	5	RA-226	PB-210	Air	6.86E-03
1	1	5	RA-226	PB-210	Floor	2.52E+00
1	1	5	RA-226	PO-210	Air	3.97E-03
1	1	5	RA-226	PO-210	Floor	1.46E+00

Results from the run

```
Numerically Time Averaged Concentrations
pCi per cubic meter of air  &  pCi per square meter of floor
 iSr iRoom iTime Parent progeny Media Concentration
 1 1 1 Ra-226  Ra-226  Air 0.1986718670725520
 1 1 1 Ra-226  Ra-226  Floor 70.25151090816844
 1 1 1 Ra-226  Pb-210  Air 7.779898989448567E-04
 1 1 1 Ra-226  Pb-210  Floor 0.2978861618467783
 1 1 1 Ra-226  Po-210  Air 1.065783140200882E-04
 1 1 1 Ra-226  Po-210  Floor 4.180645928462709E-02
 1 1 2 Ra-226  Ra-226  Air 0.1996765284119736
 1 1 2 Ra-226  Ra-226  Floor 72.97951496702181
 1 1 2 Ra-226  Pb-210  Air 2.317054318873668E-03
 1 1 2 Ra-226  Pb-210  Floor 0.8584436199898529
 1 1 2 Ra-226  Po-210  Air 6.570246603088534E-04
 1 1 2 Ra-226  Po-210  Floor 0.2456801433282598
 1 1 3 Ra-226  Ra-226  Air 0.1996514935312024
 1 1 3 Ra-226  Ra-226  Floor 73.08493150684932
 1 1 3 Ra-226  Pb-210  Air 3.843018445189624E-03
 1 1 3 Ra-226  Pb-210  Floor 1.413343353627600
 1 1 3 Ra-226  Po-210  Air 1.567295610572045E-03
 1 1 3 Ra-226  Po-210  Floor 0.5780840309487569
 1 1 4 Ra-226  Ra-226  Air 0.1996375412227296
 1 1 4 Ra-226  Ra-226  Floor 73.04706240487062
 1 1 4 Ra-226  Pb-210  Air 5.357453089326484E-03
 1 1 4 Ra-226  Pb-210  Floor 1.962406265854896
 1 1 4 Ra-226  Po-210  Air 2.701301686960934E-03
 1 1 4 Ra-226  Po-210  Floor 0.9900205479452054
 1 1 5 Ra-226  Ra-226  Air 0.1996789066463724
 1 1 5 Ra-226  Ra-226  Floor 73.28265449010654
 1 1 5 Ra-226  Pb-210  Air 6.862320542395992E-03
 1 1 5 Ra-226  Pb-210  Floor 2.518068239472349
 1 1 5 Ra-226  Po-210  Air 3.973924641679350E-03
 1 1 5 Ra-226  Po-210  Floor 1.458017630644343
```

(3) The total pathway dose results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	5.81E+00	1.07E-03	6.57E-04	8.54E-03	6.89E-04	0.00E+00	8.10E+00
2	3.48E-01	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.78E+00
3	7.94E-02	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.52E+00
4	3.25E-02	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.47E+00
Total	2.74E+00	1.31E+01	2.40E-03	1.48E-03	1.91E-02	2.68E-03	0.00E+00	1.55E+01

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	5.81E+00	1.07E-03	6.57E-04	8.54E-03	6.89E-04	0.00E+00	8.10E+00
2	3.48E-01	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.78E+00
3	7.94E-02	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.52E+00
4	3.25E-02	2.43E+00	4.41E-04	2.75E-04	3.51E-03	6.64E-04	0.00E+00	2.47E+00
Total	2.74E+00	1.31E+01	2.40E-03	1.48E-03	1.91E-02	2.68E-03	0.00E+00	1.55E+01

(4) The total pathway risk results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	4.66E-06	8.62E-10	5.30E-10	4.46E-09	7.61E-10	0.00E+00	6.45E-06
2	2.79E-07	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	2.23E-06
3	6.37E-08	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	2.02E-06
4	2.64E-08	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	1.98E-06
Total	2.20E-06	1.09E-05	1.92E-09	1.19E-09	9.96E-09	2.91E-09	0.00E+00	1.27E-05

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	4.66E-06	8.62E-10	5.30E-10	4.46E-09	7.61E-10	0.00E+00	6.45E-06
2	2.79E-07	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	2.23E-06
3	6.37E-08	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	2.02E-06
4	2.64E-08	1.95E-06	3.54E-10	2.22E-10	1.83E-09	7.16E-10	0.00E+00	1.98E-06
Total	2.20E-06	1.09E-05	1.92E-09	1.19E-09	9.96E-09	2.91E-09	0.00E+00	1.27E-05

6.2 TEST CASE 008-2

Test objectives/descriptions:

The objective of the test was to verify the release and ventilation modeling in the code and the subsequent radiation exposures associated with the releases, with the intermediate outputs of air release rate and time-averaged radionuclide concentration in air and on the floor, as well as the resultant inhalation, ingestion, and air submersion pathway dose and risk to each receptor.

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. It involved retrieving the same input file previously used for verification, launching calculations, and comparing the results and outputs with those obtained previously, which were shown to agree with the calculation results from the verification spreadsheet.

The input file, "Volume 2_S=2_EXP.BLD," associated with Test Case 008-2 was used to run the code. It considered a building with 9 rooms, 4 receptors in different rooms, and a volume source in Room 2 that released radioactivity into the air; no floor vacuuming was involved. The intermediate outputs matched those in the verification spreadsheet file, "Vol2_S=2.xlsx." The resultant pathway dose/risk to each receptor matched those provided in RESBLD-Test-001, Rev. 2.

Test result (Pass/Fail): Pass

Test details:

(1) The air release rate results from the run matched those in "Vol2_S=2.xlsx":

Results from "Vol2_S=2.xlsx"

Rate of release of source material to air						
fraction of source per second per volume (m3) of the room of release						
2.06E-11	from	time	0.00E+00	to	time	5.4E+08 seconds
8.64E+01	from	time	0.00E+00	to	time	150000 hrs

Results from the run

```
Rate of release of source material to air
fraction of source per second per volume (cubic meter) of the room of release
2.05761328E-11  from time  0.00000000E+00  to time  540000000.  seconds
```

(2) Time-averaged concentrations of radionuclide in the air and depositing on the floor from the run matched those in "Vol2_S=2.xlsx":

Results from "Vol2_S=2.xlsx"

RESRAD-BUILD input file "Volume2_S=2_Exp.BLD" from RRB

iSr	iRoom	iTime	Parent	progeny	Media	Concentration
1	1	1	RA-226	RA-226	Air	2.13E-02
1	1	1	RA-226	RA-226	Floor	1.06E+01
1	1	1	RA-226	PB-210	Air	1.06E-04
1	1	1	RA-226	PB-210	Floor	5.71E-02
1	1	1	RA-226	PO-210	Air	1.60E-05
1	1	1	RA-226	PO-210	Floor	8.87E-03
1	1	2	RA-226	RA-226	Air	5.18E-02
1	1	2	RA-226	RA-226	Floor	3.51E+01
1	1	2	RA-226	PB-210	Air	6.14E-04
1	1	2	RA-226	PB-210	Floor	4.20E-01
1	1	2	RA-226	PO-210	Air	1.77E-04
1	1	2	RA-226	PO-210	Floor	1.22E-01
1	1	3	RA-226	RA-226	Air	6.68E-02
1	1	3	RA-226	RA-226	Floor	4.97E+01
1	1	3	RA-226	PB-210	Air	1.29E-03
1	1	3	RA-226	PB-210	Floor	9.63E-01
1	1	3	RA-226	PO-210	Air	5.27E-04
1	1	3	RA-226	PO-210	Floor	3.94E-01
1	1	4	RA-226	RA-226	Air	7.23E-02
1	1	4	RA-226	RA-226	Floor	5.56E+01
1	1	4	RA-226	PB-210	Air	1.94E-03
1	1	4	RA-226	PB-210	Floor	1.49E+00
1	1	4	RA-226	PO-210	Air	9.79E-04
1	1	4	RA-226	PO-210	Floor	7.53E-01
1	1	5	RA-226	RA-226	Air	7.41E-02
1	1	5	RA-226	RA-226	Floor	5.76E+01
1	1	5	RA-226	PB-210	Air	2.55E-03
1	1	5	RA-226	PB-210	Floor	1.98E+00
1	1	5	RA-226	PO-210	Air	1.48E-03
1	1	5	RA-226	PO-210	Floor	1.15E+00

Results from the run

```
Numerically Time Averaged Concentrations
pCi per cubic meter of air  &  pCi per square meter of floor
 iSr iRoom iTime Parent progeny Media Concentration
 1 1 1 Ra-226  Ra-226  Air 2.133673420852359E-02
 1 1 1 Ra-226  Ra-226  Floor 10.62543581938102
 1 1 1 Ra-226  Pb-210  Air 1.061863466182498E-04
 1 1 1 Ra-226  Pb-210  Floor 5.710207778411974E-02
 1 1 1 Ra-226  Po-210  Air 1.599446436525419E-05
 1 1 1 Ra-226  Po-210  Floor 8.871425711884829E-03
 1 1 2 Ra-226  Ra-226  Air 5.177384576357179E-02
 1 1 2 Ra-226  Ra-226  Floor 35.14236834094368
 1 1 2 Ra-226  Pb-210  Air 6.140487879922945E-04
 1 1 2 Ra-226  Pb-210  Floor 0.4203418949771690
 1 1 2 Ra-226  Po-210  Air 1.769145653974822E-04
 1 1 2 Ra-226  Po-210  Floor 0.1218405948756976
 1 1 3 Ra-226  Ra-226  Air 6.677472571029934E-02
 1 1 3 Ra-226  Ra-226  Floor 49.74319634703196
 1 1 3 Ra-226  Pb-210  Air 1.290150789970193E-03
 1 1 3 Ra-226  Pb-210  Floor 0.9626922247590055
 1 1 3 Ra-226  Po-210  Air 5.274989545677955E-04
 1 1 3 Ra-226  Po-210  Floor 0.3940521943176052
 1 1 4 Ra-226  Ra-226  Air 7.231084316336885E-02
 1 1 4 Ra-226  Ra-226  Floor 55.56711922881786
 1 1 4 Ra-226  Pb-210  Air 1.942058654196791E-03
 1 1 4 Ra-226  Pb-210  Floor 1.492958269913749
 1 1 4 Ra-226  Po-210  Air 9.796809598554034E-04
 1 1 4 Ra-226  Po-210  Floor 0.7533056823947235
 1 1 5 Ra-226  Ra-226  Air 7.413068398021309E-02
 1 1 5 Ra-226  Ra-226  Floor 57.55016539827498
 1 1 5 Ra-226  Pb-210  Air 2.548258091942542E-03
 1 1 5 Ra-226  Pb-210  Floor 1.978492643328260
 1 1 5 Ra-226  Po-210  Air 1.475875165485477E-03
 1 1 5 Ra-226  Po-210  Floor 1.145942415017758
```

(3) The total pathway dose results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.26E+00	6.24E-01	1.62E-04	7.03E-05	1.30E-03	3.49E-03	0.00E+00	2.91E+00
2	3.48E-01	2.48E+01	7.10E-03	2.80E-03	5.67E-02	2.78E-02	0.00E+00	2.52E+01
3	7.94E-02	7.81E+00	2.13E-03	8.80E-04	1.70E-02	2.34E-02	0.00E+00	7.93E+00
4	3.29E-02	4.38E+00	1.16E-03	4.94E-04	9.27E-03	1.96E-02	0.00E+00	4.45E+00
Total	2.74E+00	3.76E+01	1.06E-02	4.24E-03	8.43E-02	7.44E-02	0.00E+00	4.05E+01

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.26E+00	6.24E-01	1.62E-04	7.03E-05	1.30E-03	3.49E-03	0.00E+00	2.91E+00
2	3.48E-01	2.48E+01	7.10E-03	2.80E-03	5.67E-02	2.78E-02	0.00E+00	2.52E+01
3	7.94E-02	7.81E+00	2.13E-03	8.80E-04	1.70E-02	2.34E-02	0.00E+00	7.93E+00
4	3.29E-02	4.38E+00	1.16E-03	4.94E-04	9.27E-03	1.96E-02	0.00E+00	4.45E+00
Total	2.74E+00	3.76E+01	1.06E-02	4.24E-03	8.43E-02	7.44E-02	0.00E+00	4.05E+01

(4) The total pathway risk results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	5.01E-07	1.30E-10	5.67E-11	6.77E-10	3.53E-09	0.00E+00	2.33E-06
2	2.79E-07	1.99E-05	5.70E-09	2.26E-09	2.96E-08	2.88E-08	0.00E+00	2.02E-05
3	6.37E-08	6.26E-06	1.71E-09	7.10E-10	8.89E-09	2.38E-08	0.00E+00	6.36E-06
4	2.64E-08	3.51E-06	9.30E-10	3.96E-10	4.84E-09	1.95E-08	0.00E+00	3.57E-06
Total	2.20E-06	3.01E-05	8.46E-09	3.42E-09	4.40E-08	7.61E-08	0.00E+00	3.25E-05

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	5.01E-07	1.30E-10	5.67E-11	6.77E-10	3.53E-09	0.00E+00	2.33E-06
2	2.79E-07	1.99E-05	5.70E-09	2.26E-09	2.96E-08	2.88E-08	0.00E+00	2.02E-05
3	6.37E-08	6.26E-06	1.71E-09	7.10E-10	8.89E-09	2.38E-08	0.00E+00	6.36E-06
4	2.64E-08	3.51E-06	9.30E-10	3.96E-10	4.84E-09	1.95E-08	0.00E+00	3.57E-06
Total	2.20E-06	3.01E-05	8.46E-09	3.42E-09	4.40E-08	7.61E-08	0.00E+00	3.25E-05

6.3 TEST CASE 008-3

Test objectives/descriptions:

The objective of the test was to verify the release and ventilation modeling in the code and the subsequent radiation exposures associated with the releases, with the intermediate outputs of air release rate and time-averaged radionuclide concentration in air and on the floor, as well as the resultant inhalation, ingestion, and air submersion pathway dose and risk to each receptor.

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. It involved retrieving the same input file previously used for verification, launching calculations, and comparing the results and outputs with those obtained previously, which were shown to agree with the calculation results from the verification spreadsheet.

The input file, "Volume 2_S=2_V=14_EXP.BLD," associated with Test Case 008-3 was used to run the code. It considered a building with 9 rooms, 4 receptors in different rooms, and a volume source in Room 2 that released radioactivity into the air; floor vacuuming was considered every 14 days with an efficiency of 80%.The intermediate outputs matched those in the verification file, "Vol2_S=2_V=14.xlsx." The resultant pathway dose/risk to each receptor matched those provided in RESBLD-Test-001, Rev. 2.

Test result (Pass/Fail): Pass

Test details:

(1) The air release rate results from the run matched those in "Vol2_S=2_V=14.xlsx":

Results from "Vol2_S=2_V=14.xlsx"

Rate of release of source material to air						
fraction of source per second per volume (m3) of the room of release						
2.06E-11	from	time	0.00E+00	to	time	5.4E+08 seconds
8.64E+01	from	time	0.00E+00	to	time	150000 hrs

Results from the run

```
Rate of release of source material to air
fraction of source per second per volume (cubic meter) of the room of release
2.05761328E-11  from time  0.00000000E+00  to time  540000000.  seconds
```

(2) Time-averaged concentrations of radionuclide in the air and depositing on the floor from the run matched those in "Vol2_S=2_V=14.xlsx":

Results from "Vol2_S=2_V=14.xlsx"

RESRAD-BUILD input file "Volume1_S=1_V=30_Exp.BLD"						from RRB
iSr	iRoom	iTime	Parent	progeny	Media	Concentration
1	1	1	RA-226	RA-226	Air	7.02E-03
1	1	1	RA-226	RA-226	Floor	1.55E+00
1	1	1	RA-226	PB-210	Air	2.81E-05
1	1	1	RA-226	PB-210	Floor	6.52E-03
1	1	1	RA-226	PO-210	Air	3.85E-06
1	1	1	RA-226	PO-210	Floor	8.97E-04
1	1	2	RA-226	RA-226	Air	7.48E-03
1	1	2	RA-226	RA-226	Floor	1.79E+00
1	1	2	RA-226	PB-210	Air	8.68E-05
1	1	2	RA-226	PB-210	Floor	2.08E-02
1	1	2	RA-226	PO-210	Air	2.46E-05
1	1	2	RA-226	PO-210	Floor	5.90E-03
1	1	3	RA-226	RA-226	Air	7.31E-03
1	1	3	RA-226	RA-226	Floor	1.71E+00
1	1	3	RA-226	PB-210	Air	1.41E-04
1	1	3	RA-226	PB-210	Floor	3.30E-02
1	1	3	RA-226	PO-210	Air	5.74E-05
1	1	3	RA-226	PO-210	Floor	1.35E-02
1	1	4	RA-226	RA-226	Air	7.46E-03
1	1	4	RA-226	RA-226	Floor	1.78E+00
1	1	4	RA-226	PB-210	Air	2.00E-04
1	1	4	RA-226	PB-210	Floor	4.79E-02
1	1	4	RA-226	PO-210	Air	1.01E-04
1	1	4	RA-226	PO-210	Floor	2.41E-02
1	1	5	RA-226	RA-226	Air	7.33E-03
1	1	5	RA-226	RA-226	Floor	1.72E+00
1	1	5	RA-226	PB-210	Air	2.52E-04
1	1	5	RA-226	PB-210	Floor	5.92E-02
1	1	5	RA-226	PO-210	Air	1.46E-04
1	1	5	RA-226	PO-210	Floor	3.43E-02

Results from the run

```
Numerically Time Averaged Concentrations
pCi per cubic meter of air  &  pCi per square meter of floor
 iSr iRoom iTime Parent progeny Media Concentration
 1 1 1 Ra-226  Ra-226  Air 7.015214754566210E-03
 1 1 1 Ra-226  Ra-226  Floor 1.553402207001522
 1 1 1 Ra-226  Pb-210  Air 2.814694796039150E-05
 1 1 1 Ra-226  Pb-210  Floor 6.521954571759259E-03
 1 1 1 Ra-226  Po-210  Air 3.850918261306894E-06
 1 1 1 Ra-226  Po-210  Floor 8.971375223950405E-04
 1 1 2 Ra-226  Ra-226  Air 7.483648152111872E-03
 1 1 2 Ra-226  Ra-226  Floor 1.792140157280568
 1 1 2 Ra-226  Pb-210  Air 8.676626668975535E-05
 1 1 2 Ra-226  Pb-210  Floor 2.078406622590056E-02
 1 1 2 Ra-226  Po-210  Air 2.460282517834281E-05
 1 1 2 Ra-226  Po-210  Floor 5.897080419996195E-03
 1 1 3 Ra-226  Ra-226  Air 7.314366914003044E-03
 1 1 3 Ra-226  Ra-226  Floor 1.713691146626078
 1 1 3 Ra-226  Pb-210  Air 1.407835025100282E-04
 1 1 3 Ra-226  Pb-210  Floor 3.300359509766616E-02
 1 1 3 Ra-226  Po-210  Air 5.740712561140442E-05
 1 1 3 Ra-226  Po-210  Floor 1.346127144374683E-02
 1 1 4 Ra-226  Ra-226  Air 7.464995857908422E-03
 1 1 4 Ra-226  Ra-226  Floor 1.784255327245053
 1 1 4 Ra-226  Pb-210  Air 2.003124746073931E-04
 1 1 4 Ra-226  Pb-210  Floor 4.788465959538305E-02
 1 1 4 Ra-226  Po-210  Air 1.010001543994364E-04
 1 1 4 Ra-226  Po-210  Floor 2.414700263191273E-02
 1 1 5 Ra-226  Ra-226  Air 7.329065888940018E-03
 1 1 5 Ra-226  Ra-226  Floor 1.723243023845763
 1 1 5 Ra-226  Pb-210  Air 2.519104530338343E-04
 1 1 5 Ra-226  Pb-210  Floor 5.923727248224252E-02
 1 1 5 Ra-226  Po-210  Air 1.458881287209459E-04
 1 1 5 Ra-226  Po-210  Floor 3.430741454211060E-02
```

(3) The total pathway dose results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	2.05E-01	2.38E-05	2.32E-05	1.89E-04	8.57E-04	0.00E+00	2.48E+00
2	9.48E-01	1.58E+01	1.91E-03	1.79E-03	1.52E-02	8.30E-03	0.00E+00	1.62E+01
3	7.94E-02	3.62E+00	4.28E-04	4.05E-04	3.40E-03	6.16E-03	0.00E+00	3.71E+00
4	3.29E-02	1.64E+00	1.92E-04	1.86E-04	1.53E-03	4.94E-03	0.00E+00	1.68E+00
Total	2.74E+00	2.13E+01	2.55E-03	2.41E-03	2.03E-02	2.03E-02	0.00E+00	2.41E+01

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.28E+00	2.05E-01	2.38E-05	2.32E-05	1.89E-04	8.57E-04	0.00E+00	2.48E+00
2	9.48E-01	1.58E+01	1.91E-03	1.79E-03	1.52E-02	8.30E-03	0.00E+00	1.62E+01
3	7.94E-02	3.62E+00	4.28E-04	4.05E-04	3.40E-03	6.16E-03	0.00E+00	3.71E+00
4	3.29E-02	1.64E+00	1.92E-04	1.86E-04	1.53E-03	4.94E-03	0.00E+00	1.68E+00
Total	2.74E+00	2.13E+01	2.55E-03	2.41E-03	2.03E-02	2.03E-02	0.00E+00	2.41E+01

(4) The total pathway risk results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	1.65E-07	1.91E-11	1.87E-11	9.87E-11	8.65E-10	0.00E+00	1.99E-06
2	2.79E-07	1.27E-05	1.53E-09	1.44E-09	7.93E-09	8.59E-09	0.00E+00	1.30E-05
3	6.37E-08	2.90E-06	3.43E-10	3.30E-10	1.78E-09	6.25E-09	0.00E+00	2.97E-06
4	2.64E-08	1.32E-06	1.54E-10	1.50E-10	7.97E-10	5.00E-09	0.00E+00	1.35E-06
Total	2.20E-06	1.71E-05	2.05E-09	1.94E-09	1.06E-08	2.07E-08	0.00E+00	1.93E-05

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.83E-06	1.65E-07	1.91E-11	1.87E-11	9.87E-11	8.65E-10	0.00E+00	1.99E-06
2	2.79E-07	1.27E-05	1.53E-09	1.44E-09	7.93E-09	8.59E-09	0.00E+00	1.30E-05
3	6.37E-08	2.90E-06	3.43E-10	3.30E-10	1.78E-09	6.25E-09	0.00E+00	2.97E-06
4	2.64E-08	1.32E-06	1.54E-10	1.50E-10	7.97E-10	5.00E-09	0.00E+00	1.35E-06
Total	2.20E-06	1.71E-05	2.05E-09	1.94E-09	1.06E-08	2.07E-08	0.00E+00	1.93E-05

6.4 TEST CASE 008-4

Test objectives/descriptions:

The objective of the test was to verify the release and ventilation modeling in the code and the subsequent radiation exposures associated with the releases, with the intermediate outputs of air release rate and time-averaged radionuclide concentration in air and on the floor, as well as the resultant inhalation, ingestion, and air submersion pathway dose and risk to each receptor.

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. It involved retrieving the same input file previously used for verification, launching calculations, and comparing the results and outputs with those obtained previously, which were shown to agree with the calculation results from the verification spreadsheet.

The input file, "Area 1_S=3_EXP.BLD," associated with Test Case 008-4 was used to run the code. It considered a building with 9 rooms, 4 receptors in different rooms, and an area source in Room 3 that released radioactivity into the air; floor vacuuming was not involved. The intermediate outputs matched those in the verification spreadsheet file, "Area1_S=3.xlsx." The resultant pathway dose/risk to each receptor matched those provided in RESBLD-Test-001, Rev. 2.

Test result (Pass/Fail): Pass

Test details:

(1) The air release rate results from the run matched those in "Area1_S=3.xlsx":

Results from "Area1_S=3.xlsx"

Rate of release of source material to air					
fraction of source per second per volume (m3) of the room of release					
4.29E-10 from	time	0 to	time	2592000 seconds	
6.43E-10 from	time	2592000 to	time	5184000 seconds	
8.04E-10 from	time	5184000 to	time	8640000 seconds	
1.93E-09 from	time	8640000 to	time	10368000 seconds	
1.61E-10 from	time	10368000 to	time	17280000 seconds	
1.84E-10 from	time	24192000 to	time	30240000 seconds	

Results from the run

```
Rate of release of source material to air
fraction of source per second per volume (cubic meter) of the room of release
4.28823393E-10  from time  0.00000000E+00  to time  2592000.00  seconds
6.43235132E-10  from time  2592000.00  to time  5184000.00  seconds
8.03838773E-10  from time  5184000.00  to time  8640000.00  seconds
1.93069027E-09  from time  8640000.00  to time  10368000.0  seconds
1.60767760E-10  from time  10368000.0  to time  17280000.0  seconds
1.83754664E-10  from time  24192000.0  to time  30240000.0  seconds
```

(2) Time-averaged concentrations of radionuclide in the air and depositing on the floor from the run matched those in "Area1_S=3.xlsx":

Results from "Area1_S=3.xlsx"

RESRAD-BUILD input file "Area1_S=3_Exp.BLD"						from RRB
iSr	iRoom	iTime	Parent	progeny	Media	Concentration (pCi/m3 or pCi/m2)
1	1	1	RA-226	RA-226	Air	2.04E-06
1	1	1	RA-226	RA-226	Floor	9.92E-04
1	1	1	RA-226	PB-210	Air	1.04E-08
1	1	1	RA-226	PB-210	Floor	5.41E-06
1	1	1	RA-226	PO-210	Air	1.59E-09
1	1	1	RA-226	PO-210	Floor	8.49E-07
1	1	2	RA-226	RA-226	Air	5.60E-06
1	1	2	RA-226	RA-226	Floor	3.93E-03
1	1	2	RA-226	PB-210	Air	6.46E-08
1	1	2	RA-226	PB-210	Floor	4.66E-05
1	1	2	RA-226	PO-210	Air	1.82E-08
1	1	2	RA-226	PO-210	Floor	1.34E-05
1	1	3	RA-226	RA-226	Air	3.34E-06
1	1	3	RA-226	RA-226	Floor	3.12E-03
1	1	3	RA-226	PB-210	Air	6.25E-08
1	1	3	RA-226	PB-210	Floor	5.87E-05
1	1	3	RA-226	PO-210	Air	2.49E-08
1	1	3	RA-226	PO-210	Floor	2.36E-05
1	1	4	RA-226	RA-226	Air	1.81E-06
1	1	4	RA-226	RA-226	Floor	1.60E-03
1	1	4	RA-226	PB-210	Air	4.82E-08
1	1	4	RA-226	PB-210	Floor	4.26E-05
1	1	4	RA-226	PO-210	Air	2.42E-08
1	1	4	RA-226	PO-210	Floor	2.13E-05
1	1	5	RA-226	RA-226	Air	9.58E-07
1	1	5	RA-226	RA-226	Floor	9.31E-04
1	1	5	RA-226	PB-210	Air	3.24E-08
1	1	5	RA-226	PB-210	Floor	3.15E-05
1	1	5	RA-226	PO-210	Air	1.86E-08
1	1	5	RA-226	PO-210	Floor	1.81E-05

Results from the run

Numerically Time Averaged Concentrations
pCi per cubic meter of air & pCi per square meter of floor

iSr	iRoom	iTime	Parent	progeny	Media	Concentration
1	1	1	Ra-226	Ra-226	Air	2.044885307323624E-06
1	1	1	Ra-226	Ra-226	Floor	9.919116495830161E-04
1	1	1	Ra-226	Pb-210	Air	1.042845121710994E-08
1	1	1	Ra-226	Pb-210	Floor	5.412824622027950E-06
1	1	1	Ra-226	Po-210	Air	1.592245964094324E-09
1	1	1	Ra-226	Po-210	Floor	8.492707480397217E-07
1	1	2	Ra-226	Ra-226	Air	5.598513865942643E-06
1	1	2	Ra-226	Ra-226	Floor	3.930282058599696E-03
1	1	2	Ra-226	Pb-210	Air	6.453409405422355E-08
1	1	2	Ra-226	Pb-210	Floor	4.662336158849212E-05
1	1	2	Ra-226	Po-210	Air	1.817616198886656E-08
1	1	2	Ra-226	Po-210	Floor	1.341201108703149E-05
1	1	3	Ra-226	Ra-226	Air	3.341391024887108E-06
1	1	3	Ra-226	Ra-226	Floor	3.121919690988077E-03
1	1	3	Ra-226	Pb-210	Air	6.245301950407295E-08
1	1	3	Ra-226	Pb-210	Floor	5.870471878864631E-05
1	1	3	Ra-226	Po-210	Air	2.495660047310975E-08
1	1	3	Ra-226	Po-210	Floor	2.355703685805013E-05
1	1	4	Ra-226	Ra-226	Air	1.808038766707097E-06
1	1	4	Ra-226	Ra-226	Floor	1.601743468773782E-03
1	1	4	Ra-226	Pb-210	Air	4.821215892793684E-08
1	1	4	Ra-226	Pb-210	Floor	4.257335691872978E-05
1	1	4	Ra-226	Po-210	Air	2.421590087076300E-08
1	1	4	Ra-226	Po-210	Floor	2.134371698961108E-05
1	1	5	Ra-226	Ra-226	Air	9.576601161985819E-07
1	1	5	Ra-226	Ra-226	Floor	9.307081589294774E-04
1	1	5	Ra-226	Pb-210	Air	3.236898881175807E-08
1	1	5	Ra-226	Pb-210	Floor	3.152568203613033E-05
1	1	5	Ra-226	Po-210	Air	1.858068580012948E-08
1	1	5	Ra-226	Po-210	Floor	1.811726888020833E-05

(3) The total pathway dose results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.16E-05	5.98E-05	1.51E-08	6.74E-09	1.21E-07	2.38E-07	0.00E+00	7.19E-05
2	1.30E-06	2.47E-03	6.83E-07	2.78E-07	5.46E-06	1.16E-06	0.00E+00	2.48E-03
3	2.92E-07	7.62E-04	2.02E-07	8.59E-08	1.61E-06	1.45E-06	0.00E+00	7.66E-04
4	1.23E-07	4.23E-04	1.09E-07	4.76E-08	8.70E-07	1.30E-06	0.00E+00	4.25E-04
Total	1.34E-05	3.71E-03	1.01E-06	4.18E-07	8.06E-06	4.15E-06	0.00E+00	3.74E-03

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.16E-05	5.98E-05	1.51E-08	6.74E-09	1.21E-07	2.38E-07	0.00E+00	7.19E-05
2	1.30E-06	2.47E-03	6.83E-07	2.78E-07	5.46E-06	1.16E-06	0.00E+00	2.48E-03
3	2.92E-07	7.62E-04	2.02E-07	8.59E-08	1.61E-06	1.45E-06	0.00E+00	7.66E-04
4	1.23E-07	4.23E-04	1.09E-07	4.76E-08	8.70E-07	1.30E-06	0.00E+00	4.25E-04
Total	1.34E-05	3.71E-03	1.01E-06	4.18E-07	8.06E-06	4.15E-06	0.00E+00	3.74E-03

(4) The total pathway risk results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	9.33E-12	4.80E-11	1.21E-14	5.44E-15	6.32E-14	2.41E-13	0.00E+00	5.76E-11
2	1.04E-12	1.98E-09	5.48E-13	2.24E-13	2.85E-12	1.23E-12	0.00E+00	1.98E-09
3	2.34E-13	6.11E-10	1.62E-13	6.93E-14	8.42E-13	1.49E-12	0.00E+00	6.14E-10
4	9.84E-14	3.39E-10	8.72E-14	3.84E-14	4.54E-13	1.33E-12	0.00E+00	3.41E-10
Total	1.07E-11	2.98E-09	8.05E-13	3.38E-13	4.21E-12	4.28E-12	0.00E+00	3.00E-09

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	9.33E-12	4.80E-11	1.21E-14	5.44E-15	6.32E-14	2.41E-13	0.00E+00	5.76E-11
2	1.04E-12	1.98E-09	5.48E-13	2.24E-13	2.85E-12	1.23E-12	0.00E+00	1.98E-09
3	2.34E-13	6.11E-10	1.62E-13	6.93E-14	8.42E-13	1.49E-12	0.00E+00	6.14E-10
4	9.84E-14	3.39E-10	8.72E-14	3.84E-14	4.54E-13	1.33E-12	0.00E+00	3.41E-10
Total	1.07E-11	2.98E-09	8.05E-13	3.38E-13	4.21E-12	4.28E-12	0.00E+00	3.00E-09

6.5 TEST CASE 008-5

Test objectives/descriptions:

The objective of the test was to verify the release and ventilation modeling in the code and the subsequent radiation exposures associated with the releases, with the intermediate outputs of air release rate and time-averaged radionuclide concentration in air and on the floor, as well as the resultant inhalation, ingestion, and air submersion pathway dose and risk to each receptor.

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. It involved retrieving the same input file previously used for verification, launching calculations, and comparing the results and outputs with those obtained previously, which were shown to agree with the calculation results from the verification spreadsheet.

The input file, "Area 2_S=5_V=14_EXP.BLD," associated with Test Case 008-5 was used to run the code. It considered a building with 9 rooms, 4 receptors in different rooms, and an area source in Room 5 that released radioactivity into the air; floor vacuuming was considered every 14 days with an efficiency of 80%. The intermediate outputs matched those in the verification spreadsheet file, "Area2_S=5_V=14.xlsx." The resultant pathway dose/risk to each receptor matched those provided in RESBLD-Test-001, Rev. 2.

Test result (Pass/Fail): Pass

Test details:

(1) The air release rate results from the run matched those in "Area 2_S=5_V=14.xlsx":

Results from "Area2_S=5_V=14.xlsx"

Rate of release of source material to air					
fraction of source per second per volume (m3) of the room of release					
2.14E-10	from	time	0.00E+00	to time	5184000 seconds
3.22E-10	from	time	5184000	to time	10368000 seconds
4.02E-10	from	time	10368000	to time	17280000 seconds
9.65E-10	from	time	17280000	to time	20736000 seconds
8.04E-11	from	time	20736000	to time	34560000 seconds
4.02E-11	from	time	34560000	to time	48384000 seconds
4.59E-11	from	time	48384000	to time	60480000 seconds

Results from the run

```
Rate of release of source material to air
 fraction of source per second per volume (cubic meter) of the room of release
2.14424936E-10  from time  0.00000000E+00  to time  5184000.00  seconds
3.21637411E-10  from time  5184000.00  to time  10368000.0  seconds
4.01926548E-10  from time  10368000.0  to time  17280000.0  seconds
9.64623714E-10  from time  17280000.0  to time  20736000.0  seconds
8.03853095E-11  from time  20736000.0  to time  34560000.0  seconds
4.01926548E-11  from time  34560000.0  to time  48384000.0  seconds
4.59403487E-11  from time  48384000.0  to time  60480000.0  seconds
```

(2) Time-averaged concentrations of radionuclide in the air and depositing on the floor from the run matched those in "Area2_S=5_V=14.xlsx":

Results from "Area2_S=5_V=14.xlsx"

RESRAD-BUILD input file "Area2_S=5_V=14_Exp.BLD"						from RRB
iSr	iRoom	iTime	Parent	progeny	Media	Concentration (pCi/m3 or pCi/m2)
1	1	1	RA-226	RA-226	Air	8.93E-07
1	1	1	RA-226	RA-226	Floor	1.96E-04
1	1	1	RA-226	PB-210	Air	3.85E-09
1	1	1	RA-226	PB-210	Floor	8.69E-07
1	1	1	RA-226	PO-210	Air	5.53E-10
1	1	1	RA-226	PO-210	Floor	1.25E-07
1	1	2	RA-226	RA-226	Air	1.41E-06
1	1	2	RA-226	RA-226	Floor	3.38E-04
1	1	2	RA-226	PB-210	Air	1.66E-08
1	1	2	RA-226	PB-210	Floor	3.99E-06
1	1	2	RA-226	PO-210	Air	4.77E-09
1	1	2	RA-226	PO-210	Floor	1.15E-06
1	1	3	RA-226	RA-226	Air	2.01E-06
1	1	3	RA-226	RA-226	Floor	4.96E-04
1	1	3	RA-226	PB-210	Air	3.74E-08
1	1	3	RA-226	PB-210	Floor	9.38E-06
1	1	3	RA-226	PO-210	Air	1.48E-08
1	1	3	RA-226	PO-210	Floor	3.77E-06
1	1	4	RA-226	RA-226	Air	3.06E-07
1	1	4	RA-226	RA-226	Floor	7.59E-05
1	1	4	RA-226	PB-210	Air	8.21E-09
1	1	4	RA-226	PB-210	Floor	2.03E-06
1	1	4	RA-226	PO-210	Air	4.14E-09
1	1	4	RA-226	PO-210	Floor	1.02E-06
1	1	5	RA-226	RA-226	Air	2.13E-07
1	1	5	RA-226	RA-226	Floor	5.34E-05
1	1	5	RA-226	PB-210	Air	7.20E-09
1	1	5	RA-226	PB-210	Floor	1.80E-06
1	1	5	RA-226	PO-210	Air	4.13E-09
1	1	5	RA-226	PO-210	Floor	1.03E-06

Results from the run

```
Numerically Time Averaged Concentrations
pCi per cubic meter of air  &  pCi per square meter of floor
 iSr iRoom iTime Parent progeny Media Concentration
 1 1 1 Ra-226  Ra-226  Air 8.931659551395008E-07
 1 1 1 Ra-226  Ra-226  Floor 1.959710200990535E-04
 1 1 1 Ra-226  Pb-210  Air 3.850586496894581E-09
 1 1 1 Ra-226  Pb-210  Floor 8.689182655028677E-07
 1 1 1 Ra-226  Po-210  Air 5.530487350979654E-10
 1 1 1 Ra-226  Po-210  Floor 1.246177760070499E-07
 1 1 2 Ra-226  Ra-226  Air 1.411581450703784E-06
 1 1 2 Ra-226  Ra-226  Floor 3.384278954012874E-04
 1 1 2 Ra-226  Pb-210  Air 1.662711975297487E-08
 1 1 2 Ra-226  Pb-210  Floor 3.993706192721092E-06
 1 1 2 Ra-226  Po-210  Air 4.766856706245244E-09
 1 1 2 Ra-226  Po-210  Floor 1.147357659071366E-06
 1 1 3 Ra-226  Ra-226  Air 2.014203823985695E-06
 1 1 3 Ra-226  Ra-226  Floor 4.964682909512145E-04
 1 1 3 Ra-226  Pb-210  Air 3.742611858821774E-08
 1 1 3 Ra-226  Pb-210  Floor 9.380547665267472E-06
 1 1 3 Ra-226  Po-210  Air 1.485126574047927E-08
 1 1 3 Ra-226  Po-210  Floor 3.767228864401745E-06
 1 1 4 Ra-226  Ra-226  Air 3.062629385202564E-07
 1 1 4 Ra-226  Ra-226  Floor 7.593438445100441E-05
 1 1 4 Ra-226  Pb-210  Air 8.209722370801391E-09
 1 1 4 Ra-226  Pb-210  Floor 2.031078077342412E-06
 1 1 4 Ra-226  Po-210  Air 4.136975040023306E-09
 1 1 4 Ra-226  Po-210  Floor 1.022243427177905E-06
 1 1 5 Ra-226  Ra-226  Air 2.133016928629728E-07
 1 1 5 Ra-226  Ra-226  Floor 5.338390704522213E-05
 1 1 5 Ra-226  Pb-210  Air 7.198406699978718E-09
 1 1 5 Ra-226  Pb-210  Floor 1.803454138312105E-06
 1 1 5 Ra-226  Po-210  Air 4.128681969243460E-09
 1 1 5 Ra-226  Po-210  Floor 1.034892433975506E-06
```

(3) The total pathway dose results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.33E-05	2.61E-05	3.00E-09	2.95E-09	2.39E-08	5.02E-08	0.00E+00	3.95E-05
2	1.48E-06	1.15E-05	1.29E-09	1.30E-09	1.03E-08	5.72E-08	0.00E+00	1.30E-05
3	2.35E-07	5.39E-06	6.03E-10	6.08E-10	4.80E-09	3.49E-08	0.00E+00	5.67E-06
4	1.40E-07	2.10E-04	2.43E-08	2.37E-08	1.93E-07	2.75E-07	0.00E+00	2.10E-04
Total	1.51E-05	2.53E-04	2.92E-08	2.85E-08	2.32E-07	4.17E-07	0.00E+00	2.68E-04

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.33E-05	2.61E-05	3.00E-09	2.95E-09	2.39E-08	5.02E-08	0.00E+00	3.95E-05
2	1.48E-06	1.15E-05	1.29E-09	1.30E-09	1.03E-08	5.72E-08	0.00E+00	1.30E-05
3	2.35E-07	5.39E-06	6.03E-10	6.08E-10	4.80E-09	3.49E-08	0.00E+00	5.67E-06
4	1.40E-07	2.10E-04	2.43E-08	2.37E-08	1.93E-07	2.75E-07	0.00E+00	2.10E-04
Total	1.51E-05	2.53E-04	2.92E-08	2.85E-08	2.32E-07	4.17E-07	0.00E+00	2.68E-04

(4) The total pathway risk results (summed over nuclides) for each receptor-source from the run matched those provided in RESBLD-Test-001, Rev. 2:

Results from RESBLD-TEST-001, Rev. 2

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.06E-11	2.09E-11	2.40E-15	2.36E-15	1.25E-14	5.09E-14	0.00E+00	3.16E-11
2	1.18E-12	9.20E-12	1.03E-15	1.04E-15	5.36E-15	5.77E-14	0.00E+00	1.05E-11
3	1.92E-13	4.32E-12	4.84E-16	4.91E-16	2.51E-15	3.52E-14	0.00E+00	4.55E-12
4	1.12E-13	1.68E-10	1.95E-14	1.91E-14	1.01E-13	2.80E-13	0.00E+00	1.69E-10
Total	1.21E-11	2.03E-10	2.34E-14	2.30E-14	1.21E-13	4.24E-13	0.00E+00	2.15E-10

Results from the run

Evaluation Time: 0.00000000E+00 years

Pathway Detail of Risks

[Risk]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	1.06E-11	2.09E-11	2.40E-15	2.36E-15	1.25E-14	5.09E-14	0.00E+00	3.16E-11
2	1.18E-12	9.20E-12	1.03E-15	1.04E-15	5.36E-15	5.77E-14	0.00E+00	1.05E-11
3	1.92E-13	4.32E-12	4.84E-16	4.91E-16	2.51E-15	3.52E-14	0.00E+00	4.55E-12
4	1.12E-13	1.68E-10	1.95E-14	1.91E-14	1.01E-13	2.80E-13	0.00E+00	1.69E-10
Total	1.21E-11	2.03E-10	2.34E-14	2.30E-14	1.21E-13	4.24E-13	0.00E+00	2.15E-10

7. TEST CASE 012

7.1 TEST CASE 012-1

Test objectives/descriptions:

To verify the external dose calculation results for a point source.

