Bounding Calculations Using RESRAD 7.0 and RESRAD-OFFSITE 3.1 [1]

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1. Summary

These calculations were performed to demonstrate that no plausible conditions for the M101 spotting round depleted uranium (DU) on Army ranges could produce annual doses and activity concentrations in water and air that exceed Nuclear Regulatory Commission standards and Environmental Protection Agency drinking water standards. The following table summarizes the results of the calculations.

Situation	Maximum Value			
	Average Annual Dose (mrem)	Water Concentration		Air Concentration (pCi/m^3 ^{238}U)
		Effluent (pCi/L ^{238}U)	Drinking water (μg/L total U)	
Regulatory standard (NRC; EPA for drinking water)	100	300	30	0.06
Typical: 1000 rounds, 1 km^2, default parameters (Section 2)	0.029	0.13	0.43	0.0000065
Maximum reasonable: 9700 rounds, 1 km^2, default parameters (Section 3)	0.28	1.3	3.7	0.0000065
Maximum bounded: 9700 rounds, 1 km^2, several changed defaults (Section 5)	0.33	0.63	1.8	0.00013
Maximum, not reasonable: 9700 rounds, 0.1 km^2, several changed defaults (Section 6)	3.2	6.3	18	0.0011
Maximum reasonable 1 km offsite: 9700 rounds, 1 km^2, default parameters (Section 7)	0.035	0.23	0.66	0.000000088

[1] RESRAD is a computer model code designed to estimate radiation doses and risks from RESidual RADioactive materials. Sponsored by the Office of Health, Safety and Security and the Office of Environmental Management, with support from the US Nuclear Regulatory Commission, Argonne National Laboratory (ANL) developed this family of codes. The Department of Energy (DOE) through ANL currently maintains code and version control (DOE 2015).

[2] This document corrects a typographical error (3000 → 300) in the table in paragraph 1 and updates the names of Army installations. It supersedes the original document submitted to the NRC in 2015.

2. Baseline Resident Farmer Scenario, 1000 M101 Rounds, RESRAD Default Parameters

To establish a conservative baseline, the "resident farmer" scenario[3] is used, even though residential farming is not a foreseeable use of an operational range in the near future, to estimate annual doses and soil, water, and air depleted uranium (DU) activity concentrations. The RESRAD calculations for this baseline calculation used the following parameters:

- The true impact area is a square, 1000 meters (m) × 1000 m = 10^6 m^2 = 1 km^2. However, in the calculations the area is assumed circular (radius ≈ 564 m) by default for simplicity. RESRAD allows other shapes, such as a square, but approximates those shapes with a set of circles when it performs its calculations. This greatly increases computation time.
- One thousand M101 spotting rounds[4] were fired into the impact area.[5] Initially, M101 DU contamination in the impact area is uniform[6] and confined to the top 15 centimeters of soil,[7] resulting in activity concentrations in soil due to the 1000

[3] According to *NUREG-1757, Consolidated Decommissioning Guidance, Vol. 2, Rev. 1* (NRC 2006), the resident farmer scenario accounts for exposure involving residual radioactivity that is initially in the surficial soil. A farmer moves onto the site, grows some of his or her diet, and uses water tapped from the aquifer under the site. Pathways include external exposure from soil, inhalation to (re)suspended soil, ingestion of soil, ingestion of drinking water from aquifer, ingestion of plant products grown in contaminated soil and using aquifer to supply irrigation needs, ingestion of animal products grown onsite (using feed and water derived from potentially contaminated sources) and ingestion of fish from a pond filled with water from the aquifer. A resident farmer scenario … is considered to be a credible bounding scenario for the purpose of [the RESRAD] manual (Yu, et al. 2001).

[4] The geometric mean of the number of rounds shipped to each installation and presumably fired is about 1500. Some installations had more than one impact area, so 1000 was chosen as a representative number for the rounds fired into a single impact area. The results of the calculations for a one-kilometer square are proportional to the number of rounds fired into that square.

[5] Each M101 round contains (3180 ± 25) grains = (0.2061 ± .0015) kg of molybdenum-DU alloy (USACE St Louis 2011). The molybdenum-DU alloy is 92 percent DU, so each M101 round contains about 0.190 kg of DU.

[6] RESRAD does not allow for non-uniform distribution of radioactive material in the contaminated zone. Experience in Hawaii and at Fort Hood (PIKA International 2007) shows that M101 spotting rounds remain mostly intact for many years and so their DU is not available for transport and uptake, and even after about 50 years since the Army fired the rounds, M101 DU has remained in a small area around the resting place of each round. Thus, assuming the rounds have completely corroded is a conservative assumption. As time goes on, the DU will become more uniformly distributed in soil than it currently is, and so the distribution will approach the assumed distribution. RESRAD does not allow for gradual corrosion adding to the source term available to contribute to dose. A conservative assumption is that all the M101 DU is immediately available and is evenly distributed throughout the RCA. Section 6 addresses the consideration that the DU might be concentrated in a smaller area.

[7] The M101 spotting round was not a high-velocity penetrating round. It has been found only on or near the ground surface. According to *MARSSIM* (NRC, DOE, EPA, DOD 2000), "Surface soil is the top layer of soil on a site that is available for direct exposure, growing plants, resuspension of particles for inhalation, and mixing from human disturbances. Surface soil may also be defined as the thickness of soil that can be measured using direct measurement or scanning techniques. Typically, this layer is represented as the top 15 cm (6 in.) of soil (40 CFR 192)."

rounds of 0.256 picocurie per gram (pCi/g) ^{238}U, 0.00236 pCi/g ^{235}U, and 0.0337 pCi/g ^{234}U.[8]

- All other parameters were RESRAD defaults.

Table 1 is an extract from Table 2.3 in the RESRAD manual (Yu, et al. 2001) that shows the key parameters that RESRAD uses in the resident farmer scenario.

Table 1 Key parameters used in the resident farmer scenario

Parameter	Value
Exposure duration	1 year
Inhalation rate [a]	8400 m^3/y
Fraction of time indoors [b]	0.50
Fraction of time outdoors [c]	0.25
Contaminated fractions of food [d]	
Plant food	0.5
Milk	1.0
Meat	1.0
Aquatic food	0.5
Soil ingestion [e]	36.5 g/y
Drinking water intake [f]	510 L/y

[a] RESRAD assumes an average inhalation of 8400 m^3/y for the resident farmer. The average inhalation rate of 15.2 m^3/d is given in the EPA *Exposure Factor Handbook* (USEPA 1997).

[b] RESRAD assumes the resident farmer spends 50 percent of the time inside on the contaminated site. The EPA *Exposure Factor Handbook* (USEPA 1997) assumes that the resident spends an average of 16.4 h/d inside.

[c] RESRAD assumes that the resident farmer spends 25 percent of the time outside on the contaminated site. The EPA *Exposure Factor Handbook* (USEPA 1997) assumes that the resident spends an average of 2 h/d outside.

[d] RESRAD corrects the contaminated fractions for plant, meat, and milk food on the basis of the contaminated area. The values in the table are for a very large contaminated area (> 20,000 m^2 for the meat and milk pathway and > 1000 m^2 for the plant food pathway).

[e] RESRAD uses 36.5 g/y as the soil ingestion rate. The actual soil ingestion rate is corrected by the occupancy factor, which is the sum of the time spent on site (time fraction inside + time fraction outside). The average value suggested in the EPA *Exposure Factor Handbook* (USEPA 1997) is 50 mg/d.

[f] RESRAD considers water ingestion only for the rural resident, and the ingestion rate is 510 L/yr. The EPA *Exposure Factor Handbook* (USEPA 1997) recommends an average drinking water intake of 1.4 L/d.

[8] Included in the calculation of the soil activity concentrations for the baseline resident farmer scenario are the RESRAD default value of 1.5 g/cm^3 for soil density and the relative mass abundances of 99.80 percent, 0.20 percent, and 0.0007 percent in DU and specific activities of 0.33 pCi/g, 6200 pCi/g, and 2.2 pCi/g for ^{238}U, ^{234}U, and ^{235}U, respectively (DOE 2009).

Figure 1 through Figure 4 [9] are selected RESRAD graphical outputs for the baseline resident farmer scenario. The RESRAD report for the baseline resident farmer scenario is in Attachment 1.[10]

Part I, page 13 of the RESRAD report for the baseline resident farmer scenario shows that the maximum annual dose of 0.029 millirem (mrem) occurs in the first year. Figure 1 shows that the annual dose declines continuously for more than 100 years to less than 0.001 mrem and then rises to approximately 0.017 mrem at approximately 450 years. All estimated annual doses are less than 1/10,000 of 311 mrem, which is the average annual background dose per individual in the US population for ubiquitous background (NCRP 2009).

Figure 2 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This explains the accompanying decrease in annual dose over the same period.

Figure 3 shows that ^{238}U does not show up in well water for about 300 years. Then its ^{238}U activity concentration gradually increases for about 150 years, eventually reaching about 0.13 pCi/L, holding steady after that. The corresponding DU concentration is 0.15 pCi/L or about 0.4 μg DU/L. The drinking water standard for uranium is 30 μg U/L.[11] RESRAD assumes that groundwater is the source for well water and a surface pond (Yu, et al. 2001), so the DU activity concentration in well water and the pond reflect the DU concentration in groundwater.

Figure 4 shows that the maximum ^{238}U activity concentration in air due to dust is about 6.5×10^{-6} pCi/m^3 and occurs during the first year. Its decrease to zero over the first one hundred years parallels the decrease in DU activity concentration in surface soil. For comparison, the NRC's effluent standard for ^{238}U is 6×10^{-14} μCi/mL = 0.06 pCi/m^3,[12] which is more than 9000 times greater than the calculated RESRAD value.

3. Bounding Value for Source Term, 9700 M101 Rounds, RESRAD Default Parameters

The greatest number of M101 rounds shipped to any installation was 9700 to Fort Benning. Fort Benning is where Infantry Soldiers received their qualification training on the Davy Crockett weapon systems. It is unlikely that Soldiers fired all 9700 rounds on a single range because eight M101 impact areas are at Fort Benning.

[9] Figures follow the bibliography.
[10] For the purpose of the RESRAD calculations, the timeline begins with DU uniformly distributed in the top15 cm of soil. As discussed in above footnotes, the true situation is more complicated and one that RESRAD cannot fully address. However, the purpose of *performing* the RESRAD calculations is to estimate maximum annual doses and maximum concentrations of DU in soil, air, and water, regardless of when those maxima occur.
[11] 40 CFR § 141.66(e)
[12] 10 CFR 20, appendix B, table 2

Fort Bragg, Fort Hood, and Fort Knox received 4212, 4038, and 3956 M101 rounds, respectively. Fort Bragg and Fort Hood each has one M101 impact area, and Fort Knox has five (with two sets of two or three overlapping impact areas). Therefore, the most conservative realistic concentration of M101 rounds occurs at Fort Bragg.

However, the source term bounding calculation will assume 9700 rounds in a single M101 impact area. The results of RESRAD calculations using this bounding value for number of rounds are 9.7 times the results of the baseline calculations in the previous section, as expected.