Test result (Pass/Fail): Pass

Test details:

Refer to Test Case 012-1 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2, for details on the test procedure. The input file associated with this test case, "point-source-verification.bld," was used. External exposure pathway dose and risks were calculated at different receptor locations with and without shielding. The receptors considered were:

Receptor 1 – no shield and @ 1 m, 1 m, 1 m
Receptor 2 – water shield 1 cm and @ 1 m, 1 m, 1 m
Receptor 3 – water shield 5 cm and @ 1 m, 1 m, 1 m
Receptor 4 - water shield 50 cm and @ 1 m, 1 m, 1 m
Receptor 5 – concrete shield 1 cm and @ 1 m, 1 m, 1 m
Receptor 6 - concrete shield 1 cm and @ 1 m, 1 m, 1 m
Receptor 7 – concrete shield 1 cm and @ 1 m, 1 m, 1 m
Receptor 8 – no shield and @ 0 m, 0 m, 0.3 m
Receptor 9 – no shield and @ 0 m, 0 m, 4 m

Dose results for the external exposure pathway in "Verification of Point Source Dose Calculations.docx" for different receptors are displayed first followed by results in RESRADB.RPT in the following screen shots. Dose results for the external exposure pathway match:

Dose (mrem/yr) Calculation Results for a Point Source at Different Receptor Locations with and without Shielding from the "Verification of Point Source Dose Calculations.docx" File

Nuclide	Without Shielding (Table 1)			With Water Shielding (Table 2) Receptor (1m, 1m, 1m)			With Concrete Shielding (Table 3) Receptor (1m, 1m, 1m)		
	Receptor (0m,0m,0.3m)	Receptor (1m,1m,1m)	Receptor (0m,0m,4m)	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	1.01E-09	3.17E-11	6.41E-12	4.04E-11	4.72E-11	3.36E-14	1.87E-11	7.13E-13	2.77E-31
Mn-54	1.13E-05	3.36E-07	6.28E-08	3.32E-07	3.18E-07	5.79E-08	3.26E-07	2.70E-07	1.46E-09
Co-60	4.36E-05	1.31E-06	2.44E-07	1.29E-06	1.22E-06	2.77E-07	1.26E-06	1.05E-06	1.39E-08
Nb-94	3.10E-05	9.28E-07	1.73E-07	9.18E-07	8.81E-07	1.55E-07	9.01E-07	7.46E-07	3.57E-09
Tc-99	3.31E-09	1.01E-10	1.97E-11	1.18E-10	1.66E-10	4.24E-12	1.12E-10	5.66E-11	3.96E-18

```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/16/22 08:14:31  Page:   8 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\point-source-verification.bld
 Evaluation Time:  0.00000000E+00  years


                        Nuclide Detail of Doses
                        =======================
                                [mrem]

Source:  1
  Nuclide  Receptor   Receptor   Receptor   Receptor   Receptor   Receptor   Receptor   Receptor   Receptor     Total
             1          2          3          4          5          6          7          8          9
  C-14     3.17E-11   4.04E-11   4.72E-11   3.36E-14   1.87E-11   7.13E-13   2.77E-31   1.01E-09   6.41E-12   1.15E-09

  Co-60    1.31E-06   1.29E-06   1.22E-06   2.77E-07   1.26E-06   1.05E-06   1.39E-08   4.36E-05   2.44E-07   5.03E-05

  Mn-54    3.36E-07   3.32E-07   3.18E-07   5.79E-08   3.26E-07   2.70E-07   1.46E-09   1.13E-05   6.28E-08   1.30E-05

  Nb-94    9.28E-07   9.18E-07   8.81E-07   1.55E-07   9.01E-07   7.46E-07   3.57E-09   3.10E-05   1.73E-07   3.57E-05

  Tc-99    1.01E-10   1.18E-10   1.66E-10   4.24E-12   1.12E-10   5.66E-11   3.96E-18   3.31E-09   1.97E-11   3.89E-09
```

Risk results for the external exposure pathway in the "Verification of Point Source Dose Calculations.docx" file are displayed first followed by results in RESRADB_R.RPT in the following screen shots. Risk results for the external exposure pathway match:

Risk (risk/yr) Calculation Results for a Point Source at Different Receptor Locations with and without Shielding from the "Verification of Point Source Dose Calculations.docx" File

Nuclide	Without Shielding (Table 5)			With Water Shielding (Table 6) Receptor (1m, 1m, 1m)			With Concrete Shielding (Table 7) Receptor (1m, 1m, 1m)		
	Receptor (0m,0m,0.3m)	Receptor (1m,1m,1m)	Receptor (0m,0m,4m)	1 cm	5 cm	50 cm	1 cm	5 cm	50 cm
C-14	5.85E-16	1.85E-17	3.73E-18	2.35E-17	2.75E-17	1.96E-20	1.09E-17	4.15E-19	1.61E-37
Mn-54	8.49E-12	2.54E-13	4.74E-14	2.51E-13	2.40E-13	4.37E-14	2.46E-13	2.04E-13	1.10E-15
Co-60	3.34E-11	9.99E-13	1.87E-13	9.85E-13	9.32E-13	2.11E-13	9.63E-13	8.01E-13	1.06E-14
Nb-94	2.34E-11	6.99E-13	1.31E-13	6.91E-13	6.64E-13	1.17E-13	6.79E-13	5.62E-13	2.69E-15
Tc-99	2.15E-15	6.56E-17	1.28E-17	7.64E-17	1.08E-16	2.75E-18	7.29E-17	3.67E-17	2.57E-24

```
** RESRAD-BUILD Risk Program Output, Version 4.0.19.0 Beta 12/16/22 08:14:31  Page:   8 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\point-source-verification.bld
 Evaluation Time:  0.00000000E+00  years


                        Nuclide Detail of Risks
                        =======================
                                [Risk]

Source:  1
  Nuclide  Receptor   Receptor   Receptor   Receptor   Receptor   Receptor   Receptor   Receptor   Receptor     Total
             1          2          3          4          5          6          7          8          9
  C-14     1.85E-17   2.35E-17   2.75E-17   1.96E-20   1.09E-17   4.15E-19   1.61E-37   5.85E-16   3.73E-18   6.70E-16

  Co-60    9.99E-13   9.85E-13   9.32E-13   2.11E-13   9.63E-13   8.01E-13   1.06E-14   3.34E-11   1.87E-13   3.85E-11

  Mn-54    2.54E-13   2.51E-13   2.40E-13   4.37E-14   2.46E-13   2.04E-13   1.10E-15   8.49E-12   4.74E-14   9.77E-12

  Nb-94    6.99E-13   6.91E-13   6.64E-13   1.17E-13   6.79E-13   5.62E-13   2.69E-15   2.34E-11   1.31E-13   2.69E-11

  Tc-99    6.56E-17   7.64E-17   1.08E-16   2.75E-18   7.29E-17   3.67E-17   2.57E-24   2.15E-15   1.28E-17   2.52E-15
```

7.2 TEST CASE 012-2

Test objectives/descriptions:

To verify the external dose calculation results for a line source.

Test result (Pass/Fail): Pass

Test details:

Refer to Test Case 012-2 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "line-source-verification.bld" associated with the test case was used. External exposure pathway dose and risks are calculated at different receptor locations with and without shielding. The receptors considered were:

Receptor 1 – no shield and @ 1 m, 1 m, 1 m
Receptor 2 – water shield 1 cm and @ 1 m, 1 m, 1 m
Receptor 3 – water shield 5 cm and @ 1 m, 1 m, 1 m
Receptor 4 - water shield 50 cm and @ 1 m, 1 m, 1 m
Receptor 5 – concrete shield 1 cm and @ 1 m, 1 m, 1 m
Receptor 6 – concrete shield 1 cm and @ 1 m, 1 m, 1 m
Receptor 7 – concrete shield 1 cm and @ 1 m, 1 m, 1 m
Receptor 8 – no shield and @ 0 m, 0 m, 0.3 m
Receptor 9 – no shield and @ 0 m, 0 m, 4 m

Dose results for the external exposure pathway from "Verification of Line Source Dose Calculations.docx" for different receptors are displayed first followed by results in RESRADB.RPT in the following screen shots. Dose results for the external exposure pathway match:

Dose (mrem/yr) Calculation Results for a Line Source at Different Receptor Locations with and without Shielding from the "Verification of Line Source Dose Calculations.docx" File

Nuclide	Without Shielding (Table 1)			With Water Shielding (Table 2) Receptor (1m, 1m, 1m)			With Concrete Shielding (Table 3) Receptor (1m, 1m, 1m)		
	Receptor 8 (0m,0m,0.3m)	Receptor 1 (1m,1m,1m)	Receptor 9 (0m,0m,4m)	Receptor 2 1 cm	Receptor 3 5 cm	Receptor 4 50 cm	Receptor 5 1 cm	Receptor 6 5 cm	Receptor 7 50 cm
C-14	6.20E-10	3.20E-11	6.38E-12	4.07E-11	4.76E-11	3.39E-14	1.89E-11	7.18E-13	2.79E-31
Mn-54	6.95E-06	3.39E-07	6.25E-08	3.35E-07	3.20E-07	5.83E-08	3.28E-07	2.72E-07	1.47E-09
Co-60	2.70E-05	1.32E-06	2.43E-07	1.30E-06	1.23E-06	2.79E-07	1.27E-06	1.06E-06	1.40E-08
Nb-94	1.92E-05	9.35E-07	1.73E-07	9.25E-07	8.88E-07	1.57E-07	9.08E-07	7.52E-07	3.60E-09
Tc-99	2.04E-09	1.02E-10	1.96E-11	1.19E-10	1.67E-10	4.27E-12	1.13E-10	5.70E-11	3.99E-18

```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/16/22 08:31:02  Page:   8 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\line-source-verification.bld
 Evaluation Time:  0.00000000E+00  years


                        Nuclide Detail of Doses
                                [mrem]

Source:  1
  Nuclide  Receptor  Receptor  Receptor  Receptor  Receptor  Receptor  Receptor  Receptor  Receptor    Total
              1         2         3         4         5         6         7         8         9
  C-14     3.20E-11  4.07E-11  4.76E-11  3.39E-14  1.89E-11  7.18E-13  2.79E-31  6.20E-10  6.38E-12  7.67E-10

  Co-60    1.32E-06  1.30E-06  1.23E-06  2.79E-07  1.27E-06  1.06E-06  1.40E-08  2.70E-05  2.43E-07  3.37E-05

  Mn-54    3.39E-07  3.35E-07  3.20E-07  5.83E-08  3.28E-07  2.72E-07  1.47E-09  6.95E-06  6.25E-08  8.67E-06

  Nb-94    9.35E-07  9.25E-07  8.88E-07  1.57E-07  9.08E-07  7.52E-07  3.60E-09  1.92E-05  1.73E-07  2.39E-05

  Tc-99    1.02E-10  1.19E-10  1.67E-10  4.27E-12  1.13E-10  5.70E-11  3.99E-18  2.04E-09  1.96E-11  2.62E-09
```

Risk results for the external exposure pathway in the "Verification of Line Source Dose Calculations.docx" file are displayed first followed by results in RESRADB_R.RPT in the following screen shots. Risk results for the external exposure pathway match:

Risk (risk/yr) Calculation Results for a Line Source at Different Receptor Locations with and without Shielding from the "Verification of Line Source Dose Calculations.docx" File

Nuclide	Without Shielding (Table 5)			With Water Shielding (Table 6) Receptor (1m, 1m, 1m)			With Concrete Shielding (Table 7) Receptor (1m, 1m, 1m)		
	Receptor 8 (0m,0m,0.3m)	Receptor 1 (1m,1m,1m)	Receptor 9 (0m,0m,4m)	Receptor 2 1 cm	Receptor 3 5 cm	Receptor 4 50 cm	Receptor 5 1 cm	Receptor 6 5 cm	Receptor 7 50 cm
C-14	3.61E-16	1.86E-17	3.71E-18	2.37E-17	2.77E-17	1.97E-20	1.10E-17	4.18E-19	1.62E-37
Mn-54	5.24E-12	2.56E-13	4.72E-14	2.53E-13	2.42E-13	4.40E-14	2.48E-13	2.05E-13	1.11E-15
Co-60	2.06E-11	1.01E-12	1.86E-13	9.93E-13	9.39E-13	2.13E-13	9.71E-13	8.07E-13	1.07E-14
Nb-94	1.45E-11	7.04E-13	1.30E-13	6.97E-13	6.69E-13	1.18E-13	6.84E-13	5.66E-13	2.71E-15
Tc-99	1.32E-15	6.61E-17	1.27E-17	7.69E-17	1.08E-16	2.77E-18	7.35E-17	3.70E-17	2.59E-24

```
** RESRAD-BUILD Risk Program Output, Version 4.0.19.0 Beta 12/16/22 08:31:02  Page:   8 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\line-source-verification.bld
 Evaluation Time:  0.00000000E+00  years


                        Nuclide Detail of Risks
                                [Risk]

Source:  1
  Nuclide  Receptor  Receptor  Receptor  Receptor  Receptor  Receptor  Receptor  Receptor  Receptor    Total
              1         2         3         4         5         6         7         8         9
  C-14     1.86E-17  2.37E-17  2.77E-17  1.97E-20  1.10E-17  4.18E-19  1.62E-37  3.61E-16  3.71E-18  4.46E-16

  Co-60    1.01E-12  9.93E-13  9.39E-13  2.13E-13  9.71E-13  8.07E-13  1.07E-14  2.06E-11  1.86E-13  2.57E-11

  Mn-54    2.56E-13  2.53E-13  2.42E-13  4.40E-14  2.48E-13  2.05E-13  1.11E-15  5.24E-12  4.72E-14  6.54E-12

  Nb-94    7.04E-13  6.97E-13  6.69E-13  1.18E-13  6.84E-13  5.66E-13  2.71E-15  1.44E-11  1.30E-13  1.80E-11

  Tc-99    6.61E-17  7.69E-17  1.08E-16  2.77E-18  7.35E-17  3.70E-17  2.59E-24  1.32E-15  1.27E-17  1.70E-15
```

7.3 TEST CASE 012-3

Test objectives/descriptions:

To verify the external dose calculation results for floor deposition.

Test result (Pass/Fail): Pass

Test details:

Refer to Test Case 012-3 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "Deposition-1.bld" associated with the test case was used. External exposure pathway dose and risks are calculated at different receptor locations with and without shielding. The receptors considered were:

Receptor 1 – Room 1 (area = 10 m^2) @ 0 m, 0 m, 1 m
Receptor 2 – Room 2 (area = 36 m^2) @ 6 m, 6 m, 1 m
Receptor 3 – Room 3 (area = 100 m^2) @ 10 m, 10 m, 1 m
Receptor 4 - Room 4 (area = 1,000 m^2) @ 25 m, 40 m, 1 m

Dose results for external exposure from deposition pathway from "Verification of External Exposure Dose and Risk from Deposition.docx" for different receptors are displayed first followed by results in RESRADB.RPT in the following screen shots. Dose results for external exposure from deposition pathway match:

Dose (mrem/yr) Calculation Results for Floor Deposition at Different Receptor Locations (receptors in different rooms) from Table 5 in the "Verification of External Exposure Dose and Risk from Deposition.docx" File				
Radionuclide	Receptor 1 Room 1 - 10 m^2	Receptor 2 Room 2 - 36 m^2	Receptor 3 Room 3 - 100 m^2	Receptor 4 Room 4 - 1000 m^2
Mn-54 (Source 2)	3.60E-08	1.15E-08	9.80E-09	2.41E-09
C-14 (Source 1)	4.28E-13	1.49E-13	1.33E-13	3.63E-14
Mn-54 (Source 3)	3.60E-08	1.15E-08	9.80E-09	2.41E-09
Tc-99 (Source 4)	4.29E-13	1.48E-13	1.30E-13	3.46E-14

** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/16/22 09:10:00 Page: 9 **
Title : Default Case for RESRAD-BUILD
Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\Deposition-1.bld
Evaluation Time: 0.00000000E+00 years

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	5.30E-06	1.37E-09	4.28E-13	2.62E-15	3.42E-09	0.00E+00	0.00E+00	5.30E-06
2	2.13E-08	2.75E-10	1.49E-13	5.24E-16	6.62E-10	0.00E+00	0.00E+00	2.22E-08
3	4.13E-09	1.76E-10	1.33E-13	3.35E-16	4.16E-10	0.00E+00	0.00E+00	4.72E-09
4	5.81E-11	2.73E-11	3.63E-14	5.20E-17	6.36E-11	0.00E+00	0.00E+00	1.49E-10
Total	5.32E-06	1.85E-09	7.45E-13	3.53E-15	4.56E-09	0.00E+00	0.00E+00	5.33E-06

Source: 2

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	2.09E-07	6.85E-09	3.60E-08	7.44E-10	6.93E-09	0.00E+00	0.00E+00	2.59E-07
2	6.77E-06	1.29E-09	1.15E-08	1.40E-10	1.26E-09	0.00E+00	0.00E+00	6.79E-06
3	4.76E-07	8.04E-10	9.80E-09	8.72E-11	7.74E-10	0.00E+00	0.00E+00	4.87E-07
4	9.49E-09	1.22E-10	2.41E-09	1.32E-11	1.16E-10	0.00E+00	0.00E+00	1.21E-08
Total	7.47E-06	9.07E-09	5.97E-08	9.84E-10	9.07E-09	0.00E+00	0.00E+00	7.55E-06

Source: 3

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	8.06E-08	6.85E-09	3.60E-08	7.44E-10	6.93E-09	0.00E+00	0.00E+00	1.31E-07
2	5.28E-07	1.29E-09	1.15E-08	1.40E-10	1.26E-09	0.00E+00	0.00E+00	5.42E-07
3	4.33E-06	8.04E-10	9.80E-09	8.72E-11	7.74E-10	0.00E+00	0.00E+00	4.34E-06
4	1.35E-08	1.22E-10	2.41E-09	1.32E-11	1.16E-10	0.00E+00	0.00E+00	1.62E-08
Total	4.95E-06	9.07E-09	5.97E-08	9.84E-10	9.07E-09	0.00E+00	0.00E+00	5.03E-06

Source: 4

Receptor	External directly from Source	Inhalation	External from Deposition on floor	External from Suspension in air	Ingestion of Deposition	Radon	Ingestion of Source	Total
1	3.30E-13	1.30E-09	4.29E-13	4.50E-15	5.69E-10	0.00E+00	0.00E+00	1.87E-09
2	4.67E-13	2.60E-10	1.48E-13	9.01E-16	1.10E-10	0.00E+00	0.00E+00	3.71E-10
3	6.08E-13	1.66E-10	1.30E-13	5.76E-16	6.92E-11	0.00E+00	0.00E+00	2.36E-10
4	4.50E-10	2.58E-11	3.46E-14	8.94E-17	1.06E-11	0.00E+00	0.00E+00	4.87E-10
Total	4.52E-10	1.75E-09	7.42E-13	6.06E-15	7.58E-10	0.00E+00	0.00E+00	2.96E-09

Risk results for external exposure from deposition pathway from "Verification of External Exposure Dose and Risk from Deposition.docx" for different receptors are displayed first followed by results in RESRADB_R.RPT in the following screen shots. Risk results for external exposure from deposition pathway match:

Risk (risk/yr) Calculation Results for Floor Deposition at Different Receptor Locations (receptors in different rooms) from Table 5 in the "Verification of External Exposure Dose and Risk from Deposition.docx" File				
Radionuclide	Receptor 1 Room 1 - 10 m^2	Receptor 2 Room 2 - 36 m^2	Receptor 3 Room 3 - 100 m^2	Receptor 4 Room 4 - 1000 m^2
Mn-54 (Source 2)	2.72E-14	8.69E-15	7.39E-15	1.82E-15
C-14 (Source 1)	2.49E-19	8.65E-20	7.72E-20	2.11E-20
Mn-54 (Source 3)	2.72E-14	8.69E-15	7.39E-15	1.82E-15
Tc-99 (Source 4)	2.79E-19	9.58E-20	8.44E-20	2.25E-20

7.4 TEST CASE 012-4

Test objectives/descriptions:

To verify the external dose calculation results for area sources.

Test result (Pass/Fail): Pass

Test details:

Refer to Test Case 012-4 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "area-source-verification.bld" associated with this test case was used. External exposure pathway dose and risks are calculated at different receptor locations with and without shielding for 6 different area sources (Source 1 – Area = 10000 m^2, Source 4 – Area = 1000 m^2, Source 2 – Area = 100 m^2, Source 3 – Area = 36 m^2, Source 5 – Area = 10 m^2, and Source 6 – Area = 4 m^2). The receptors considered were:

Receptor 1 – no shield and @ 0 m, 0 m, 1 m
Receptor 2 – concrete shield 5 cm and @ 0 m, 0 m, 1 m
Receptor 3 – concrete shield 1 cm and @ 0 m, 0 m, 1 m
Receptor 4 – no shield and @ 0 m, 0 m, 0.3 m
Receptor 5 – no shield and @ 0 m, 0 m, 4 m

Dose results for the external exposure pathway from "Verification of Area Source Dose Calculations.docx" for different receptors and sources are displayed first followed by results in RESRADB.RPT in the following screen shots. Three separate tables for each radionuclide from the verification report are provided. Dose results for the external exposure pathway match:

External Exposure Pathway Dose (mrem/yr) for Area Sources with C-14 Contamination from Table 2 and Table 5 in "Verification of Area Source Dose Calculations.docx"					
Source size	Receptor 1 (no shield) Location (0m, 0m, 1m)	Receptor 2 (5 cm concrete) Location (0m, 0m, 1m)	Receptor 3 (1 cm concrete) Location (0m, 0m, 1m)	Receptor 4 (no shield) Location (0m, 0m, 0.3m)	Receptor 5 (no shield) Location (0m, 0m, 4m)
Source 1 – 10000 m^2	1.58E-09	2.81E-12	8.54E-11	1.96E-09	1.13E-09
Source 4 – 1000 m^2	1.04E-09	2.81E-12	8.54E-11	1.42E-09	6.00E-10
Source 2 – 100 m^2	5.83E-10	2.81E-12	8.53E-11	9.52E-10	1.98E-10
Source 3 – 36 m^2	4.11E-10	2.81E-12	8.17E-11	7.72E-10	9.56E-11
Source 5 – 10 m^2	2.29E-10	2.81E-12	6.35E-11	5.62E-10	3.17E-11
Source 6 – 4 m^2	1.30E-10	2.63E-12	4.23E-11	4.22E-10	1.34E-11

External Exposure Pathway Dose (mrem/yr) for Area Sources with Mn-54 Contamination from Table 3 and Table 6 in "Verification of Area Source Dose Calculations.docx"					
Source size	Receptor 1 (no shield) Location (0m, 0m, 1m)	Receptor 2 (5 cm concrete) Location (0m, 0m, 1m)	Receptor 3 (1 cm concrete) Location (0m, 0m, 1m)	Receptor 4 (no shield) Location (0m, 0m, 0.3m)	Receptor 5 (no shield) Location (0m, 0m, 4m)
Source 1 – 10000 m^2	4.80E-05	9.87E-06	2.49E-05	6.25E-05	3.13E-05
Source 4 – 1000 m^2	3.46E-05	9.87E-06	2.42E-05	4.92E-05	1.82E-05
Source 2 – 100 m^2	2.10E-05	9.75E-06	1.76E-05	3.55E-05	6.58E-06
Source 3 – 36 m^2	1.52E-05	8.82E-06	1.32E-05	2.94E-05	3.25E-06
Source 5 – 10 m^2	8.65E-06	6.11E-06	7.65E-06	2.17E-05	1.09E-06
Source 6 – 4 m^2	4.97E-06	3.80E-06	4.43E-06	1.65E-05	4.61E-07

External Exposure Pathway Dose (mrem/yr) for Area Sources with Tc-99 Contamination from Table 1 and Table 4 in "Verification of Area Source Dose Calculations.docx"					
Source size	Receptor 1 (no shield) Location (0m, 0m, 1m)	Receptor 2 (5 cm concrete) Location (0m, 0m, 1m)	Receptor 3 (1 cm concrete) Location (0m, 0m, 1m)	Receptor 4 (no shield) Location (0m, 0m, 0.3m)	Receptor 5 (no shield) Location (0m, 0m, 4m)
Source 1 – 10000 m^2	6.50E-09	1.23E-10	1.10E-09	8.12E-09	4.61E-09
Source 4 – 1000 m^2	4.19E-09	1.23E-10	1.10E-09	5.80E-09	2.34E-09
Source 2 – 100 m^2	2.41E-09	1.23E-10	9.97E-10	3.99E-09	7.88E-10
Source 3 – 36 m^2	1.72E-09	1.23E-10	8.08E-10	3.27E-09	3.84E-10
Source 5 – 10 m^2	9.66E-10	1.10E-10	4.91E-10	2.41E-09	1.28E-10
Source 6 – 4 m^2	5.53E-10	8.25E-11	2.87E-10	1.81E-09	5.39E-11

```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/16/22 09:32:46  Page:  11 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\area-source-verification.bld
 Evaluation Time:  0.00000000E+00  years


                        Nuclide Detail of Doses
                                [mrem]

Source:  1
  Nuclide  Receptor  Receptor  Receptor  Receptor  Receptor    Total
              1         2         3         4         5
  C-14     1.58E-09  2.81E-12  8.54E-11  1.96E-09  1.13E-09  4.76E-09

  Mn-54    4.80E-05  9.87E-06  2.49E-05  6.25E-05  3.13E-05  1.77E-04

  Tc-99    6.50E-09  1.23E-10  1.10E-09  8.12E-09  4.61E-09  2.05E-08


Source:  2
  Nuclide  Receptor  Receptor  Receptor  Receptor  Receptor    Total
              1         2         3         4         5
  C-14     5.83E-10  2.81E-12  8.53E-11  9.52E-10  1.98E-10  1.82E-09

  Mn-54    2.10E-05  9.75E-06  1.76E-05  3.55E-05  6.58E-06  9.04E-05

  Tc-99    2.41E-09  1.23E-10  9.97E-10  3.99E-09  7.88E-10  8.31E-09


Source:  3
  Nuclide  Receptor  Receptor  Receptor  Receptor  Receptor    Total
              1         2         3         4         5
  C-14     4.11E-10  2.81E-12  8.17E-11  7.72E-10  9.56E-11  1.36E-09

  Mn-54    1.52E-05  8.82E-06  1.32E-05  2.94E-05  3.25E-06  6.98E-05

  Tc-99    1.72E-09  1.23E-10  8.08E-10  3.27E-09  3.84E-10  6.30E-09


Source:  4
  Nuclide  Receptor  Receptor  Receptor  Receptor  Receptor    Total
              1         2         3         4         5
  C-14     1.04E-09  2.81E-12  8.54E-11  1.42E-09  6.00E-10  3.15E-09

  Mn-54    3.46E-05  9.87E-06  2.42E-05  4.92E-05  1.82E-05  1.36E-04

  Tc-99    4.19E-09  1.23E-10  1.10E-09  5.80E-09  2.34E-09  1.36E-08


Source:  5
  Nuclide  Receptor  Receptor  Receptor  Receptor  Receptor    Total
              1         2         3         4         5
  C-14     2.29E-10  2.81E-12  6.35E-11  5.62E-10  3.17E-11  8.89E-10

  Mn-54    8.65E-06  6.11E-06  7.65E-06  2.17E-05  1.09E-06  4.52E-05

  Tc-99    9.66E-10  1.10E-10  4.91E-10  2.41E-09  1.28E-10  4.10E-09


Source:  6
  Nuclide  Receptor  Receptor  Receptor  Receptor  Receptor    Total
              1         2         3         4         5
  C-14     1.30E-10  2.63E-12  4.23E-11  4.22E-10  1.34E-11  6.11E-10

  Mn-54    4.97E-06  3.80E-06  4.43E-06  1.65E-05  4.61E-07  3.01E-05

  Tc-99    5.53E-10  8.25E-11  2.87E-10  1.81E-09  5.39E-11  2.79E-09
```

Risk results for the external exposure pathway from "Verification of Area Source Dose Calculations.docx" for different receptors and sources are displayed first followed by results in RESRADB_R.RPT in the following screen shots. Three separate tables for each radionuclide from the verification report are provided. Risk results for the external exposure pathway match:

External Exposure Pathway Risk (risk/yr) for Area Sources with C-14 Contamination from Table 9 in "Verification of Area Source Dose Calculations.docx"			
Source size	Receptor 1 (no shield) Location (0m, 0m, 1m)	Receptor 4 (no shield) Location (0m, 0m, 0.3m)	Receptor 5 (no shield) Location (0m, 0m, 4m)
Source 1 – 10000 m^2	9.22E-16	1.14E-15	6.57E-16
Source 4 – 1000 m^2	6.08E-16	8.26E-16	3.49E-16
Source 2 – 100 m^2	3.39E-16	5.54E-16	1.15E-16
Source 3 – 36 m^2	2.39E-16	4.49E-16	5.57E-17
Source 5 – 10 m^2	1.33E-16	3.27E-16	1.85E-17
Source 6 – 4 m^2	7.59E-17	2.46E-16	7.77E-18

External Exposure Pathway Risk (risk/yr) for Area Sources with Mn-54 Contamination from Table 10 in "Verification of Area Source Dose Calculations.docx"			
Source size	Receptor 1 (no shield) Location (0m, 0m, 1m)	Receptor 4 (no shield) Location (0m, 0m, 0.3m)	Receptor 5 (no shield) Location (0m, 0m, 4m)
Source 1 – 10000 m^2	3.62E-11	4.72E-11	2.35E-11
Source 4 – 1000 m^2	2.61E-11	3.71E-11	1.37E-11
Source 2 – 100 m^2	1.59E-11	2.68E-11	4.96E-12
Source 3 – 36 m^2	1.15E-11	2.21E-11	2.45E-12
Source 5 – 10 m^2	6.52E-12	1.64E-11	8.23E-13
Source 6 – 4 m^2	3.75E-12	1.24E-11	3.47E-13

External Exposure Pathway Risk (risk/yr) for Area Sources with Tc-99 Contamination from Table 8 in "Verification of Area Source Dose Calculations.docx"			
Source size	Receptor 1 (no shield) Location (0m, 0m, 1m)	Receptor 4 (no shield) Location (0m, 0m, 0.3m)	Receptor 5 (no shield) Location (0m, 0m, 4m)
Source 1 – 10000 m^2	4.22E-15	5.20E-15	2.99E-15
Source 4 – 1000 m^2	2.61E-15	3.76E-15	1.52E-15
Source 2 – 100 m^2	1.59E-15	2.59E-15	5.11E-16
Source 3 – 36 m^2	1.15E-15	2.12E-15	2.49E-16
Source 5 – 10 m^2	6.27E-16	1.56E-15	8.30E-17
Source 6 – 4 m^2	3.58E-16	1.18E-15	3.50E-17

Title : Default Case for RESRAD-BUILD
Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\area-source-verification.bld
Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Risks

[Risk]

Source: 1

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	9.22E-16	1.64E-18	4.97E-17	1.14E-15	6.57E-16	2.77E-15
Mn-54	3.62E-11	7.44E-12	1.88E-11	4.72E-11	2.36E-11	1.33E-10
Tc-99	4.22E-15	7.95E-17	7.12E-16	5.27E-15	2.99E-15	1.33E-14

Source: 2

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	3.39E-16	1.64E-18	4.97E-17	5.54E-16	1.15E-16	1.06E-15
Mn-54	1.59E-11	7.35E-12	1.33E-11	2.68E-11	4.96E-12	6.82E-11
Tc-99	1.56E-15	7.95E-17	6.46E-16	2.59E-15	5.11E-16	5.39E-15

Source: 3

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	2.39E-16	1.64E-18	4.76E-17	4.49E-16	5.57E-17	7.94E-16
Mn-54	1.15E-11	6.65E-12	9.94E-12	2.21E-11	2.45E-12	5.27E-11
Tc-99	1.11E-15	7.95E-17	5.24E-16	2.12E-15	2.49E-16	4.09E-15

Source: 4

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	6.08E-16	1.64E-18	4.97E-17	8.26E-16	3.49E-16	1.84E-15
Mn-54	2.61E-11	7.44E-12	1.82E-11	3.71E-11	1.37E-11	1.03E-10
Tc-99	2.72E-15	7.95E-17	7.12E-16	3.76E-15	1.52E-15	8.79E-15

Source: 5

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	1.33E-16	1.64E-18	3.69E-17	3.27E-16	1.85E-17	5.18E-16
Mn-54	6.52E-12	4.61E-12	5.77E-12	1.64E-11	8.23E-13	3.41E-11
Tc-99	6.27E-16	7.16E-17	3.19E-16	1.56E-15	8.30E-17	2.66E-15

Source: 6

Nuclide	Receptor 1	Receptor 2	Receptor 3	Receptor 4	Receptor 5	Total
C-14	7.59E-17	1.53E-18	2.46E-17	2.46E-16	7.77E-18	3.55E-16
Mn-54	3.75E-12	2.86E-12	3.34E-12	1.24E-11	3.47E-13	2.27E-11
Tc-99	3.58E-16	5.35E-17	1.86E-16	1.18E-15	3.50E-17	1.81E-15

7.5 TEST CASE 012-5

Test objectives/descriptions:

To verify the external dose calculation results for rectangular area sources.

Test result (Pass/Fail): Pass

Test details:

Refer to Test Case 012-5 in the document RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "rectangle-area-source-verification.bld" associated with this test case was used. External exposure pathway dose is calculated for 6 different area sources (Source 1 – Area = 16 m^2, Source 2 – Area = 12 m^2, Source 3 – Area = 8 m^2, Source 4 – Area = 4 m^2, Source 5 – Area = 36 m^2, and Source 6 – Area = 100 m^2).

Dose results for the external exposure pathway from "Verification of Area Source Dose Calculations.docx" for different receptors and sources are shown first followed by results in RESRADB.RPT in the following screen shots. Dose results for the external exposure pathway match:

Dose (mrem/yr) for Rectangular Area Source with C-14 Contamination from Table 11 in "Area Source Dose Calculations.docx"		
Source	Receptor @ 0m, 0m, 1m	Rectangle Size
Source 6 – 100 m^2	5.79E-10	10 × 10
Source 5 – 36 m^2	4.09E-10	6 × 6
Source 1 – 16 m^2	2.88E-10	4 × 4
Source 2 – 12 m^2	2.46E-10	4 × 3
Source 3 – 8 m^2	1.89E-10	4 × 2
Source 4 – 4 m^2	1.29E-10	2 × 2

Title : Default Case for RESRAD-BUILD
Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\rectangle-area-source-verification.bld
Evaluation Time: 0.00000000E+00 years

Nuclide Detail of Doses

[mrem]

Source: 1

Nuclide	Receptor 1	Total
C-14	2.88E-10	2.88E-10

Source: 2

Nuclide	Receptor 1	Total
C-14	2.46E-10	2.46E-10

Source: 3

Nuclide	Receptor 1	Total
C-14	1.89E-10	1.89E-10

Source: 4

Nuclide	Receptor 1	Total
C-14	1.29E-10	1.29E-10

Source: 5

Nuclide	Receptor 1	Total
C-14	4.09E-10	4.09E-10

Source: 6

Nuclide	Receptor 1	Total
C-14	5.79E-10	5.79E-10

7.6 TEST CASE 012-6

Test objectives/descriptions:

To verify the external dose calculation results for volume sources.

Test result (Pass/Fail): Pass

Test details:

Refer to Test Case 012-6 in the document RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "volume-source-verification.bld" associated with the test case was used. Dose results for the external exposure pathway from "Verification of volume source dose calculations.docx" for different receptors and sources are displayed first followed by results in RESRADB.RPT in the following screen shots. Dose results for the external exposure pathway match:

Dose Rates (mrem/yr) from Co-60 and Mn-54 Sources (1 mCi/g, Volume Source Located at (0, 0, -5 cm), Length = 6 m, Width = 6 m, Thickness = 10 cm, Density = 2.4 g/cm^3) at Different Receptor Source Configurations		
Receptor	Source 1 – Co-60[a]	Source 2 – Mn-54[b]
Receptor 1 – no shield @ (0, 0, 30 cm)	1.17E+10	2.84E+09
Receptor 2 – 1 cm concrete shield @ (0, 0, 30 cm)	9.88E+09	2.29E+09
Receptor 3 – 5 cm concrete shield @ (0, 0, 30 cm)	4.72E+09	9.96E+08
Receptor 4 – no shield @ (0, 0, 100 cm)	8.49E+09	2.09E+09
Receptor 5 – 1 cm concrete shield @ (0, 0, 100 cm)	7.66E+09	1.83E+09
Receptor 6 – 5 cm concrete shield @ (0, 0, 100 cm)	4.41E+09	9.47E+08
Receptor 7 – no shield @ (0, 0, 400 cm)	2.25E+09	5.65E+08
Receptor 8 – 1 cm concrete shield @ (0, 0, 400 cm)	2.14E+09	5.25E+08
Receptor 9 – 5 cm concrete shield @ (0, 0, 400 cm)	1.53E+09	3.50E+08

[a] Values from Table 9 in the verification report.

[b] Values from Table 10 in the verification report.

```
** RESRAD-BUILD Dose Program Output, Version 4.0.19.0 Beta 12/16/22 12:53:57  Page:   7 **
 Title : Volume sources verification
 Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\volume-source-verification.bld
 Evaluation Time:  0.00000000E+00  years
```

RESRAD-BUILD Dose Tables

Source Contributions to Receptor Doses

[mrem]

	Source 1	Source 2	Total
Receptor 1	1.17E+10	2.84E+09	1.46E+10
Receptor 2	9.88E+09	2.29E+09	1.22E+10
Receptor 3	4.72E+09	9.96E+08	5.72E+09
Receptor 4	8.49E+09	2.09E+09	1.06E+10
Receptor 5	7.66E+09	1.83E+09	9.49E+09
Receptor 6	4.41E+09	9.47E+08	5.35E+09
Receptor 7	2.25E+09	5.65E+08	2.82E+09
Receptor 8	2.14E+09	5.25E+08	2.66E+09
Receptor 9	1.53E+09	3.50E+08	1.88E+09
Total	5.28E+10	1.24E+10	6.52E+10

Risk results for the external exposure pathway from "Verification of volume source dose calculations.docx" for different receptors and sources are displayed first followed by results in RESRADB_R.RPT in the following screen shots. Risk results for the external exposure pathway match:

Risk (risk/yr) from Co-60 and Mn-54 Sources (1 mCi/g, Volume Source Located at (0, 0, -5 cm), Length = 6 m, Width = 6 m, Thickness = 10 cm, Density = 2.4 g/cm3) at Different Receptor Source Configurations		
Receptor	Source 1 – Co-60[a]	Source 2 – Mn-54[a]
Receptor 1 – no shield @ (0, 0, 30 cm)	8.97E+03	2.14E+03
Receptor 2 – 1 cm concrete shield @ (0, 0, 30 cm)	7.55E+03	1.73E+03
Receptor 3 – 5 cm concrete shield @ (0, 0, 30 cm)	3.61E+03	7.51E+02
Receptor 4 – no shield @ (0, 0, 100 cm)	6.49E+03	1.58E+03
Receptor 5 – 1 cm concrete shield @ (0, 0, 100 cm)	5.85E+03	1.38E+03
Receptor 6 – 5 cm concrete shield @ (0, 0, 100 cm)	3.37E+03	7.15E+02
Receptor 7 – no shield @ (0, 0, 400 cm)	1.72E+03	4.26E+02
Receptor 8 – 1 cm concrete shield @ (0, 0, 400 cm)	1.63E+03	3.96E+02
Receptor 9 – 5 cm concrete shield @ (0, 0, 400 cm)	1.17E+03	2.64E+02

[a] Values from Table 12 in the verification report.

Title : Volume sources verification
Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\volume-source-verification.bld
Evaluation Time: 0.00000000E+00 years

RESRAD-BUILD Risk Tables

Source Contributions to Receptor Risks

[Risk]

	Source 1	Source 2	Total
Receptor 1	8.97E+03	2.14E+03	1.11E+04
Receptor 2	7.55E+03	1.73E+03	9.28E+03
Receptor 3	3.61E+03	7.51E+02	4.36E+03
Receptor 4	6.49E+03	1.58E+03	8.07E+03
Receptor 5	5.85E+03	1.38E+03	7.23E+03
Receptor 6	3.37E+03	7.15E+02	4.08E+03
Receptor 7	1.72E+03	4.26E+02	2.15E+03
Receptor 8	1.63E+03	3.96E+02	2.03E+03
Receptor 9	1.17E+03	2.64E+02	1.44E+03
Total	4.04E+04	9.38E+03	4.98E+04

8. TEST CASE 017

Test objectives/descriptions:

To test the selection, viewing, printing, and saving text reports.

Test result (Pass/Fail): Pass

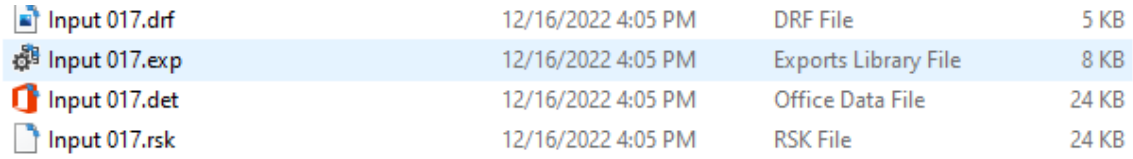
Test details:

(1) Copied the files “Input 017.bld” and “Input 017-1.bld” associated with the test case to the UserFiles folder under the RESRAD-BUILD installation directory.