Again assuming the M101 DU contamination in the impact area is uniform and confined to the top 15 centimeters of soil, the resulting activity concentrations in soil due to the 9700 rounds are 2.48 pCi/g ^{238}U, 0.0228 pCi/g ^{235}U, and 0.327 pCi/g ^{234}U.

The RESRAD report for the 9700 M101 rounds bounding scenario is in Attachment 2. Figure 5 through Figure 8 for the 9700 M101 rounds bounding scenario are the same as the corresponding Figure 1 through Figure 4 for the resident farmer scenario (1000 M101 rounds), except that the resulting values vs. time are 9.7 times larger.

Part I, page 13 of the RESRAD report and Figure 5 for the 9700 M101 rounds bounding scenario show that the maximum annual dose of 0.28 mrem occurs in the first year.

Figure 6 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This explains the accompanying decrease in annual dose over the same period.

Similar to the baseline resident farmer scenario, ^{238}U does not show up in well water for about 300 years (Figure 7). Then its ^{238}U activity concentration gradually increases for about 150 years, eventually reaching about 1.3 pCi/L. The corresponding DU concentration is 1.5 pCi/L or about 4 μg DU/L. The drinking water standard for uranium is 30 μg U/L.[11] RESRAD assumes that groundwater is the source for well water and a surface pond (Yu, et al. 2001), so the DU activity concentration in well water and the pond reflect the DU concentration in groundwater.

Similar to the baseline resident farmer scenario, the maximum ^{238}U activity concentration in air due to dust is about 6.5×10^{-5} pCi/m^3 and occurs during the first year (Figure 8). Its decrease to zero over the first one hundred years parallels the decrease in DU activity concentration in surface soil. For comparison, the NRC's effluent standard for ^{238}U is 6×10^{-14} μCi/mL = 0.06 pCi/m^3,[12] which is more than 900 times greater than the calculated RESRAD value.

4. Other Bounding Values with 9700 M101 Rounds Resident Farmer Scenario

The following RESRAD results are for the 9700 M101 Rounds Resident Farmer Scenario with only one default parameter changed.

a. Water table 7.5 cm below ground surface instead of default 4 m

To set up this scenario, in the "contaminated zone parameters" dialog box, "Does the initial contamination penetrate the water table?" check "yes," and set the "contaminated fraction below the water table" to 0.5 (that is, 50 percent). This means the water table is only 7.5 cm below the ground surface.[13] The default depth of the water table is 4 m.

The RESRAD report for this bounding scenario is in Attachment 3.

Part I, page 12 of the RESRAD report and Figure 9 for the 9700 M101 rounds bounding scenario for a high water table show that the maximum annual dose of 0.32 mrem occurs in the first year.

Figure 10 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for most of the decrease in annual dose over that same period.

Part IV, page 2 of the RESRAD concentration report shows that the activity concentration of ^{238}U in well water in the first year is 0.37 pCi/L. Figure 11 then shows it gradually increases for about 100 years, eventually reaching about 1.3 pCi/L. The corresponding DU concentration in well water is 1.5 pCi/L or about 4 μg DU/L. It then gradually drops to zero beginning at about 500 years.

Similar to the baseline resident farmer scenario with 9700 rounds, the maximum ^{238}U activity concentration in air due to dust is about 6.5×10^{-5} pCi/m^3 and occurs during the first year (Figure 12). Its decrease to zero over the first one hundred years parallels the decrease in DU activity concentration in surface soil.

b. Contaminated zone erosion rate is 0.01 m/y instead of default 0.001 m/y

To set up this scenario, in the "cover and contaminated zone hydrological data" dialog box, change the "contaminated zone erosion rate" from the default 0.001 m/y to 0.01 m/y.[14]

The RESRAD report for this bounding scenario is in Attachment 4.[15]

[13] The contaminated zone is the top 15 cm of soil. None of the impact areas is normally submerged in water. Setting the top of the water table halfway in the top 15 cm allows for direct contact of the water table with half of the contamination while keeping the water below the surface.

[14] If this scenario produced a large change in the maximum annual dose and activity concentration results, an additional calculation with ten times less erosion rate than the default could be performed. However, a large change did not occur.

[15] When the water table parameter was changed (Section 4a), RESRAD 7.0 automatically changed another parameter, the water table drop rate, from its default value of 1 mm/y to zero. This was not noticed until all additional RESRAD 7.0 calculations described in sections 4b through 5 were completed and discussed herein. Since this oversight did not affect the maximum values of annual dose and of soil, water, and air concentrations and because of time constraints, these calculations were not redone.

Part 1, page 12 of the RESRAD report and Figure 13 for the 9700 M101 rounds bounding scenario for a high erosion rate that the maximum annual dose of 0.28 mrem occurs in the first year.

Figure 14 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for most of the decrease in annual dose over that same period.

Part IV, page 3 of the RESRAD report shows that the activity concentration of ^{238}U in well water at the first year is 0.006 pCi/L. Figure 15 then shows it gradually increases, reaching about 0.4 pCi/L in about 15 years. The corresponding DU concentration in well water is about 0.5 pCi/L or about 1.1 μg DU/L. It then gradually drops to zero beginning at about 500 years.

Similar to the baseline resident farmer scenario with 9700 rounds, the maximum ^{238}U activity concentration in air due to dust is about 6.5×10^{-5} pCi/m^3 and occurs during the first year (Figure 16). It decreases to zero in about twenty years.

c. Contaminated zone total porosity is 0.6 instead of default 0.4

The highest value for total porosity in Table E.8 of the RESRAD manual (Yu, et al. 2001) is 0.57 for clay or for weathered granite, so a porosity of 0.6 is chosen as a bounding value.[16]

The RESRAD report for this bounding scenario is in Attachment 5.

Part 1, page 12 of the RESRAD report and Figure 17 for the 9700 M101 rounds bounding scenario for high total porosity show that the maximum annual dose of 0.28 mrem occurs in the first year.

Figure 18 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for much of the decrease in annual dose over that same period.

Part IV, page 3 of the RESRAD report shows that the activity concentration of ^{238}U in well water at the first year is 0.006 pCi/L. Figure 19 then shows it gradually increases, reaching about 1.25 pCi/L in about 100 years. The corresponding DU concentration in well water is about 1.4 pCi/L or about 3.6 μg DU/L. It then gradually drops to zero beginning at about 600 years.

Similar to the baseline resident farmer scenario with 9700 rounds, the maximum ^{238}U activity concentration in air due to dust is about 6.5×10^{-5} pCi/m^3 and occurs during the first year (Figure 20). It decreases to zero in about 100 years.

[16] If this scenario produced a large change in the maximum annual dose and activity concentration results, an additional calculation with porosity than the default could be performed. However, a large change did not occur.

d. Contaminated zone hydraulic conductivity is 6000 m/y instead of default 10 m/y

The highest value for contaminated zone hydraulic conductivity in Table E.2 of the RESRAD manual (Yu, et al. 2001) is 5550 m/y for sand, so a hydraulic conductivity of 6000 m/y is chosen as a bounding value.[17]

The RESRAD report for this bounding scenario is in Attachment 6.

Part 1, page 12 of the RESRAD report and Figure 21 for the 9700 M101 rounds bounding scenario for high hydraulic conductivity show that the maximum annual dose of 0.28 mrem occurs in the first year.

Figure 22 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for much of the decrease in annual dose over that same period.

Part IV, page 3 of the RESRAD report shows that the activity concentration of ^{238}U in well water at the first year is 0.006 pCi/L. Figure 23 then shows it gradually increases, reaching about 1.25 pCi/L in about 100 years. The corresponding DU concentration in well water is about 1.4 pCi/L or about 3.6 μg DU/L. It then gradually drops to zero beginning at about 600 years.

Similar to the baseline resident farmer scenario with 9700 rounds, the maximum ^{238}U activity concentration in air due to dust is about 6.5×10^{-5} pCi/m^3 and occurs during the first year (Figure 24). It decreases to zero in about 100 years.

e. Average annual wind speed is 1 m/h instead of default 2 m/h

The smallest value for average annual wind speed in Table B.2 of the RESRAD manual (Yu, et al. 2001) is 1 m/y, so that is chosen as a bounding value.

The RESRAD report for this bounding scenario is in Attachment 7.

Part 1, page 12 of the RESRAD report and Figure 25 for the 9700 M101 rounds bounding scenario for low average wind speed show that the maximum annual dose of 0.29 mrem occurs in the first year.

Figure 26 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for much of the decrease in annual dose over that same period.

Part IV, page 3 of the RESRAD report shows that the activity concentration of ^{238}U in well water at the first year is 0.006 pCi/L. Figure 27 then shows it gradually increases,

[17] If this scenario produced a large change in the maximum annual dose and activity concentration results, an additional calculation with a hydraulic conductivity than the default could be performed. However, a large change did not occur.

reaching about 1.25 pCi/L in about 100 years. The corresponding DU concentration in well water is about 1.4 pCi/L or about 3.6 μg DU/L. It then gradually drops to zero beginning at about 600 years.

Similar to the baseline resident farmer scenario with 9700 rounds, the maximum ^{238}U activity concentration in air due to dust is about 6.5 $\times 10^{-5}$ pCi/m^3 and occurs during the first year (Figure 28). It decreases to zero in about 100 years.

f. Average annual wind speed is 10 m/h instead of default 2 m/h

The largest value for average annual wind speed in Table B.2 of the RESRAD manual (Yu, et al. 2001) is 10 m/y, so that is chosen as a bounding value.

The RESRAD report for this bounding scenario is in Attachment 8.

Part 1, page 12 of the RESRAD report and Figure 29 for the 9700 M101 rounds bounding scenario for low average wind speed show that the maximum annual dose of 0.28 mrem occurs in the first year.

Figure 30 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for much of the decrease in annual dose over that same period.

Part IV, page 3 of the RESRAD report shows that the activity concentration of ^{238}U in well water at the first year is 0.006 pCi/L. Figure 27 then shows it gradually increases, reaching about 1.25 pCi/L in about 100 years. The corresponding DU concentration in well water is about 1.4 pCi/L or about 3.6 μg DU/L. It then gradually drops to zero beginning at about 600 years.

Similar to the baseline resident farmer scenario with 9700 rounds, the maximum ^{238}U activity concentration in air due to dust is about 6.5 $\times 10^{-5}$ pCi/m^3 and occurs during the first year (Figure 28). It decreases to zero in about 100 years.

g. Average annual precipitation is 2 m instead of default 1 m

Hawaii has the highest average total annual precipitation of about 64 inches or 1.6 m (NOAA 2015). Two meters is used as a bounding value in RESRAD.

The RESRAD report for this bounding scenario is in Attachment 9.

Part 1, page 12 of the RESRAD report and Figure 33 for the 9700 M101 rounds bounding scenario for low average wind speed show that the maximum annual dose of 0.28 mrem occurs in the first year.

Figure 34 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for much of the decrease in annual dose over that same period.

Part IV, page 3 of the RESRAD report shows that the activity concentration of ^{238}U in well water at the first year is 0.11 pCi/L. Figure 35 then shows it gradually increases, reaching about 1.4 pCi/L in about 100 years. The corresponding DU concentration in well water is about 1.5 pCi/L or about 3.9 μg DU/L. It then gradually drops to zero beginning at about 600 years.

Similar to the baseline resident farmer scenario with 9700 rounds, the maximum ^{238}U activity concentration in air due to dust is about 6.6×10^{-5} pCi/m^3 and occurs during the first year (Figure 36). It decreases to zero in about 100 years.

5. All above bounding values

Clearly, adjusting environmental parameters from their default values in RESRAD has little or no effect on the maximum annual dose. Using all the above bounding environmental parameters (with low average annual wind speed instead of high average annual wind speed) simultaneously produces similar results.

The RESRAD report for this bounding scenario is in Attachment 10.

Part 1, page 12 of the RESRAD report and Figure 37 for the 9700 M101 rounds bounding scenario with several bounding environmental parameters show that the maximum annual dose of about 0.33 mrem occurs in the first year.

Figure 38 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for much of the decrease in annual dose over that same period.

Part IV, page 2 of the RESRAD report shows that the activity concentration of ^{238}U in well water at the first year is 0.37 pCi/L. Figure 39 then shows it gradually increases, reaching about 0.63 pCi/L in about 10 years. The corresponding DU concentration in well water is about 0.72 pCi/L or about 1.8 μg DU/L. It then gradually drops to zero beginning after about 300 years.

The maximum ^{238}U activity concentration in air due to dust is about 1.3×10^{-4} pCi/m^3 and occurs during the first year (Figure 40). It decreases to zero in less than 30 years.

6. All above bounding values in 0.1 km^2

Instead of assuming that the DU from 9700 completely corroded M101 spotting rounds is evenly distributed in an area of 1 km^2, assume the area to be 0.1 km^2. This bounding value assumption is made because trainers may have avoided firing near the boundaries of the range. Using only 10 percent of the available area in the RESRAD calculations is a highly conservative assumption, but it will provide an additional bounding condition.

With this assumption of the same amount of DU in an area 10 times smaller than used above (that is, 0.1 km^2 or a circle of radius 178 m), the concentrations of the uranium isotopes will be ten times larger than those used above (that is, 24.8 pCi/g ^{238}U, 0.228 pCi/g ^{235}U, and 3.27 pCi/g ^{234}U).

The RESRAD report for this bounding scenario is in Attachment 11.

Part 1, page 12 of the RESRAD report and Figure 41 for the 9700 M101 rounds bounding scenario with several bounding environmental parameters show that the maximum annual dose of about 3.2 mrem occurs in the first year.

Figure 42 shows that ^{238}U soil concentration (and hence, the M101 DU soil concentration) decreases significantly over the first hundred years due to erosion and leaching. This accounts for much of the decrease in annual dose over that same period.

Part IV, page 2 of the RESRAD report shows that the activity concentration of ^{238}U in well water at the first year is 5.2 pCi/L. Figure 43 then shows it gradually increases, reaching about 6.3 pCi/L in about 10 years. The corresponding DU concentration in well water is about 7.2 pCi/L or about 18 μg DU/L. It then gradually drops to zero beginning after about 300 years.

The maximum ^{238}U activity concentration in air due to dust is about 1.1×10^{-3} pCi/m^3 and occurs during the first year (Figure 44). It decreases to zero in less than 30 years.

7. RESRAD-OFFSITE, 9700 M101 Rounds, Default Parameters, Resident Farmer about 1 km from DU Impact Area

Instead assuming the resident farmer lives on the former DU impact area, assume the resident farmer lives about one kilometer from the DU impact area. One kilometer is a typical minimum distance from current Army training ranges to normally occupied areas. RESRAD-OFFSITE performs these calculations, which also suffice to demonstrate compliance with the NRC requirement to measure or calculate the maximum annual dose to a member of the public (10 CFR 20, § 20.1101) to assure that NRC standards are not exceeded.

The RESRAD-OFFSITE report for this bounding scenario is in Attachment 12.

Part 1, page 39 of the RESRAD-OFFSITE report and Figure 45 for the 9700 M101 rounds offsite resident farmer scenario show that the maximum annual dose of about 0.035 mrem occurs in the first year.

Figure 46 shows that ^{238}U soil concentration rises to about 5.7×10^{-8} pCi/g in the first 20 years. It then decreases to zero over the next 100 years or so.

Figure 47 shows that the maximum activity concentration of ^{238}U in surface water near the offsite dwelling is about 0.23 pCi/L. The corresponding DU concentration in well water is about 0.26 pCi/L or about 0.7 μg DU/L.

Figure 48 shows that the maximum ^{238}U activity concentration in air above the offsite dwelling due to dust is about 8.8×10^{-8} pCi/m^3.

8. Bibliography

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Figures

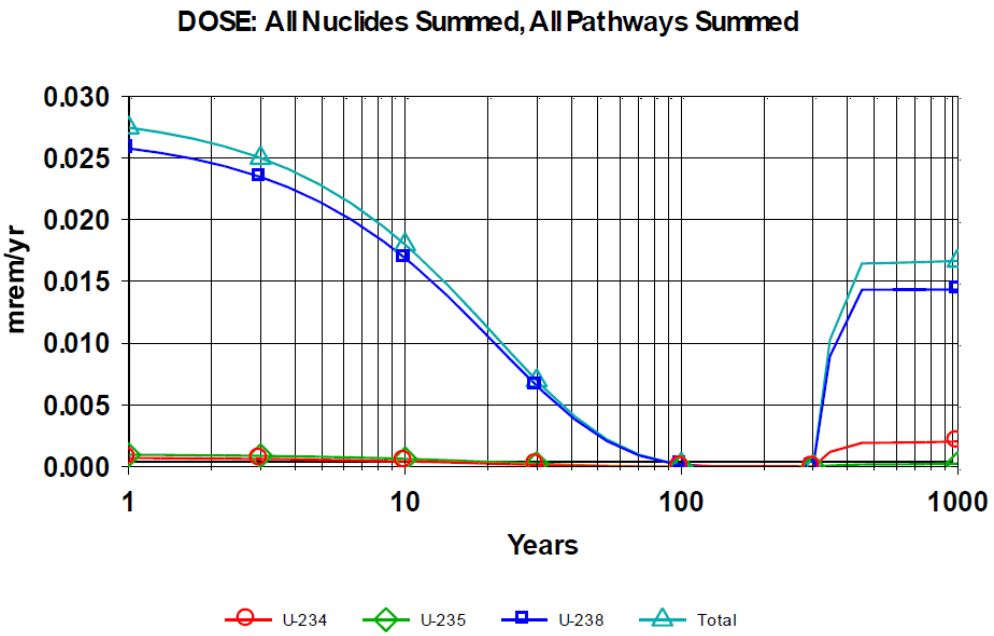

Figure 1 Annual dose vs. time for DU from 1000 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area, using RESRAD 7.0 defaults for resident farmer scenario

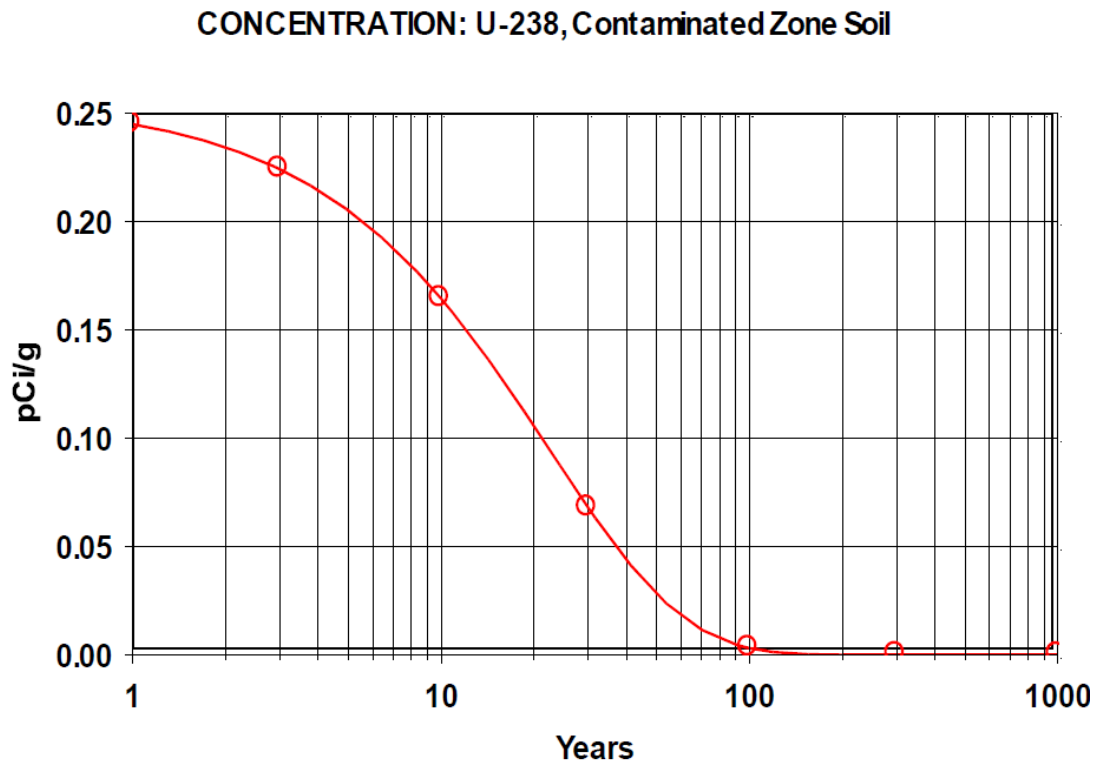

Figure 2 Uranium-238 activity concentration in impact area soil vs. time for DU from 1000 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area, using RESRAD 7.0 defaults for resident farmer scenario

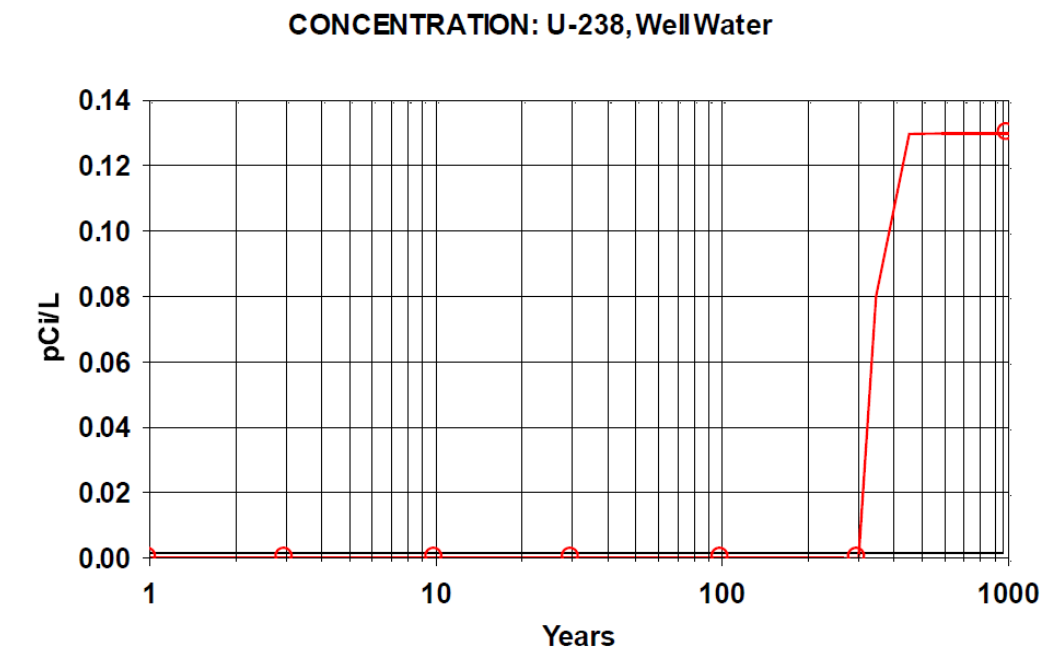

Figure 3 Uranium-238 activity concentration in well water vs. time for DU from 1000 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area, using RESRAD 7.0 defaults for resident farmer scenario