(2) Ran “Input 017.bld” file. The summary report would pop up after the calculation. Closed it.

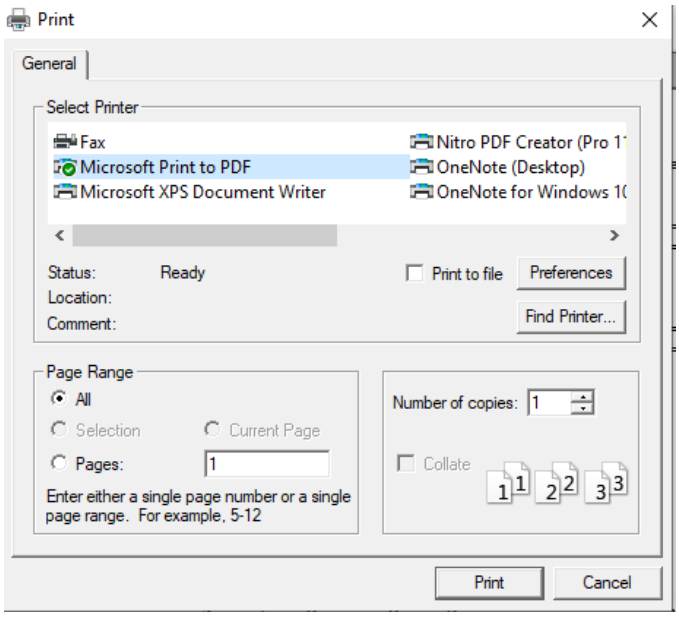
(3) Clicked View –> Last Report menu option, and the summary report opened. Tested the following menus in the Report Viewer, and all worked as expected.

1) File –> Save all.

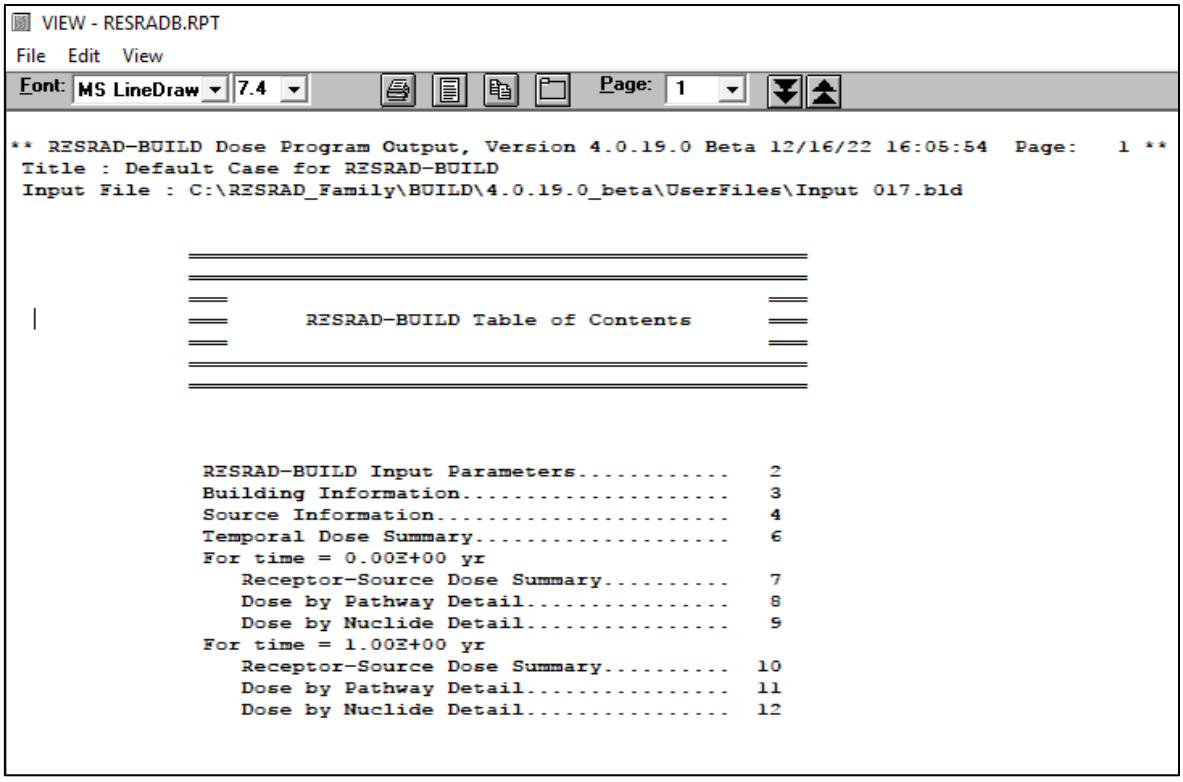


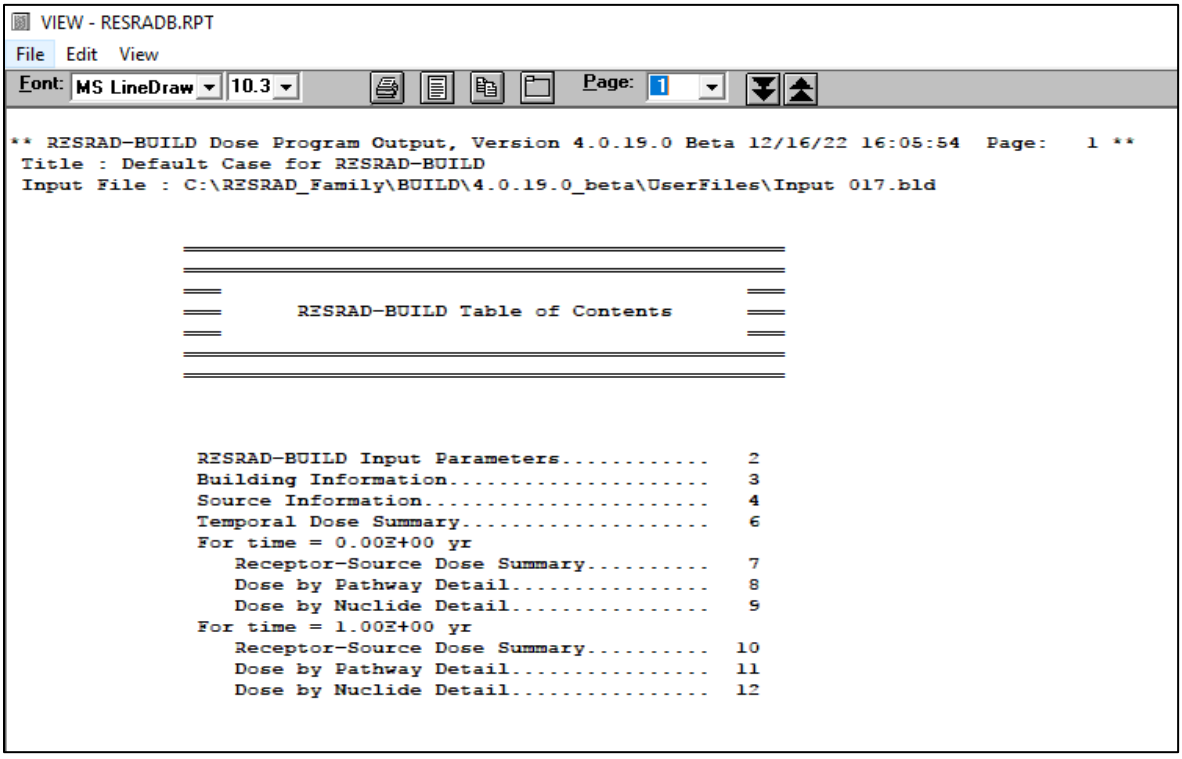
2) File –> Save to “test017-1.txt.”

3) File –> Print to “test017-print.pdf.”



4) File –> Adjust Font. The 1st figure below shows the summary report before the font adjustment; the 2nd figure shows the report after the font adjustment.

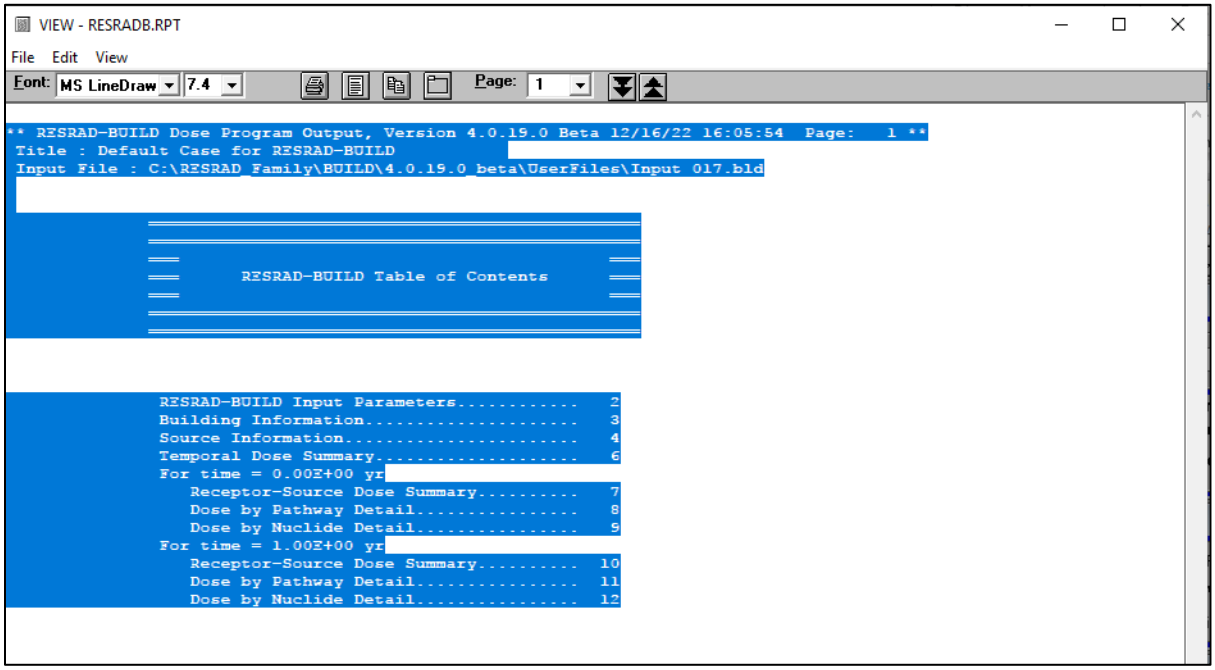




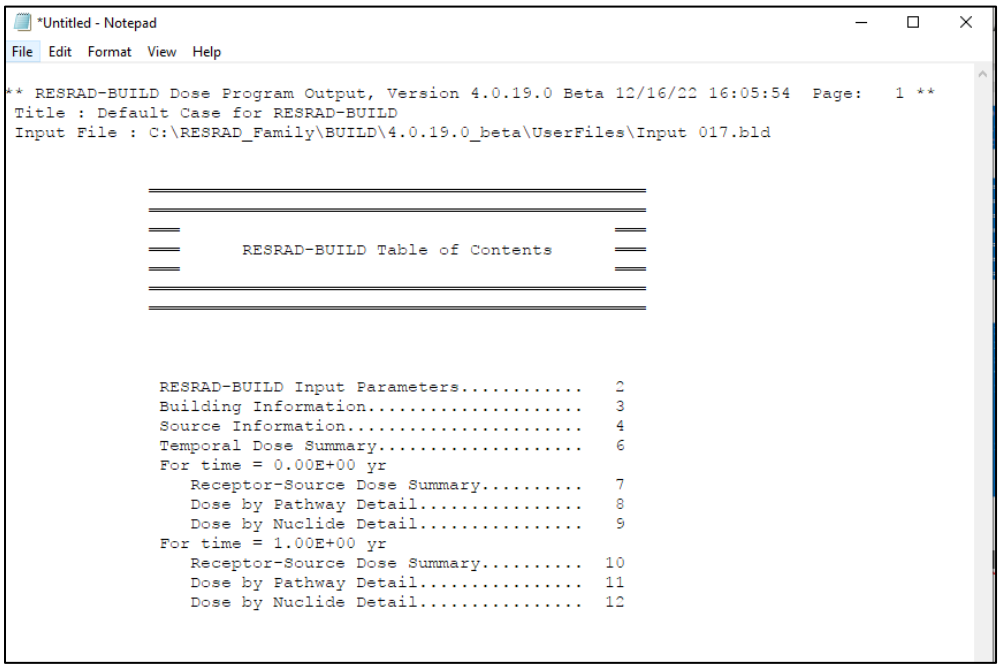
5) File –> Make New "MyFonts.dat." A new "MyFonts.dat" file was generated.

6) File –> Exit Viewer. The view window was closed.

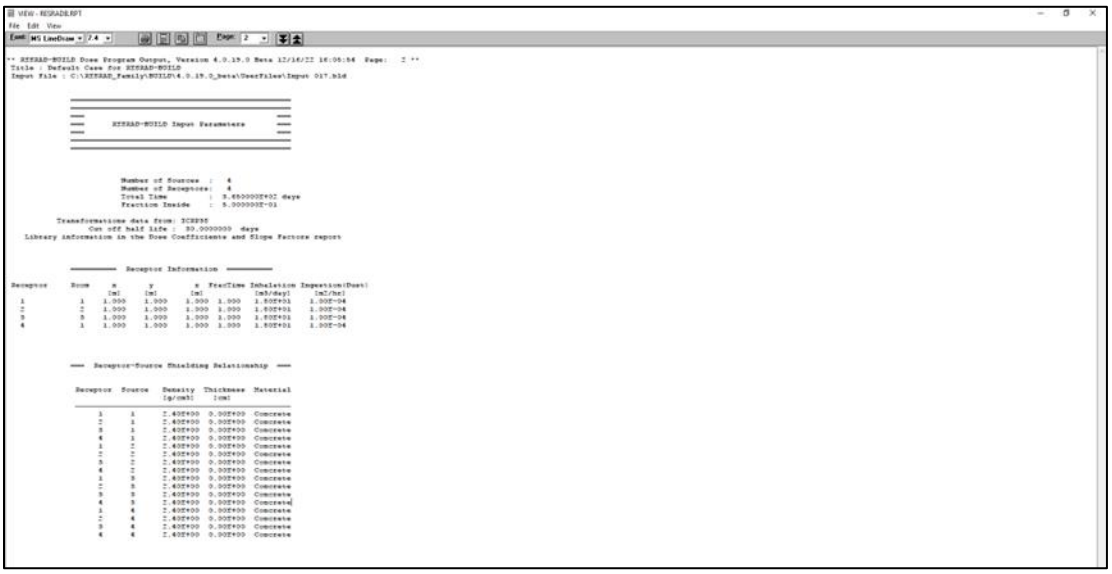
7) Edit –> Select All. All texts in the report were selected.



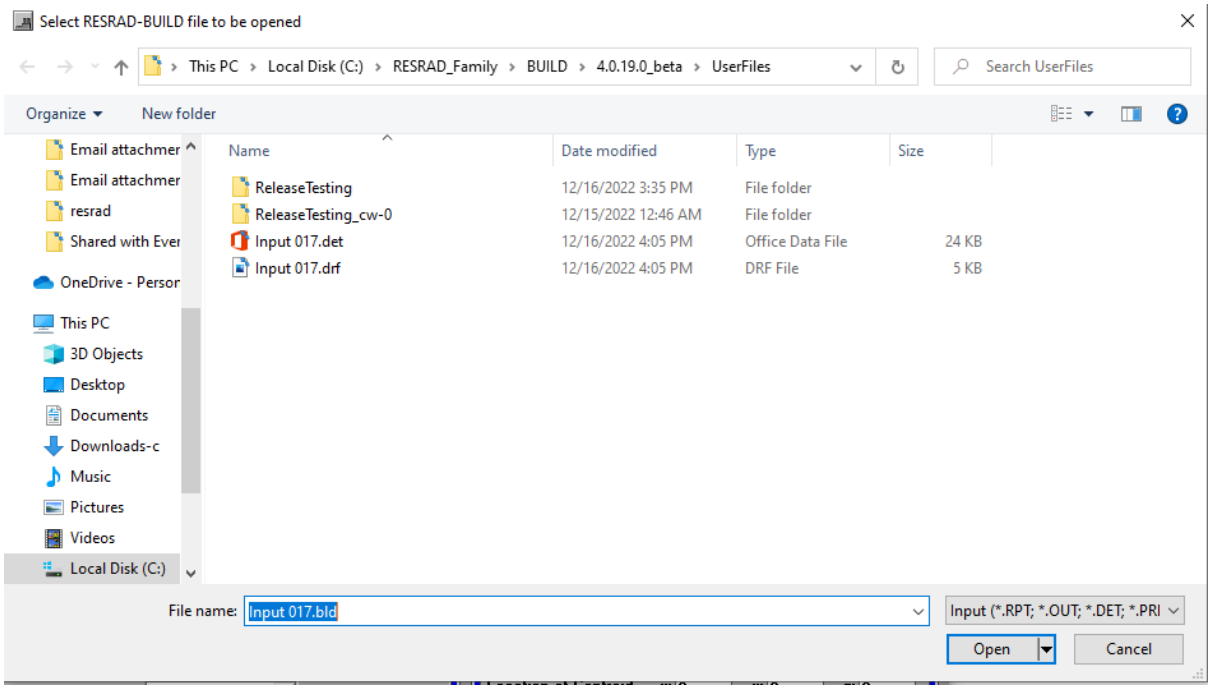
8) Edit –> Copy, and then Paste to Notepad.



9) View –> Full Window.



10) View –> Another File.



VIEW - C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Input 017.bld

File Edit View

Font: MS LineDraw 7.4 Page: 1

```
&INDATA
 VERS = '4.0.19.0 Beta' ,
 TITLE = 'Default Case for RESRAD-BUILD',
 IntDoseDCF = 'ICRP 72 (Adult)',
 ExtDoseDCF = 'ICRP 60',
 RiskLib = 'FGR 13 Morbidity',
 BaseIntDoseDCF = 'ICRP 72 (Adult)',
 BaseExtDoseDCF = 'ICRP 60',
 BaseRiskLib = 'FGR 13 Morbidity',
 Transformations = 'ICRP38',
 CutOffHalflifeD =  30 ,
 NUM_SAMPS = 0, NUMVAR = 0, NUM_SENS = 0,
 ND =  4 , NS =  4 , NTIME =  2 , NROOM = 3 ,
 TTIME = 365, FTIN = 0.5 ,
 DOSE_TIME =  0 , 1 ,
 RM =  2 , 3 ,
 QINPUT =  60 , 60 ,
 LINPUT =  1 , 1 ,
 N12 =  0 ,
 N23 = 0 ,
 AREA =  36 , 36 , 36 ,
 H =  2.5 , 2.5 , 2.5 ,
 VOLUME =  90 , 90 , 90 ,
 DKSUS = 0.0000005, 0.0000005 , 0.0000005 ,
 DLVL =  1 , 2 , 3 , 1 ,
 TWGHT = 1, 1 , 1 , 1 ,
 BRTRATE = 18, 18 , 18 , 18 ,
 INGE2 = 0.0001, 0.0001 , 0.0001 , 0.0001 ,
 DX( 1 , 1 )=1,
 DX( 1 , 2 )=1,
 DX( 1 , 3 )=1,
 DX( 2 , 1 )= 1 ,
 DX( 2 , 2 )= 1 ,
 DX( 2 , 3 )= 1 ,
 DX( 3 , 1 )= 1 ,
 DX( 3 , 2 )= 1 ,
 DX( 3 , 3 )= 1 ,
 DX( 4 , 1 )= 1 ,
 DX( 4 , 2 )= 1 ,
 DX( 4 , 3 )= 1 ,
 SX( 1 , 1 )=0,
 SX( 1 , 2 )=0,
 SX( 1 , 3 )=0,
 SX( 2 , 1 )= 0 ,
 SX( 2 , 2 )= 0 ,
 SX( 2 , 3 )= 0 ,
 SX( 3 , 1 )= 0 ,
 SX( 3 , 2 )= 0 ,
 SX( 3 , 3 )= 0 ,
 SX( 4 , 1 )= 0 ,
 SX( 4 , 2 )= 0 ,
 SX( 4 , 3 )= 0 ,
 SDIR =  1 , 1 , 1 , 1 ,
 VOLSRCDIR =  1 , 1 , 1 , 1 ,
 STYPE =  4 , 3 , 2 , 1 ,
 SAREA =  36 , 36 , 36 , 36 ,
 NNUCS =  1 , 1 , 1 , 1 ,
 RRF =  0.1 , 0.1 , 0.1 , 0.1 ,
 AIRFR =  0.1 , 0.1 , 0.1 , 0.1 ,
 RMVFR =  0.5 , 0.5 , 0.5 , 0.5 ,
```

11) View −> Page Selection: highlighted the Page dropdown box.

12) View −> Text Selection: enabled the selection of text.

(4) Compared the dose and risk report with the provided verification output files and saved the comparison to “test017-dose-tradition.diff” and “test017-risk-tradition.diff,” respectively. No differences were found.

(5) Compared the intermediate output files and saved the comparison to files with “.dif” file extension. No differences were found.

(6) Ran file “Input 017-1.bld,” compared the dose and risk output files and intermediate files with the provided verification output files and saved the comparison to files with the “-1.dif” extension. No differences were found.

9. TEST CASE 018

Test objectives/descriptions:

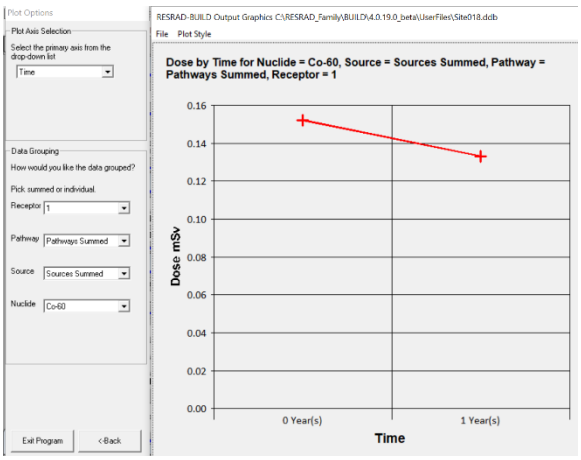
This test is to verify the standard graphics module works as expected, including selecting, viewing, printing, and saving graphic results.

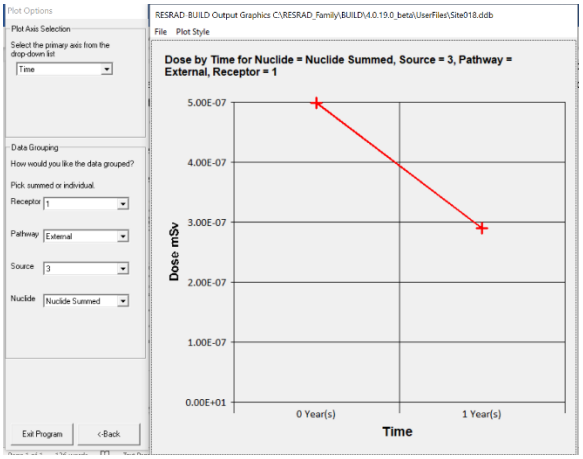
Test result (Pass/Fail): Pass

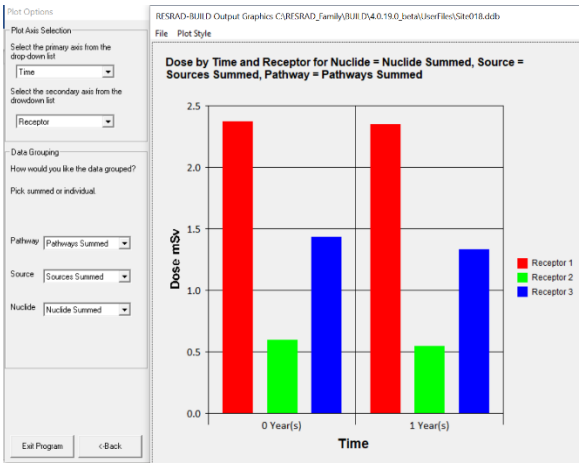
Test details:

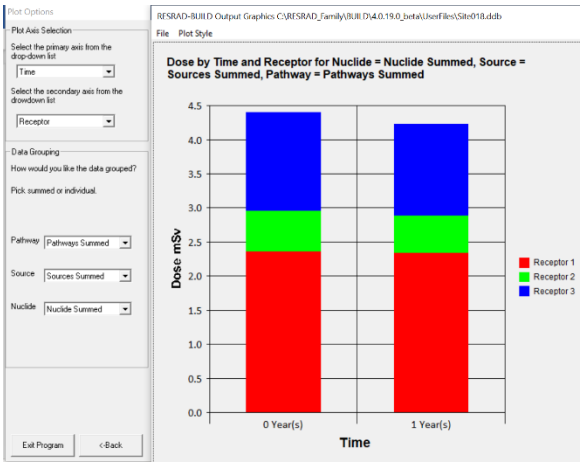
The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. An input file containing 4 different types of radiation sources each located in different rooms was created to run the code. After calculations were completed, the deterministic graphics viewer was opened to view the dose and risk results in the graphics mode. Different plot types with different combinations of dose/risk attributes were selected to generate graphics without any issue. The generated graphics correctly showed the calculated dose/risk results and could be saved and printed without any issue.

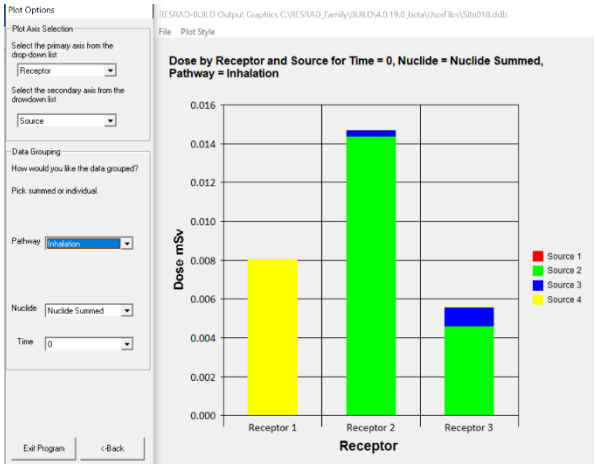
A few graphics generated during the testing are shown below:

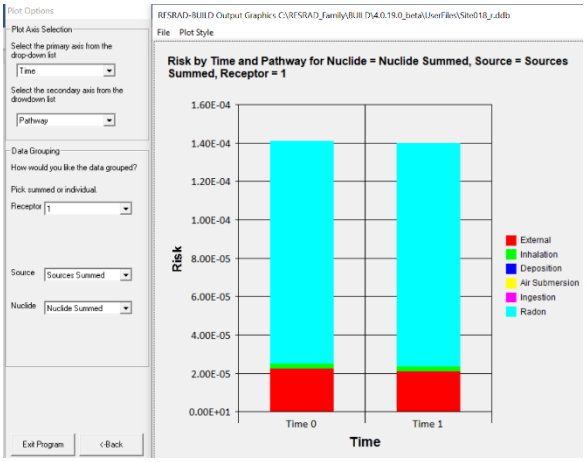


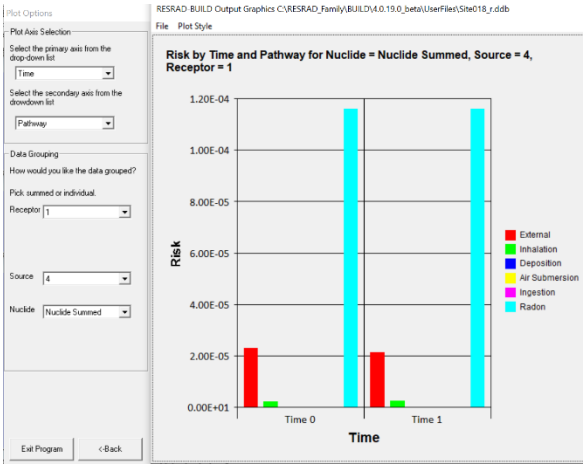





Plot Options
Plot Axis Selection
Select the primary axis from the drop-down list
Time
Select the secondary axis from the drowdown list
Receptor
Data Grouping
How would you like the data grouped?
Pick summed or individual.
Pathway
Pathways Summed
Source
Sources Summed
Nuclide
Nuclide Summed
Exit Program
<-Back
RESRAD-BUILD Output Graphics C:\RESRAD_family\BUILD\4.0.19.0_beta\UserFiles\Site018.ddb
File
Plot Style
Dose by Time and Receptor for Nuclide = Nuclide Summed, Source = Sources Summed, Pathway = Pathways Summed
Dose mSv
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 Year(s)
1 Year(s)
Time
Receptor 1
Receptor 2
Receptor 3


Plot Options
Plot Axis Selection
Select the primary axis from the drop-down list
Receptor
Select the secondary axis from the drowdown list
Source
Data Grouping
How would you like the data grouped?
Pick summed or individual.
Pathway
Inhalation
Nuclide
Nuclide Summed
Time
0
Exit Program
<-Back
RESRAD-BUILD Output Graphics C:\RESRAD_family\BUILD\4.0.19.0_beta\UserFiles\Site018.ddb
File
Plot Style
Dose by Receptor and Source for Time = 0, Nuclide = Nuclide Summed, Pathway = Inhalation
Dose mSv
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Receptor 1
Receptor 2
Receptor 3
Receptor
Source 1
Source 2
Source 3
Source 4


Plot Options
Plot Axis Selection
Select the primary axis from the drop-down list
Time
Select the secondary axis from the drowdown list
Pathway
Data Grouping
How would you like the data grouped?
Pick summed or individual.
Receptor
1
Source
Sources Summed
Nuclide
Nuclide Summed
Exit Program
<-Back
RESRAD-BUILD Output Graphics C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Site018_r.ddb
File
Plot Style
Risk by Time and Pathway for Nuclide = Nuclide Summed, Source = Sources Summed, Receptor = 1
Risk
1.60E-04
1.40E-04
1.20E-04
1.00E-04
8.00E-05
6.00E-05
4.00E-05
2.00E-05
0.00E+01
Time 0
Time 1
Time
External
Inhalation
Deposition
Air Submersion
Ingestion
Radon


Plot Options
Plot Axis Selection
Select the primary axis from the drop-down list
Time
Select the secondary axis from the drowdown list
Pathway
Data Grouping
How would you like the data grouped?
Pick summed or individual.
Receptor
1
Source
4
Nuclide
Nuclide Summed
Exit Program
<-Back
RESRAD-BUILD Output Graphics C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\Site018_r.ddb
File
Plot Style
Risk by Time and Pathway for Nuclide = Nuclide Summed, Source = 4, Receptor = 1
Risk
1.20E-04
1.00E-04
8.00E-05
6.00E-05
4.00E-05
2.00E-05
0.00E+01
Time 0
Time 1
Time
External
Inhalation
Deposition
Air Submersion
Ingestion
Radon

10. TEST CASE 019

Test objectives/descriptions:

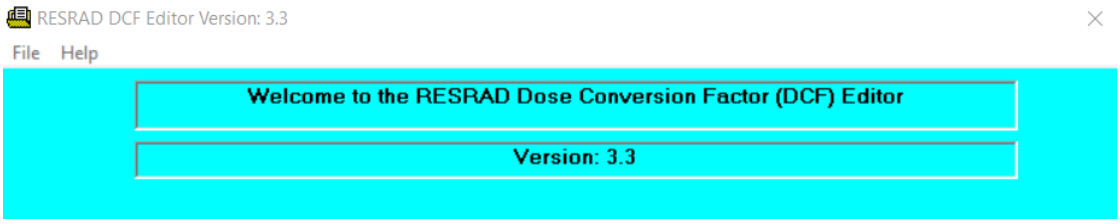
To test the DCF Editor for viewing, creating, editing, copying, renaming, exporting, and importing a dose/risk coefficient library and providing general and context-specific help information.

Test result (Pass/Fail): Pass

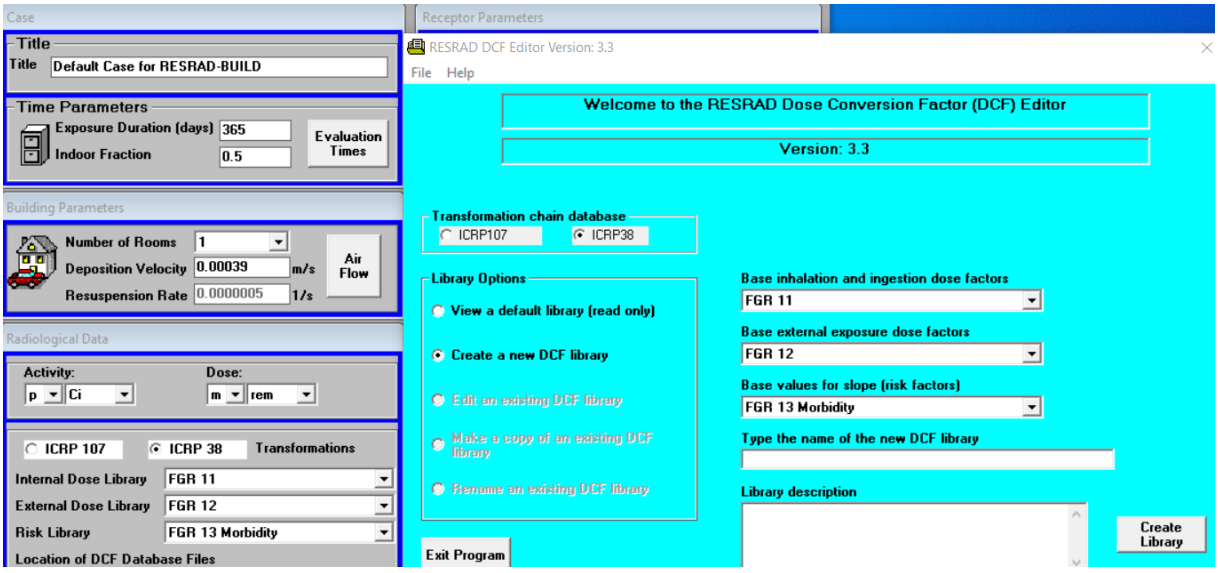
Test details:

Results are given only for procedure steps with an expected action. Refer to Test Case 019 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure.

(1) DCF Editor version number is 3.3:

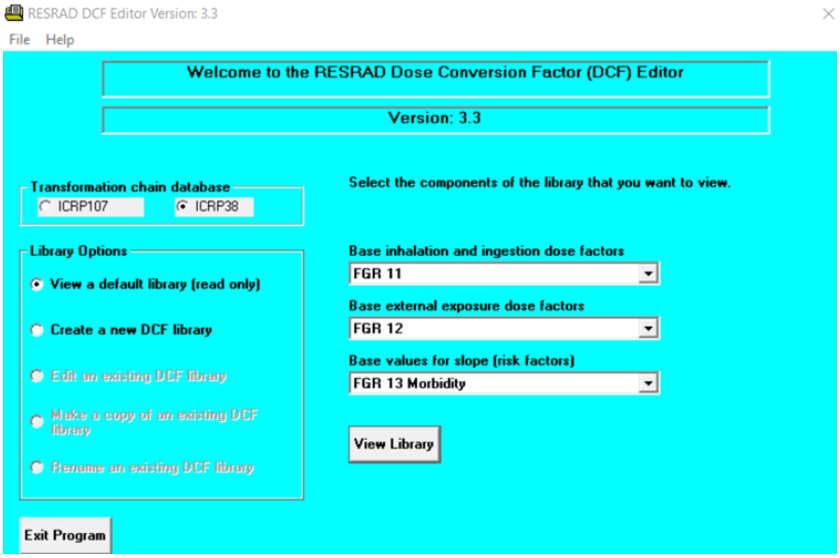


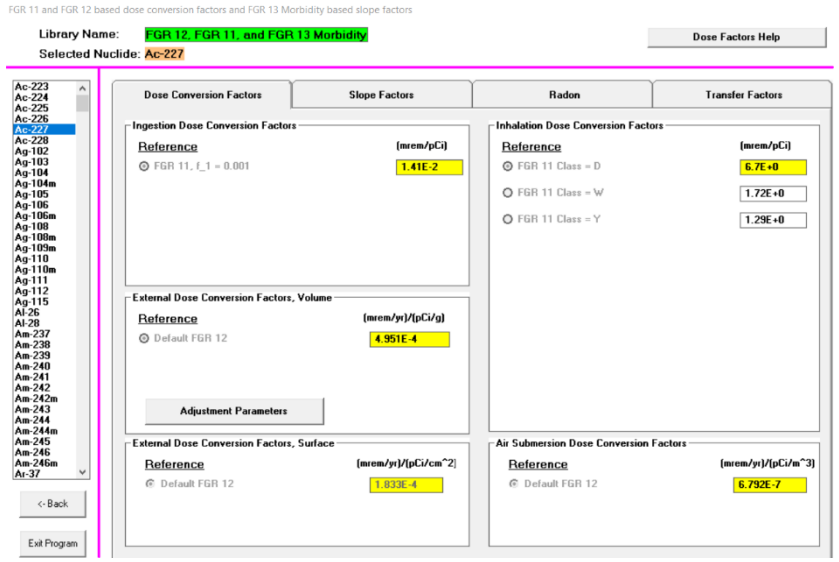
(2) The radionuclide transformation library, library option, base inhalation and ingestion dose factors, base external exposure dose factors, base values for slope (risk) factors in the DCF Editor main window match the RESRAD-BUILD code's interface:



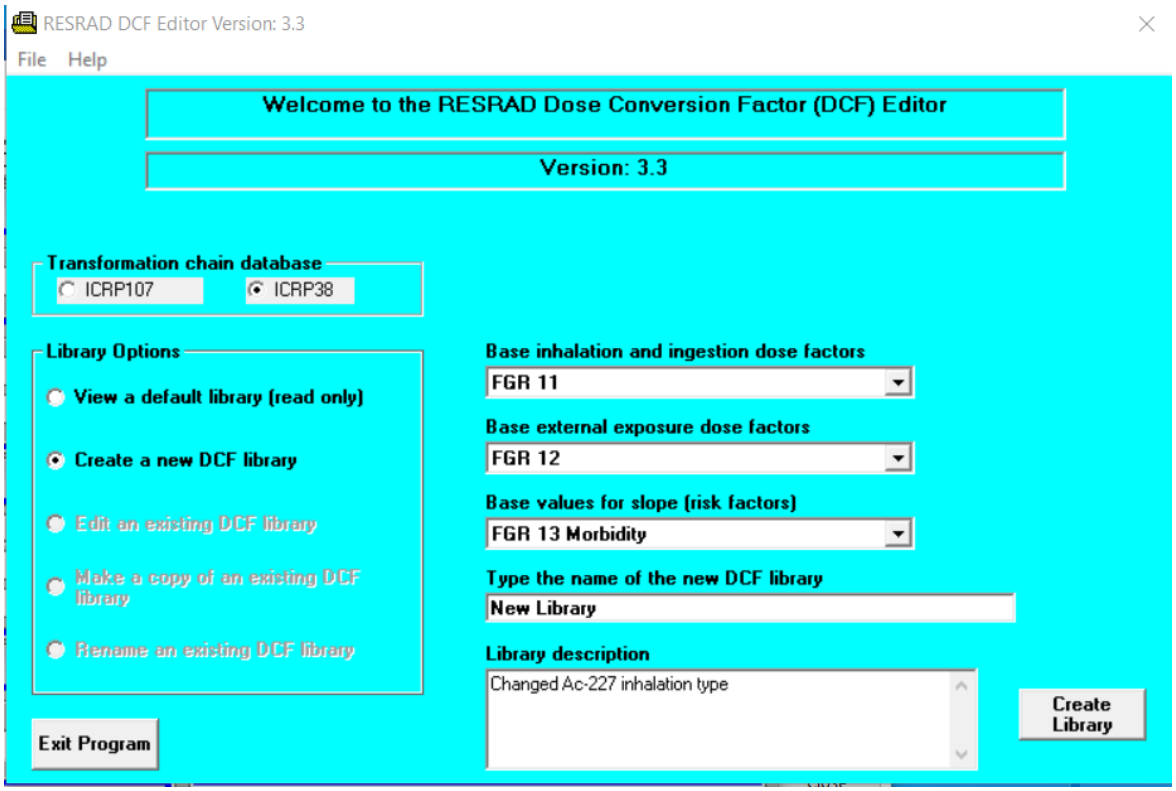
(3) The DCF Editor allowed to view a default library, create a new DCF library, edit an existing DCF library, rename an existing DCF library, and import and export a DCF library.