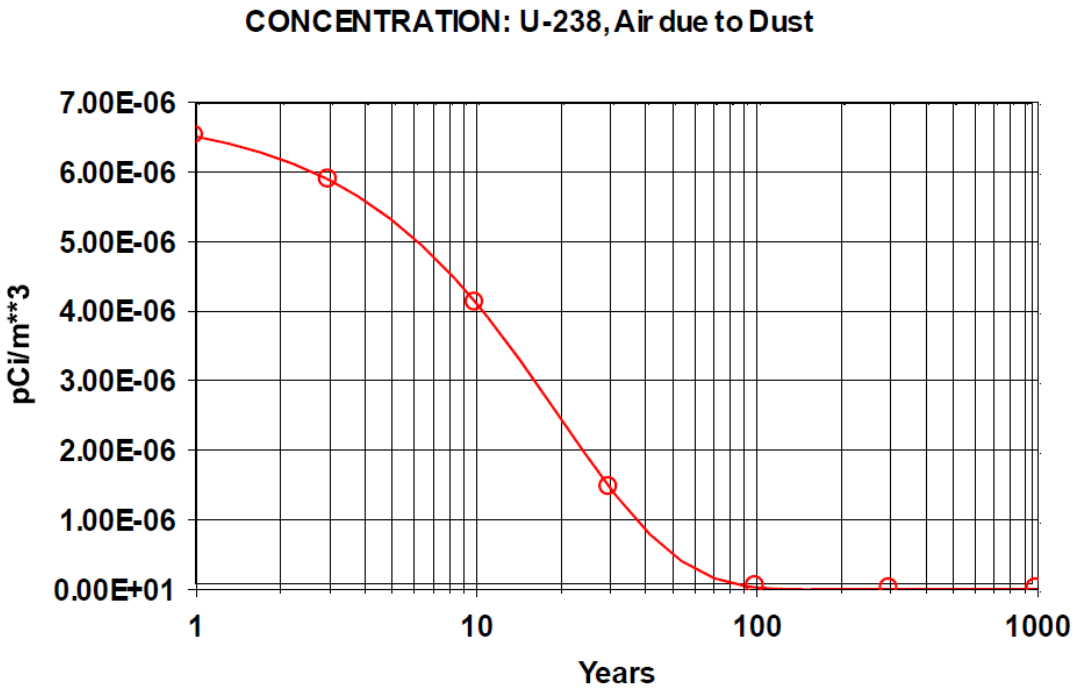

Figure 4 Uranium-238 activity concentration in air over impact area vs. time for DU from 1000 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area, using RESRAD 7.0 defaults for resident farmer scenario

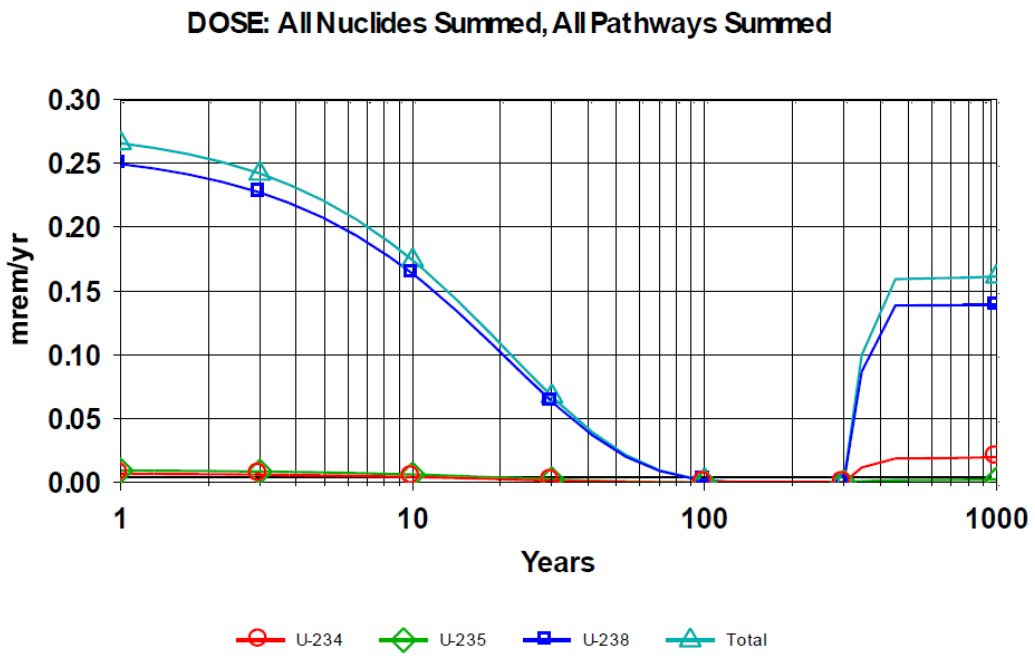

Figure 5 Annual dose vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area, using RESRAD 7.0 defaults for resident farmer scenario

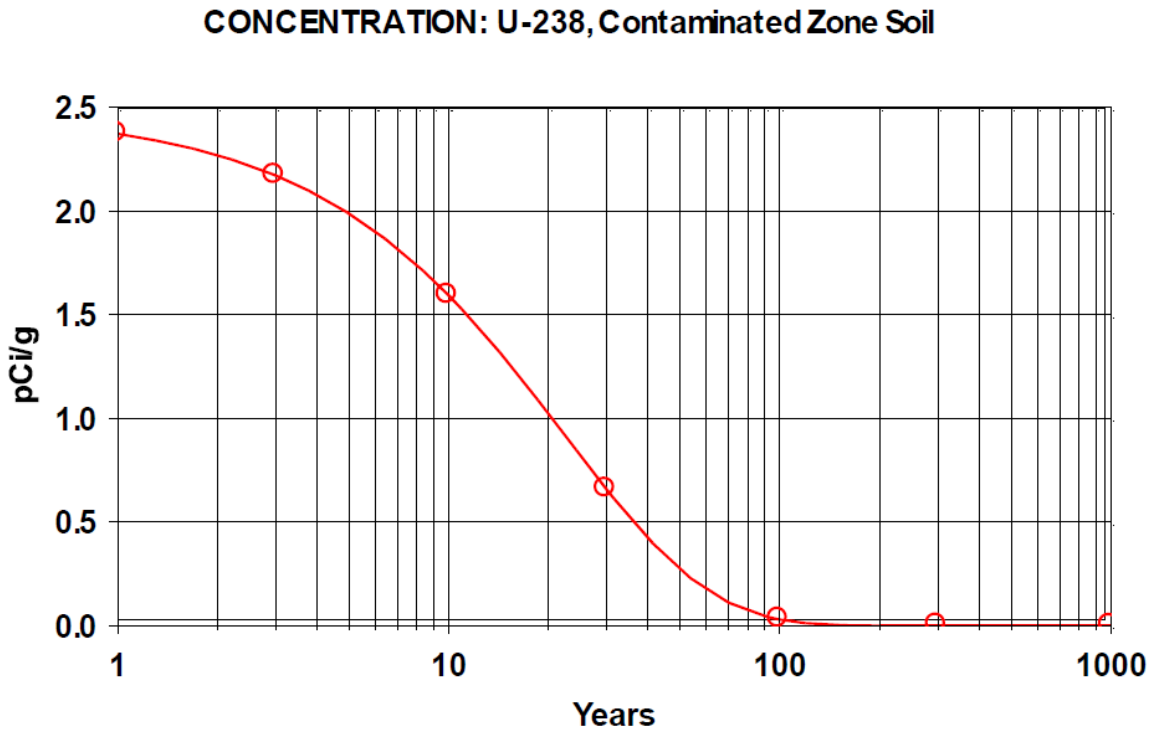

Figure 6 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area, using RESRAD 7.0 defaults for resident farmer scenario

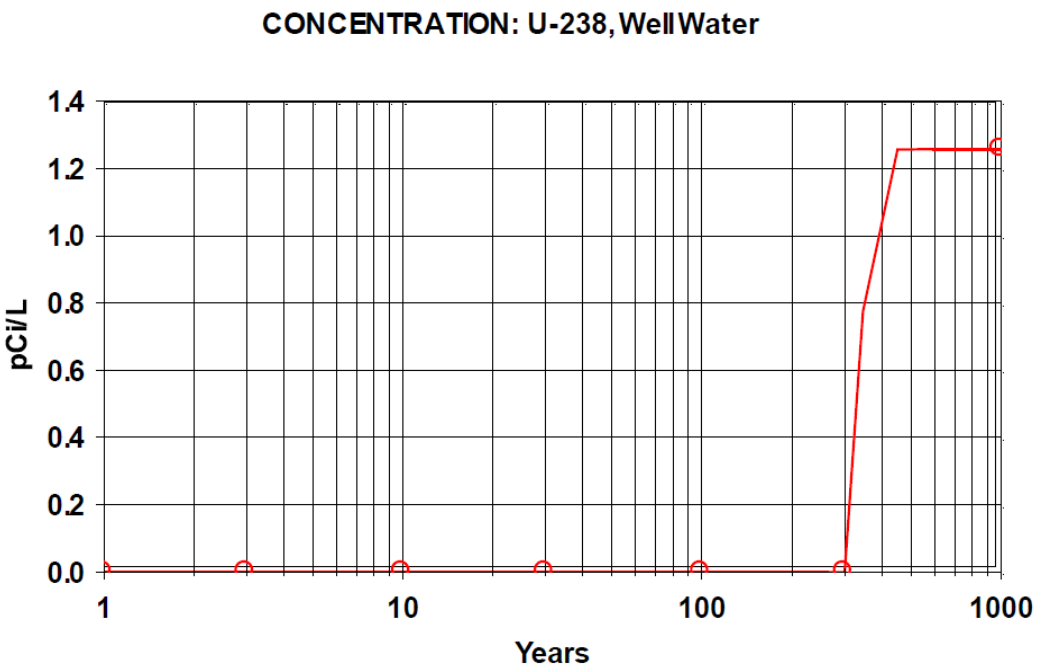

Figure 7 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area, using RESRAD 7.0 defaults for resident farmer scenario

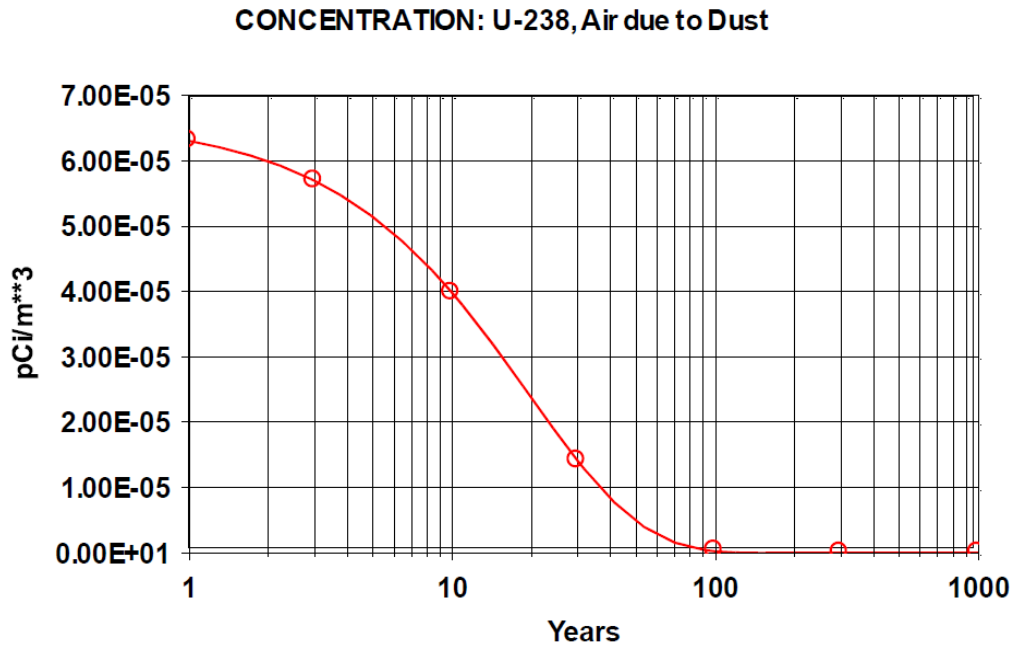

Figure 8 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area, using RESRAD 7.0 defaults for resident farmer scenario

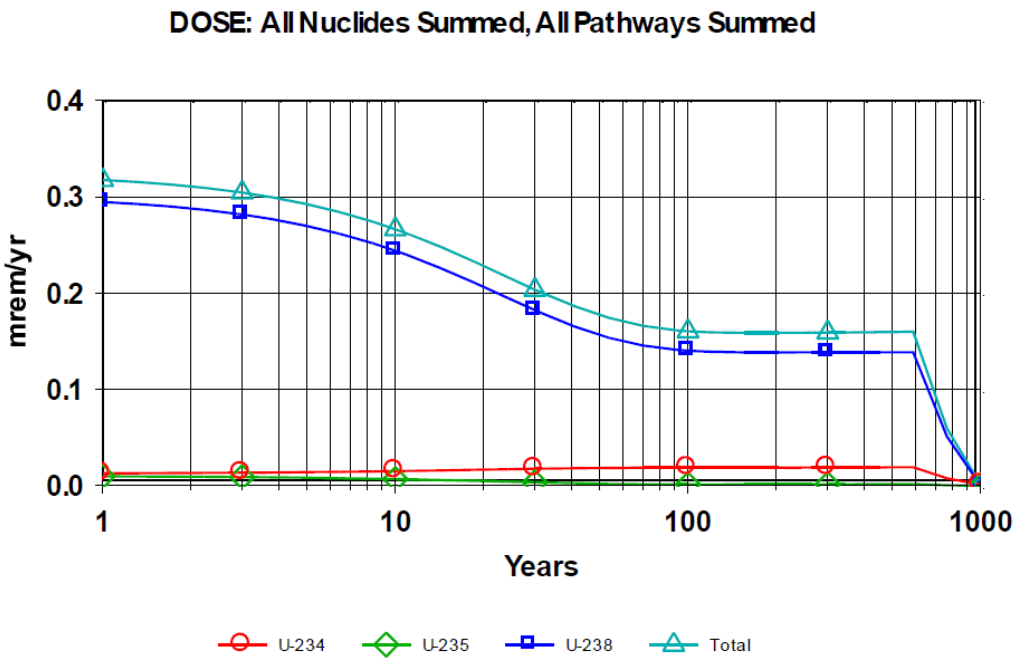

Figure 9 Annual dose vs. time from bounding value for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and water table 7.5 cm below ground surface, otherwise using RESRAD 7.0 defaults for resident farmer scenario

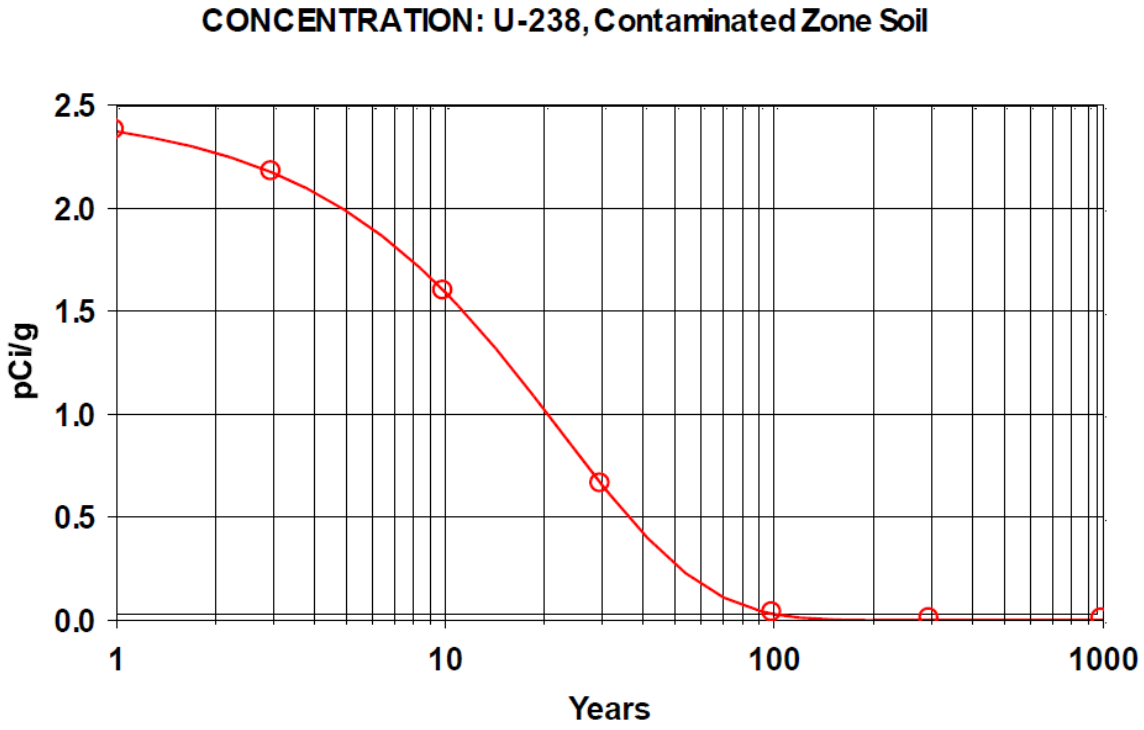

Figure 10 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and water table 7.5 cm below ground surface, otherwise using RESRAD 7.0 defaults for resident farmer scenario

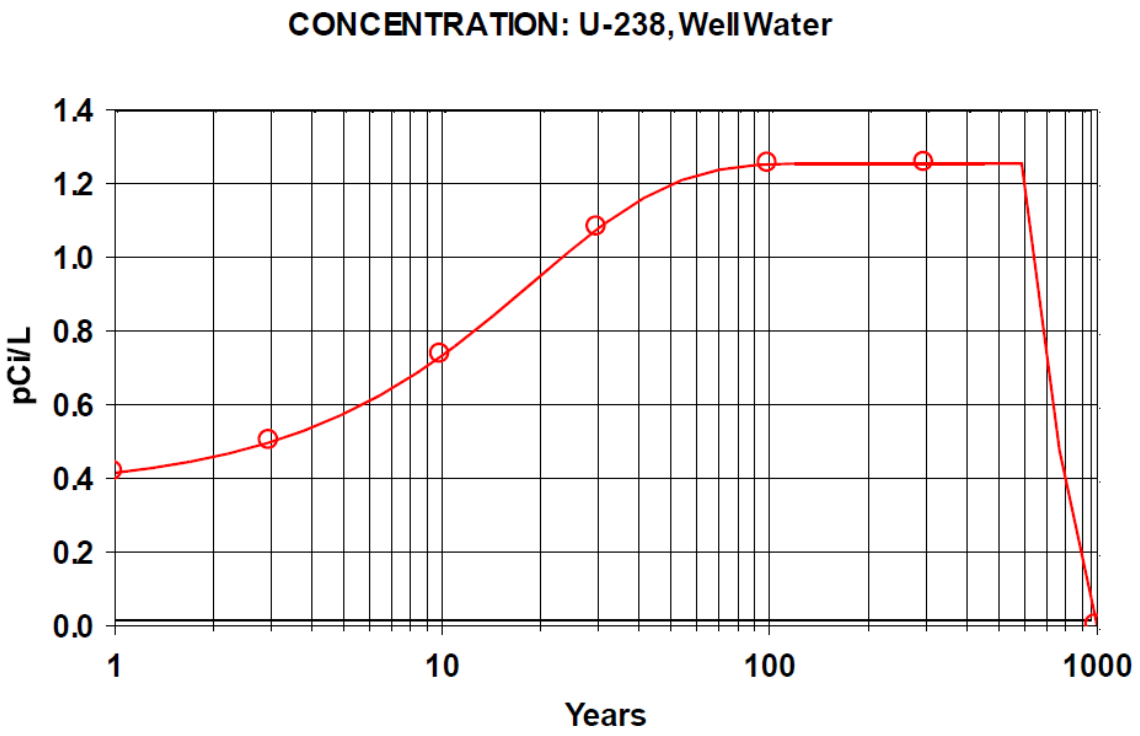

Figure 11 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and water table 7.5 cm below ground surface, otherwise using RESRAD 7.0 defaults for resident farmer scenario