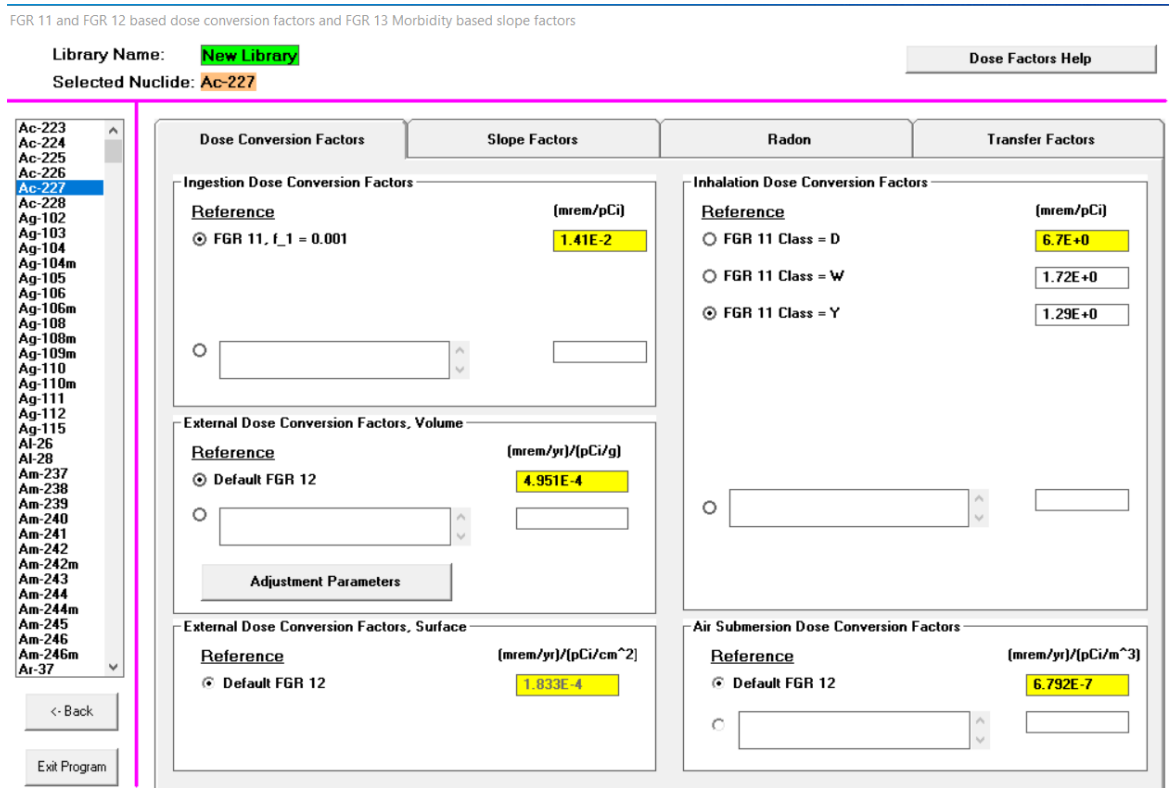
1) View a default library:



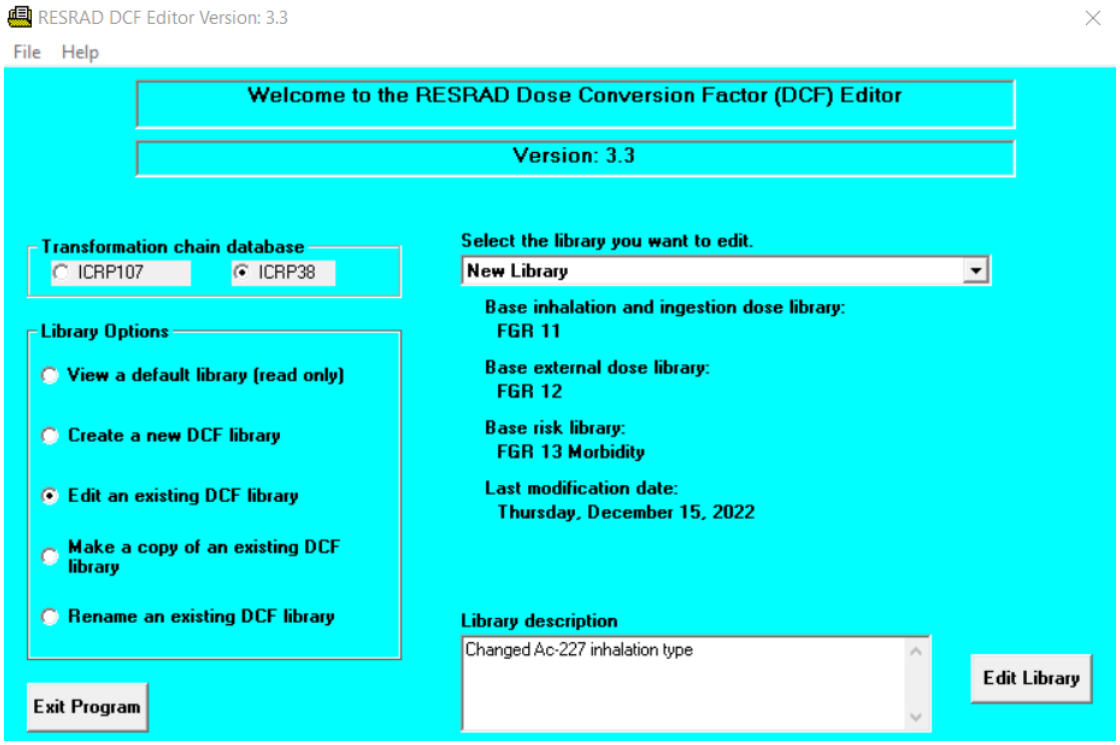


2) Create a new DCF library:

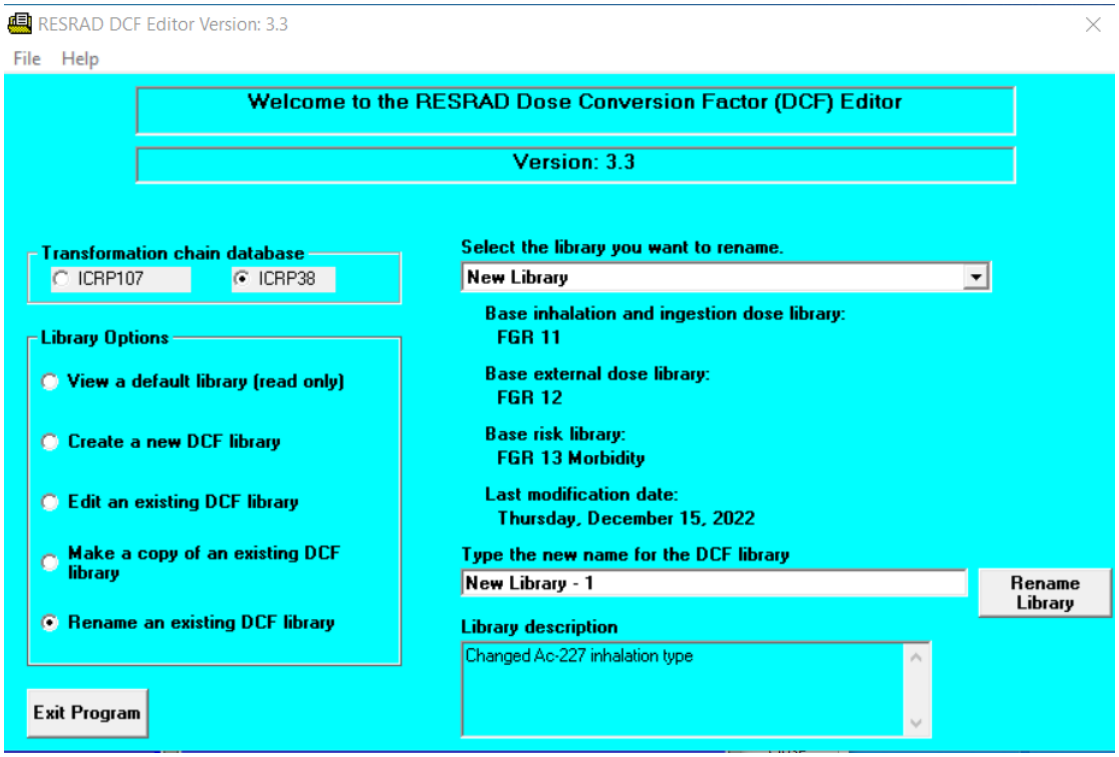




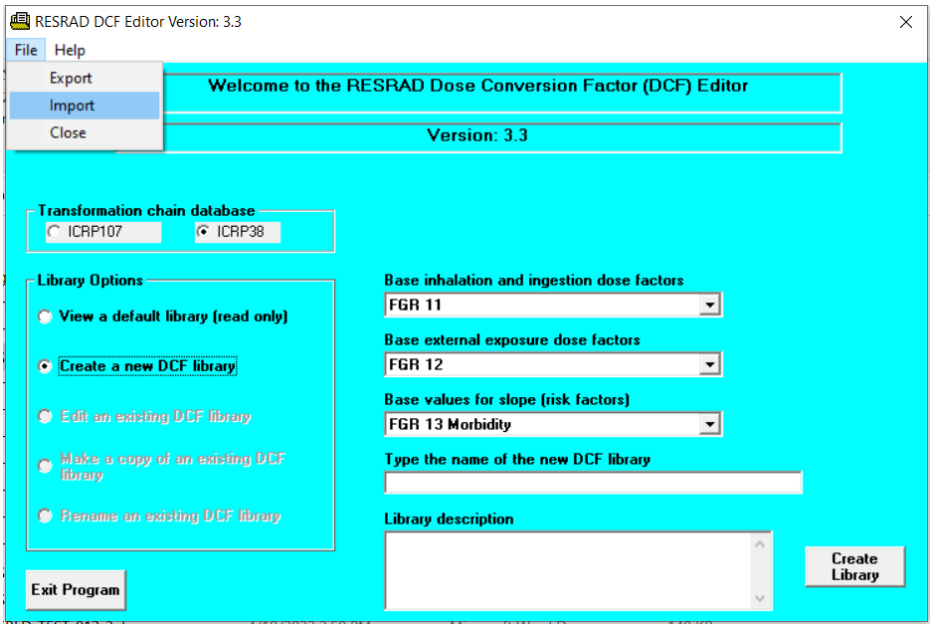
3) Edit an existing DCF library:

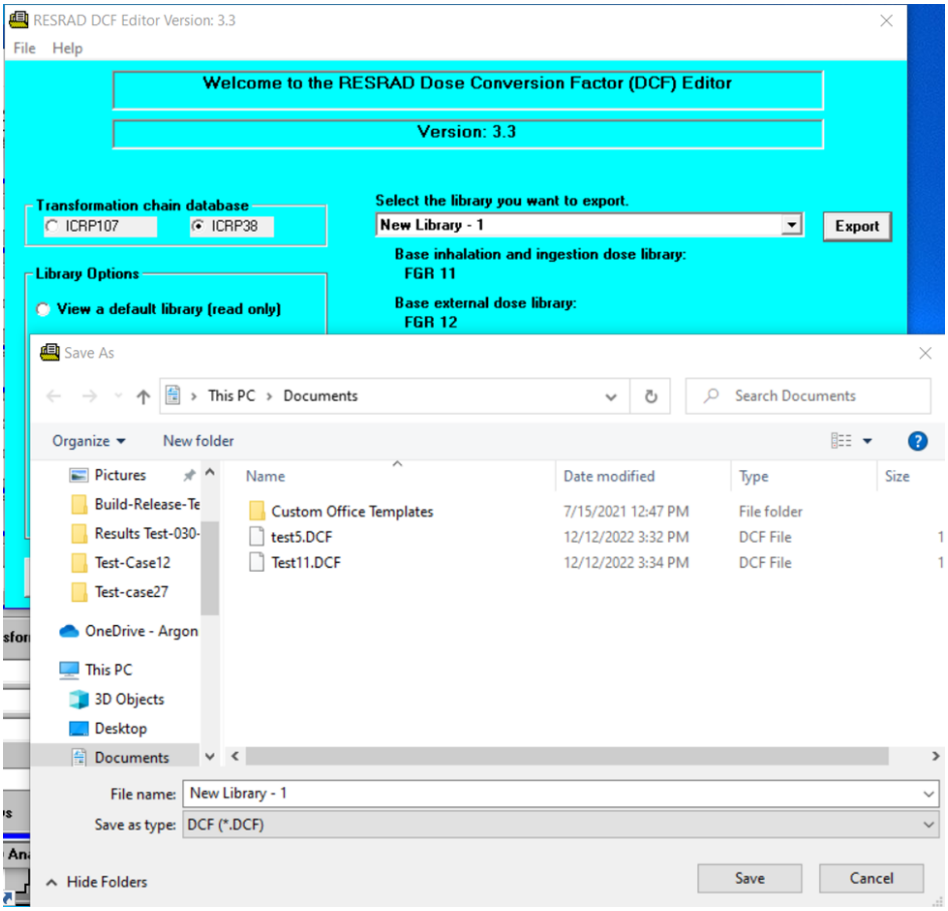


4) Rename an existing DCF library:

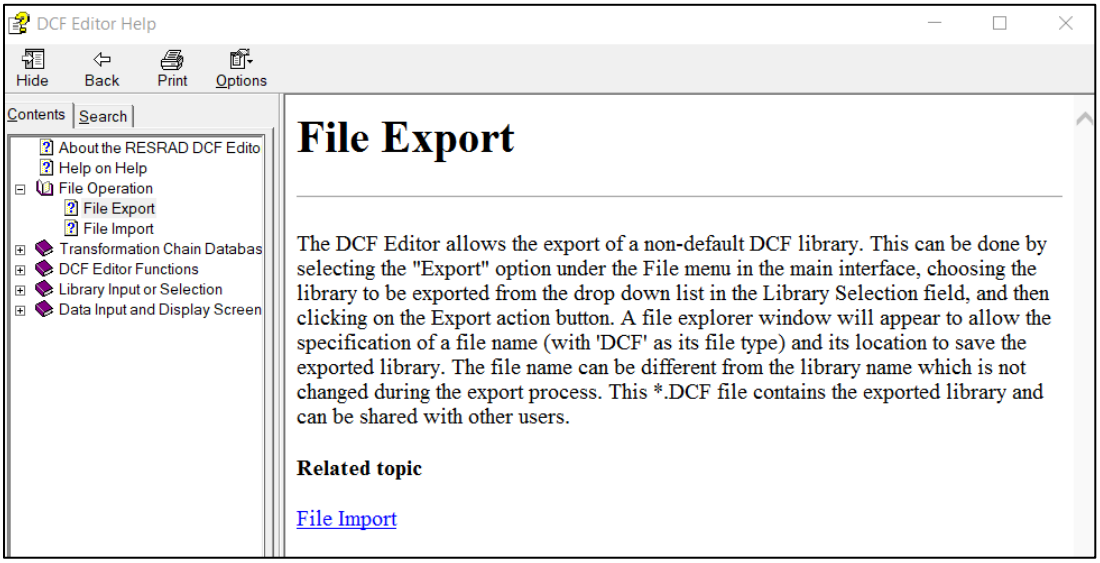


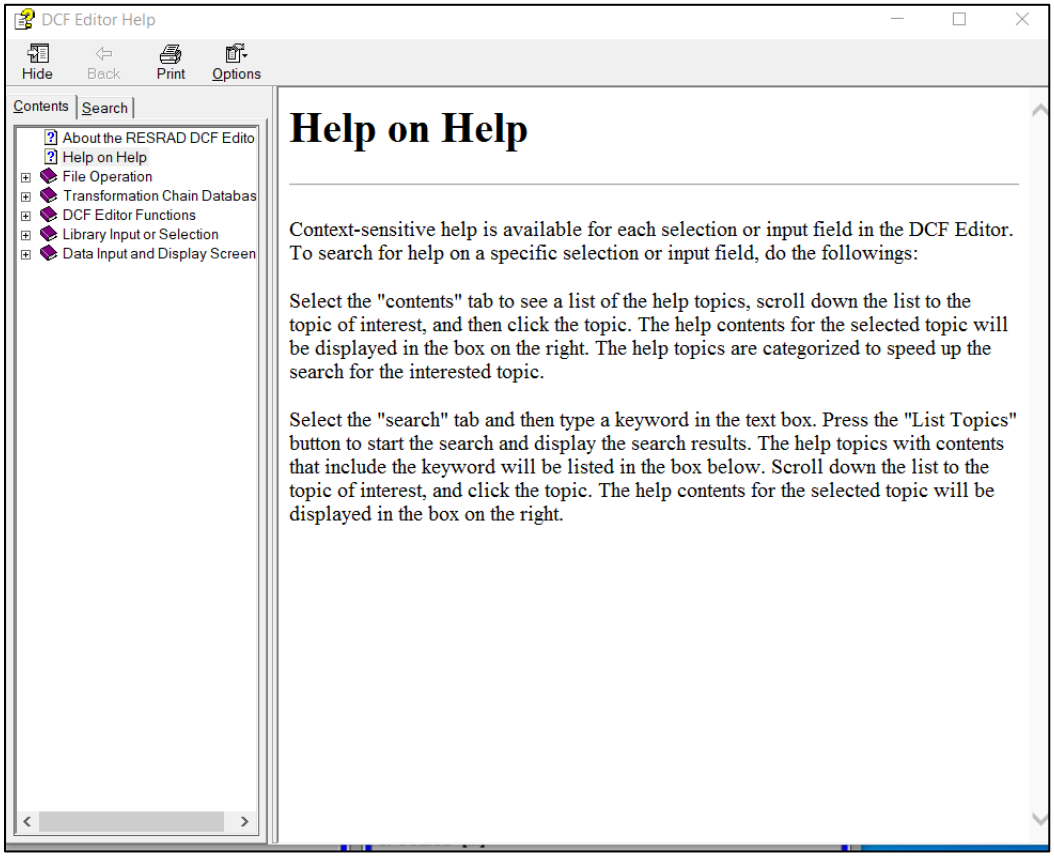
5) Import and export a DCF library:



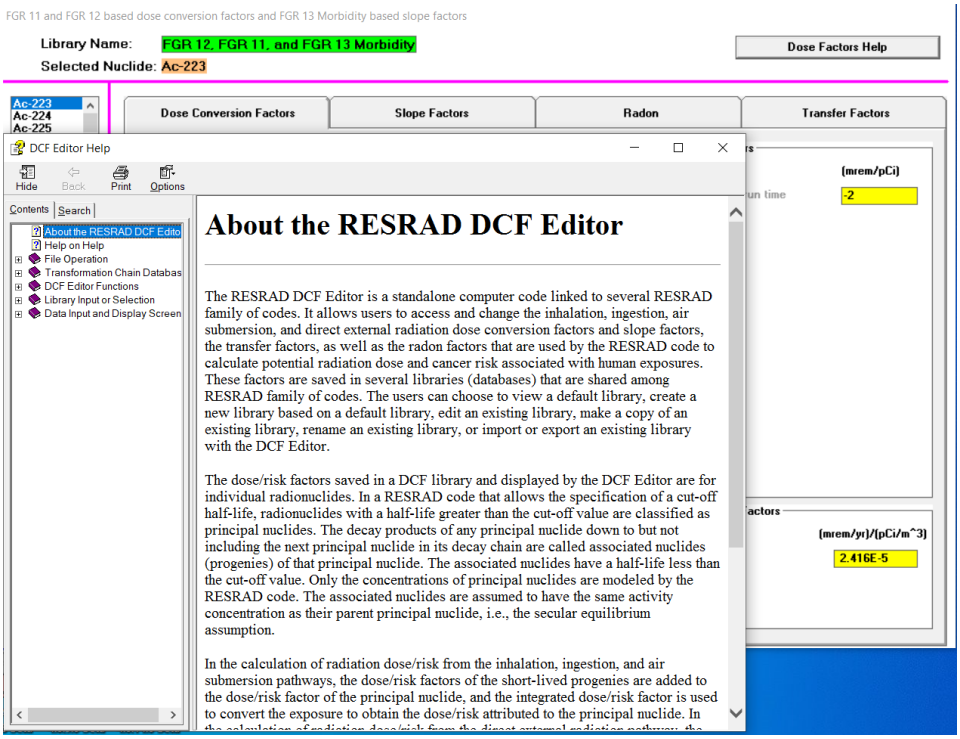


(4) General Help worked as described:



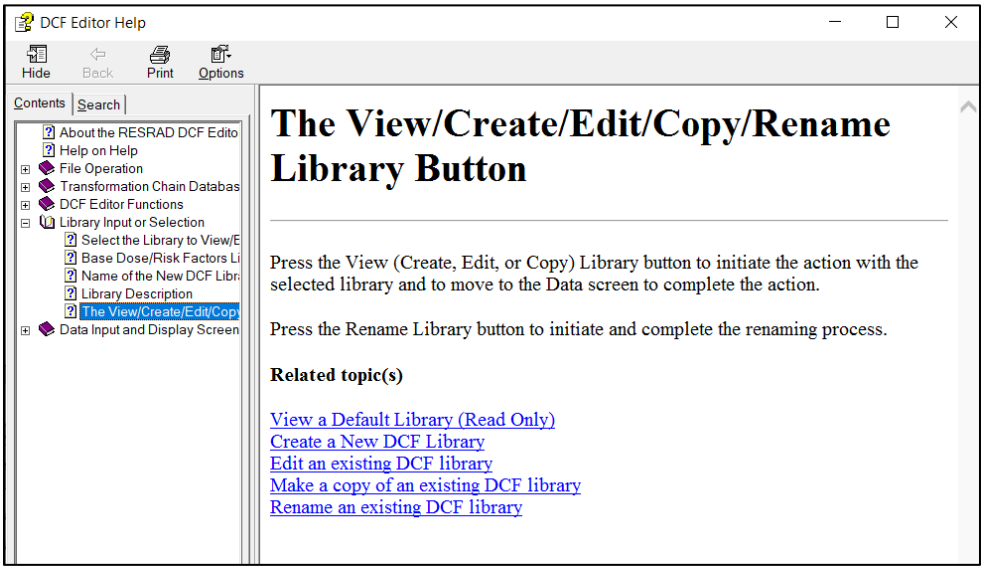


(5) Dose factors Help worked properly:



(6) The Back button worked properly.

(7) Clicking on F1 caused DCF Editor Help window to pop up:



11. TEST CASE 022-2

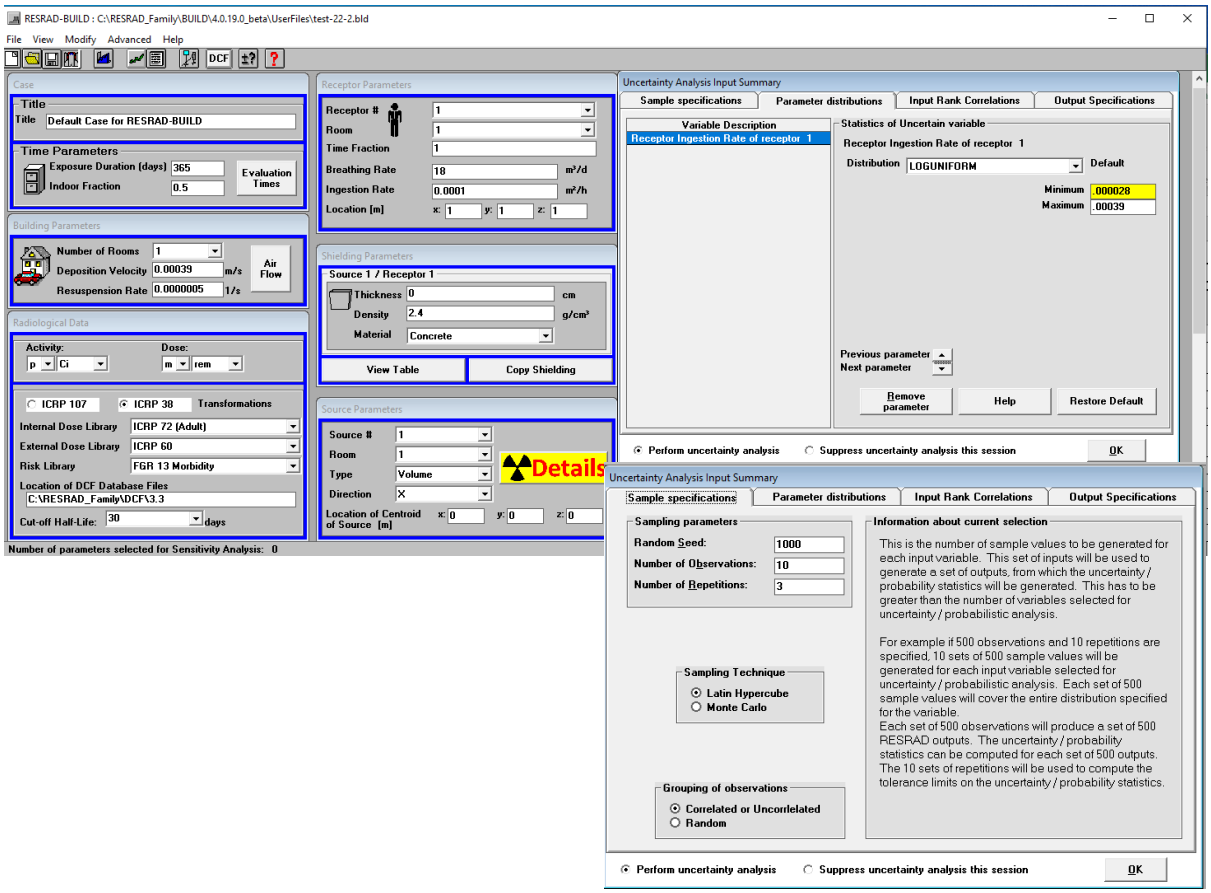
Test objectives/descriptions:

To test the options under the View, Modify, Advanced, and Help menus in the menu bar, hotkeys, and the Toolbar icon for launching the DCF Editor.

Test result (Pass/Fail): Pass

Test details:

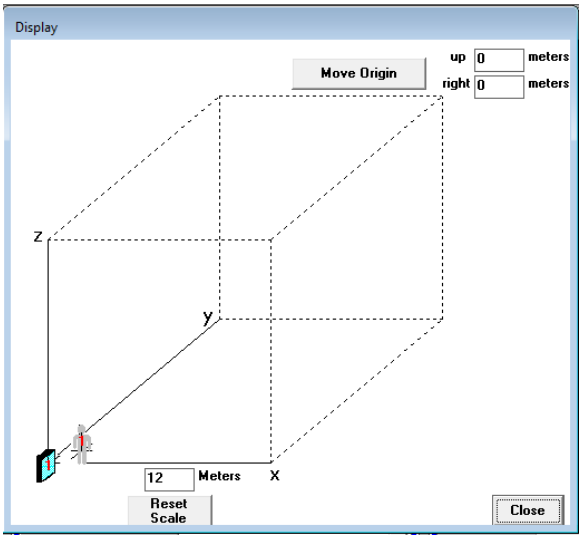
(1) In the Traditional Appearance, with Ingestion Rate focused, pressed F8 to perform uncertainty analysis, then changed the default maximum value, as shown below:



(2) After calculations were completed, closed the popped-up report viewer. Then performed the following testing on the various options under the View, Modify, Advanced, and Help menus as well as the corresponding icons in the main interface.

1) View

- 3D Display: From View|3D Display –> Close; from View 3D Display icon -> Close:

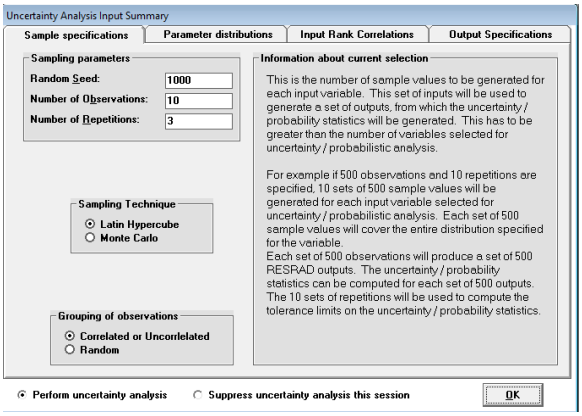


- Sensitivity Summary:

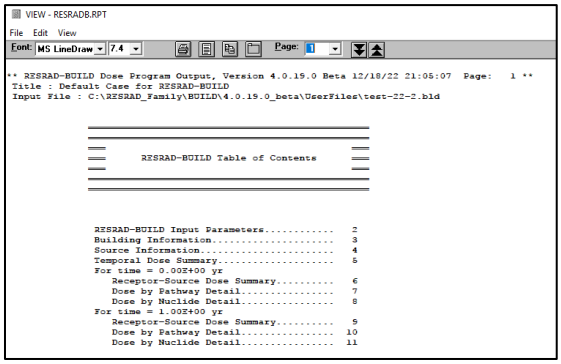
  — Menu|Sensitivity Summary toggle on:

  — Menu|Sensitivity Summary toggle off – the sensitivity summary disappeared at the bottom of the interface window.

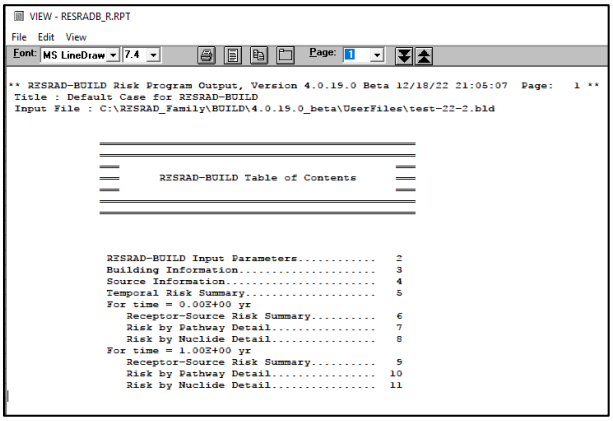
- Uncertainty Input: Uncertainty input window appeared.



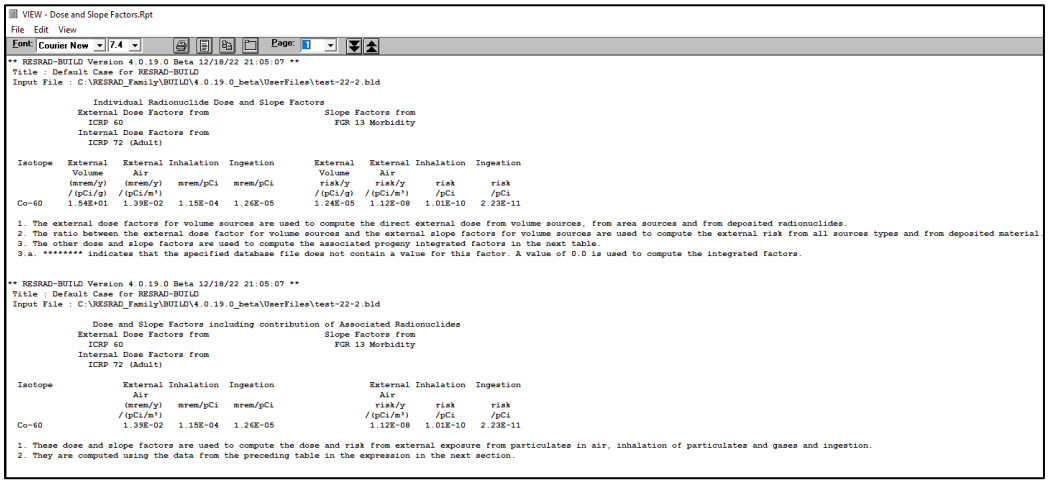
- Last Report: Last dose report was brought up.



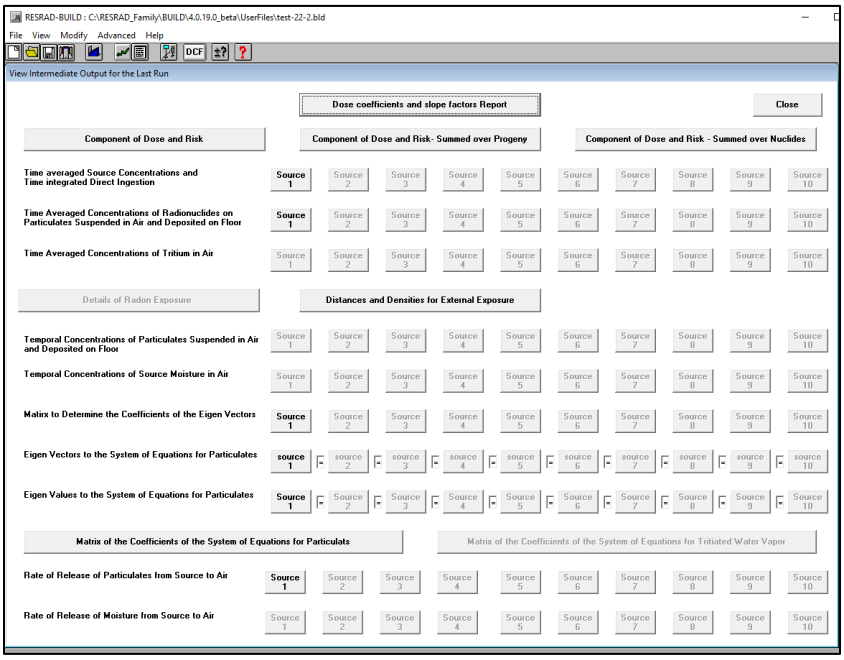
- Last Risk Report: Last risk report was brought up.



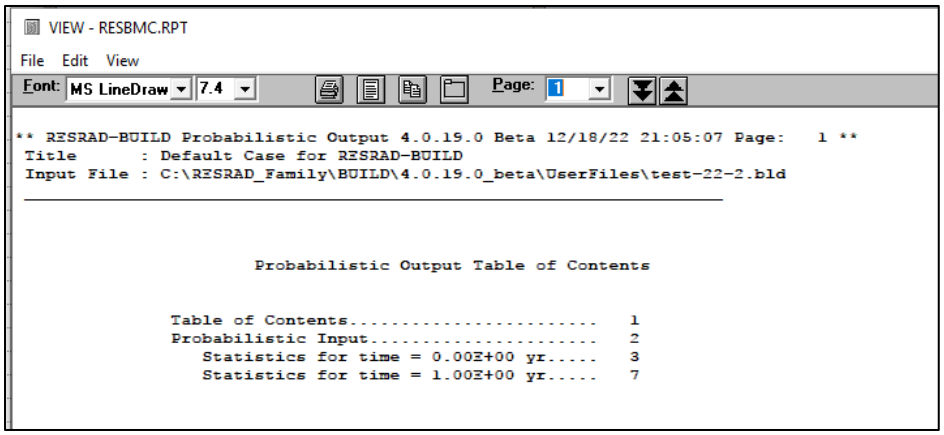
- Dose Coefficients and Slope Factors: Report was brought up.



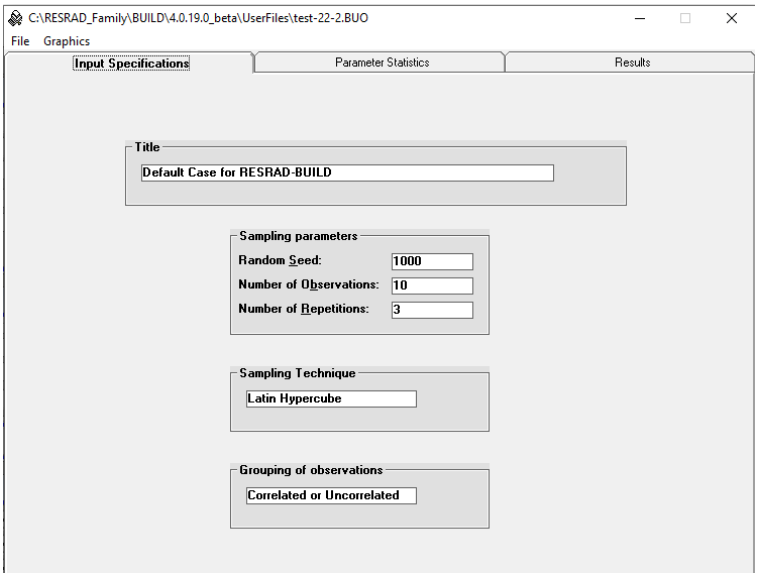
- Last Intermediate Output Files: A window with intermediate files for selection appeared.



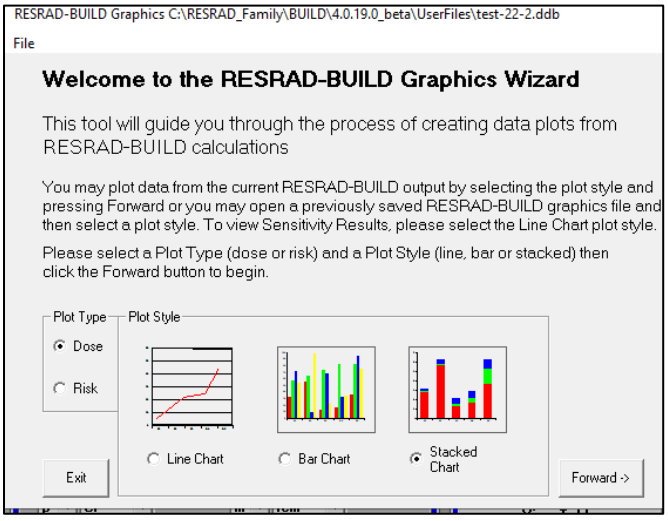
- Last Probabilistic Report: Report from the last analysis appeared.



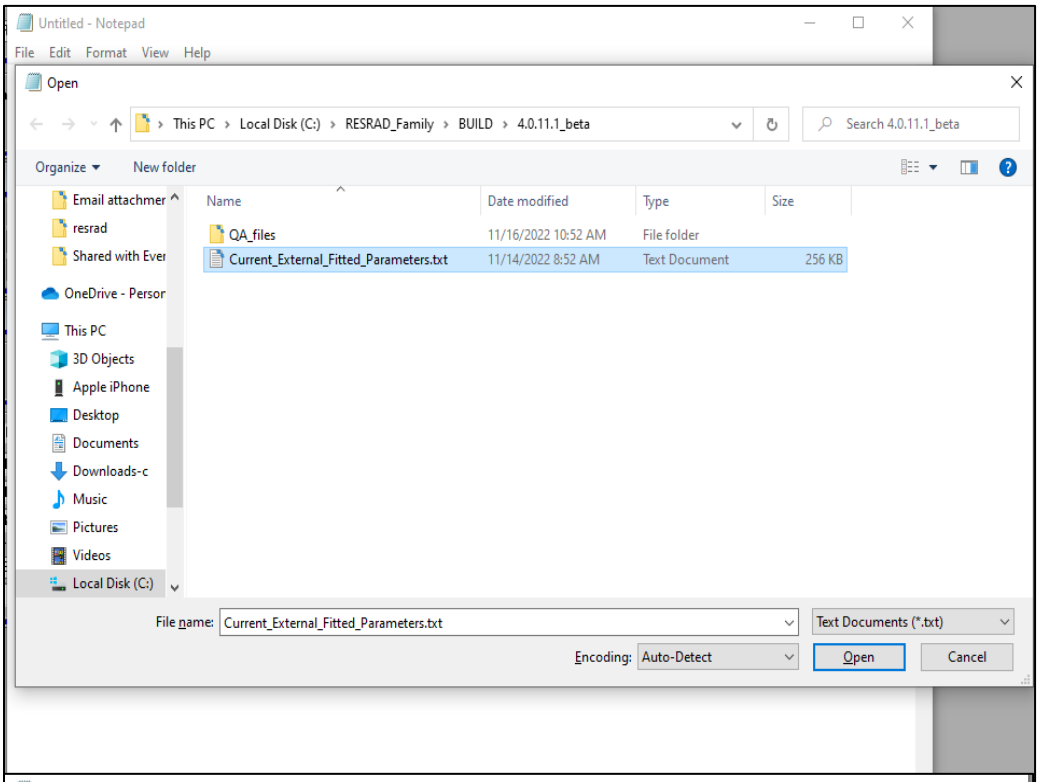
- Uncertainty Graphics: The corresponding window appeared.

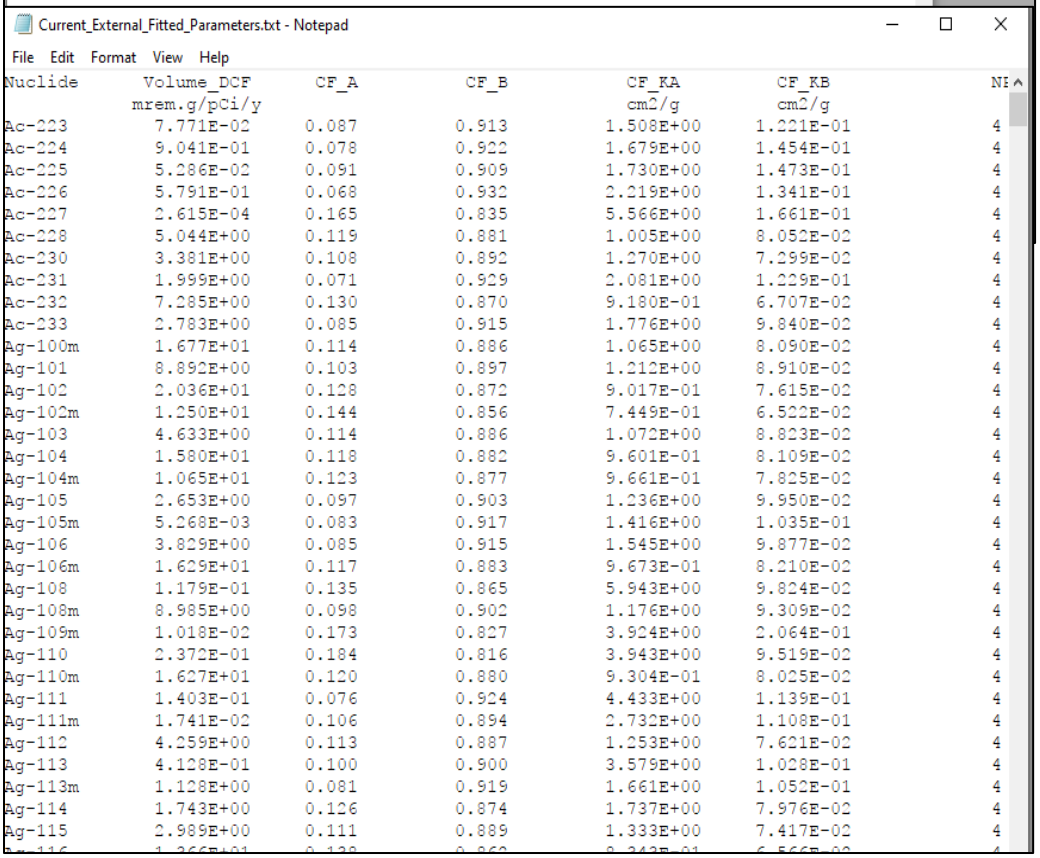


- Standard Graphics: The corresponding window appeared.



- Any File: A window allowing the selection of any file popped up, then the selected file was opened.



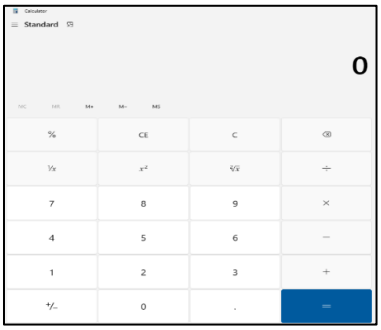


Current_External_Fitted_Parameters.txt - Notepad

File Edit Format View Help

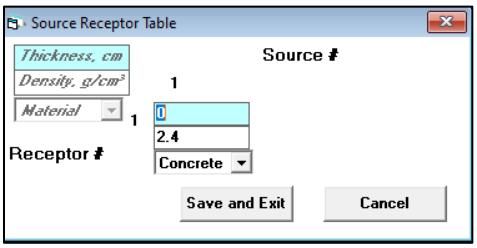
Nuclide	Volume_DCF	CF_A	CF_B	CF_KA	CF_KB	NI
	mrem.g/pCi/y			cm2/g	cm2/g	
Ac-223	7.771E-02	0.087	0.913	1.508E+00	1.221E-01	4
Ac-224	9.041E-01	0.078	0.922	1.679E+00	1.454E-01	4
Ac-225	5.286E-02	0.091	0.909	1.730E+00	1.473E-01	4
Ac-226	5.791E-01	0.068	0.932	2.219E+00	1.341E-01	4
Ac-227	2.615E-04	0.165	0.835	5.566E+00	1.661E-01	4
Ac-228	5.044E+00	0.119	0.881	1.005E+00	8.052E-02	4
Ac-230	3.381E+00	0.108	0.892	1.270E+00	7.299E-02	4
Ac-231	1.999E+00	0.071	0.929	2.081E+00	1.229E-01	4
Ac-232	7.285E+00	0.130	0.870	9.180E-01	6.707E-02	4
Ac-233	2.783E+00	0.085	0.915	1.776E+00	9.840E-02	4
Ag-100m	1.677E+01	0.114	0.886	1.065E+00	8.090E-02	4
Ag-101	8.892E+00	0.103	0.897	1.212E+00	8.910E-02	4
Ag-102	2.036E+01	0.128	0.872	9.017E-01	7.615E-02	4
Ag-102m	1.250E+01	0.144	0.856	7.449E-01	6.522E-02	4
Ag-103	4.633E+00	0.114	0.886	1.072E+00	8.823E-02	4
Ag-104	1.580E+01	0.118	0.882	9.601E-01	8.109E-02	4
Ag-104m	1.065E+01	0.123	0.877	9.661E-01	7.825E-02	4
Ag-105	2.653E+00	0.097	0.903	1.236E+00	9.950E-02	4
Ag-105m	5.268E-03	0.083	0.917	1.416E+00	1.035E-01	4
Ag-106	3.829E+00	0.085	0.915	1.545E+00	9.877E-02	4
Ag-106m	1.629E+01	0.117	0.883	9.673E-01	8.210E-02	4
Ag-108	1.179E-01	0.135	0.865	5.943E+00	9.824E-02	4
Ag-108m	8.985E+00	0.098	0.902	1.176E+00	9.309E-02	4
Ag-109m	1.018E-02	0.173	0.827	3.924E+00	2.064E-01	4
Ag-110	2.372E-01	0.184	0.816	3.943E+00	9.519E-02	4
Ag-110m	1.627E+01	0.120	0.880	9.304E-01	8.025E-02	4
Ag-111	1.403E-01	0.076	0.924	4.433E+00	1.139E-01	4
Ag-111m	1.741E-02	0.106	0.894	2.732E+00	1.108E-01	4
Ag-112	4.259E+00	0.113	0.887	1.253E+00	7.621E-02	4
Ag-113	4.128E-01	0.100	0.900	3.579E+00	1.028E-01	4
Ag-113m	1.128E+00	0.081	0.919	1.661E+00	1.052E-01	4
Ag-114	1.743E+00	0.126	0.874	1.737E+00	7.976E-02	4
Ag-115	2.989E+00	0.111	0.889	1.333E+00	7.417E-02	4

- Calculator: A calculator appeared for use.

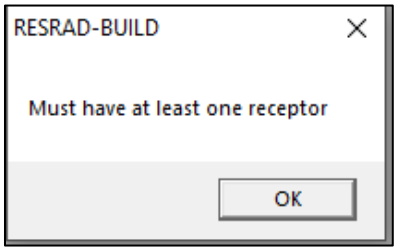


2) Modify:

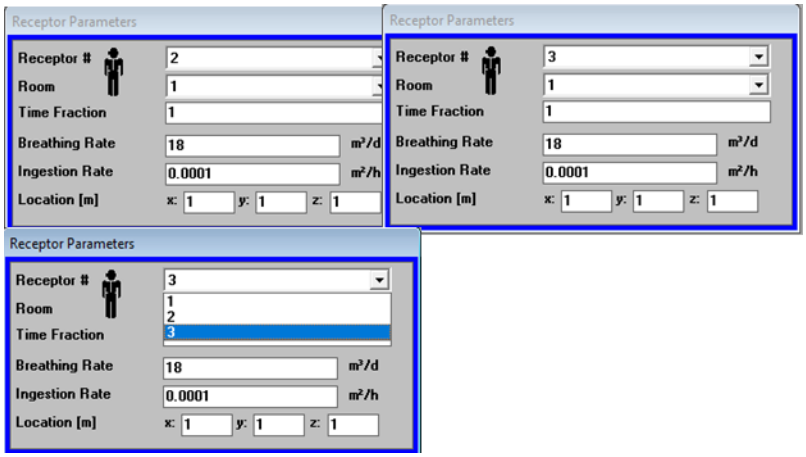
- Source/Receptor Table: The corresponding table appeared.



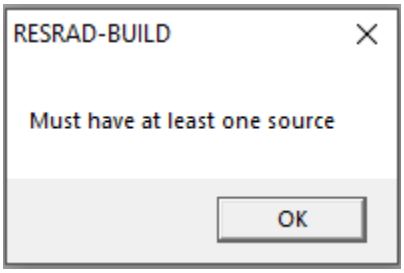
- Delete Receptor: A warning message popped up because there was only one receptor.



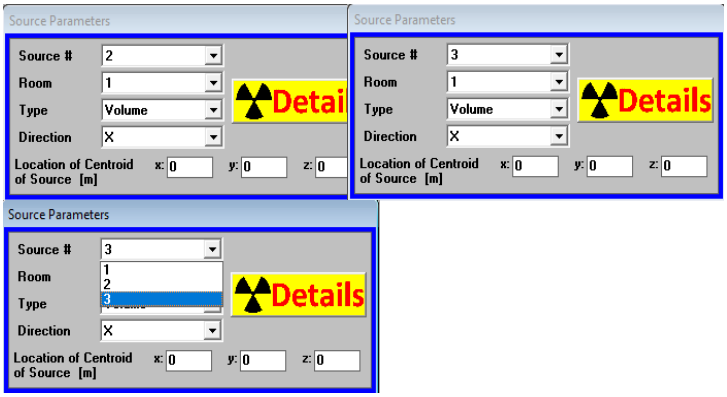
- Add Receptor: Chose this option to add Receptors 2 and 3, then chose Receptor 3 to delete with the "Delete Receptor" option.

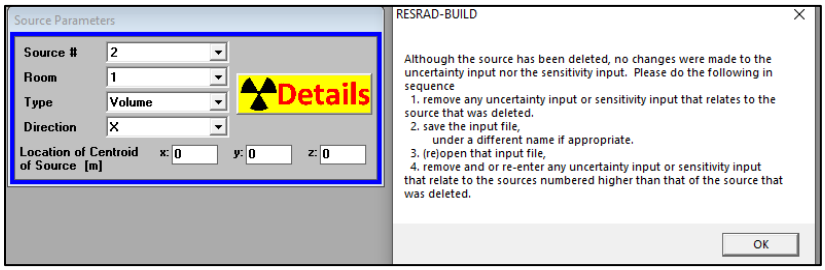


- Delete Source: A warning message window popped up due to only one source available currently.

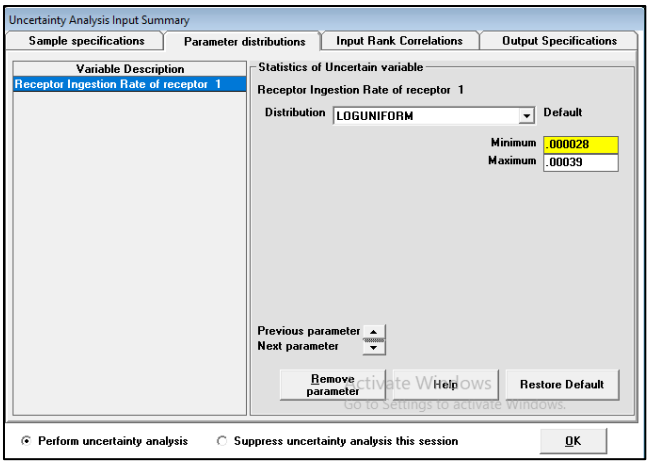


- Add Source: Added Sources 2 and 3, as shown in the screenshot, then deleted Source 2. Warning messages regarding the deleted source appeared.

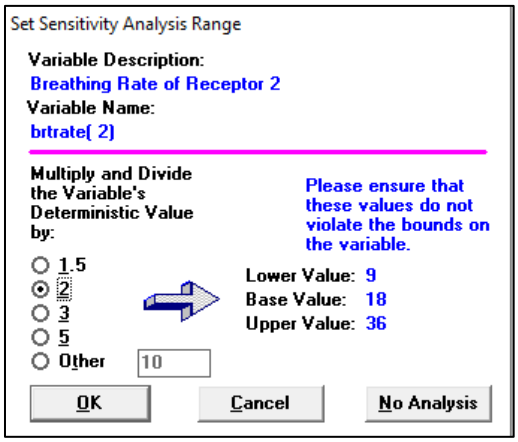




- Uncertainty Analysis: The corresponding input window appeared.

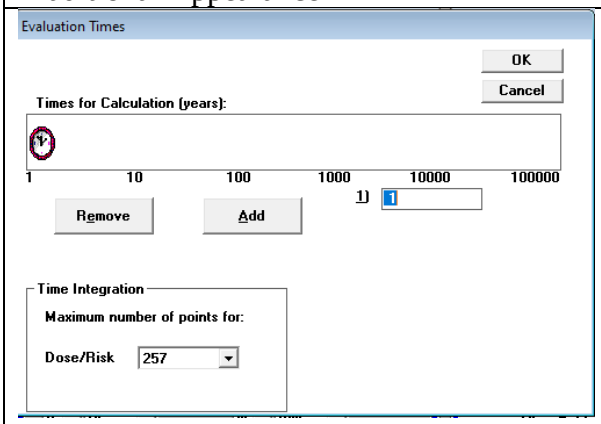
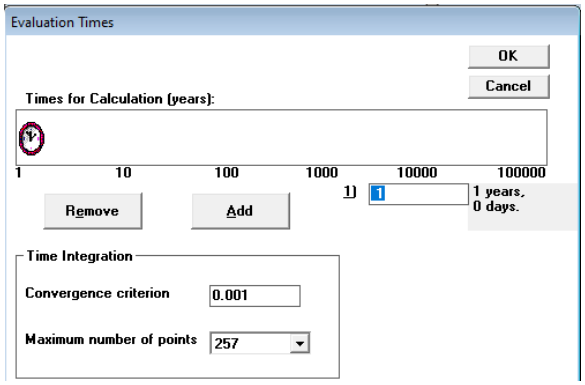
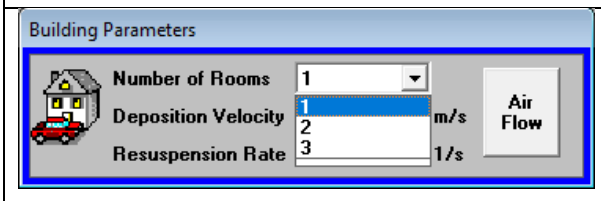
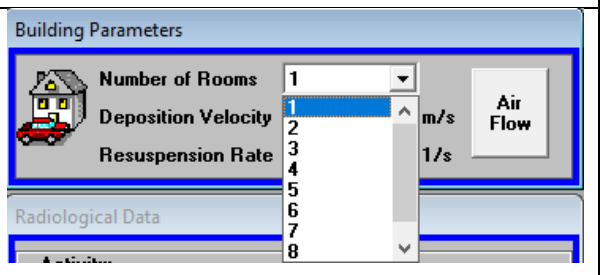


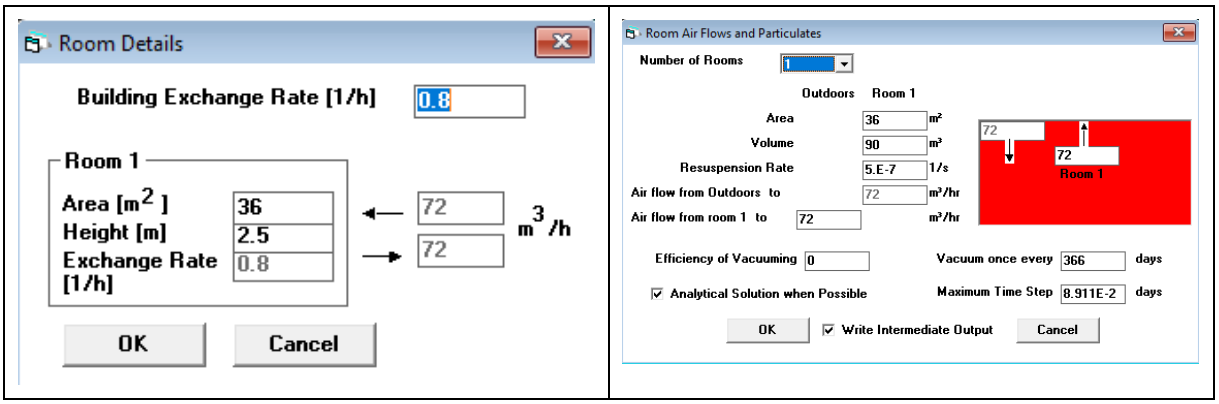
- Sensitivity Analysis: put cursor in the breathing rate input field and chose the View|Sensitivity Analysis menu option. Saved the inputs to "test-22-2-2.bld."



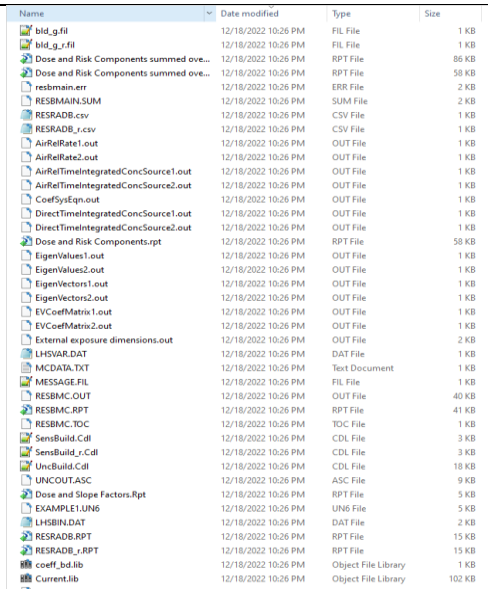
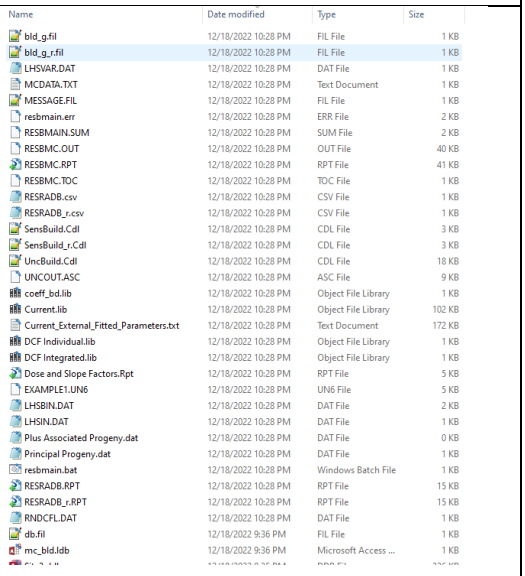
3) Advanced:

- With Traditional Appearance selected, switching to New Appearance caused the following windows to change:

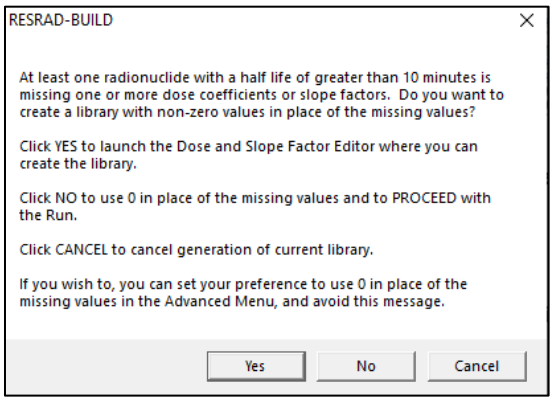
Traditional Appearance	New Appearance
	
	



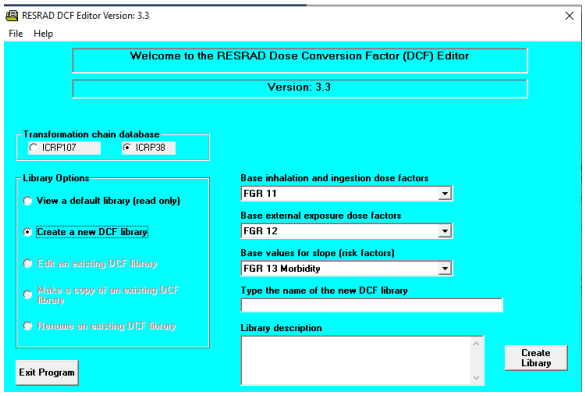
- Write Intermediate Output: when this option was toggled on, the intermediate output files were generated after running the code. Toggled this option off. When the inputs were saved to "test-22-2-3.bld," the code was run again; no intermediate output files were generated.

On	Off
	

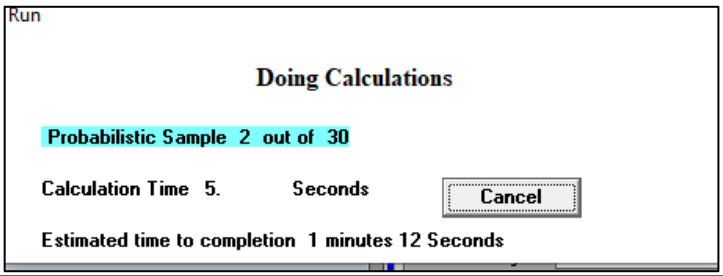
- Use 0 for Missing DC SF: Added U-238 to the radiation source and saved the inputs to "test-22-2-3.bld." Toggled off this option and then ran the code. The following warning message popped up:



Clicking "Yes" opened the DCF Editor:



Clicking “No” launched the calculation. Checked the dose/risk coefficient file.



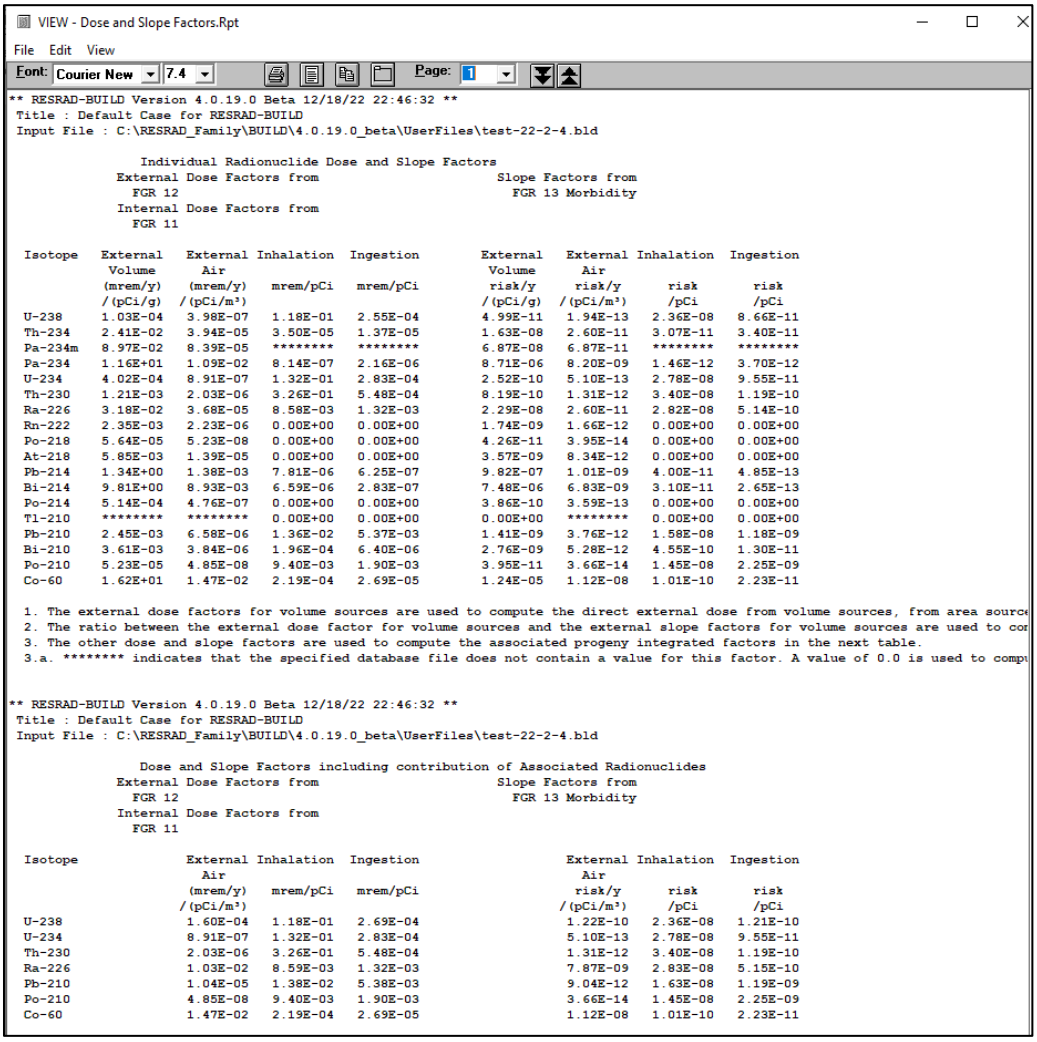
VIEW - Dose and Slope Factors.Rpt

File Edit View

Font: Courier New 7.4 Page: 1

```
** RESRAD-BUILD Version 4.0.19.0 Beta 12/18/22 22:37:46 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\test-22-2-3.bld

                Individual Radionuclide Dose and Slope Factors
              External Dose Factors from                        Slope Factors from
                FGR 12                                            FGR 13 Morbidity
              Internal Dose Factors from
                FGR 11

 Isotope   External    External Inhalation  Ingestion        External   External Inhalation  Ingestion
            Volume       Air                                 Volume      Air
           (mrem/y)    (mrem/y)   mrem/pCi   mrem/pCi         risk/y    risk/y      risk       risk
          /(pCi/g)   /(pCi/m³)                              /(pCi/g)  /(pCi/m³)     /pCi       /pCi
 U-238    1.03E-04   3.98E-07   1.18E-01   2.55E-04        4.99E-11  1.94E-13  2.36E-08   8.66E-11
 Th-234   2.41E-02   3.94E-05   3.50E-05   1.37E-05        1.63E-08  2.60E-11  3.07E-11   3.40E-11
 Pa-234m  8.97E-02   8.39E-05   ********   ********        6.87E-08  6.87E-11  ********   ********
 Pa-234   1.16E+01   1.09E-02   8.14E-07   2.16E-06        8.71E-06  8.20E-09  1.46E-12   3.70E-12
 U-234    4.02E-04   8.91E-07   1.32E-01   2.83E-04        2.52E-10  5.10E-13  2.78E-08   9.55E-11
 Th-230   1.21E-03   2.03E-06   3.26E-01   5.48E-04        8.19E-10  1.31E-12  3.40E-08   1.19E-10
 Ra-226   3.18E-02   3.68E-05   8.58E-03   1.32E-03        2.29E-08  2.60E-11  2.82E-08   5.14E-10
 Rn-222   2.35E-03   2.23E-06   0.00E+00   0.00E+00        1.74E-09  1.66E-12  0.00E+00   0.00E+00
 Po-218   5.64E-05   5.23E-08   0.00E+00   0.00E+00        4.26E-11  3.95E-14  0.00E+00   0.00E+00
 At-218   5.85E-03   1.39E-05   0.00E+00   0.00E+00        3.57E-09  8.34E-12  0.00E+00   0.00E+00
 Pb-214   1.34E+00   1.38E-03   7.81E-06   6.25E-07        9.82E-07  1.01E-09  4.00E-11   4.85E-13
 Bi-214   9.81E+00   8.93E-03   6.59E-06   2.83E-07        7.48E-06  6.83E-09  3.10E-11   2.65E-13
 Po-214   5.14E-04   4.76E-07   0.00E+00   0.00E+00        3.86E-10  3.59E-13  0.00E+00   0.00E+00
 Tl-210   ********   ********   0.00E+00   0.00E+00        0.00E+00  ********  0.00E+00   0.00E+00
 Pb-210   2.45E-03   6.58E-06   1.36E-02   5.37E-03        1.41E-09  3.76E-12  1.58E-08   1.18E-09
 Bi-210   3.61E-03   3.84E-06   1.96E-04   6.40E-06        2.76E-09  5.28E-12  4.55E-10   1.30E-11
 Po-210   5.23E-05   4.85E-08   9.40E-03   1.90E-03        3.95E-11  3.66E-14  1.45E-08   2.25E-09
 Co-60    1.62E+01   1.47E-02   2.19E-04   2.69E-05        1.24E-05  1.12E-08  1.01E-10   2.23E-11

 1. The external dose factors for volume sources are used to compute the direct external dose from volume sources, from area sources and from deposited radionuclides.
 2. The ratio between the external dose factor for volume sources and the external slope factors for volume sources are used to compute the external risk from all sources
 3. The other dose and slope factors are used to compute the associated progeny integrated factors in the next table.
 3.a. ******** indicates that the specified database file does not contain a value for this factor. A value of 0.0 is used to compute the integrated factors.


** RESRAD-BUILD Version 4.0.19.0 Beta 12/18/22 22:37:46 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\test-22-2-3.bld

                Dose and Slope Factors including contribution of Associated Radionuclides
              External Dose Factors from                        Slope Factors from
                FGR 12                                            FGR 13 Morbidity
              Internal Dose Factors from
                FGR 11

 Isotope             External Inhalation  Ingestion                 External Inhalation  Ingestion
                      Air                                            Air
                     (mrem/y)   mrem/pCi   mrem/pCi                  risk/y      risk       risk
                    /(pCi/m³)                                      /(pCi/m³)     /pCi       /pCi
 U-238               1.60E-04   1.18E-01   2.69E-04                 1.22E-10  2.36E-08   1.21E-10
 U-234               8.91E-07   1.32E-01   2.83E-04                 5.10E-13  2.78E-08   9.55E-11
 Th-230              2.03E-06   3.26E-01   5.48E-04                 1.31E-12  3.40E-08   1.19E-10
 Ra-226              1.03E-02   8.59E-03   1.32E-03                 7.87E-09  2.83E-08   5.15E-10
 Pb-210              1.04E-05   1.38E-02   5.38E-03                 9.04E-12  1.63E-08   1.19E-09
 Po-210              4.85E-08   9.40E-03   1.90E-03                 3.66E-14  1.45E-08   2.25E-09
 Co-60               1.47E-02   2.19E-04   2.69E-05                 1.12E-08  1.01E-10   2.23E-11
```

Toggled on this option, saved the inputs to "test-22-2-4.bld," and ran the code. No warning message popped up before the calculation was conducted. Checked the dose/risk coefficient file; 0 was used when DC or SF was missing from the library database.



VIEW - Dose and Slope Factors.Rpt

File Edit View

Font: Courier New 7.4 Page: 1

** RESRAD-BUILD Version 4.0.19.0 Beta 12/18/22 22:46:32 **
Title : Default Case for RESRAD-BUILD
Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\test-22-2-4.bld

Individual Radionuclide Dose and Slope Factors
External Dose Factors from FGR 12
Internal Dose Factors from FGR 11
Slope Factors from FGR 13 Morbidity

Isotope	External Volume (mrem/y) /(pCi/g)	External Inhalation Air (mrem/y) /(pCi/m³)	Ingestion mrem/pCi	Ingestion mrem/pCi	External Volume risk/y /(pCi/g)	External Inhalation Air risk/y /(pCi/m³)	Ingestion risk /pCi	Ingestion risk /pCi
U-238	1.03E-04	3.98E-07	1.18E-01	2.55E-04	4.99E-11	1.94E-13	2.36E-08	8.66E-11
Th-234	2.41E-02	3.94E-05	3.50E-05	1.37E-05	1.63E-08	2.60E-11	3.07E-11	3.40E-11
Pa-234m	8.97E-02	8.39E-05	********	********	6.87E-08	6.87E-11	********	********
Pa-234	1.16E+01	1.09E-02	8.14E-07	2.16E-06	8.71E-06	8.20E-09	1.46E-12	3.70E-12
U-234	4.02E-04	8.91E-07	1.32E-01	2.83E-04	2.52E-10	5.10E-13	2.78E-08	9.55E-11
Th-230	1.21E-03	2.03E-06	3.26E-01	5.48E-04	8.19E-10	1.31E-12	3.40E-08	1.19E-10
Ra-226	3.18E-02	3.68E-05	8.58E-03	1.32E-03	2.29E-08	2.60E-11	2.82E-08	5.14E-10
Rn-222	2.35E-03	2.23E-06	0.00E+00	0.00E+00	1.74E-09	1.66E-12	0.00E+00	0.00E+00
Po-218	5.64E-05	5.23E-08	0.00E+00	0.00E+00	4.26E-11	3.95E-14	0.00E+00	0.00E+00
At-218	5.85E-03	1.39E-05	0.00E+00	0.00E+00	3.57E-09	8.34E-12	0.00E+00	0.00E+00
Pb-214	1.34E+00	1.38E-03	7.81E-06	6.25E-07	9.82E-07	1.01E-09	4.00E-11	4.85E-13
Bi-214	9.81E+00	8.93E-03	6.59E-06	2.83E-07	7.48E-06	6.83E-09	3.10E-11	2.65E-13
Po-214	5.14E-04	4.76E-07	0.00E+00	0.00E+00	3.86E-10	3.59E-13	0.00E+00	0.00E+00
Tl-210	********	********	0.00E+00	0.00E+00	0.00E+00	********	0.00E+00	0.00E+00
Pb-210	2.45E-03	6.58E-06	1.36E-02	5.37E-03	1.41E-09	3.76E-12	1.58E-08	1.18E-09
Bi-210	3.61E-03	3.84E-06	1.96E-04	6.40E-06	2.76E-09	5.28E-12	4.55E-10	1.30E-11
Po-210	5.23E-05	4.85E-08	9.40E-03	1.90E-03	3.95E-11	3.66E-14	1.45E-08	2.25E-09
Co-60	1.62E+01	1.47E-02	2.19E-04	2.69E-05	1.24E-05	1.12E-08	1.01E-10	2.23E-11

1. The external dose factors for volume sources are used to compute the direct external dose from volume sources, from area sourc
2. The ratio between the external dose factor for volume sources and the external slope factors for volume sources are used to co
3. The other dose and slope factors are used to compute the associated progeny integrated factors in the next table.
3.a. ******** indicates that the specified database file does not contain a value for this factor. A value of 0.0 is used to comp

** RESRAD-BUILD Version 4.0.19.0 Beta 12/18/22 22:46:32 **
Title : Default Case for RESRAD-BUILD
Input File : C:\RESRAD_Family\BUILD\4.0.19.0_beta\UserFiles\test-22-2-4.bld

Dose and Slope Factors including contribution of Associated Radionuclides
External Dose Factors from FGR 12
Internal Dose Factors from FGR 11
Slope Factors from FGR 13 Morbidity

Isotope	External Inhalation Air (mrem/y) /(pCi/m³)	Ingestion mrem/pCi	Ingestion mrem/pCi	External Inhalation Air risk/y /(pCi/m³)	Ingestion risk /pCi	Ingestion risk /pCi
U-238	1.60E-04	1.18E-01	2.69E-04	1.22E-10	2.36E-08	1.21E-10
U-234	8.91E-07	1.32E-01	2.83E-04	5.10E-13	2.78E-08	9.55E-11
Th-230	2.03E-06	3.26E-01	5.48E-04	1.31E-12	3.40E-08	1.19E-10
Ra-226	1.03E-02	8.59E-03	1.32E-03	7.87E-09	2.83E-08	5.15E-10
Pb-210	1.04E-05	1.38E-02	5.38E-03	9.04E-12	1.63E-08	1.19E-09
Po-210	4.85E-08	9.40E-03	1.90E-03	3.66E-14	1.45E-08	2.25E-09
Co-60	1.47E-02	2.19E-04	2.69E-05	1.12E-08	1.01E-10	2.23E-11

- Display Check Sensitivity or Uncertainty Analysis Inputs Warning:

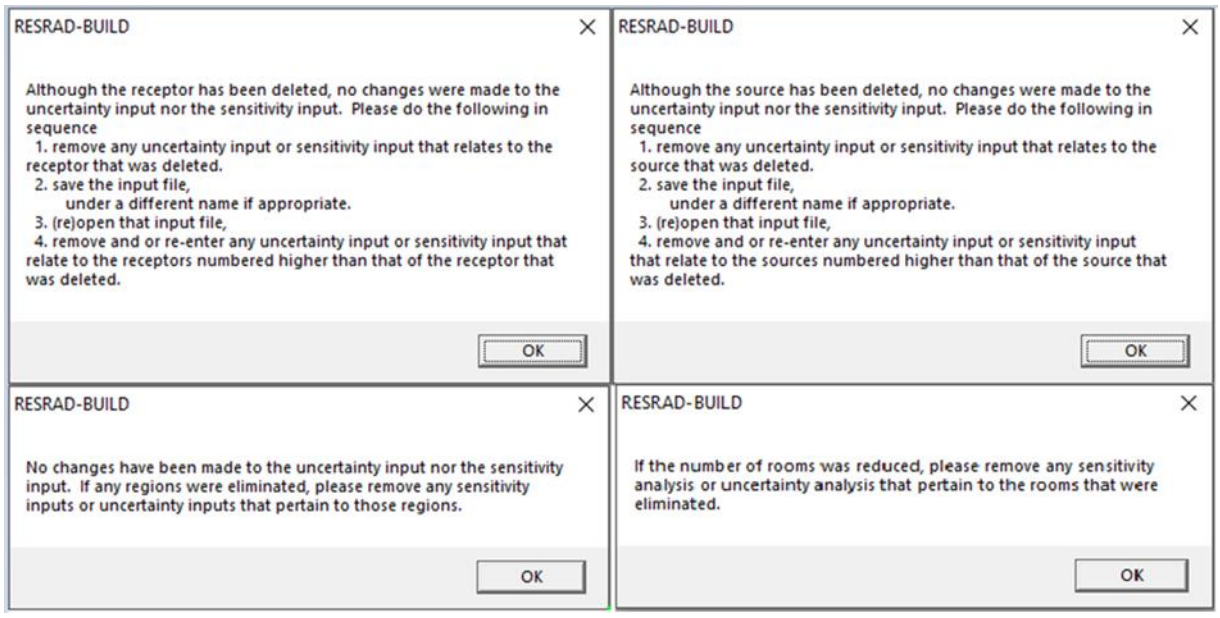
  By default, this display warning option was toggled on. Performing the following actions in sequence brought up warning messages.

  i. Deleted a receptor.

  ii. Deleted a source.

  iii. Added a region.

  iv. Switched from the New Appearance to the Traditional Appearance.



Added back a receptor, a source, and switched back to the new appearance. Toggled off this display warning option and then performed the following actions again. No warning messages popped up.

i Deleted a receptor.

ii Deleted a source.

iii Added a region.

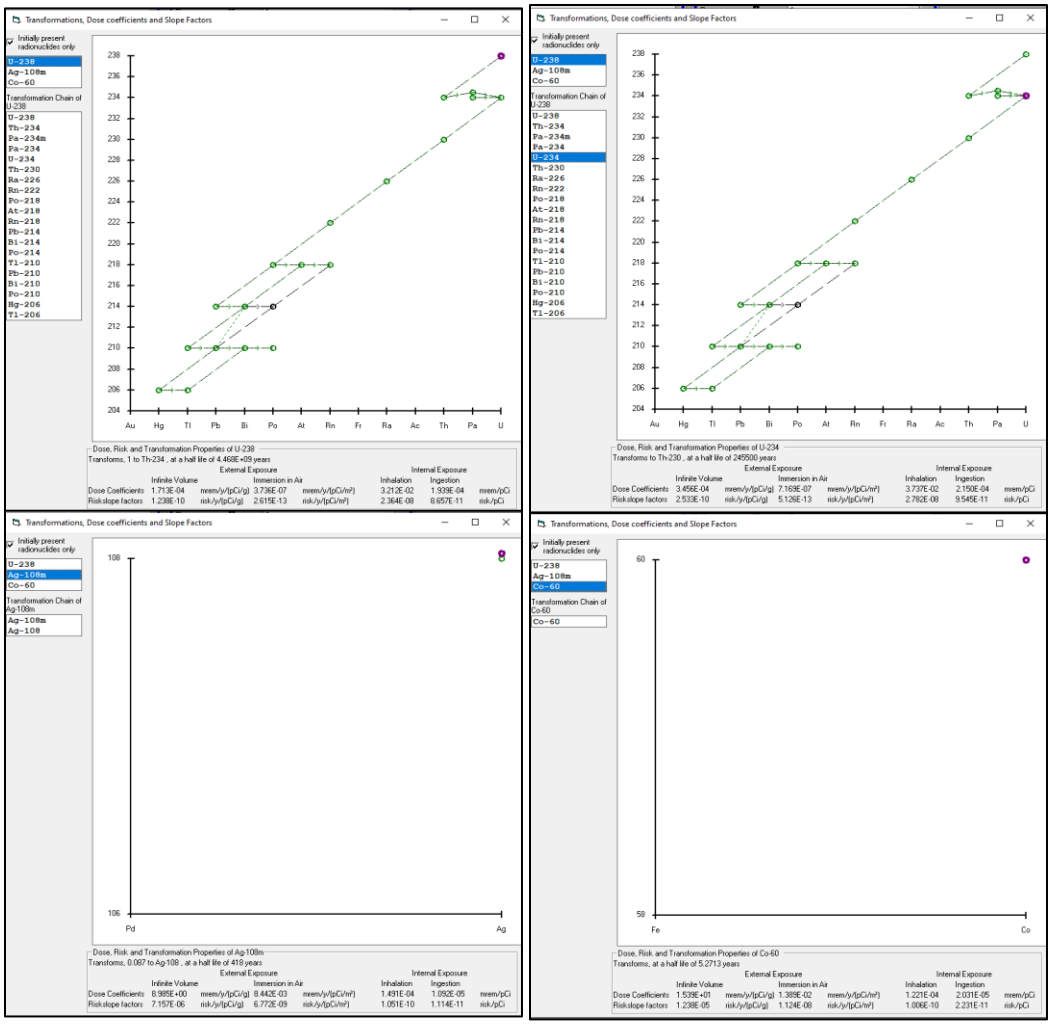
iv Switched from the New Appearance to the Traditional Appearance.