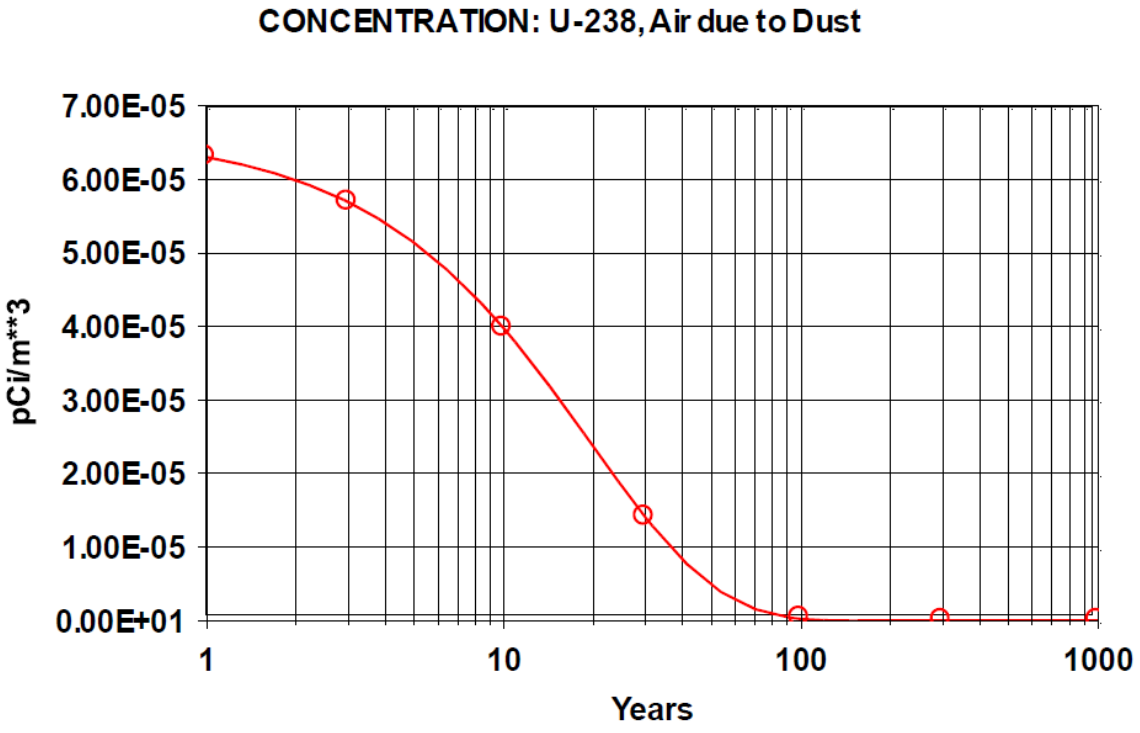

Figure 12 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and water table 7.5 cm below ground surface, otherwise using RESRAD 7.0 defaults for resident farmer scenario

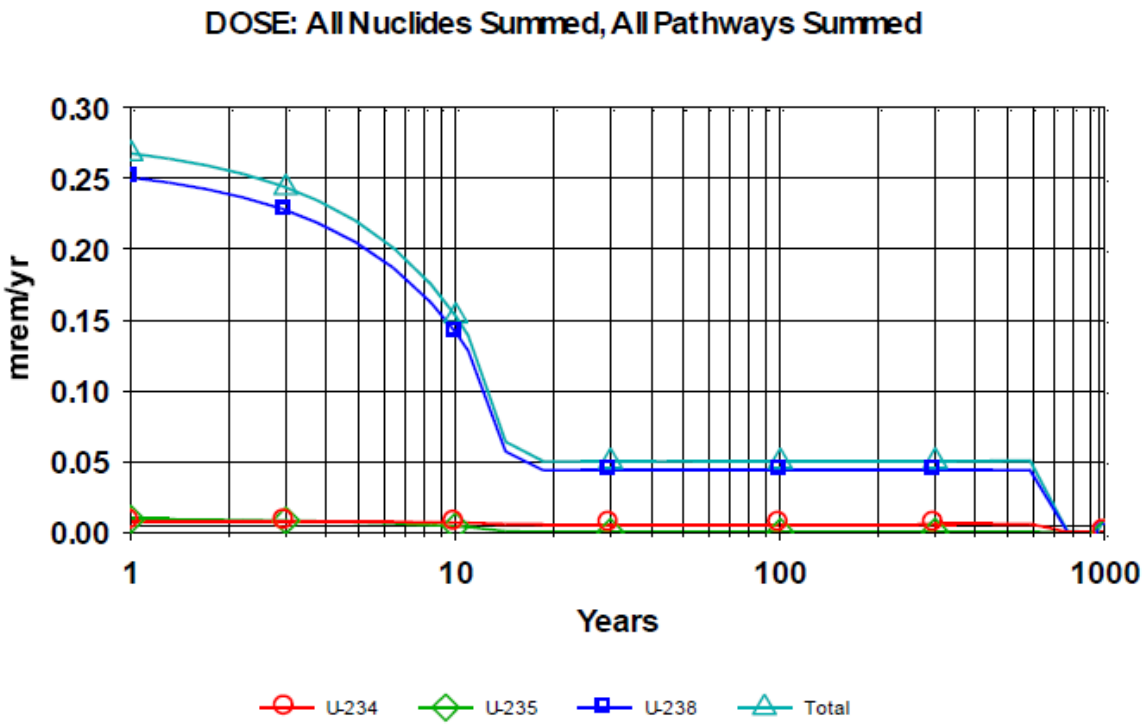

Figure 13 Annual dose vs. time from bounding value for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone erosion rate of 0.01 m/y, otherwise using RESRAD 7.0 defaults for resident farmer scenario

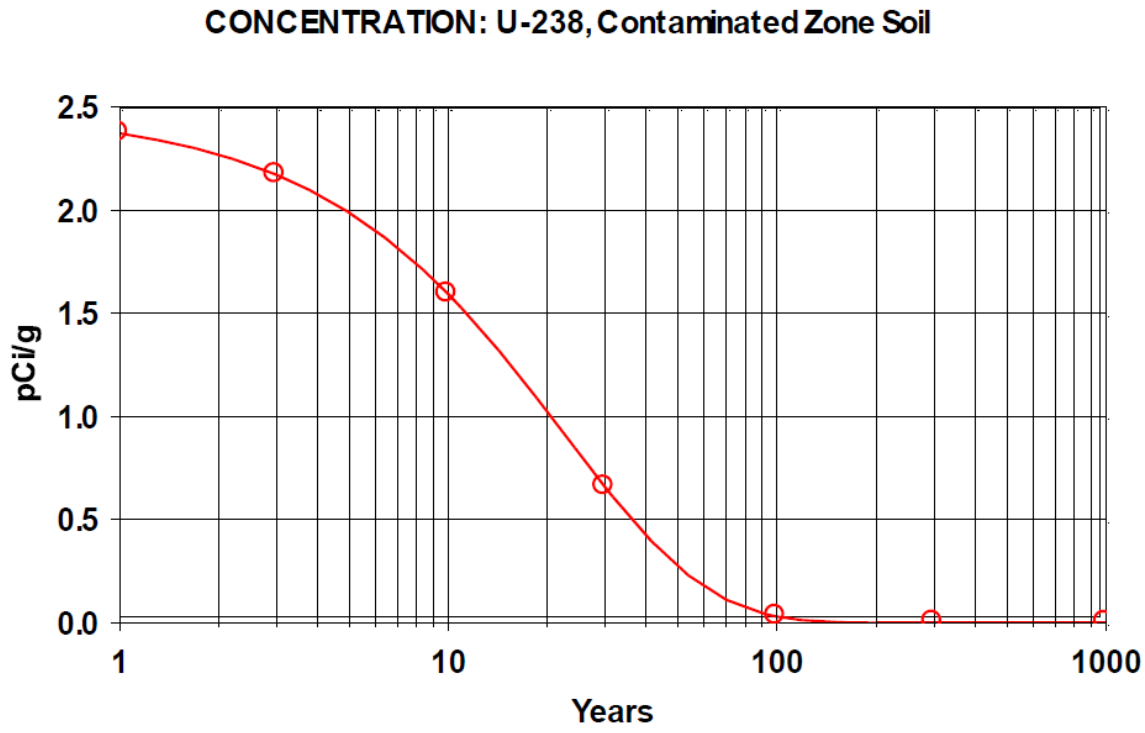

Figure 14 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone erosion rate of 0.01 m/y, otherwise using RESRAD 7.0 defaults for resident farmer scenario

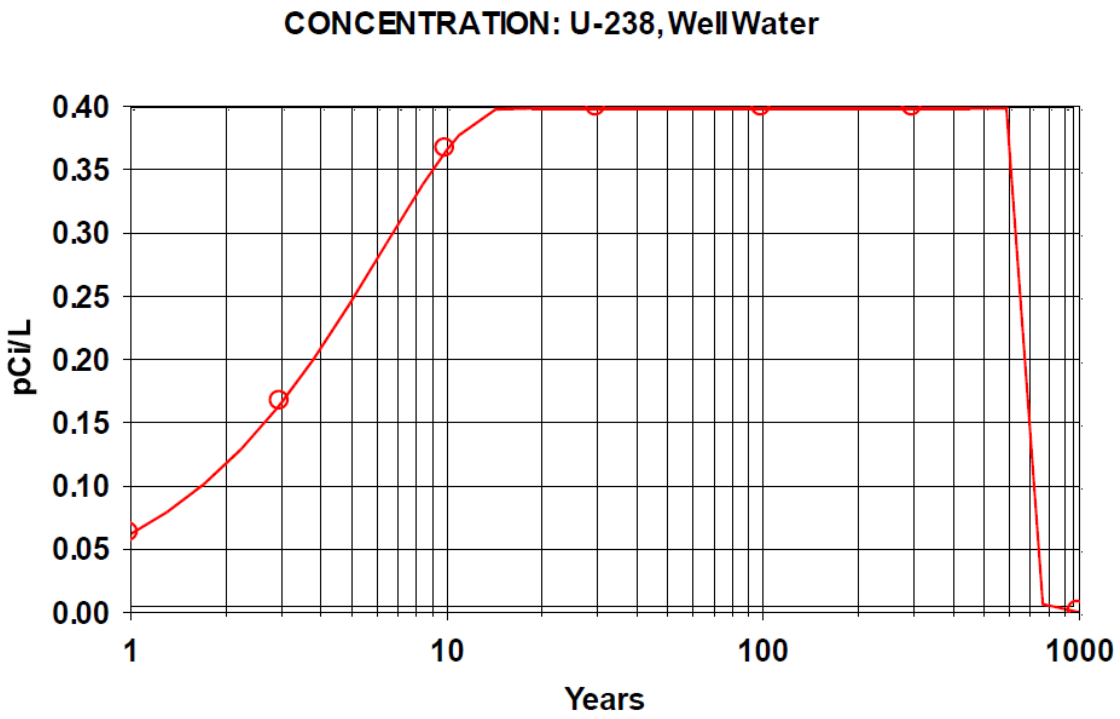

Figure 15 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone erosion rate of 0.01 m/y, otherwise using RESRAD 7.0 defaults for resident farmer scenario