- Save Preferences When Exiting Code:

  When this option was toggled on, the radionuclide and DCF databases recorded in the configuration file were updated with the current selections when the code was closed. Launched the code again, changed the radionuclide database to ICRP-107, toggled off this option, and then ran and closed the code. Checked the configuration file; the radionuclide database recorded was not updated to ICRP-107 (it was ICRP-38). Launched the code again and found all the database settings were from the previous run before the last one

- Generate Dose, Risk, and Transformation Data:

  Changed the cutoff half-life to 1.0E-7 days and selected U-238 and Ag-108m to add to the radiation source. Clicking this option under the "Advanced" menu popped up the window "Transformation, Dose Coefficient and Slope Factors." Selected a parent radionuclide from the 1st list in the window, then all the radionuclides in its decay chain were presented and their sequence in the decay was displayed. Selected a radionuclide from the decay chain (2nd list). Its dose coefficients and risk factors appeared at the bottom of the window:



4) Help

- User's Manual: Upon choosing this option, the User's Manual popped up:

COVER

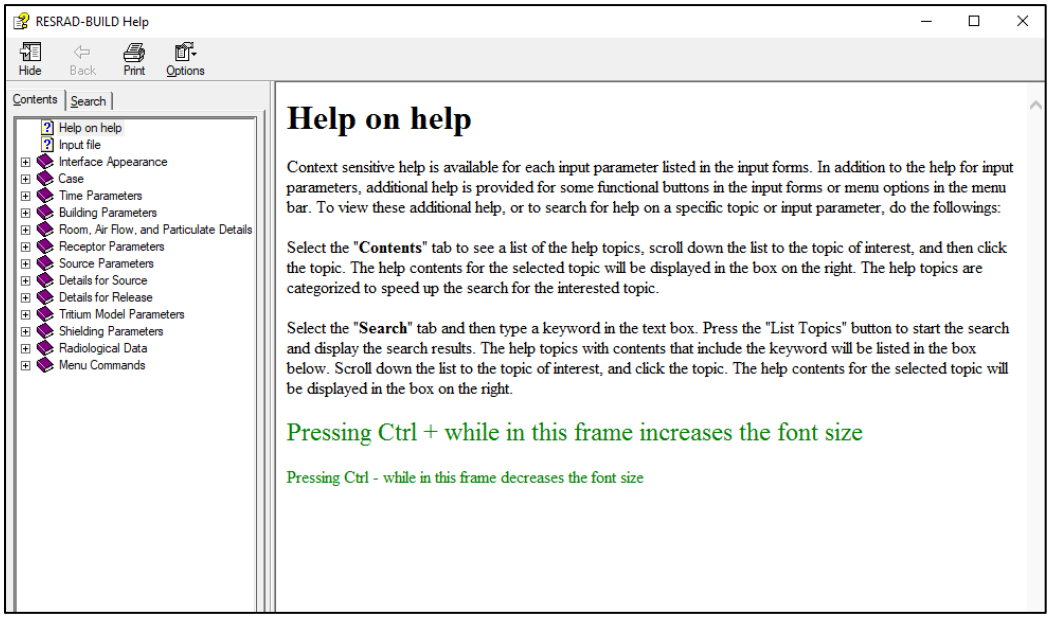
User's Manual for RESRAD-BUILD Code Version 4
Vol. 1 – Methodology and Models Used in RESRAD-BUILD Code

- User's Guide: Upon choosing this option, the User's Guide popped up:

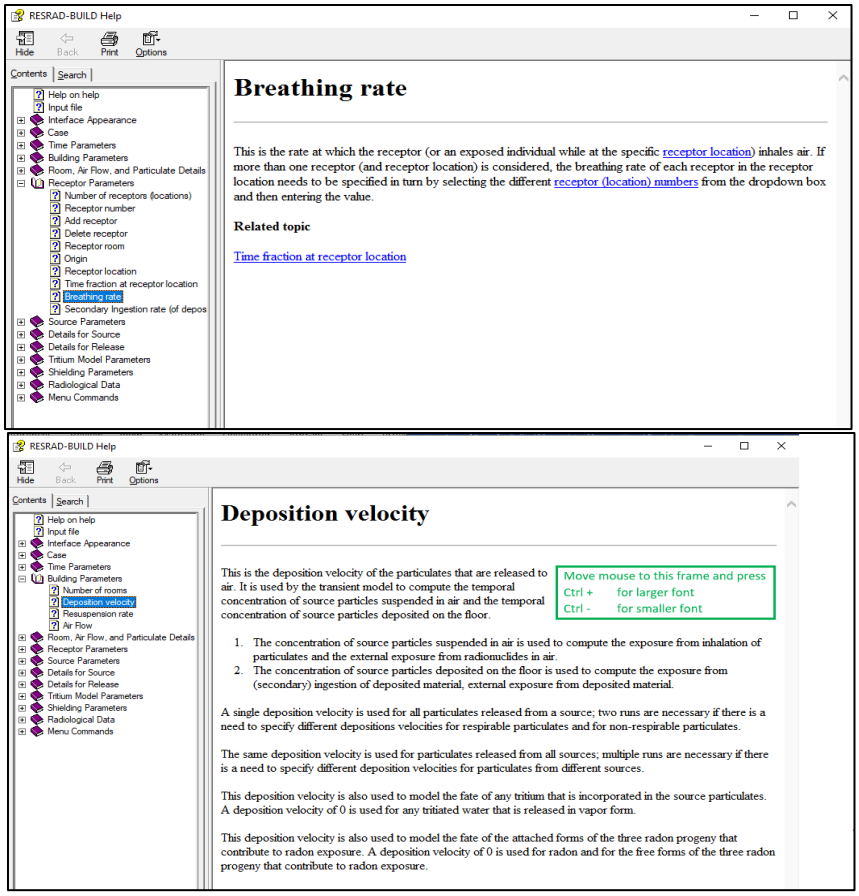
COVER

User's Manual for RESRAD-BUILD Code Version 4
Vol. 2 – User's Guide for RESRAD-BUILD Version 4

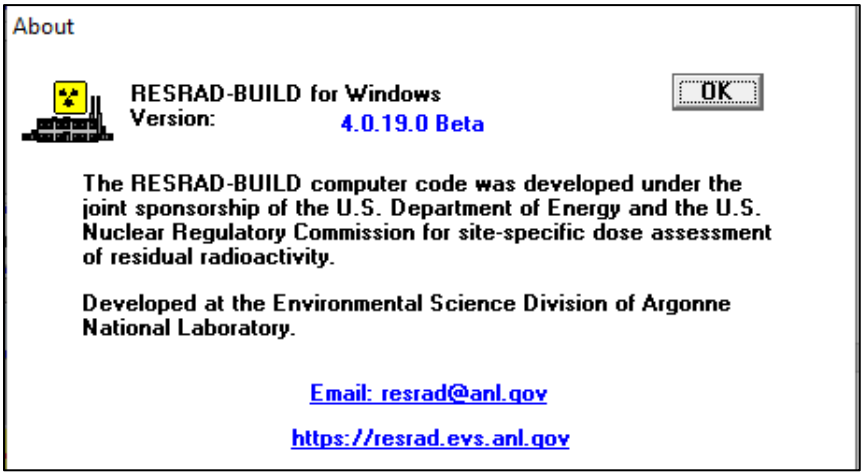
- General Help: Upon clicking this option, the Help window popped up.



- Context Help: Tested two parameters and the context help for each of them appeared upon request:



- About: The About screen appeared when this option was selected.



12. TEST CASE 025

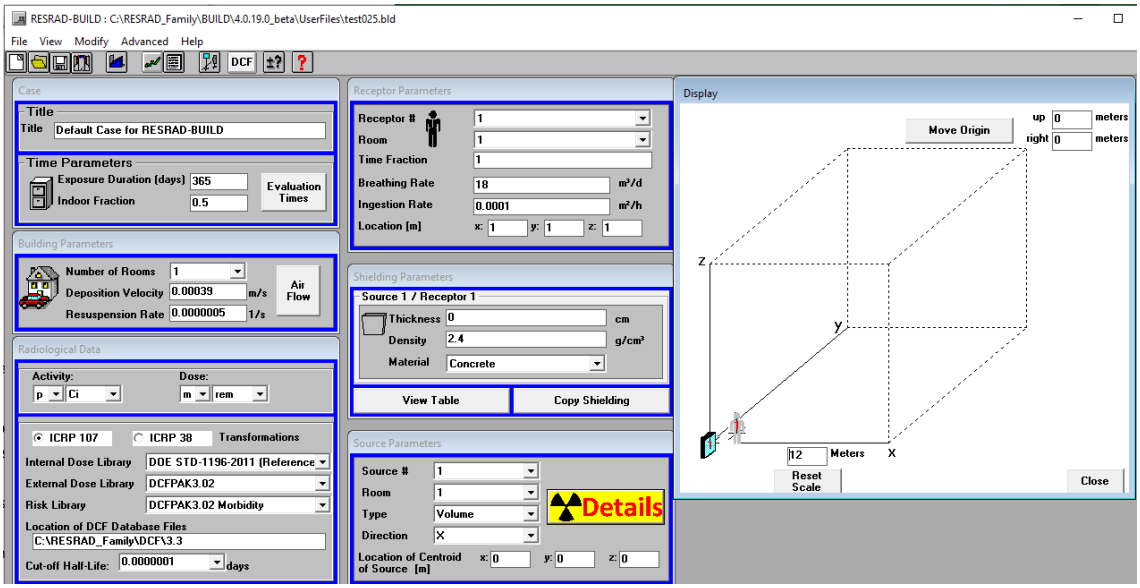
Test objectives/descriptions:

To test the 3D display of the source and receptor locations.

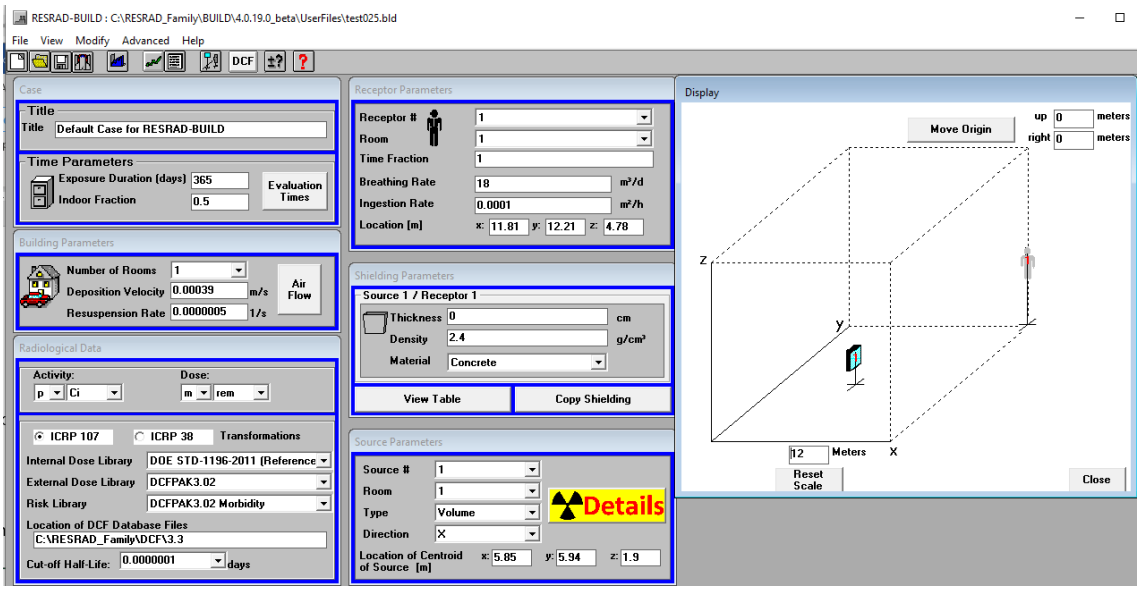
Test result (Pass/Fail): Pass

Test details:

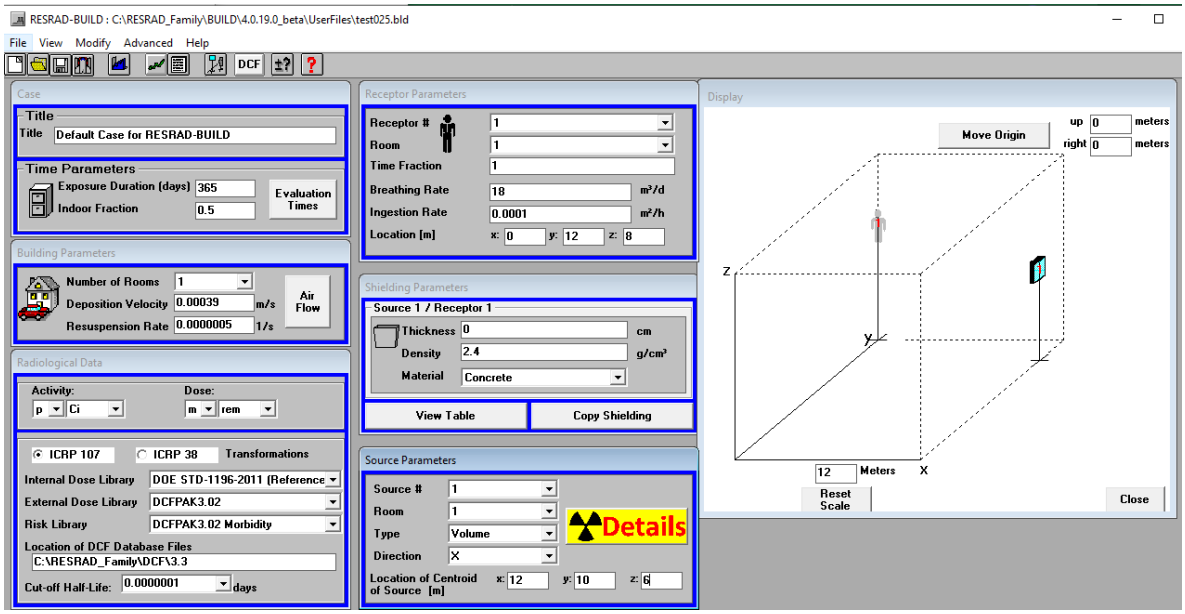
(1) When a new input file was opened and saved to "test025.bld," the opened 3D display reflected the current source and receptor locations"

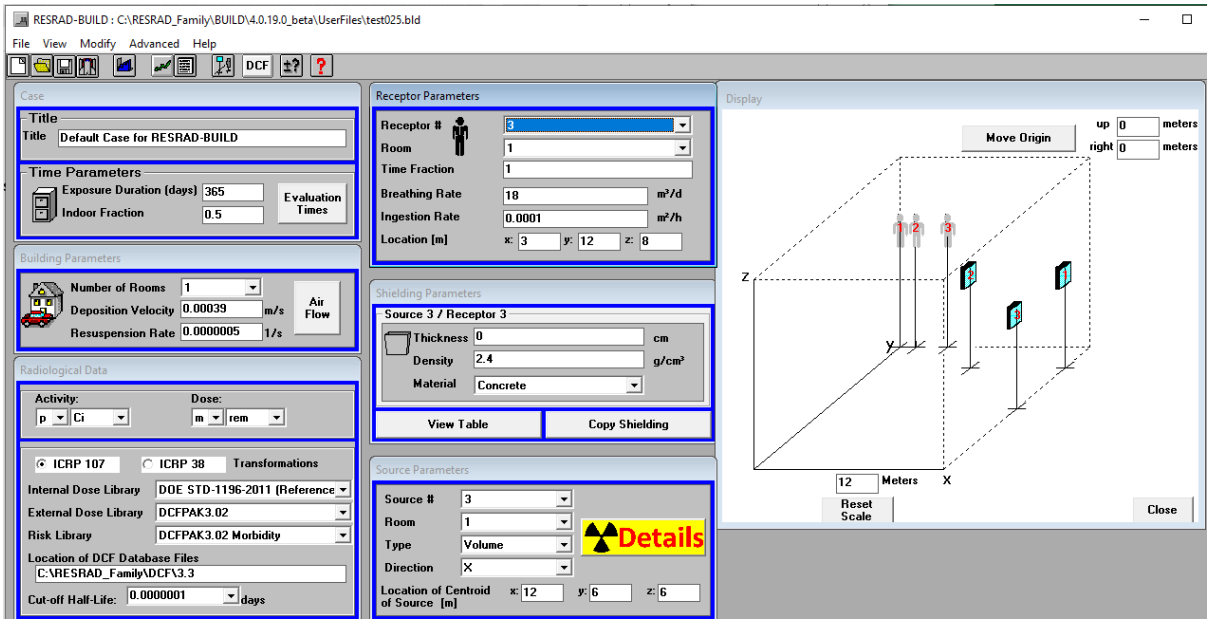


(2) When the locators for source and receptor were moved to new locations, as shown below, their location coordinates were updated appropriately in the main interface:



(3) When the x, y, and z coordinates for the source and receptor were changed from the interface, the 3D display was updated accordingly.

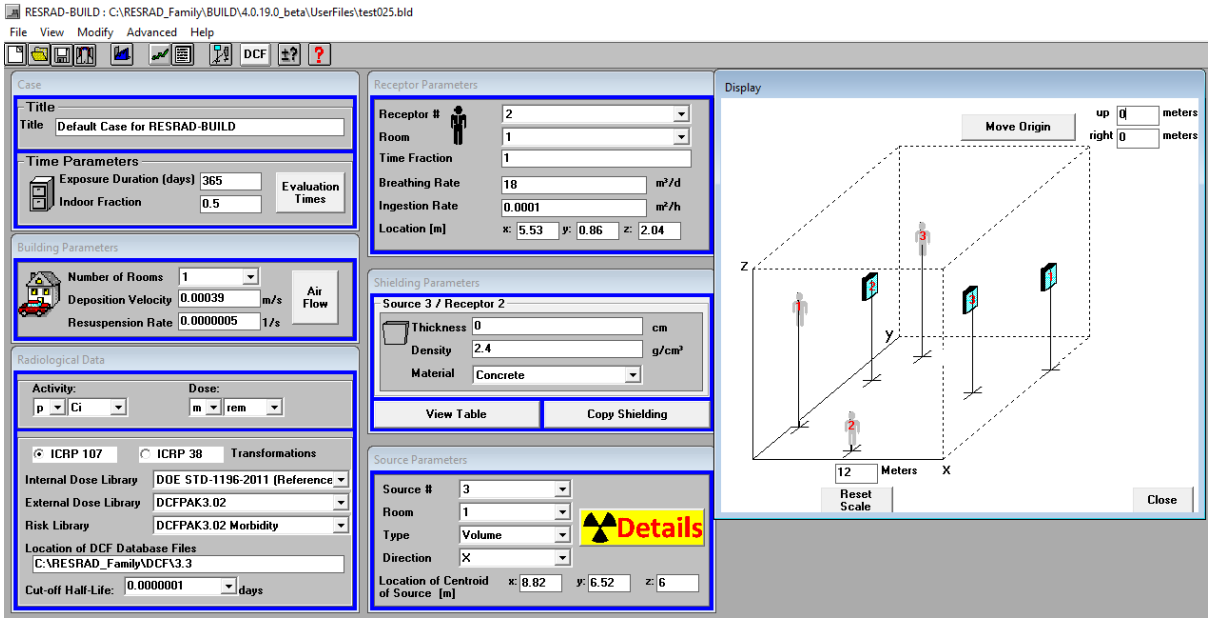




(4) When 2 sources and 2 receptors were added with the following coordinates, the 3D display updated accordingly.

	x	y	z
Source 1	12	10	6
Source 2	6	10	6
Source 3	12	6	6
Receptor 1	0	12	8
Receptor 2	1	12	8
Receptor 3	3	12	8

(5) When the locations of sources and receptors were changed from the 3D display, their coordinates in the interface were correctly updated. When the inputs were saved, the coordinates in the generated input file matched the inputs.



	X	y	z
Source 1	12.04	8.77	6
Source 2	1.52	7.77	6
Source 3	8.82	6.52	6
Receptor 1	.49	3.19	8
Receptor 2	5.53	0.86	2.04
Receptor 3	2.89	10.11	8

```
DX( 1 , 1 )=0.49,
DX( 1 , 2 )=3.19,
DX( 1 , 3 )=8,
DX( 2 , 1 )=5.53,
DX( 2 , 2 )=0.86,
DX( 2 , 3 )=2.04,
DX( 3 , 1 )=2.89,
DX( 3 , 2 )=10.11,
DX( 3 , 3 )=8,
SX( 1 , 1 )=12.04,
SX( 1 , 2 )=8.77,
SX( 1 , 3 )=6,
SX( 2 , 1 )=1.52,
SX( 2 , 2 )=7.77,
SX( 2 , 3 )=6,
SX( 3 , 1 )=8.82,
SX( 3 , 2 )=6.52,
SX( 3 , 3 )=6,
```

13. TEST CASE 027

13.1 TEST CASE 027-1

Test objectives/descriptions:

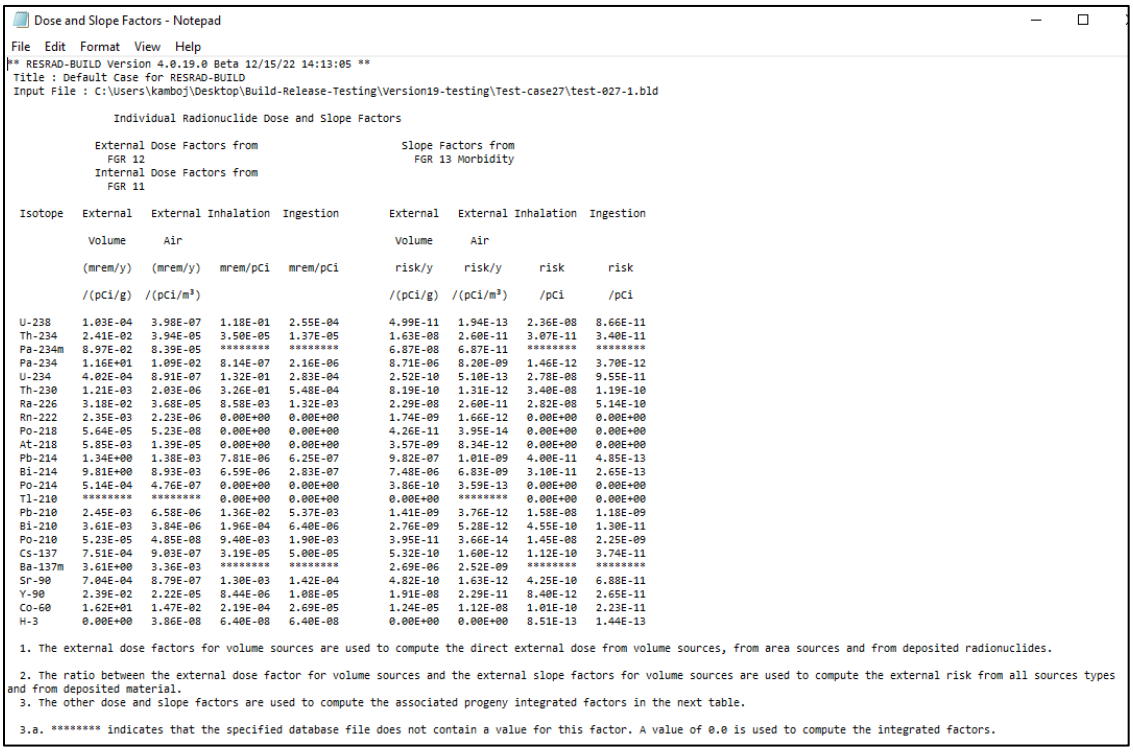
To verify that the DCF data stored in the DCF Editor database are the same as in the referenced source document and that the aggregated air submersion, inhalation, and ingestion DCFs, i.e., including short-lived progeny contributions, are calculated correctly and used in dose calculations.

Test result (Pass/Fail): Pass

Test details:

Results are given only for procedure steps with an expected action. Refer to Test Case 027-1 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "Test-027-001.bld" associated with the test case was used. The initial principal radionuclides selected for this test were Co-60, Cs-137, Sr-90, U-238, and H-3.

(1) DCF data in "Dose and Slope Factors.RPT" is displayed first followed by DCF data in the "DCF individual.LIB" file in the following screen shots. The DCF values matched:



Dose and Slope Factors - Notepad

File Edit Format View Help

```
** RESRAD-BUILD Version 4.0.19.0 Beta 12/15/22 14:13:05 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\Version19-testing\Test-case27\test-027-1.bld

              Individual Radionuclide Dose and Slope Factors

            External Dose Factors from                    Slope Factors from
              FGR 12                                        FGR 13 Morbidity
            Internal Dose Factors from
              FGR 11

 Isotope   External    External Inhalation  Ingestion       External    External Inhalation  Ingestion

            Volume       Air                               Volume       Air

           (mrem/y)    (mrem/y)   mrem/pCi   mrem/pCi       risk/y      risk/y      risk       risk

           /(pCi/g)   /(pCi/m³)                           /(pCi/g)   /(pCi/m³)     /pCi       /pCi

 U-238     1.03E-04   3.98E-07   1.18E-01   2.55E-04       4.99E-11   1.94E-13   2.36E-08   8.66E-11
 Th-234    2.41E-02   3.94E-05   3.50E-05   1.37E-05       1.63E-08   2.60E-11   3.07E-11   3.40E-11
 Pa-234m   8.97E-02   8.39E-05   ********   ********       6.87E-08   6.87E-11   ********   ********
 Pa-234    1.16E+01   1.09E-02   8.14E-07   2.16E-06       8.71E-06   8.20E-09   1.46E-12   3.70E-12
 U-234     4.02E-04   8.91E-07   1.32E-01   2.83E-04       2.52E-10   5.10E-13   2.78E-08   9.55E-11
 Th-230    1.21E-03   2.03E-06   3.26E-01   5.48E-04       8.19E-10   1.31E-12   3.40E-08   1.19E-10
 Ra-226    3.18E-02   3.68E-05   8.58E-03   1.32E-03       2.29E-08   2.60E-11   2.82E-08   5.14E-10
 Rn-222    2.35E-03   2.23E-06   0.00E+00   0.00E+00       1.74E-09   1.66E-12   0.00E+00   0.00E+00
 Po-218    5.64E-05   5.23E-08   0.00E+00   0.00E+00       4.26E-11   3.95E-14   0.00E+00   0.00E+00
 At-218    5.85E-03   1.39E-05   0.00E+00   0.00E+00       3.57E-09   8.34E-12   0.00E+00   0.00E+00
 Pb-214    1.34E+00   1.38E-03   7.81E-06   6.25E-07       9.82E-07   1.01E-09   4.00E-11   4.85E-13
 Bi-214    9.81E+00   8.93E-03   6.59E-06   2.83E-07       7.48E-06   6.83E-09   3.10E-11   2.65E-13
 Po-214    5.14E-04   4.76E-07   0.00E+00   0.00E+00       3.86E-10   3.59E-13   0.00E+00   0.00E+00
 Tl-210    ********   ********   0.00E+00   0.00E+00       0.00E+00   ********   0.00E+00   0.00E+00
 Pb-210    2.45E-03   6.58E-06   1.36E-02   5.37E-03       1.41E-09   3.76E-12   1.58E-08   1.18E-09
 Bi-210    3.61E-03   3.84E-06   1.96E-04   6.40E-06       2.76E-09   5.28E-12   4.55E-10   1.30E-11
 Po-210    5.23E-05   4.85E-08   9.40E-03   1.90E-03       3.95E-11   3.66E-14   1.45E-08   2.25E-09
 Cs-137    7.51E-04   9.03E-07   3.19E-05   5.00E-05       5.32E-10   1.60E-12   1.12E-10   3.74E-11
 Ba-137m   3.61E+00   3.36E-03   ********   ********       2.69E-06   2.52E-09   ********   ********
 Sr-90     7.04E-04   8.79E-07   1.30E-03   1.42E-04       4.82E-10   1.63E-12   4.25E-10   6.88E-11
 Y-90      2.39E-02   2.22E-05   8.44E-06   1.08E-05       1.91E-08   2.29E-11   8.40E-12   2.65E-11
 Co-60     1.62E+01   1.47E-02   2.19E-04   2.69E-05       1.24E-05   1.12E-08   1.01E-10   2.23E-11
 H-3       0.00E+00   3.86E-08   6.40E-08   6.40E-08       0.00E+00   0.00E+00   8.51E-13   1.44E-13

  1. The external dose factors for volume sources are used to compute the direct external dose from volume sources, from area sources and from deposited radionuclides.

  2. The ratio between the external dose factor for volume sources and the external slope factors for volume sources are used to compute the external risk from all sources types
and from deposited material.
  3. The other dose and slope factors are used to compute the associated progeny integrated factors in the next table.

  3.a. ******** indicates that the specified database file does not contain a value for this factor. A value of 0.0 is used to compute the integrated factors.
```

(2) External DCFs from Table C-8 is displayed first followed by DCFs in Table A-5 of the User's Manual, Volume 1, and the "Dose and Slope Factor.RPT" file in the following screen shots. Values in Table C-8 and Table A-5 matched the values in the "Dose and Slope Factors.RPT" file:

DCF Individual - Notepad

File Edit Format View Help

FGR 11 FGR 12 FGR 13 Morbidity
FGR 11 FGR 12 FGR 13 Morbidity

Nuclide Units	ExtVolDC (mrem/y) /(pCi/g)	ExtImmDC (mrem/y) /(pCi/m3)	InhalaDC mrem /pCi	IngestDC mrem /pCi	ExtVolSF (1/yr) /(pCi/g)	ExtImmSF (1/yr) /(pCi/m3)	InhalaSF 1 /pCi	IngestSF 1 /pCi
U-238	1.031E-04	3.980E-07	1.180E-01	2.550E-04	4.990E-11	1.938E-13	2.360E-08	8.660E-11
Th-234	2.410E-02	3.945E-05	3.500E-05	1.370E-05	1.630E-08	2.604E-11	3.070E-11	3.400E-11
Pa-234m	8.967E-02	8.391E-05	-2.00E+00	-2.00E+00	6.870E-08	6.866E-11	-2.00E+00	-2.00E+00
Pa-234	1.155E+01	1.090E-02	8.140E-07	2.160E-06	8.710E-06	8.197E-09	1.460E-12	3.700E-12
U-234	4.017E-04	8.905E-07	1.320E-01	2.830E-04	2.520E-10	5.103E-13	2.780E-08	9.550E-11
Th-230	1.209E-03	2.031E-06	3.260E-01	5.480E-04	8.190E-10	1.308E-12	3.400E-08	1.190E-10
Ra-226	3.176E-02	3.676E-05	8.580E-03	1.320E-03	2.290E-08	2.604E-11	2.820E-08	5.140E-10
Rn-222	2.354E-03	2.229E-06	0.000E+00	0.000E+00	1.740E-09	1.658E-12	0.000E+00	0.000E+00
Po-218	5.642E-05	5.228E-08	0.000E+00	0.000E+00	4.260E-11	3.947E-14	0.000E+00	0.000E+00
At-218	5.847E-03	1.389E-05	0.000E+00	0.000E+00	3.570E-09	8.337E-12	0.000E+00	0.000E+00
Pb-214	1.341E+00	1.377E-03	7.810E-06	6.250E-07	9.820E-07	1.006E-09	4.000E-11	4.850E-13
Bi-214	9.808E+00	8.928E-03	6.590E-06	2.830E-07	7.480E-06	6.831E-09	3.100E-11	2.650E-13
Po-214	5.138E-04	4.762E-07	0.000E+00	0.000E+00	3.860E-10	3.585E-13	0.000E+00	0.000E+00
Tl-210	-1.00E+00	-1.00E+00	0.000E+00	0.000E+00	0.000E+00	-1.00E+00	0.000E+00	0.000E+00
Pb-210	2.447E-03	6.582E-06	1.360E-02	5.370E-03	1.410E-09	3.760E-12	1.580E-08	1.180E-09
Bi-210	3.606E-03	3.840E-06	1.960E-04	6.400E-06	2.760E-09	5.278E-12	4.550E-10	1.300E-11
Po-210	5.231E-05	4.855E-08	9.400E-03	1.900E-03	3.950E-11	3.655E-14	1.450E-08	2.250E-09
Cs-137	7.510E-04	9.033E-07	3.190E-05	5.000E-05	5.320E-10	1.600E-12	1.120E-10	3.740E-11
Ba-137m	3.606E+00	3.361E-03	-2.00E+00	-2.00E+00	2.690E-06	2.522E-09	-2.00E+00	-2.00E+00
Sr-90	7.043E-04	8.788E-07	1.300E-03	1.420E-04	4.820E-10	1.635E-12	4.250E-10	6.880E-11
Y-90	2.391E-02	2.217E-05	8.440E-06	1.080E-05	1.910E-08	2.289E-11	8.400E-12	2.650E-11
Co-60	1.622E+01	1.471E-02	2.190E-04	2.690E-05	1.240E-05	1.124E-08	1.010E-10	2.230E-11
H-3	0.000E+00	3.863E-08	6.400E-08	6.400E-08	0.000E+00	0.000E+00	8.510E-13	1.440E-13

TABLE C-7 Effective Dose Equivalent Coefficients for External Exposure (Infinite) and Air Submersion from FGR 12 for Radionuclides with Half-life of at least 30 Days and Their Associated Progeny

Radionuclide	Infinite (mrem/yr per pCi/g)	Air Submersion (mrem/yr per pCi/m3)
U-238	1.03E-04	3.98E-07
Th-234	2.41E-02	3.94E-05
Pa-234m	8.97E-02	8.39E-05
Pa-234	1.16E+01	1.09E-02
U-234	4.02E-04	8.91E-07
Th-230	1.21E-03	2.03E-06
Ra-226	3.18E-02	3.68E-05
Rn-222	2.35E-03	2.23E-06
Po-218	5.64E-05	5.23E-08
At-218	5.85E-03	1.39E-05
Pb-214	1.34E+00	1.38E-03
Bi-214	9.81E+00	8.93E-03
Po-214	5.14E-04	4.76E-07
Tl-210	0.00E+00	0.00E+00
Pb-210	2.45E-03	6.58E-06
Bi-210	3.61E-03	3.84E-06
Po-210	5.23E-05	4.85E-08
Cs-137	7.51E-04	9.03E-07
Ba-137m	3.61E+00	3.36E-03
Sr-90	7.04E-04	8.79E-07
Y-90	2.39E-02	2.22E-05
Co-60	1.62E+01	1.47E-02
H-3	0.00E+00	3.86E-08

TABLE A-4 Default Ingestion, Inhalation, and Air Submersion Dose Coefficients for at least 30 Day Half-life Radionuclides from FGR-11 and FGR-12 in RESRAD-BUILD Code

Radionuclide	Associated Radionuclides	Ingestion (mrem/pCi)	Inhalation (mrem/pCi)	Air Submersion (mrem/yr per pCi/m^3)
U-238+D	Th-234, (Pa-234m 0.998), (Pa-234 0.0033)	2.69E-04	1.18E-01	1.60E-04
U-234	—	2.83E-04	1.32E-01	8.91E-07
Th-230	—	5.48E-04	3.26E-01	2.03E-06
Ra-226+D	Rn-222,Po-218, (Pb-214 9.9980E-01), Bi-214, (Po-214 9.9980E-01), (Tl-210 2.0000E-04), (At-218 2.0000E-04)	1.32E-03	8.59E-03	1.03E-02
Pb-210+D	Bi-210	5.38E-03	1.38E-02	1.04E-05
Po-210	—	1.90E-03	9.40E-03	4.85E-08
Cs-137+D	(Ba-137m 0.946)	5.00E-05	3.19E-05	3.18E-03
Sr-90+D	Y-90	1.53E-04	1.31E-03	2.31E-05
Co-60	—	2.69E-05	2.19E-04	1.47E-02
H-3	—	6.40E-08	6.40E-08	3.86E-08

[a] Dose conversion factors for entries labeled with "+D" are aggregated dose conversion factors of the principal radionuclide together with the associated decay progenies.

[b] The associated decay progenies are listed. If a branching fraction is anything other than 1, it is listed along with the radionuclide in the bracket.

[c] Dash indicates there is no associated radionuclide.

Dose and Slope Factors - Notepad

File Edit Format View Help

```
** RESRAD-BUILD Version 4.0.19.0 Beta 12/15/22 14:32:07 **
Title : Default Case for RESRAD-BUILD
Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\Version19-testing\Test-case27\test-027-1.bld

               Dose and Slope Factors including contribution of Associated Radionuclides

            External Dose Factors from                      Slope Factors from
              FGR 12                                          FGR 13 Morbidity
            Internal Dose Factors from
              FGR 11

 Isotope              External Inhalation  Ingestion                 External Inhalation  Ingestion
                        Air                                             Air
                      (mrem/y)   mrem/pCi   mrem/pCi                  risk/y      risk       risk
                     /(pCi/m³)                                       /(pCi/m³)     /pCi       /pCi

 U-238                1.60E-04   1.18E-01   2.69E-04                  1.22E-10   2.36E-08   1.21E-10
 U-234                8.91E-07   1.32E-01   2.83E-04                  5.10E-13   2.78E-08   9.55E-11
 Th-230               2.03E-06   3.26E-01   5.48E-04                  1.31E-12   3.40E-08   1.19E-10
 Ra-226               1.03E-02   8.59E-03   1.32E-03                  7.87E-09   2.83E-08   5.15E-10
 Pb-210               1.04E-05   1.38E-02   5.38E-03                  9.04E-12   1.63E-08   1.19E-09
 Po-210               4.85E-08   9.40E-03   1.90E-03                  3.66E-14   1.45E-08   2.25E-09
 Cs-137               3.18E-03   3.19E-05   5.00E-05                  2.39E-09   1.12E-10   3.74E-11
 Sr-90                2.31E-05   1.31E-03   1.53E-04                  2.45E-11   4.33E-10   9.53E-11
 Co-60                1.47E-02   2.19E-04   2.69E-05                  1.12E-08   1.01E-10   2.23E-11
 H-3                  3.86E-08   6.40E-08   6.40E-08                  0.00E+00   8.51E-13   1.44E-13

 1. These dose and slope factors are used to compute the dose and risk from external exposure from particulates in air, inhalation of particulates and gases and ingestion.

 2. They are computed using the data from the preceding table in the expression in the next section.
```

13.2 TEST CASE 027-2

Test objectives/descriptions:

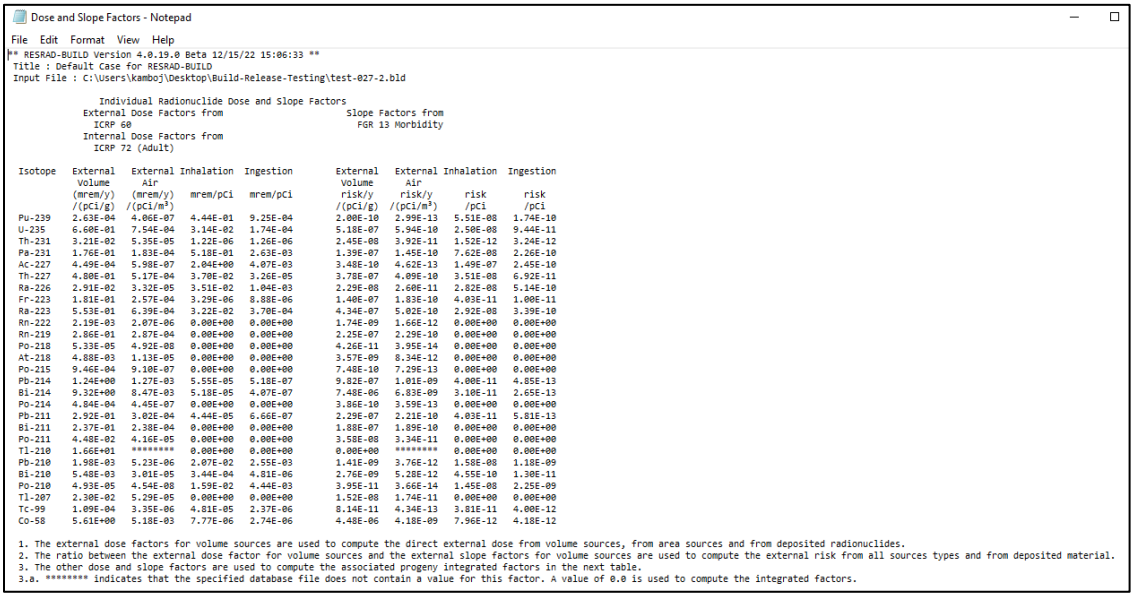
To verify the DCF data stored in the DCF Editor database are the same as in the referenced source document and that the aggregated air submersion, inhalation, and ingestion DCFs, i.e., including short-lived progeny contributions, are calculated correctly and used in dose calculations.

Test result (Pass/Fail): Pass

Test details:

Results are given only for procedure steps with an expected action. Refer to Test Case 027-2 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "Test-027-002.bld" associated with the test case was used. The initial principal radionuclides selected for this test were Co-58, Pu-239, Ra-226, and Tc-99.

(1) DCF data in "Dose and Slope Factors.RPT" is displayed first followed by DCF data in "DCF individual.LIB" file in the following screen shots. DCF values matched:



Dose and Slope Factors - Notepad

File Edit Format View Help

** RESRAD-BUILD Version 4.0.19.0 Beta 12/15/22 15:06:33 **
Title : Default Case for RESRAD-BUILD
Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\test-027-2.bld

Individual Radionuclide Dose and Slope Factors
External Dose Factors from ICRP 60
Internal Dose Factors from ICRP 72 (Adult)
Slope Factors from FGR 13 Morbidity

Isotope	External Volume (mrem/y) /(pCi/g)	External Inhalation Air (mrem/y) /(pci/m³)	Ingestion mrem/pCi	Ingestion mrem/pCi	External Volume risk/y /(pCi/g)	External Inhalation Air risk/y /(pCi/m³)	Ingestion risk /pCi	Ingestion risk /pCi
Pu-239	2.63E-04	4.06E-07	4.44E-01	9.25E-04	2.00E-10	2.99E-13	5.51E-08	1.74E-10
U-235	6.60E-01	7.54E-04	3.14E-02	1.74E-04	5.18E-07	5.94E-10	2.50E-08	9.44E-11
Th-231	3.21E-02	5.35E-05	1.22E-06	1.26E-06	2.45E-08	3.92E-11	1.52E-12	3.24E-12
Pa-231	1.76E-01	1.83E-04	5.18E-01	2.63E-03	1.39E-07	1.45E-10	7.62E-08	2.26E-10
Ac-227	4.49E-04	5.98E-07	2.04E+00	4.07E-03	3.48E-10	4.62E-13	1.49E-07	2.45E-10
Th-227	4.80E-01	5.17E-04	3.70E-02	3.26E-05	3.78E-07	4.09E-10	3.51E-08	6.92E-11
Ra-226	2.91E-02	3.32E-05	3.51E-02	1.04E-03	2.29E-08	2.60E-11	2.82E-08	5.14E-10
Fr-223	1.81E-01	2.57E-04	3.29E-06	8.88E-06	1.40E-07	1.83E-10	4.03E-11	1.00E-11
Ra-223	5.53E-01	6.39E-04	3.22E-02	3.70E-04	4.34E-07	5.02E-10	2.92E-08	3.39E-10
Rn-222	2.19E-03	2.07E-06	0.00E+00	0.00E+00	1.74E-09	1.66E-12	0.00E+00	0.00E+00
Rn-219	2.86E-01	2.87E-04	0.00E+00	0.00E+00	2.25E-07	2.29E-10	0.00E+00	0.00E+00
Po-218	5.33E-05	4.92E-08	0.00E+00	0.00E+00	4.26E-11	3.95E-14	0.00E+00	0.00E+00
At-218	4.88E-03	1.13E-05	0.00E+00	0.00E+00	3.57E-09	8.34E-12	0.00E+00	0.00E+00
Po-215	9.46E-04	9.10E-07	0.00E+00	0.00E+00	7.48E-10	7.29E-13	0.00E+00	0.00E+00
Pb-214	1.24E+00	1.27E-03	5.55E-05	5.18E-07	9.82E-07	1.01E-09	4.00E-11	4.85E-13
Bi-214	9.32E+00	8.47E-03	5.18E-05	4.07E-07	7.48E-06	6.83E-09	3.10E-11	2.65E-13
Po-214	4.84E-04	4.45E-07	0.00E+00	0.00E+00	3.86E-10	3.59E-13	0.00E+00	0.00E+00
Pb-211	2.92E-01	3.02E-04	4.44E-05	6.66E-07	2.29E-07	2.21E-10	4.03E-11	5.81E-13
Bi-211	2.37E-01	2.38E-04	0.00E+00	0.00E+00	1.88E-07	1.89E-10	0.00E+00	0.00E+00
Po-211	4.48E-02	4.16E-05	0.00E+00	0.00E+00	3.58E-08	3.34E-11	0.00E+00	0.00E+00
Tl-210	1.66E+01	********	0.00E+00	0.00E+00	0.00E+00	********	0.00E+00	0.00E+00
Pb-210	1.98E-03	5.23E-06	2.07E-02	2.55E-03	1.41E-09	3.76E-12	1.58E-08	1.18E-09
Bi-210	5.48E-03	3.01E-05	3.44E-04	4.81E-06	2.76E-09	5.28E-12	4.55E-10	1.30E-11
Po-210	4.93E-05	4.54E-08	1.59E-02	4.44E-03	3.95E-11	3.66E-14	1.45E-08	2.25E-09
Tl-207	2.30E-02	5.29E-05	0.00E+00	0.00E+00	1.52E-08	1.74E-11	0.00E+00	0.00E+00
Tc-99	1.09E-04	3.35E-06	4.81E-05	2.37E-06	8.14E-11	4.34E-13	3.81E-11	4.00E-12
Co-58	5.61E+00	5.18E-03	7.77E-06	2.74E-06	4.48E-06	4.18E-09	7.96E-12	4.18E-12

1. The external dose factors for volume sources are used to compute the direct external dose from volume sources, from area sources and from deposited radionuclides.
2. The ratio between the external dose factor for volume sources and the external slope factors for volume sources are used to compute the external risk from all sources types and from deposited material.
3. The other dose and slope factors are used to compute the associated progeny integrated factors in the next table.
3.a. ******** indicates that the specified database file does not contain a value for this factor. A value of 0.0 is used to compute the integrated factors.

DCF Individual - Notepad

File Edit Format View Help

ICRP 72 (Adult) ICRP 60 FGR 13 Morbidity
ICRP 72 (Adult) ICRP 60 FGR 13 Morbidity

Nuclide Units	ExtVolDC (mrem/y) /(pCi/g)	ExtImmDC (mrem/y) /(pCi/m3)	InhalaDC mrem /pCi	IngestDC mrem /pCi	ExtVolSF (1/yr) /(pCi/g)	ExtImmSF (1/yr) /(pCi/m3)	InhalaSF 1 /pCi	IngestSF 1 /pCi
Pu-239	2.635E-04	4.063E-07	4.440E-01	9.250E-04	2.000E-10	2.989E-13	5.510E-08	1.740E-10
U-235	6.597E-01	7.543E-04	3.145E-02	1.739E-04	5.180E-07	5.943E-10	2.500E-08	9.440E-11
Th-231	3.214E-02	5.348E-05	1.221E-06	1.258E-06	2.450E-08	3.923E-11	1.520E-12	3.240E-12
Pa-231	1.762E-01	1.833E-04	5.180E-01	2.627E-03	1.390E-07	1.448E-10	7.620E-08	2.260E-10
Ac-227	4.485E-04	5.978E-07	2.035E+00	4.070E-03	3.480E-10	4.624E-13	1.490E-07	2.450E-10
Th-227	4.803E-01	5.173E-04	3.700E-02	3.256E-05	3.780E-07	4.087E-10	3.510E-08	6.920E-11
Ra-226	2.915E-02	3.316E-05	3.515E-02	1.036E-03	2.290E-08	2.604E-11	2.820E-08	5.140E-10
Fr-223	1.813E-01	2.569E-04	3.293E-06	8.880E-06	1.400E-07	1.833E-10	4.030E-11	1.000E-11
Ra-223	5.532E-01	6.387E-04	3.219E-02	3.700E-04	4.340E-07	5.021E-10	2.920E-08	3.390E-10
Rn-222	2.186E-03	2.067E-06	0.000E+00	0.000E+00	1.740E-09	1.658E-12	0.000E+00	0.000E+00
Rn-219	2.859E-01	2.872E-04	0.000E+00	0.000E+00	2.250E-07	2.289E-10	0.000E+00	0.000E+00
Po-218	5.326E-05	4.916E-08	0.000E+00	0.000E+00	4.260E-11	3.947E-14	0.000E+00	0.000E+00
At-218	4.878E-03	1.134E-05	0.000E+00	0.000E+00	3.570E-09	8.337E-12	0.000E+00	0.000E+00
Po-215	9.456E-04	9.096E-07	0.000E+00	0.000E+00	7.480E-10	7.286E-13	0.000E+00	0.000E+00
Pb-214	1.243E+00	1.273E-03	5.550E-05	5.180E-07	9.820E-07	1.006E-09	4.000E-11	4.850E-13
Bi-214	9.325E+00	8.465E-03	5.180E-05	4.070E-07	7.480E-06	6.831E-09	3.100E-11	2.650E-13
Po-214	4.840E-04	4.449E-07	0.000E+00	0.000E+00	3.860E-10	3.585E-13	0.000E+00	0.000E+00
Pb-211	2.915E-01	3.024E-04	4.440E-05	6.660E-07	2.290E-07	2.207E-10	4.030E-11	5.810E-13
Bi-211	2.373E-01	2.382E-04	0.000E+00	0.000E+00	1.880E-07	1.892E-10	0.000E+00	0.000E+00
Po-211	4.485E-02	4.157E-05	0.000E+00	0.000E+00	3.580E-08	3.339E-11	0.000E+00	0.000E+00
Tl-210	1.661E+01	-1.00E+00	0.000E+00	0.000E+00	0.000E+00	-1.00E+00	0.000E+00	0.000E+00
Pb-210	1.981E-03	5.231E-06	2.072E-02	2.553E-03	1.410E-09	3.760E-12	1.580E-08	1.180E-09
Bi-210	5.476E-03	3.012E-05	3.441E-04	4.810E-06	2.760E-09	5.278E-12	4.550E-10	1.300E-11
Po-210	4.934E-05	4.542E-08	1.591E-02	4.440E-03	3.950E-11	3.655E-14	1.450E-08	2.250E-09
Tl-207	2.299E-02	5.289E-05	0.000E+00	0.000E+00	1.520E-08	1.740E-11	0.000E+00	0.000E+00
Tc-99	1.086E-04	3.351E-06	4.810E-05	2.368E-06	8.140E-11	4.344E-13	3.810E-11	4.000E-12
Co-58	5.606E+00	5.184E-03	7.770E-06	2.738E-06	4.480E-06	4.180E-09	7.960E-12	4.180E-12

(2) External DCFs from Table C-8 is displayed first followed by DCFs in Table A-5 of the User's Manual, Volume 1 and the "Dose and Slope Factor.RPT" file in the following screen shots. The values in Table C-8 and Table A-5 matched the values in the "Dose and Slope Factors.RPT" file.

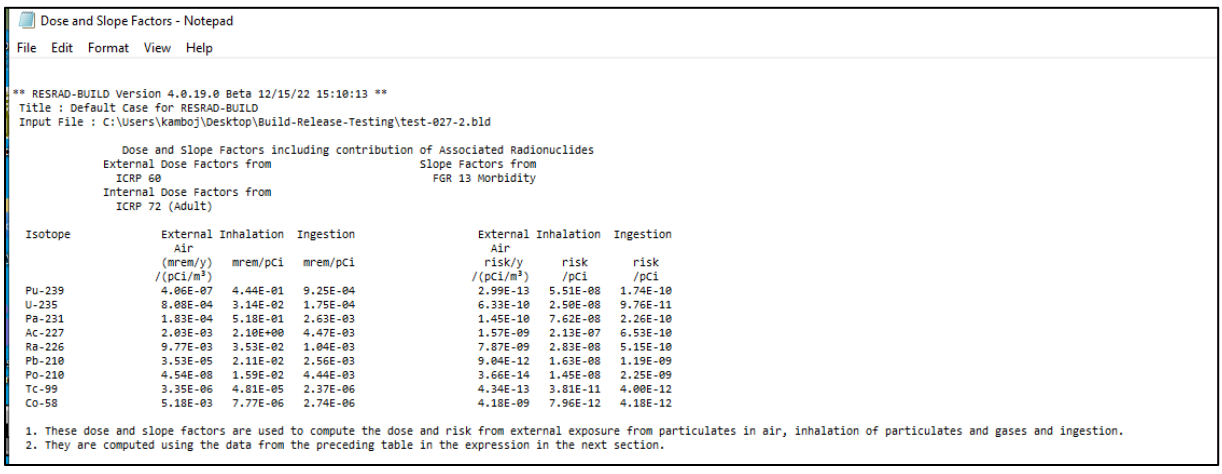
TABLE A-5 Default Ingestion, Inhalation, and Air Submersion Dose Coefficients for at least 30 Day Half-life Radionuclides from ICRP-72 and FGR-13 in RESRAD-BUILD Code

Radionuclide[a]	Associated Progeny Radionuclides[b]	Ingestion (mrem/pCi)	Inhalation (mrem/pCi)	Air Submersion (mrem/yr per pCi/m3)
Pu-239	—	9.25E-04	4.44E-01	4.06E-07
U-235+D	Th-231	1.75E-04	3.14E-02	8.08E-04
Pa-231	—	2.63E-03	5.18E-01	1.83E-04
Ac-227+D	(Th-227 9.8620E-01), Ra-223, Rn-219, Po-215, Pb-211, Bi-211, (Tl-207 9.9720E-01), (Po-211 2.8000E-03), (Fr-223 1.3800E-02)	4.47E-03	2.10E+00	2.03E-03
Ra-226+D	Rn-222,Po-218, (Pb-214 9.9980E-01), Bi-214, (Po-214 9.9980E-01), (Tl-210 2.0000E-04), (At-218 2.0000E-04)	1.04E-03	3.53E-02	9.77E-03
Pb-210+D	Bi-210	2.56E-03	2.11E-02	3.53E-05
Po-210	—	4.44E-03	1.59E-02	4.54E-08
Tc-99	—	2.37E-06	4.81E-05	3.35E-06
Co-58	—	2.74E-06	7.77E-06	5.18E-03

[a] Dose conversion factors for entries labeled with "+D" are aggregated dose conversion factors of the principal radionuclide together with the associated decay progenies.
b The associated decay progenies are listed. If a branching fraction is anything other than 1, it is listed along with the radionuclide in the bracket.
[c] Dash indicates there is no associated radionuclide.

TABLE C-8 Effective Dose Coefficients for External Exposure (Infinite and Air Submersion) from FGR 13 for 30 Day Cutoff Half-life Principal Radionuclides and Associated Radionuclides

Radionuclide	Infinite (mrem/yr per pCi/g)	Air Submersion (mrem/yr per pCi/m^3)
Pu-239	2.64E-04	4.06E-07
U-235	6.60E-01	7.54E-04
Th-231	3.21E-02	5.35E-05
Pa-231	1.76E-01	1.83E-04
Ac-227	4.49E-04	5.98E-07
Th-227	4.80E-01	5.17E-04
Ra-226	2.92E-02	3.32E-05
Fr-223	1.81E-01	2.57E-04
Ra-223	5.53E-01	6.39E-04
Rn-222	2.19E-03	2.07E-06
Rn-219	2.86E-01	2.87E-04
Po-218	5.33E-05	4.92E-08
At-218	4.88E-03	1.13E-05
Po-215	9.46E-04	9.10E-07
Pb-214	1.24E+00	1.27E-03
Bi-214	9.33E+00	8.47E-03
Po-214	4.84E-04	4.45E-07
Pb-211	2.92E-01	3.02E-04
Bi-211	2.37E-01	2.38E-04
Po-211	4.49E-02	4.16E-05
Tl-210	1.66E+01	0.00E+00
Pb-210	1.98E-03	5.23E-06
Bi-210	5.48E-03	3.01E-05
Po-210	4.93E-05	4.54E-08
Tl-207	2.30E-02	5.29E-05
Tc-99	1.09E-04	3.35E-06
Co-58	5.61E+00	5.18E-03



Dose and Slope Factors - Notepad

File Edit Format View Help

** RESRAD-BUILD Version 4.0.19.0 Beta 12/15/22 15:10:13 **
Title : Default Case for RESRAD-BUILD
Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\test-027-2.bld

Dose and Slope Factors including contribution of Associated Radionuclides

Isotope	External Dose Factors from ICRP 60 / Internal Dose Factors from ICRP 72 (Adult): External Inhalation Air (mrem/y)/(pCi/m^3)	Inhalation mrem/pCi	Ingestion mrem/pCi	Slope Factors from FGR 13 Morbidity: External Inhalation Air risk/y/(pCi/m^3)	Inhalation risk/pCi	Ingestion risk/pCi
Pu-239	4.06E-07	4.44E-01	9.25E-04	2.99E-13	5.51E-08	1.74E-10
U-235	8.08E-04	3.14E-02	1.75E-04	6.33E-10	2.50E-08	9.76E-11
Pa-231	1.83E-04	5.18E-01	2.63E-03	1.45E-10	7.62E-08	2.26E-10
Ac-227	2.03E-03	2.10E+00	4.47E-03	1.57E-09	2.13E-07	6.53E-10
Ra-226	9.77E-03	3.53E-02	1.04E-03	7.87E-09	2.83E-08	5.15E-10
Pb-210	3.53E-05	2.11E-02	2.56E-03	9.04E-12	1.63E-08	1.19E-09
Po-210	4.54E-08	1.59E-02	4.44E-03	3.66E-14	1.45E-08	2.25E-09
Tc-99	3.35E-06	4.81E-05	2.37E-06	4.34E-13	3.81E-11	4.00E-12
Co-58	5.18E-03	7.77E-06	2.74E-06	4.18E-09	7.96E-12	4.18E-12

1. These dose and slope factors are used to compute the dose and risk from external exposure from particulates in air, inhalation of particulates and gases and ingestion.
2. They are computed using the data from the preceding table in the expression in the next section.

13.3 TEST CASE 027-3

Test objectives/descriptions:

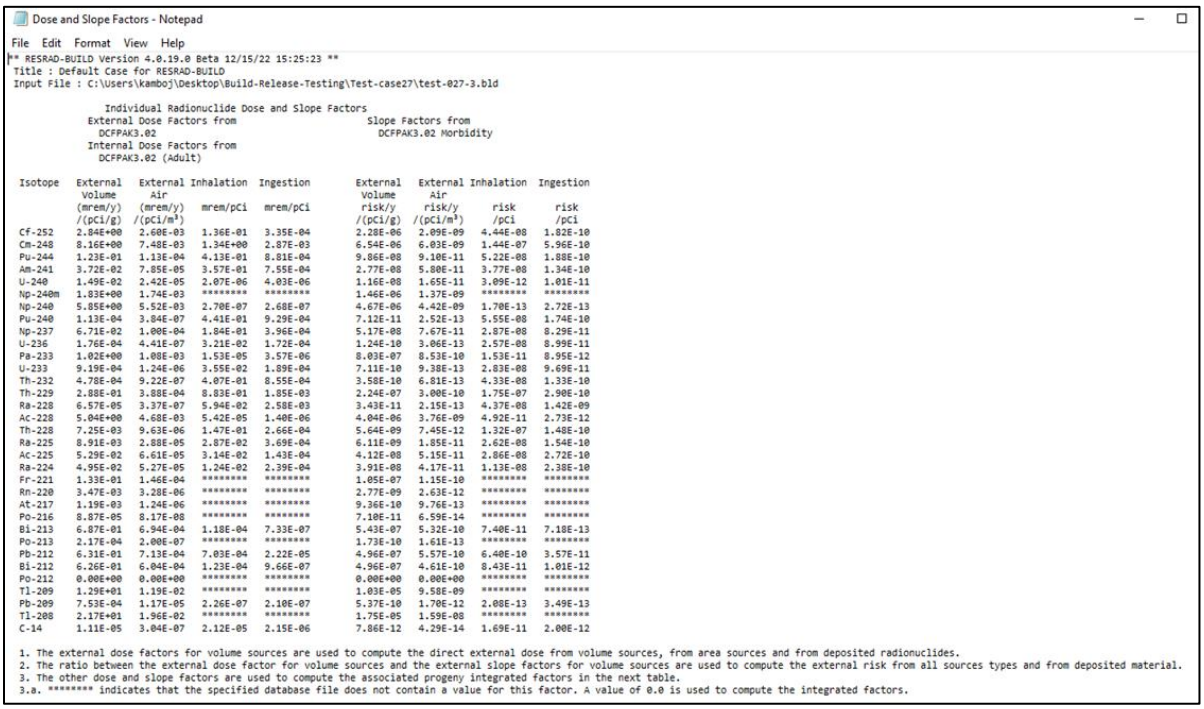
To verify the DCF data stored in the DCF Editor database are the same as in the referenced source document and that the aggregated air submersion, inhalation, and ingestion DCFs, i.e., including short-lived progeny contributions, are calculated correctly and used in dose calculations.

Test result (Pass/Fail): Pass

Test details:

Results are given only for procedure steps with an expected action. Refer to Test Case 027-3 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "Test-027-003.bld" associated with the test case was used. The initial principal radionuclides selected for this test were Am-241, C-14, Cf-252, and Th-232.

(1) DCF data in "Dose and Slope Factors.RPT" is displayed first followed by DCF data in the "DCF individual.LIB" file in the following screen shots. DCF values matched:



Dose and Slope Factors - Notepad

File Edit Format View Help

** RESRAD-BUILD Version 4.0.19.0 Beta 12/15/22 15:25:23 **
Title : Default Case for RESRAD-BUILD
Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\Test-case27\test-027-3.bld

Individual Radionuclide Dose and Slope Factors
External Dose Factors from DCFPAK3.02
Internal Dose Factors from DCFPAK3.02 (Adult)
Slope Factors from DCFPAK3.02 Morbidity

Isotope	External Volume (mrem/y) /(pCi/g)	External Air (mrem/y) /(pCi/m³)	Inhalation mrem/pCi	Ingestion mrem/pCi	External Volume risk/y /(pCi/g)	External Air risk/y /(pCi/m³)	Inhalation risk /pCi	Ingestion risk /pCi
Cf-252	2.84E+00	2.60E-03	1.36E-01	3.35E-04	2.28E-06	2.09E-09	4.44E-08	1.82E-10
Cm-248	8.16E+00	7.48E-03	1.34E+00	2.87E-03	6.54E-06	6.03E-09	1.44E-07	5.96E-10
Pu-244	1.23E-01	1.13E-04	4.13E-01	8.81E-04	9.86E-08	9.10E-11	5.22E-08	1.88E-10
Am-241	3.72E-02	7.85E-05	3.57E-01	7.55E-04	2.77E-08	5.80E-11	3.77E-08	1.34E-10
U-240	1.49E-02	2.42E-05	2.07E-06	4.03E-06	1.16E-08	1.65E-11	3.09E-12	1.01E-11
Np-240m	1.83E+00	1.74E-03	********	********	1.46E-06	1.37E-09	********	********
Np-240	5.85E+00	5.52E-03	2.70E-07	2.68E-07	4.67E-06	4.42E-09	1.70E-13	2.72E-13
Pu-240	1.13E-04	3.84E-07	4.41E-01	9.29E-04	7.12E-11	2.52E-13	5.55E-08	1.74E-10
Np-237	6.71E-02	1.00E-04	1.84E-01	3.96E-04	5.17E-08	7.67E-11	2.87E-08	8.29E-11
U-236	1.76E-04	4.41E-07	3.21E-02	1.72E-04	1.24E-10	3.06E-13	2.57E-08	8.99E-11
Pa-233	1.02E+00	1.08E-03	1.53E-05	3.57E-06	8.03E-07	8.53E-10	1.53E-11	8.95E-12
U-233	9.19E-04	1.24E-06	3.55E-02	1.89E-04	7.11E-10	9.38E-13	2.83E-08	9.69E-11
Th-232	4.78E-04	9.22E-07	4.07E-01	8.55E-04	3.58E-10	6.81E-13	4.33E-08	1.33E-10
Th-229	2.88E-01	3.88E-04	8.83E-01	1.85E-03	2.24E-07	3.00E-10	1.75E-07	2.90E-10
Ra-228	6.57E-05	3.37E-07	5.94E-02	2.58E-03	3.43E-11	2.15E-13	4.37E-08	1.42E-09
Ac-228	5.04E+00	4.68E-03	5.42E-05	1.40E-06	4.04E-06	3.76E-09	4.92E-11	2.73E-12
Th-228	7.25E-03	9.63E-06	1.47E-01	2.66E-04	5.64E-09	7.45E-12	1.32E-07	1.48E-10
Ra-225	8.91E-03	2.88E-05	2.87E-02	3.69E-04	6.11E-09	1.85E-11	2.62E-08	1.54E-10
Ac-225	5.29E-02	6.61E-05	3.14E-02	1.43E-04	4.12E-08	5.15E-11	2.86E-08	2.72E-10
Ra-224	4.95E-02	5.27E-05	1.24E-02	2.39E-04	3.91E-08	4.17E-11	1.13E-08	2.38E-10
Fr-221	1.33E-01	1.46E-04	********	********	1.05E-07	1.15E-10	********	********
Rn-220	3.47E-03	3.28E-06	********	********	2.77E-09	2.63E-12	********	********
At-217	1.19E-03	1.24E-06	********	********	9.36E-10	9.76E-13	********	********
Po-216	8.87E-05	8.17E-08	********	********	7.10E-11	6.59E-14	********	********
Bi-213	6.87E-01	6.94E-04	1.18E-04	7.33E-07	5.43E-07	5.32E-10	7.40E-11	7.18E-13
Po-213	2.17E-04	2.00E-07	********	********	1.73E-10	1.61E-13	********	********
Pb-212	6.31E-01	7.13E-04	7.03E-04	2.22E-05	4.96E-07	5.57E-10	6.40E-10	3.57E-11
Bi-212	6.26E-01	6.04E-04	1.23E-04	9.66E-07	4.96E-07	4.61E-10	8.43E-11	1.01E-12
Po-212	0.00E+00	0.00E+00	********	********	0.00E+00	0.00E+00	********	********
Tl-209	1.29E+01	1.19E-02	********	********	1.03E-05	9.58E-09	********	********
Pb-209	7.53E-04	1.17E-05	2.26E-07	2.10E-07	5.37E-10	1.70E-12	2.08E-13	3.49E-13
Tl-208	2.17E+01	1.96E-02	********	********	1.75E-05	1.59E-08	********	********
C-14	1.11E-05	3.04E-07	2.12E-05	2.15E-06	7.86E-12	4.29E-14	1.69E-11	2.00E-12

1. The external dose factors for volume sources are used to compute the direct external dose from volume sources, from area sources and from deposited radionuclides.
2. The ratio between the external dose factor for volume sources and the external slope factors for volume sources are used to compute the external risk from all sources types and from deposited material.
3. The other dose and slope factors are used to compute the associated progeny integrated factors in the next table.
3.a. ******** indicates that the specified database file does not contain a value for this factor. A value of 0.0 is used to compute the integrated factors.

DCF Individual - Notepad

File Edit Format View Help

DCFPAK3.02 (Adult) DCFPAK3.02 DCFPAK3.02 Morbidity

DCFPAK3.02 (Adult) DCFPAK3.02 DCFPAK3.02 Morbidity

Nuclide Units	ExtVolDC (mrem/y) /(pCi/g)	ExtImmDC (mrem/y) /(pCi/m3)	InhalaDC mrem /pCi	IngestDC mrem /pCi	ExtVolSF (1/yr) /(pCi/g)	ExtImmSF (1/yr) /(pCi/m3)	InhalaSF 1 /pCi	IngestSF 1 /pCi
Cf-252	2.839E+00	2.604E-03	1.360E-01	3.349E-04	2.277E-06	2.090E-09	4.440E-08	1.824E-10
Cm-248	8.163E+00	7.485E-03	1.339E+00	2.868E-03	6.538E-06	6.025E-09	1.439E-07	5.956E-10
Pu-244	1.231E-01	1.133E-04	4.132E-01	8.806E-04	9.865E-08	9.096E-11	5.216E-08	1.879E-10
Am-241	3.717E-02	7.846E-05	3.566E-01	7.548E-04	2.767E-08	5.803E-11	3.774E-08	1.336E-10
U-240	1.494E-02	2.417E-05	2.067E-06	4.033E-06	1.155E-08	1.646E-11	3.089E-12	1.014E-11
Np-240m	1.834E+00	1.740E-03	-2.00E+00	-2.00E+00	1.459E-06	1.366E-09	-2.00E+00	-2.00E+00
Np-240	5.847E+00	5.523E-03	2.702E-07	2.683E-07	4.670E-06	4.425E-09	1.698E-13	2.723E-13
Pu-240	1.130E-04	3.842E-07	4.410E-01	9.287E-04	7.122E-11	2.522E-13	5.549E-08	1.743E-10
Np-237	6.706E-02	1.004E-04	1.839E-01	3.959E-04	5.172E-08	7.671E-11	2.867E-08	8.287E-11
U-236	1.758E-04	4.414E-07	3.211E-02	1.724E-04	1.238E-10	3.059E-13	2.568E-08	8.990E-11
Pa-233	1.018E+00	1.082E-03	1.532E-05	3.574E-06	8.032E-07	8.535E-10	1.528E-11	8.953E-12
U-233	9.191E-04	1.238E-06	3.549E-02	1.894E-04	7.110E-10	9.376E-13	2.830E-08	9.693E-11
Th-232	4.782E-04	9.224E-07	4.070E-01	8.547E-04	3.584E-10	6.807E-13	4.329E-08	1.332E-10
Th-229	2.877E-01	3.877E-04	8.831E-01	1.846E-03	2.242E-07	3.001E-10	1.746E-07	2.904E-10
Ra-228	6.575E-05	3.374E-07	5.938E-02	2.575E-03	3.432E-11	2.148E-13	4.366E-08	1.424E-09
Ac-228	5.044E+00	4.682E-03	5.416E-05	1.399E-06	4.040E-06	3.760E-09	4.920E-11	2.734E-12
Th-228	7.248E-03	9.633E-06	1.468E-01	2.664E-04	5.639E-09	7.449E-12	1.324E-07	1.480E-10
Ra-225	8.910E-03	2.884E-05	2.869E-02	3.685E-04	6.106E-09	1.845E-11	2.616E-08	1.535E-10
Ac-225	5.286E-02	6.609E-05	3.137E-02	1.428E-04	4.121E-08	5.149E-11	2.856E-08	2.716E-10
Ra-224	4.950E-02	5.266E-05	1.242E-02	2.390E-04	3.911E-08	4.168E-11	1.132E-08	2.383E-10
Fr-221	1.332E-01	1.460E-04	-2.00E+00	-2.00E+00	1.048E-07	1.152E-10	-2.00E+00	-2.00E+00
Rn-220	3.474E-03	3.281E-06	-2.00E+00	-2.00E+00	2.767E-09	2.627E-12	-2.00E+00	-2.00E+00
At-217	1.186E-03	1.238E-06	-2.00E+00	-2.00E+00	9.363E-10	9.761E-13	-2.00E+00	-2.00E+00
Po-216	8.873E-05	8.173E-08	-2.00E+00	-2.00E+00	7.098E-11	6.585E-14	-2.00E+00	-2.00E+00
Bi-213	6.874E-01	6.936E-04	1.183E-04	7.326E-07	5.429E-07	5.324E-10	7.399E-11	7.177E-13
Po-213	2.167E-04	1.997E-07	-2.00E+00	-2.00E+00	1.728E-10	1.611E-13	-2.00E+00	-2.00E+00
Pb-212	6.314E-01	7.134E-04	7.033E-04	2.220E-05	4.962E-07	5.570E-10	6.400E-10	3.566E-11
Bi-212	6.258E-01	6.037E-04	1.229E-04	9.657E-07	4.962E-07	4.612E-10	8.435E-11	1.010E-12
Po-212	0.000E+00	0.000E+00	-2.00E+00	-2.00E+00	0.000E+00	0.000E+00	-2.00E+00	-2.00E+00
Tl-209	1.287E+01	1.191E-02	-2.00E+00	-2.00E+00	1.032E-05	9.575E-09	-2.00E+00	-2.00E+00
Pb-209	7.528E-04	1.168E-05	2.255E-07	2.098E-07	5.371E-10	1.705E-12	2.079E-13	3.485E-13
Tl-208	2.167E+01	1.962E-02	-2.00E+00	-2.00E+00	1.751E-05	1.588E-08	-2.00E+00	-2.00E+00
C-14	1.106E-05	3.036E-07	2.120E-05	2.150E-06	7.857E-12	4.285E-14	1.694E-11	1.998E-12

(2) External DCFs from Table C-8 is displayed first followed by DCFs in Table A-5 of the User's Manual, Volume 1 and the "Dose and Slope Factor.RPT" file in the following screen shots. Values in Table C-8 and Table A-5 match values in the "Dose and Slope Factors.RPT" file:

TABLE C-9 Effective Dose Coefficients for External (Infinite and Air Submersion) Exposure from DCFPAK3.02 for 30 Day Cut-off Half-life Principal Radionuclides and Associated Radionuclides

Radionuclide	Infinite (mrem/yr per pCi/g)	Air Submersion (mrem/yr per pCi/m^3)
Cf-252	2.84E+00	2.60E-03
Cm-248	8.16E+00	7.49E-03
Pu-244	1.23E-01	1.13E-04
Am-241	3.72E-02	7.85E-05
U-240	1.49E-02	2.42E-05
Np-240m	1.83E+00	1.74E-03
Pu-240	1.13E-04	3.84E-07
Np-237	6.71E-02	1.00E-04
U-236	1.76E-04	4.41E-07
Pa-233	1.02E+00	1.08E-03
U-233	9.19E-04	1.24E-06
Th-232	4.78E-04	9.22E-07
Th-229	2.88E-01	3.88E-04
Ra-228	6.58E-05	3.37E-07
Ac-228	5.04E+00	4.68E-03
Th-228	7.25E-03	9.63E-06
Ra-225	8.91E-03	2.88E-05
Ac-225	5.29E-02	6.61E-05
Ra-224	4.95E-02	5.27E-05
Fr-221	1.33E-01	1.46E-04
Rn-220	3.47E-03	3.28E-06
At-217	1.19E-03	1.24E-06
Po-216	8.87E-05	8.17E-08
Bi-213	6.87E-01	6.94E-04
Po-213	2.17E-04	2.00E-07
Pb-212	6.31E-01	7.13E-04
Bi-212	6.26E-01	6.04E-04
Po-212	0.00E+00	0.00E+00
Tl-209	1.29E+01	1.19E-02
Pb-209	7.53E-04	1.17E-05
Tl-208	2.17E+01	1.96E-02
C-14	1.11E-05	3.04E-07

TABLE A-6 Default Ingestion, Inhalation, and Air Submersion Dose Coefficients for at least 30 Day Half-life Radionuclides from DCFPAK3.02 in RESRAD-BUILD Code

Principal Radionuclide[a]	Associated Decay Chain[b]	Ingestion (mrem/pCi)	Inhalation (mrem/pCi)	Air Submersion (mrem/yr per pCi/m3)
Cf-252	—	3.35E-04	1.36E-01	2.60E-03
Cm-248	—	2.87E-03	1.34E+00	7.48E-03
Pu-244+D	U-240, Np-240m, (Np-240 1.1000E-03)	8.85E-04	4.13E-01	1.88E-03
Am-241	—	7.55E-04	3.57E-01	7.85E-05
Pu-240	—	9.29E-04	4.41E-01	3.84E-07
Np-237+D	Pa-233	3.99E-04	1.84E-01	1.18E-03
U-236	—	1.72E-04	3.21E-02	4.41E-07
U-233	—	1.89E-04	3.55E-02	1.24E-06
Th-232	—	8.55E-04	4.07E-01	9.22E-07
Th-229+D	Ra-225, Ac-225, Fr-221, At-217, Bi-213, (Po-213 9.7910E-01), Pb-209, (Tl-209 2.0900E-02)	2.36E-03	9.43E-01	1.58E-03
Ra-228+D	Ac-228	2.58E-03	5.94E-02	4.68E-03
Th-228+D	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, (Po-212 6.4060E-01), (Tl-208 3.5940E-01)	5.29E-04	1.60E-01	8.43E-03
C-14	—	2.15E-06	2.12E-05	3.04E-07

[a] Dose conversion factors for entries labeled with "+D" are aggregated dose conversion factors of the principal radionuclide together with the associated decay progenies.
b The associated decay progenies are listed. If a branching fraction is anything other than 1, it is listed along with the radionuclide in the bracket.
[c] Dash indicates there is no associated radionuclide.

Dose and Slope Factors - Notepad

File Edit Format View Help

```
** RESRAD-BUILD Version 4.0.19.0 Beta 12/15/22 15:29:44 **
 Title : Default Case for RESRAD-BUILD
 Input File : C:\Users\kamboj\Desktop\Build-Release-Testing\Test-case27\test-027-3.bld

              Dose and Slope Factors including contribution of Associated Radionuclides
           External Dose Factors from                    Slope Factors from
             DCFPAK3.02                                    DCFPAK3.02 Morbidity
           Internal Dose Factors from
             DCFPAK3.02 (Adult)

 Isotope             External Inhalation  Ingestion                 External Inhalation  Ingestion
                       Air                                            Air
                       (mrem/y)   mrem/pCi   mrem/pCi                 risk/y      risk       risk
                      /(pCi/m³)                                      /(pCi/m³)     /pCi       /pCi
 Cf-252               2.60E-03   1.36E-01   3.35E-04                 2.09E-09   4.44E-08   1.82E-10
 Cm-248               7.48E-03   1.34E+00   2.87E-03                 6.03E-09   1.44E-07   5.96E-10
 Pu-244               1.88E-03   4.13E-01   8.85E-04                 1.48E-09   5.22E-08   1.98E-10
 Am-241               7.85E-05   3.57E-01   7.55E-04                 5.80E-11   3.77E-08   1.34E-10
 Pu-240               3.84E-07   4.41E-01   9.29E-04                 2.52E-13   5.55E-08   1.74E-10
 Np-237               1.18E-03   1.84E-01   3.99E-04                 9.30E-10   2.87E-08   9.18E-11
 U-236                4.41E-07   3.21E-02   1.72E-04                 3.06E-13   2.57E-08   8.99E-11
 U-233                1.24E-06   3.55E-02   1.89E-04                 9.38E-13   2.83E-08   9.69E-11
 Th-232               9.22E-07   4.07E-01   8.55E-04                 6.81E-13   4.33E-08   1.33E-10
 Th-229               1.58E-03   9.43E-01   2.36E-03                 1.22E-09   2.29E-07   7.17E-10
 Ra-228               4.68E-03   5.94E-02   2.58E-03                 3.76E-09   4.37E-08   1.43E-09
 Th-228               8.43E-03   1.60E-01   5.29E-04                 6.78E-09   1.44E-07   4.23E-10
 C-14                 3.04E-07   2.12E-05   2.15E-06                 4.29E-14   1.69E-11   2.00E-12

 1. These dose and slope factors are used to compute the dose and risk from external exposure from particulates in air, inhalation of particulates and gases and ingestion.
 2. They are computed using the data from the preceding table in the expression in the next section.
```

14. TEST CASE 028

Test objectives/descriptions:

This test verified that the slope factor values stored in the DCF Editor database are the same as those in the source document and that when a base slope factor library is selected in the interface, the default slope factor values are used in dose/risk calculations.

Test result (Pass/Fail): Pass

Test details:

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases.

Four RESRAD-BUILD runs were conducted with an input file that had a source containing Ac-225 and Am-246 as the initial radionuclides (30 radionuclides, if including progenies); the slope factor libraries, FGR13 morbidity, FGR13 mortality, DCFPAK 3.02 morbidity, and DCFPAK3.02 mortality, were sequentially selected for use in the runs. The slope factors of individual radionuclides listed in the "dose and slope factors.rpt" output file were compared and agreed with the values stored in the DCF Editor database as well as with those listed in the source document.

The attachment file, "Attachment for test report for Case 028.xlsx" contains the details of the comparison.

15. TEST CASE 030

15.1 TEST CASE 030-1

Test objectives/descriptions:

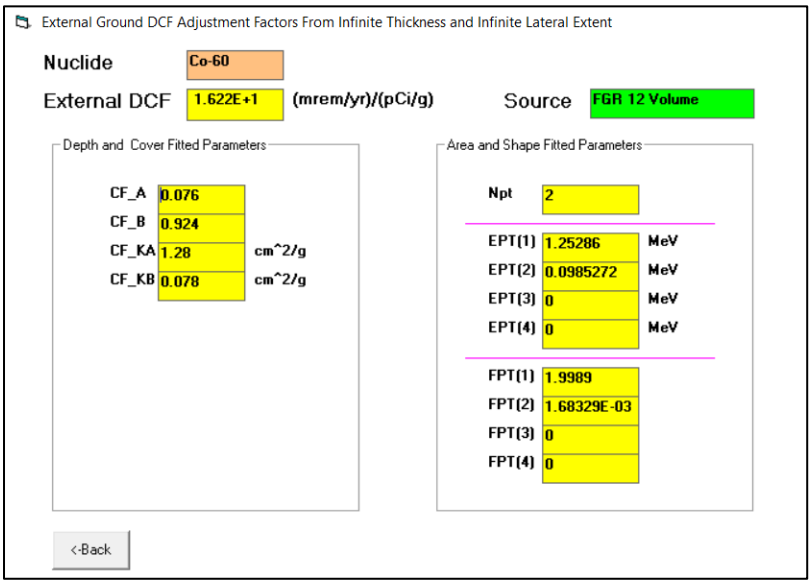
This test verifies that the adjustment factors used with the external dose conversion factors for sources of finite thickness and lateral extent are the same as in the reference. The initial primary radionuclide selected for this test was Co-60.

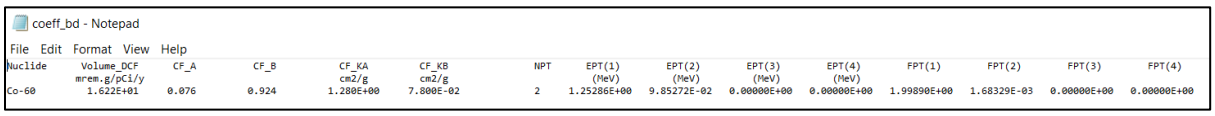
Test result (Pass/Fail): Pass

Test details:

Results are given only for procedure steps with an expected action. Refer to Test Case 030-1 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure. The input file "Test-030-001.bld" associated with this test case was used.

(1) The fitted parameter data in DCF Editor is displayed first followed by data in the "coeff_bd.Lib" file in the following screen shots. The fitted parameters matched:





(2) The fitted parameter data in Table C-1 of the User's Manual, Vol. 1 is displayed first followed by data in Table C-4 in the following screen shots. The values in Table C-1 and Table C-4 matched the data in the "coeff_bd" file:

TABLE C-1 Fitted Parameters *A, B, K_A,* and *K_B* for at least 30 Day Cutoff Half-life Radionuclides and Their Associated Progeny Determined with the Dose Coefficients from FGR 12

Radionuclide	Fitted Parameters			
	A	B	K_A (cm^2/g)	K_B (cm^2/g)
Co-60	7.60E-02	9.24E-01	1.28E+00	7.80E-02

TABLE C-4 Collapsed Photon Energies (EPT) (MeV) and Yield Fractions (FPT) for ICRP-38 Radionuclides with Half-life of at least 30 Days and Their Associated Progeny

Nuclide	EPT(1) (MeV)	EPT(2) (MeV)	EPT(3) (MeV)	EPT(4) (MeV)	FPT(1)	FPT(2)	FPT(3)	FPT(4)
Co-60	1.25E+00	9.85E-02	0.00E+00	0.00E+00	2.00E+00	1.68E-03	0.00E+00	0.00E+00

15.2 TEST CASE 030-2

Test objectives/descriptions:

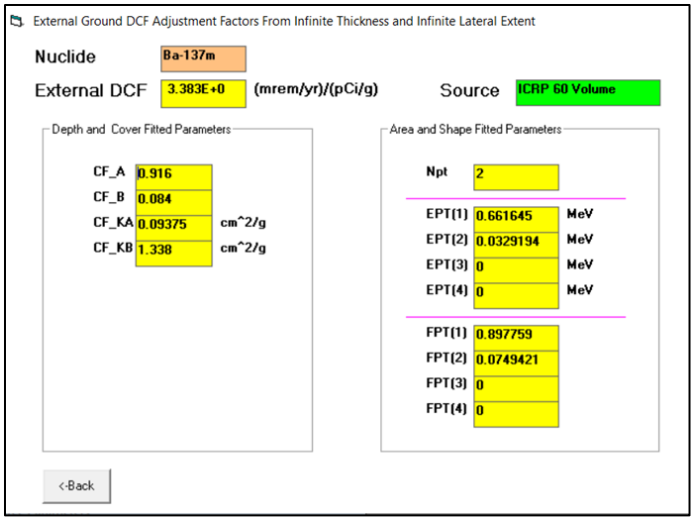
This test verifies that the adjustment factors used with the external dose conversion factors for sources of finite thickness and lateral extent are the same as in the reference. The initial primary radionuclide selected for this test was Cs-137.

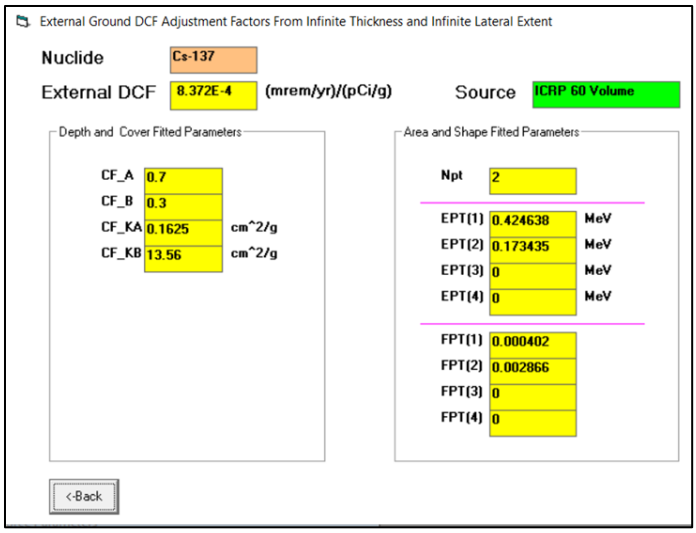
Test result (Pass/Fail): Pass

Test details:

Results are given only for procedure steps with an expected action. Refer to Test Case 030-2 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure.

(1) The fitted parameter data in the DCF Editor is displayed first followed by data in the "coeff_bd.Lib" file in the following screen shots. The fitted parameters matched:





coeff_bd - Notepad

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Nuclide	Volume_DCF mrem.g/pCi/y	CF_A	CF_B	CF_KA cm2/g	CF_KB cm2/g	NPT	EPT(1) (MeV)	EPT(2) (MeV)	EPT(3) (MeV)	EPT(4) (MeV)	FPT(1)	FPT(2)	FPT(3)	FPT(4)
Cs-137	8.372E-04	0.700	0.300	1.625E-01	1.356E+01	2	4.24638E-01	1.73435E-01	0.00000E+00	0.00000E+00	4.02000E-04	2.86600E-03	0.00000E+00	0.00000E+00
Ba-137m	3.383E+00	0.916	0.084	9.375E-02	1.338E+00	2	6.61645E-01	3.29194E-02	0.00000E+00	0.00000E+00	8.97759E-01	7.49421E-02	0.00000E+00	0.00000E+00

(2) The fitted parameter data in Table C-2 of the User's Manual, Vol. 1 is displayed first followed by data in Table C-4 in the following screen shots. The values in Table C-2 and Table C-4 matched the data in the "coeff_bd file."