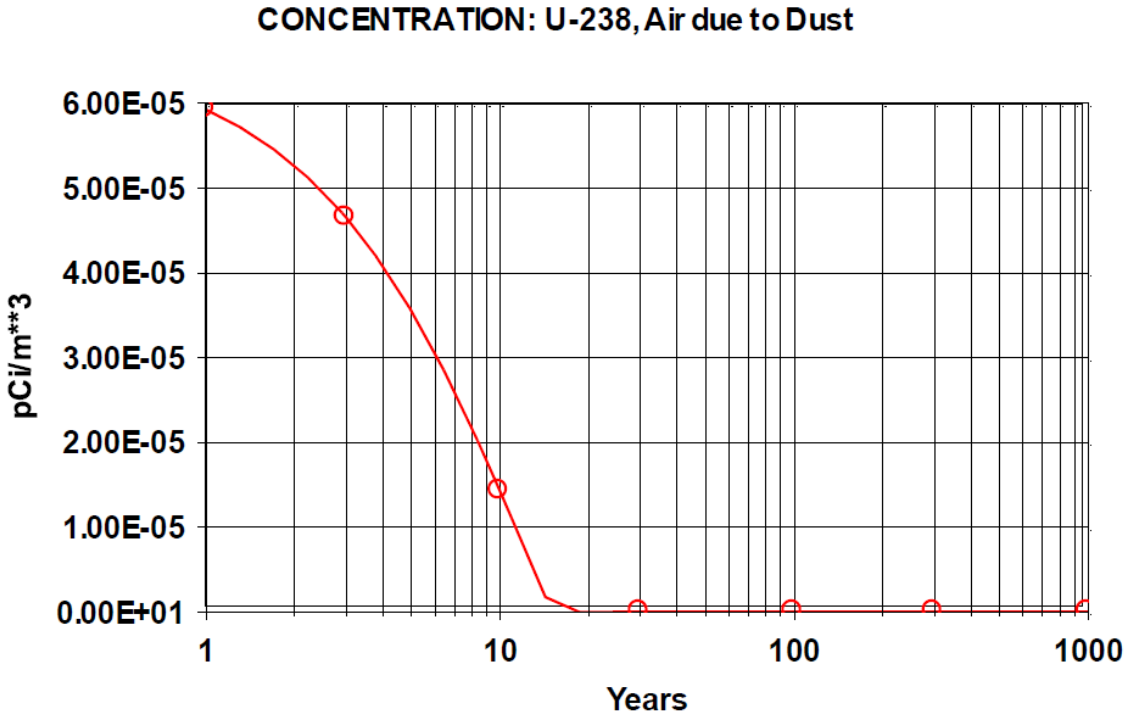

Figure 16 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone erosion rate of 0.01 m/y, otherwise using RESRAD 7.0 defaults for resident farmer scenario

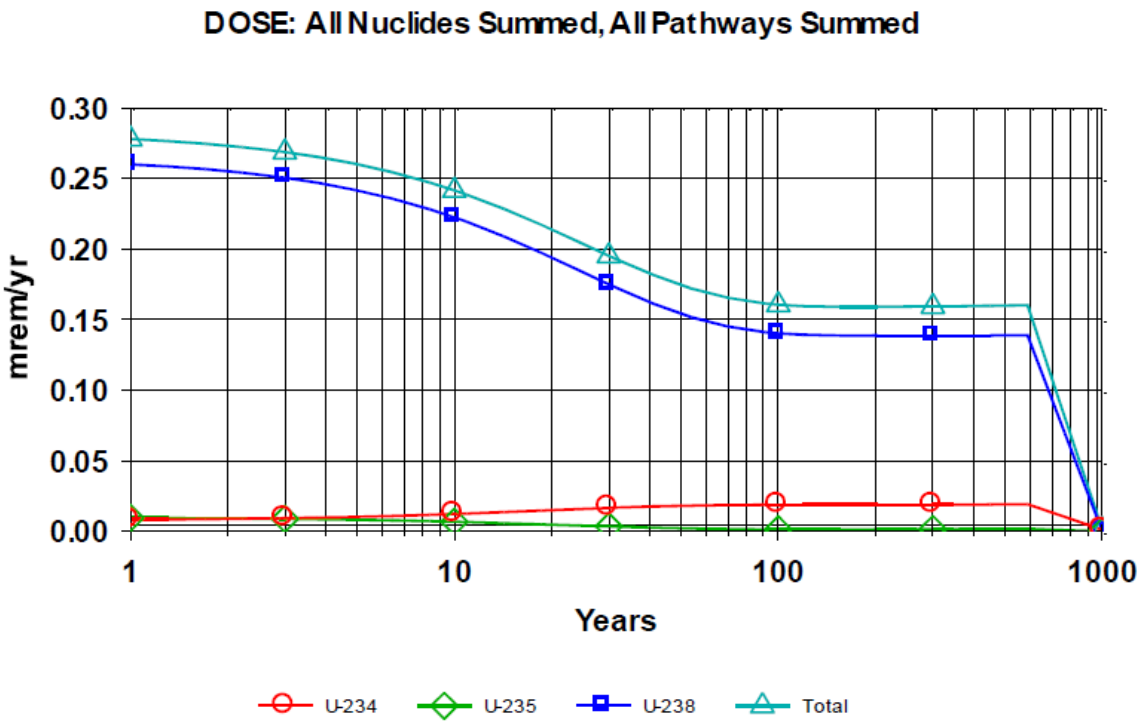

Figure 17 Annual dose vs. time from bounding value for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone total porosity of 0.6, otherwise using RESRAD 7.0 defaults for resident farmer scenario

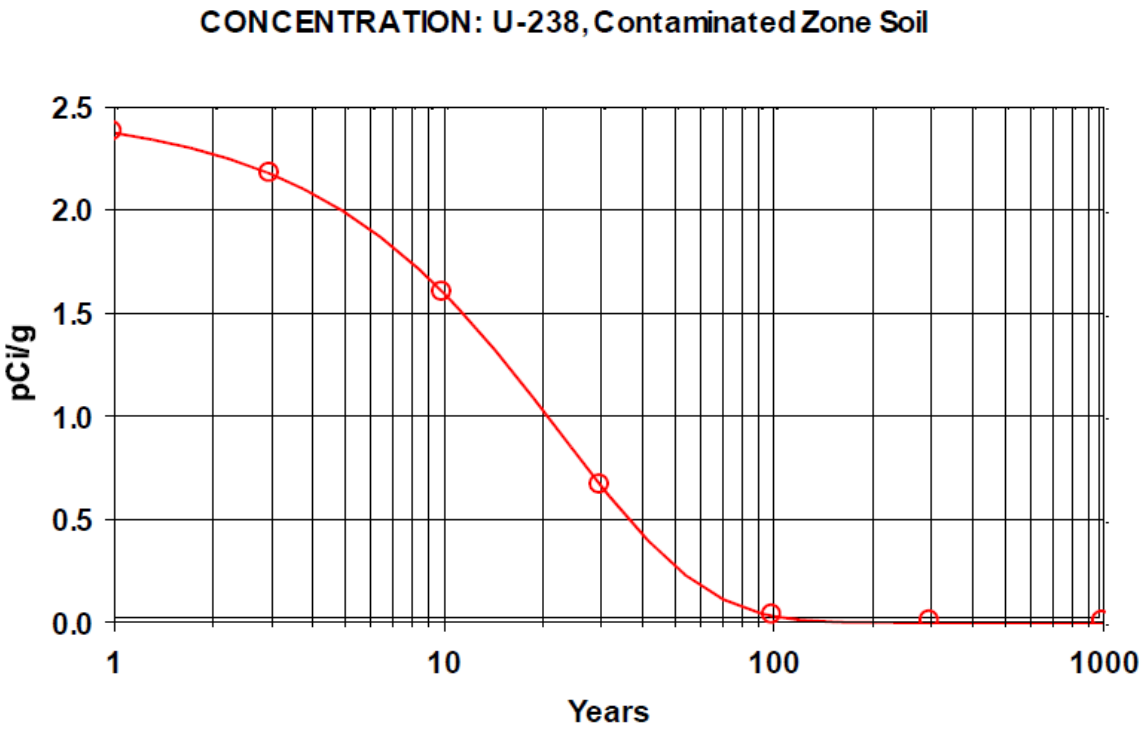

Figure 18 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone total porosity of 0.6, otherwise using RESRAD 7.0 defaults for resident farmer scenario

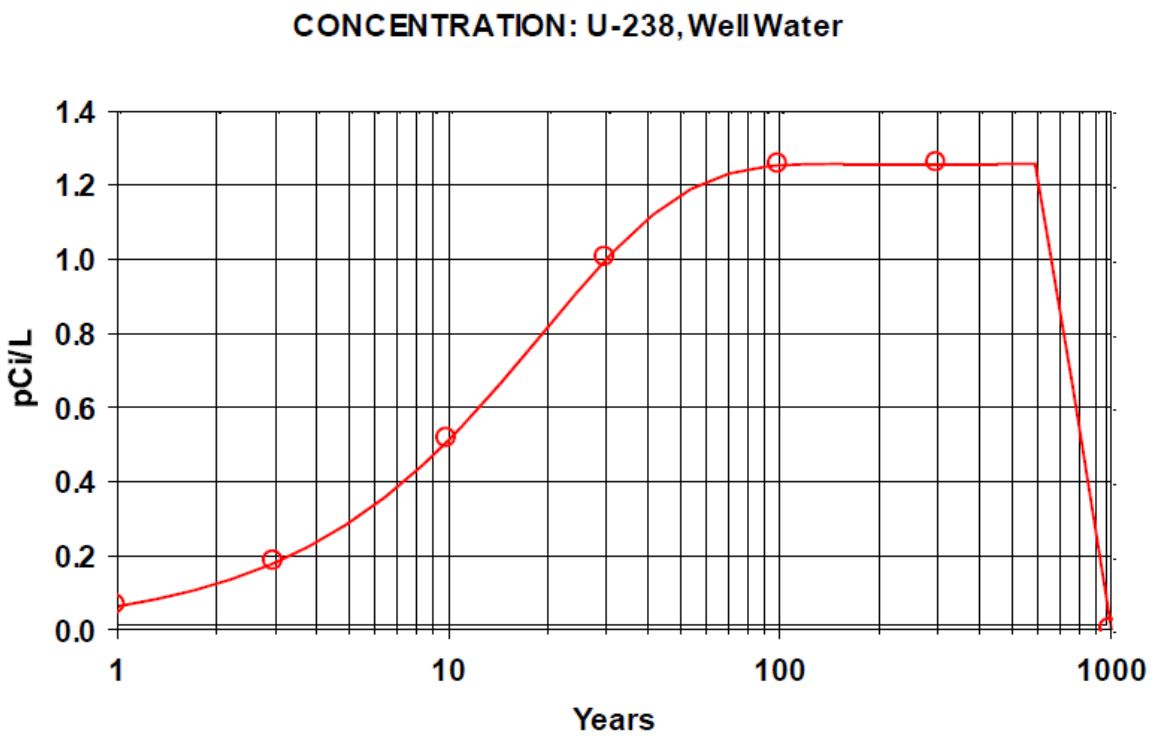

Figure 19 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone total porosity of 0.6, otherwise using RESRAD 7.0 defaults for resident farmer scenario