TABLE C-2 Fitted Parameters A, B, KA, and KB for at least 30 Day Cutoff Half-life Radionuclides and Their Associated Progeny Determined with the Dose Coefficients from FGR-13

Radionuclide	Fitted Parameters			
	A	B	KA (cm2/g)	KB (cm2/g)
Ba-137m	0.916	0.084	0.09375	1.338
Cs-137	0.7	0.3	0.1625	13.56

TABLE C-4 Collapsed Photon Energies (EPT) (MeV) and Yield Fractions (FPT) for ICRP-38 Radionuclides with Half-life of at least 30 Days and Their Associated Progeny

Nuclide	EPT(1)	EPT(2)	EPT(3)	EPT(4)	FPT(1)	FPT(2)	FPT(3)	FPT(4)
	(MeV)	(MeV)	(MeV)	(MeV)				
Ba-137m	6.62E-01	3.29E-02	0.00E+00	0.00E+00	8.98E-01	7.49E-02	0.00E+00	0.00E+00
Cs-137	4.25E-01	1.73E-01	0.00E+00	0.00E+00	4.02E-04	2.87E-03	0.00E+00	0.00E+00

15.3 TEST CASE 030-3

Test objectives/descriptions:

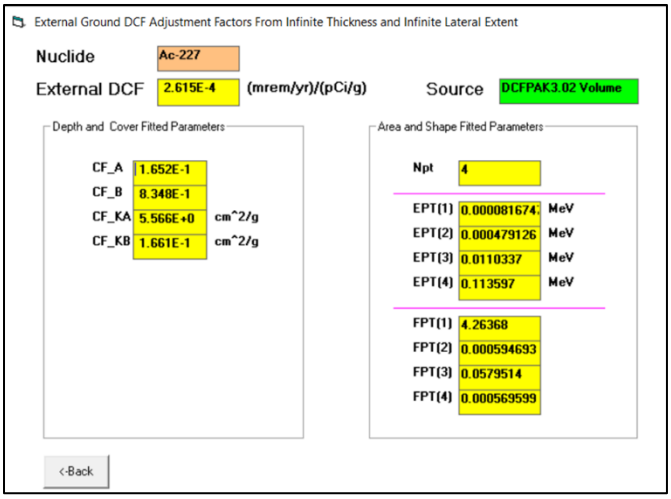
This test verifies that the adjustment factors used with the external dose conversion factors for sources of finite thickness and lateral extent are the same as in the reference. The initial primary radionuclide selected for this test was Ac-227.

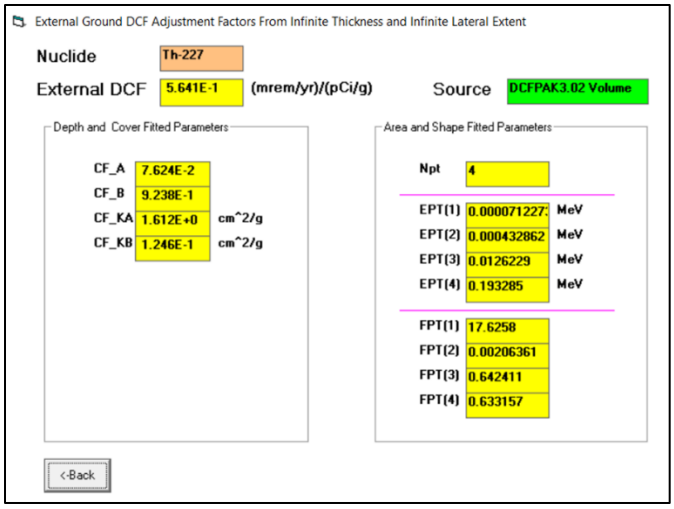
Test result (Pass/Fail): Pass

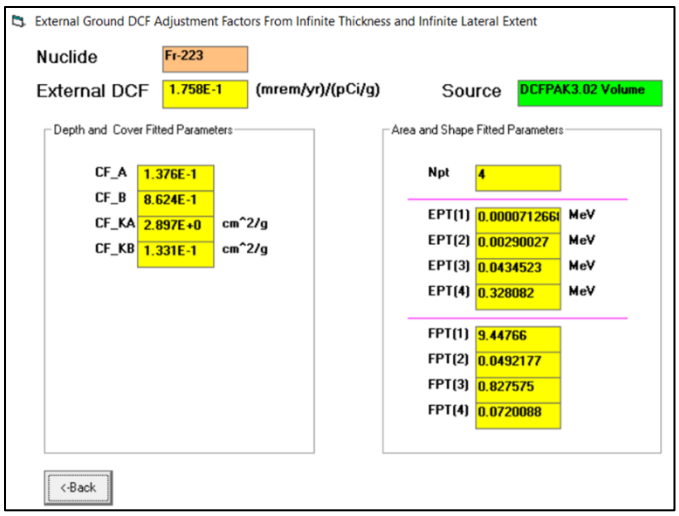
Test details:

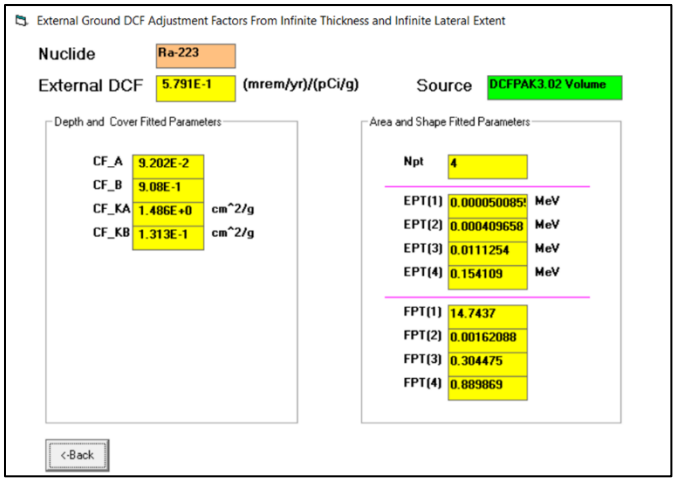
Results are given only for procedure steps with an expected action. Refer to Test Case 030-3 in RESBLD-TEST-001, RESRAD-BUILD Test Cases, Rev. 2 for details on the test procedure.

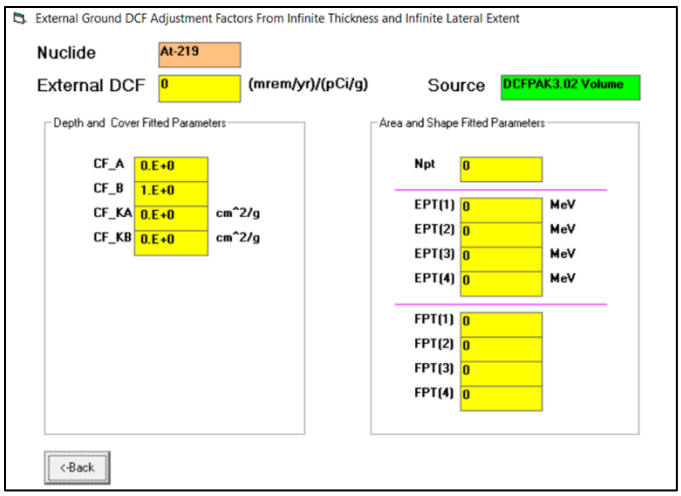
(1) The fitted parameter data in the DCF Editor is displayed first followed by data in the "coeff_bd.Lib" file in the following screen shots. The fitted parameters matched:

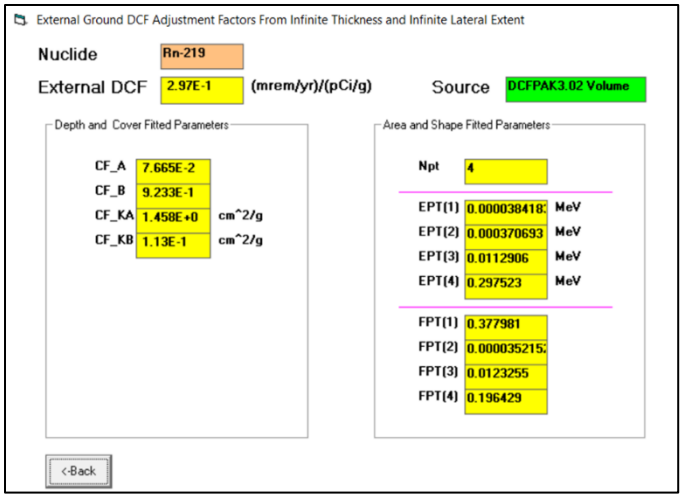

External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Ac-227
External DCF
2.615E-4
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
1.652E-1
CF_B
8.348E-1
CF_KA
5.566E+0
cm^2/g
CF_KB
1.661E-1
cm^2/g
Area and Shape Fitted Parameters
Npt
4
EPT(1)
0.000081674
MeV
EPT(2)
0.000479126
MeV
EPT(3)
0.0110337
MeV
EPT(4)
0.113597
MeV
FPT(1)
4.26368
FPT(2)
0.000594693
FPT(3)
0.0579514
FPT(4)
0.000569599
<-Back

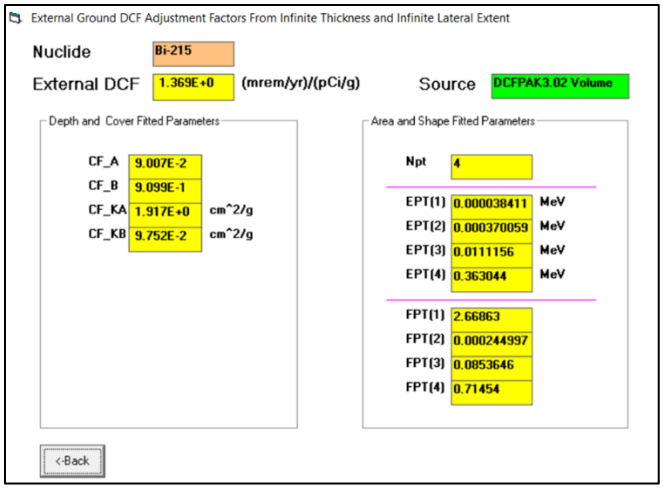

External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Th-227
External DCF
5.641E-1
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
7.624E-2
CF_B
9.238E-1
CF_KA
1.612E+0
cm^2/g
CF_KB
1.246E-1
cm^2/g
Area and Shape Fitted Parameters
Npt
4
EPT(1)
0.000071227
MeV
EPT(2)
0.000432862
MeV
EPT(3)
0.0126229
MeV
EPT(4)
0.193285
MeV
FPT(1)
17.6258
FPT(2)
0.00206361
FPT(3)
0.642411
FPT(4)
0.633157
<-Back

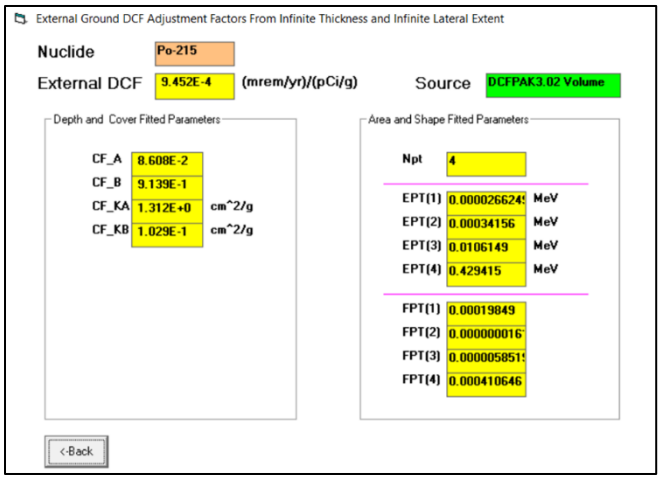

External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Fr-223
External DCF
1.758E-1
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
1.376E-1
CF_B
8.624E-1
CF_KA
2.897E+0
cm^2/g
CF_KB
1.331E-1
cm^2/g
Area and Shape Fitted Parameters
Npt
4
EPT(1)
0.000071266
MeV
EPT(2)
0.00290027
MeV
EPT(3)
0.0434523
MeV
EPT(4)
0.328082
MeV
FPT(1)
9.44766
FPT(2)
0.0492177
FPT(3)
0.827575
FPT(4)
0.0720088
<-Back

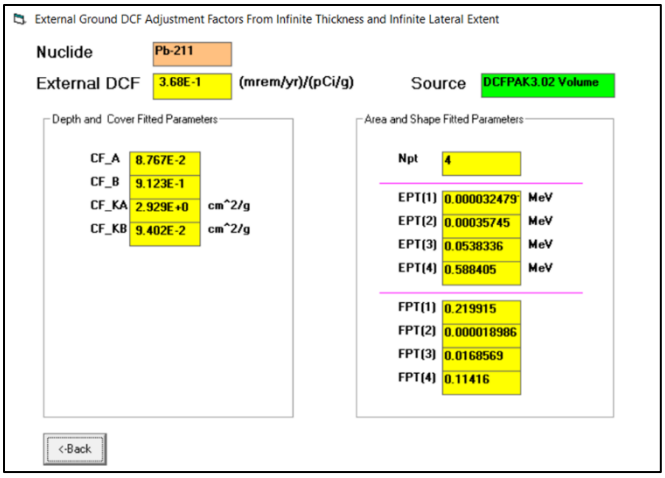

External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Ra-223
External DCF
5.791E-1
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
9.202E-2
CF_B
9.08E-1
CF_KA
1.486E+0
cm^2/g
CF_KB
1.313E-1
cm^2/g
Area and Shape Fitted Parameters
Npt
4
EPT(1)
0.000050085
MeV
EPT(2)
0.000409658
MeV
EPT(3)
0.0111254
MeV
EPT(4)
0.154109
MeV
FPT(1)
14.7437
FPT(2)
0.00162088
FPT(3)
0.304475
FPT(4)
0.889869
<-Back

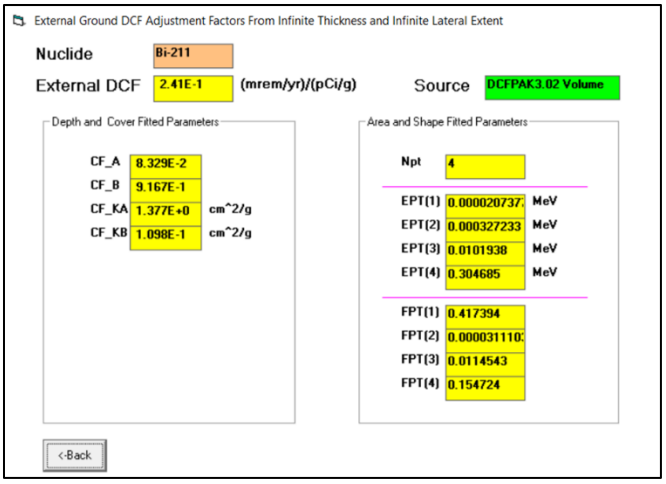

External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
At-219
External DCF
0
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
0.E+0
CF_B
1.E+0
CF_KA
0.E+0
cm^2/g
CF_KB
0.E+0
cm^2/g
Area and Shape Fitted Parameters
Npt
0
EPT(1)
0
MeV
EPT(2)
0
MeV
EPT(3)
0
MeV
EPT(4)
0
MeV
FPT(1)
0
FPT(2)
0
FPT(3)
0
FPT(4)
0
<-Back

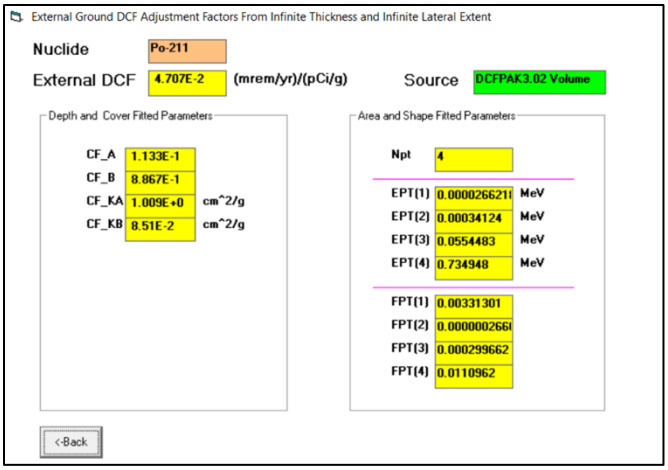

External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Rn-219
External DCF
2.97E-1
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
7.665E-2
CF_B
9.233E-1
CF_KA
1.458E+0
cm^2/g
CF_KB
1.13E-1
cm^2/g
Area and Shape Fitted Parameters
Npt
4
EPT(1)
0.000038418
MeV
EPT(2)
0.000370693
MeV
EPT(3)
0.0112906
MeV
EPT(4)
0.297523
MeV
FPT(1)
0.377981
FPT(2)
0.000035215
FPT(3)
0.0123255
FPT(4)
0.196429
<-Back

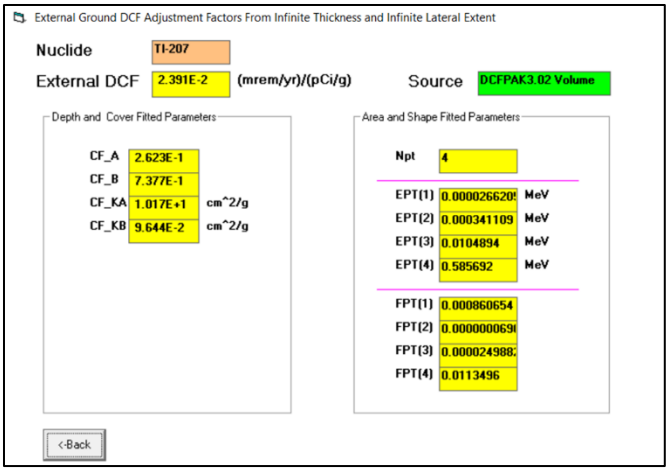

External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Bi-215
External DCF
1.369E+0
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A 9.007E-2
CF_B 9.099E-1
CF_KA 1.917E+0 cm^2/g
CF_KB 9.752E-2 cm^2/g
Area and Shape Fitted Parameters
Npt 4
EPT(1) 0.000038411 MeV
EPT(2) 0.000370059 MeV
EPT(3) 0.0111156 MeV
EPT(4) 0.363044 MeV
FPT(1) 2.66863
FPT(2) 0.000244997
FPT(3) 0.0853646
FPT(4) 0.71454
<-Back


External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Po-215
External DCF
9.452E-4
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A 8.608E-2
CF_B 9.139E-1
CF_KA 1.312E+0 cm^2/g
CF_KB 1.029E-1 cm^2/g
Area and Shape Fitted Parameters
Npt 4
EPT(1) 0.000026624 MeV
EPT(2) 0.00034156 MeV
EPT(3) 0.0106149 MeV
EPT(4) 0.429415 MeV
FPT(1) 0.00019849
FPT(2) 0.000000016
FPT(3) 0.0000058515
FPT(4) 0.000410646
<-Back


External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Pb-211
External DCF
3.68E-1
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A 8.767E-2
CF_B 9.123E-1
CF_KA 2.929E+0 cm^2/g
CF_KB 9.402E-2 cm^2/g
Area and Shape Fitted Parameters
Npt 4
EPT(1) 0.000032479 MeV
EPT(2) 0.00035745 MeV
EPT(3) 0.0538336 MeV
EPT(4) 0.588405 MeV
FPT(1) 0.219915
FPT(2) 0.000018986
FPT(3) 0.0168569
FPT(4) 0.11416
<-Back


External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Bi-211
External DCF
2.41E-1
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
8.329E-2
CF_B
9.167E-1
CF_KA
1.377E+0
cm^2/g
CF_KB
1.098E-1
cm^2/g
Area and Shape Fitted Parameters
Npt
4
EPT(1)
0.000020737
MeV
EPT(2)
0.000327233
MeV
EPT(3)
0.0101938
MeV
EPT(4)
0.304685
MeV
FPT(1)
0.417394
FPT(2)
0.000031110
FPT(3)
0.0114543
FPT(4)
0.154724
<-Back


External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Po-211
External DCF
4.707E-2
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
1.133E-1
CF_B
8.867E-1
CF_KA
1.009E+0
cm^2/g
CF_KB
8.51E-2
cm^2/g
Area and Shape Fitted Parameters
Npt
4
EPT(1)
0.000026621
MeV
EPT(2)
0.00034124
MeV
EPT(3)
0.0554483
MeV
EPT(4)
0.734948
MeV
FPT(1)
0.00331301
FPT(2)
0.000000266
FPT(3)
0.000299662
FPT(4)
0.0110962
<-Back


External Ground DCF Adjustment Factors From Infinite Thickness and Infinite Lateral Extent
Nuclide
Tl-207
External DCF
2.391E-2
(mrem/yr)/(pCi/g)
Source
DCFPAK3.02 Volume
Depth and Cover Fitted Parameters
CF_A
2.623E-1
CF_B
7.377E-1
CF_KA
1.017E+1
cm^2/g
CF_KB
9.644E-2
cm^2/g
Area and Shape Fitted Parameters
Npt
4
EPT(1)
0.000026620
MeV
EPT(2)
0.000341109
MeV
EPT(3)
0.0104894
MeV
EPT(4)
0.585692
MeV
FPT(1)
0.000860654
FPT(2)
0.000000069
FPT(3)
0.000024988
FPT(4)
0.0113496
<-Back

coeff_bd - Notepad

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Nuclide	Volume_DCF mrem.g/pCi/y	CF_A	CF_B	CF_KA cm2/g	CF_KB cm2/g	NPT	EPT(1) (MeV)	EPT(2) (MeV)	EPT(3) (MeV)	EPT(4) (MeV)	FPT(1)	FPT(2)	FPT(3)	FPT(4)
Ac-227	2.615E-04	0.165	0.835	5.566E+00	1.661E-01	4	8.16747E-05	4.79126E-04	1.10337E-02	1.13597E-01	4.26368E+00	5.94693E-04	5.79514E-02	5.69599E-04
Th-227	5.641E-01	0.076	0.924	1.612E+00	1.246E-01	4	7.12273E-05	4.32862E-04	1.26229E-02	1.93285E-01	1.76258E+01	2.06361E-03	6.42411E-01	6.33157E-01
Fr-223	1.758E-01	0.138	0.862	2.897E+00	1.331E-01	4	7.12668E-05	2.90027E-03	4.34523E-02	3.28082E-01	9.44766E+00	4.92177E-02	8.27575E-01	7.20088E-02
Ra-223	5.791E-01	0.092	0.908	1.486E+00	1.313E-01	4	5.00855E-05	4.09658E-04	1.11254E-02	1.54109E-01	1.47437E+01	1.62088E-03	3.04475E-01	8.89869E-01
At-219	0.000E+00	0.000	1.000	0.000E+00	0.000E+00	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
Rn-219	2.970E-01	0.077	0.923	1.458E+00	1.130E-01	4	3.84183E-05	3.70693E-04	1.12906E-02	2.97523E-01	3.77981E-01	3.52152E-05	1.23255E-02	1.96429E-01
Bi-215	1.369E+00	0.090	0.910	1.917E+00	9.752E-02	4	3.84110E-05	3.70059E-04	1.11156E-02	3.63044E-01	2.66863E+00	2.44997E-04	8.53646E-02	7.14540E-01
Po-215	9.452E-04	0.086	0.914	1.312E+00	1.029E-01	4	2.66249E-05	3.41560E-04	1.06149E-02	4.29415E-01	1.98490E-04	1.61133E-08	5.85196E-06	4.10646E-04
Pb-211	3.680E-01	0.088	0.912	2.929E+00	9.402E-02	4	3.24791E-05	3.57450E-04	5.38336E-02	5.88405E-01	2.19915E-01	1.89860E-05	1.68569E-02	1.14160E-01
Bi-211	2.410E-01	0.083	0.917	1.377E+00	1.098E-01	4	2.07377E-05	3.27233E-04	1.01938E-02	3.04685E-01	4.17394E-01	3.11103E-05	1.14543E-02	1.54724E-01
Po-211	4.707E-02	0.113	0.887	1.009E+00	8.510E-02	4	2.66218E-05	3.41240E-04	5.54483E-02	7.34948E-01	3.31301E-03	2.66635E-07	2.99662E-04	1.10962E-02
Tl-207	2.391E-02	0.262	0.738	1.017E+01	9.644E-02	4	2.66205E-05	3.41109E-04	1.04894E-02	5.85692E-01	8.60654E-04	6.90200E-08	2.49882E-05	1.13496E-02

(2) The fitted parameter data in Table C-3 of the User's Manual, Vol. 1 is displayed first followed by data in Table C-5 in the following screen shots. The values in Table C-3 and Table C-5 matched the data in the "coeff_bd file":

TABLE C-3 Fitted Parameters *A*, *B*, K_A, and K_B for at least 30 Day Cutoff Half-life Radionuclides and Their Associated Progeny Determined with the Dose Coefficients from DCFPAK3.02

Radionuclide	Fitted Parameters[a]			
	A	B	K_A (cm²/g)	K_B (cm²/g)
Ac-227	1.65E-01	8.35E-01	5.57E+00	1.66E-01
Th-227	0.076	0.924	1.612	0.1246
Fr-223	0.138	0.862	2.897	0.1331
Ra-223	0.092	0.908	1.486	0.1313
At-219	0	1	0	0
Rn-219	0.077	0.923	1.458	0.113
Bi-215	0.09	0.91	1.917	0.09752
Po-215	0.086	0.914	1.312	0.1029
Pb-211	0.088	0.912	2.929	0.09402
Bi-211	0.083	0.917	1.377	0.1098
Po-211	0.113	0.887	1.009	0.0851
Tl-207	0.262	0.738	10.17	0.09644

TABLE C-5 Collapsed Photon Energies (EPT) (MeV) and Yield Fractions (FPT) for ICRP-107 Radionuclides with Half-Life of at least 30 Days and Their Associated Progeny

Nuclide	EPT(1) (MeV)	EPT(2) (MeV)	EPT(3) (MeV)	EPT(4) (MeV)	FPT(1)	FPT(2)	FPT(3)	FPT(4)
Ac-227	8.17E-05	4.79E-04	1.10E-02	1.14E-01	4.26E+00	5.95E-04	5.80E-02	5.70E-04
Th-227	7.12E-05	4.33E-04	1.26E-02	1.93E-01	1.76E+01	2.06E-03	6.42E-01	6.33E-01
Fr-223	7.13E-05	2.90E-03	4.35E-02	3.28E-01	9.45E+00	4.92E-02	8.28E-01	7.20E-02
Ra-223	5.01E-05	4.10E-04	1.11E-02	1.54E-01	1.47E+01	1.62E-03	3.04E-01	8.90E-01
At-219	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn-219	3.84E-05	3.71E-04	1.13E-02	2.98E-01	3.78E-01	3.52E-05	1.23E-02	1.96E-01
Bi-215	3.84E-05	3.70E-04	1.11E-02	3.63E-01	2.67E+00	2.45E-04	8.54E-02	7.15E-01
Po-215	2.66E-05	3.42E-04	1.06E-02	4.29E-01	1.98E-04	1.61E-08	5.85E-06	4.11E-04
Pb-211	3.25E-05	3.57E-04	5.38E-02	5.88E-01	2.20E-01	1.90E-05	1.69E-02	1.14E-01
Bi-211	2.07E-05	3.27E-04	1.02E-02	3.05E-01	4.17E-01	3.11E-05	1.15E-02	1.55E-01
Po-211	2.66E-05	3.41E-04	5.54E-02	7.35E-01	3.31E-03	2.67E-07	3.00E-04	1.11E-02
Tl-207	2.66E-05	3.41E-04	1.05E-02	5.86E-01	8.61E-04	6.90E-08	2.50E-05	1.13E-02

16. TEST CASE 034

Test objectives/descriptions:

This test verified the code's capability of estimating instantaneous external dose at t=0 when this feature is made available and is selected to launch calculations with the IND template input files as well as with the modified input files. The IND template input files were also examined to ensure the inputs were properly set, including 96 IND nuclides in area sources reflecting the exposure scenarios considered in the RESRAD-IND code.

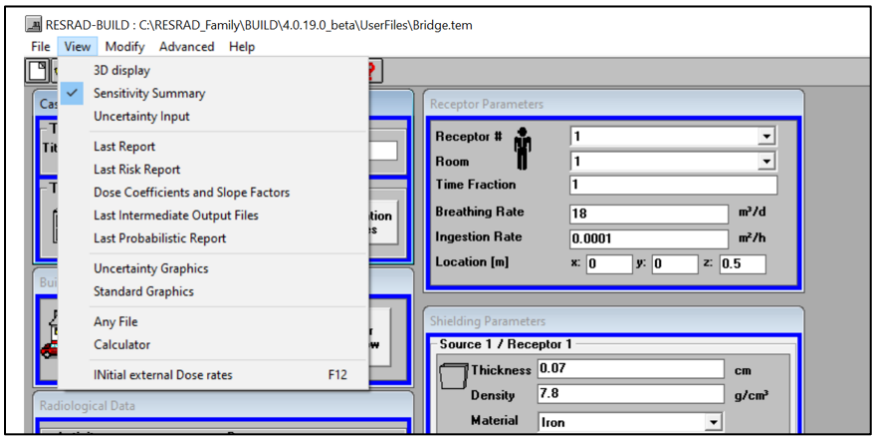
Test result (Pass/Fail): Pass

Test details:

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. The template files, "street.tem" and "monument.tem," were chosen for this test. "Street.tem" was modified by deleting all radionuclides in the source except for Cs-134, Cs-137, and Co-60, and the exposure duration was changed to create input files "street-*.tem," where * denotes the exposure duration in day. "Monument.tem" was modified by deleting Sources 2, 3, 4, and 5 and all radionuclides in the remaining Source 1, except for Cf-252 and Cm-244, and the exposure duration was changed to create input files "monument-*.tem," where * denotes the exposure duration in day.

When "street-*.tem" and "monument-*.tem" were run with the "INitial external Dose rates" menu option, input files "street-*.iie" and "monument-*.iie" were created. Detailed comparisons of results of "street-*.tem" vs. "street-*.iie" and "monument-*.tem" vs. "monument-*.iie" are documented in the attachment file, "Attachment for test report for Case 034.xlsx."

(1) The "INitial external Dose rates" option was available after the file "ind96dcf.key" was copied and placed in the folder where the code was installed.



(2) The template input file "Street.tem" had the proper settings for the calculation of dose/risk at time 0 for an area source.

(3) The results show that the normalized annual dose based on the results of the "street-*.iie" input files stay constant with varied exposure duration.

Results obtained with the IND feature using DCFPCK 3.02 DCFs (input file has .iie extention)

Total dose incurred during the exposure duration

	Input Duration (d)								
Nuclide	365	182.5	73	36.5	18.25	3.65	1	0.365	0.0365
Co-60	1.92E-04	9.61E-05	3.84E-05	1.92E-05	9.61E-06	1.92E-06	5.26E-07	1.92E-07	1.92E-08
Cs-134	1.26E-04	6.32E-05	2.53E-05	1.26E-05	6.32E-06	1.26E-06	3.46E-07	1.26E-07	1.26E-08
Cs-137	2.63E-07	1.32E-07	5.27E-08	2.63E-08	1.32E-08	2.63E-09	7.22E-10	2.63E-10	2.63E-11

Normalized total dose for a duration of 365 days

	Input Duration (d)								
Nuclide	365	182.5	73	36.5	18.25	3.65	1	0.365	0.0365
Co-60	1.92E-04	1.92E-04	1.92E-04	1.92E-04	1.92E-04	1.92E-04	1.92E-04	1.92E-04	1.92E-04
Cs-134	1.26E-04	1.26E-04	1.27E-04	1.26E-04	1.26E-04	1.26E-04	1.26E-04	1.26E-04	1.26E-04
Cs-137	2.63E-07	2.64E-07	2.64E-07	2.63E-07	2.64E-07	2.63E-07	2.64E-07	2.63E-07	2.63E-07

(4) The results also show that the normalized annual dose based on results of the "street-*.tem" input files display the trend of getting closer to the normalized annual dose based on results of the "street-*.iie" input files as the exposure duration becomes shorter.

Results from regular calculations using DCFPAK 3.02 DCFs (input file has .tem extention)

Total dose incurred over the exposure duration

	Input Duration (d)								
Nuclide	365	182.5	73	36.5	18.25	3.65	1	0.365	0.0365
Co-60	1.36E-04	8.15E-05	3.60E-05	1.86E-05	9.46E-06	1.92E-06	5.26E-07	1.92E-07	1.92E-08
Cs-134	8.21E-05	5.11E-05	2.33E-05	1.21E-05	6.19E-06	1.26E-06	3.46E-07	1.26E-07	1.26E-08
Cs-137	1.96E-07	1.15E-07	4.99E-08	2.57E-08	1.30E-08	2.63E-09	7.21E-10	2.63E-10	2.63E-11

Normalized total dose for a duration of 365 days

	Input Duration (d)								
Nuclide	365	182.5	73	36.5	18.25	3.65	1	0.365	0.0365
Co-60	1.36E-04	1.63E-04	1.80E-04	1.86E-04	1.89E-04	1.92E-04	1.92E-04	1.92E-04	1.92E-04
Cs-134	8.21E-05	1.02E-04	1.17E-04	1.21E-04	1.24E-04	1.26E-04	1.26E-04	1.26E-04	1.26E-04
Cs-137	1.96E-07	2.30E-07	2.50E-07	2.57E-07	2.60E-07	2.63E-07	2.63E-07	2.63E-07	2.63E-07

(5) The template input file "monument.tem" had the proper settings for the calculation of dose/risk at time 0 from five area sources.

(6) The results show that the normalized annual dose based on the result of the "monument-*.iie" input files stay constant with varied exposure duration.

Results obtained with the IND feature using DCFPCK 3.02 DCFs (input file has .iie extention)

Total dose incurred during the exposure duration

	Input Duration (d)								
Nuclide	365	182.5	73	36.5	18.25	3.65	1	0.365	0.0365
Cf-252	2.57E-05	1.28E-05	5.13E-06	2.57E-06	1.28E-06	2.57E-07	7.03E-08	2.57E-08	2.57E-09
Cm-244	6.74E-08	3.37E-08	1.35E-08	6.74E-09	3.37E-09	6.74E-10	1.85E-10	6.74E-11	6.74E-12

Normalized total dose for a duration of 365 days

	Input Duration (d)								
Nuclide	365	182.5	73	36.5	18.25	3.65	1	0.365	0.0365
Cf-252	2.57E-05	2.56E-05	2.57E-05	2.57E-05	2.56E-05	2.57E-05	2.57E-05	2.57E-05	2.57E-05
Cm-244	6.74E-08	6.74E-08	6.75E-08	6.74E-08	6.74E-08	6.74E-08	6.75E-08	6.74E-08	6.74E-08

(7) The results also show that the normalized annual dose based on the results of the "monument-*.tem" input files display the trend of getting closer to the normalized annual dose based on results of the "monument-*.iie" input files as the exposure duration becomes shorter.

Results from regular calculations using DCFPAK 3.02 DCFs (input file has .tem extention)

Total dose incurred over the exposure duration

	Input Duration (d)								
Nuclide	365	182.5	73	36.5	18.25	3.65	1	0.365	0.0365
Cf-252	1.72E-05	1.06E-05	4.75E-06	2.47E-06	1.26E-06	2.56E-07	7.02E-08	2.57E-08	2.57E-09
Cm-244	4.97E-08	2.92E-08	1.28E-08	6.56E-09	3.32E-09	6.72E-10	1.84E-10	6.74E-11	6.74E-12

Normalized total dose for a duration of 365 days

	Input Duration (d)								
Nuclide	365	182.5	73	36.5	18.25	3.65	1	0.365	0.0365
Cf-252	1.72E-05	2.12E-05	2.38E-05	2.47E-05	2.52E-05	2.56E-05	2.56E-05	2.57E-05	2.57E-05
Cm-244	4.97E-08	5.84E-08	6.40E-08	6.56E-08	6.64E-08	6.72E-08	6.72E-08	6.74E-08	6.74E-08

17. TEST CASE 036

Test objectives/descriptions:

This test verified that Version 4.0 can read the input files created by Version 3.5, convert them into the format of Version 4.0, and perform dose/risk calculations.

Test result (Pass/Fail): Pass

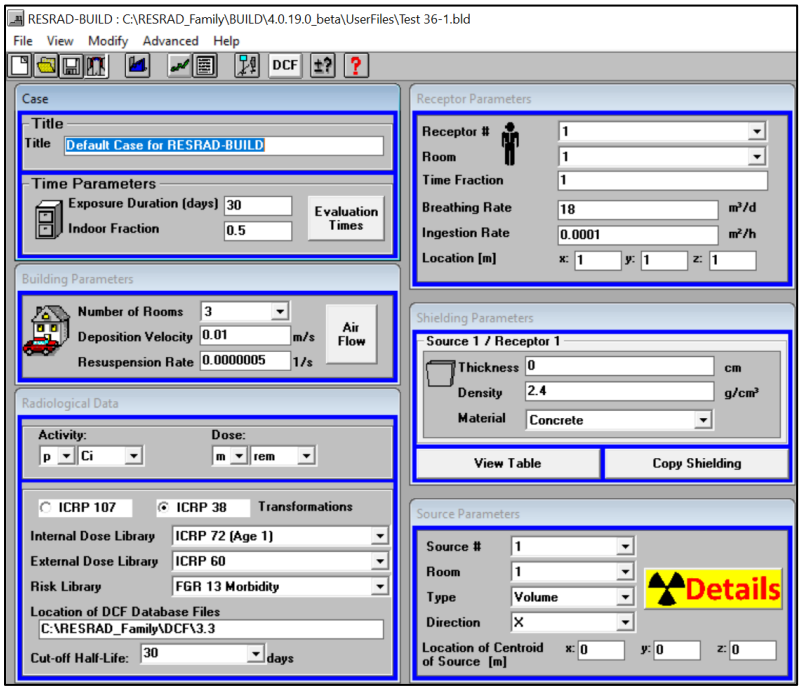
Test details:

The test was conducted following the instructions provided in RESBLD-Test-001, Rev. 2, RESRAD-BUILD Test Cases. It involves retrieving two input files generated with the previously released Version 3.5, checking input parameter values, saving the input file, and launching calculations.

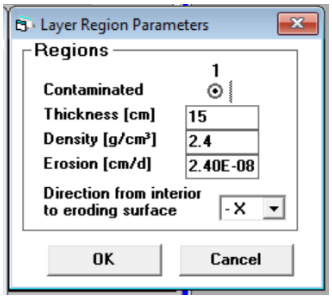
The two input files associated with this test case, which were created with Version 3.5, "Test 36-1.BLD" and "Test 36-2.BLD," were successfully retrieved. The input information was preserved, the files were saved with the format of the current version, and calculations were completed without any issue.

(1) Retrieval of "Test 36-1.BLD:"

The Traditional Appearance option and the Write Intermediate Output option were selected. All the input information was preserved:



The new parameter, direction from interior to eroding surface, was set to "-X" for Source 1, a volume source:

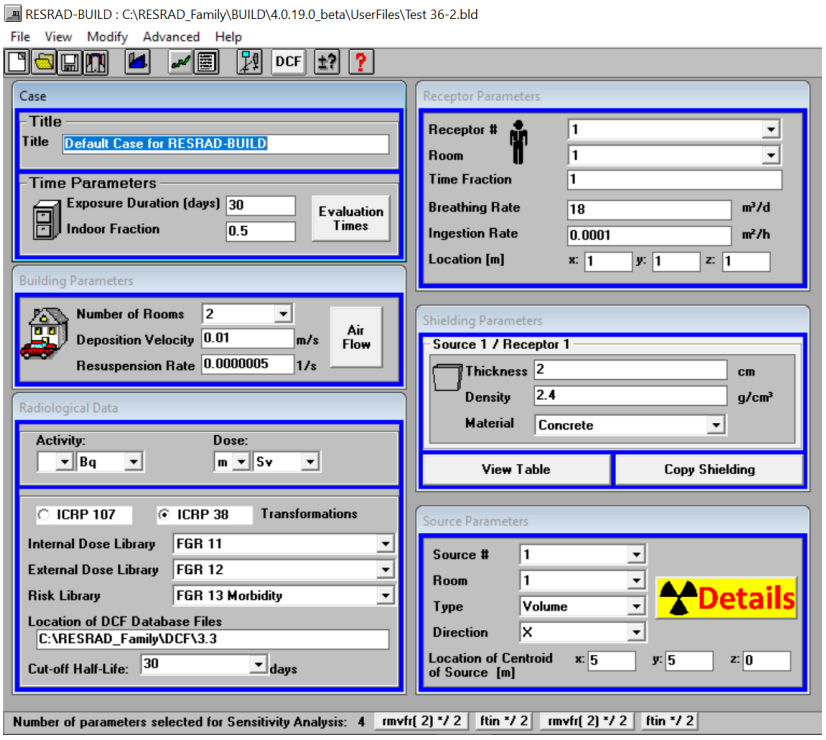


The inputs were saved to a new file, "Test 36-1-new.BLD." Calculations were completed without any issue.

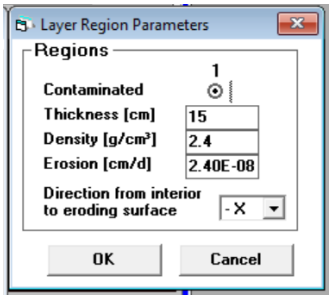
(2) Retrieval of "Test 36-2.BLD":

The Traditional Appearance option and the Write Intermediate Output option were selected.

All the input information was preserved:



The new parameter, direction from interior to eroding surface, was set to "-X" for Source 1, a volume source:



The inputs were saved to a new file, "Test 36-2-new.BLD." Calculations were completed without any issue.

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