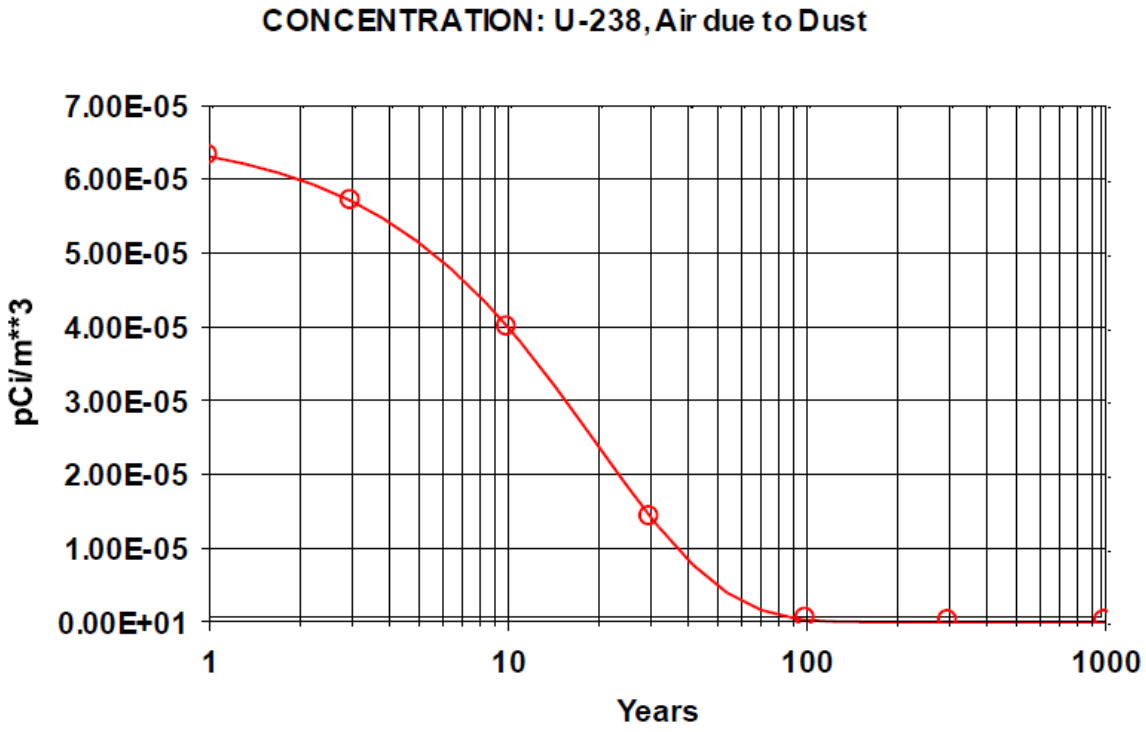

Figure 20 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone total porosity of 0.6, otherwise using RESRAD 7.0 defaults for resident farmer scenario

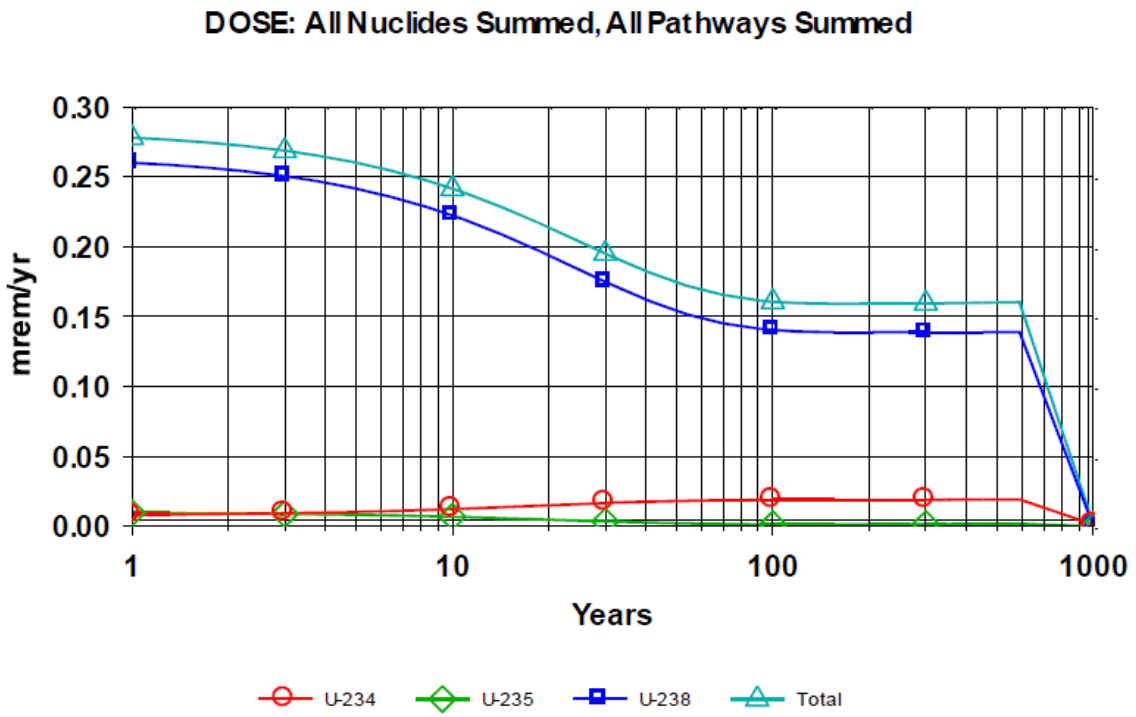

Figure 21 Annual dose vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone hydraulic conductivity of 6000 m/y, otherwise using RESRAD 7.0 defaults for resident farmer scenario

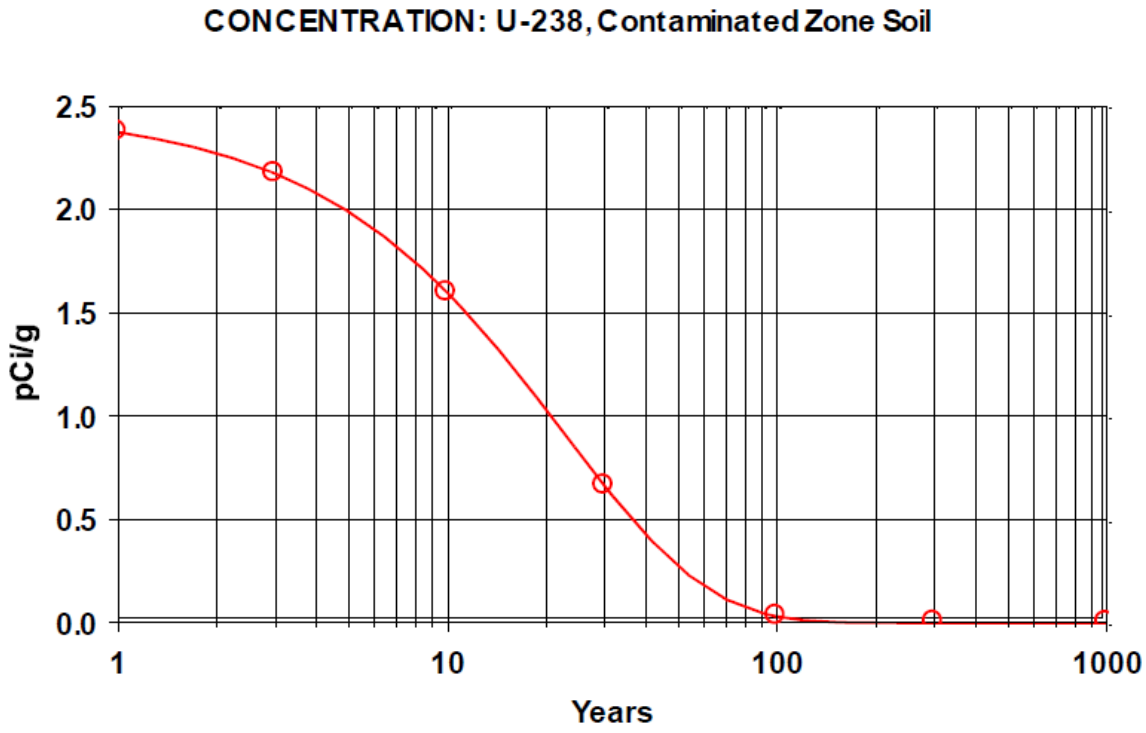

Figure 22 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone hydraulic conductivity of 6000 m/y, otherwise using RESRAD 7.0 defaults for resident farmer scenario

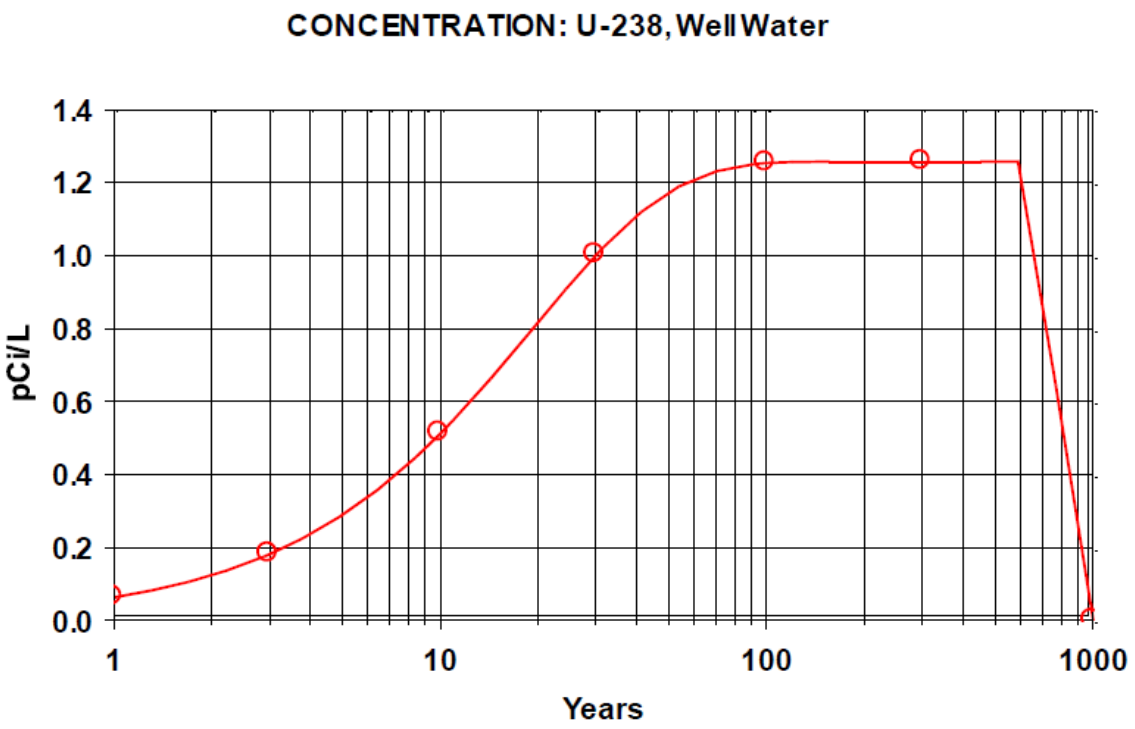

Figure 23 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone hydraulic conductivity of 6000 m/y, otherwise using RESRAD 7.0 defaults for resident farmer scenario

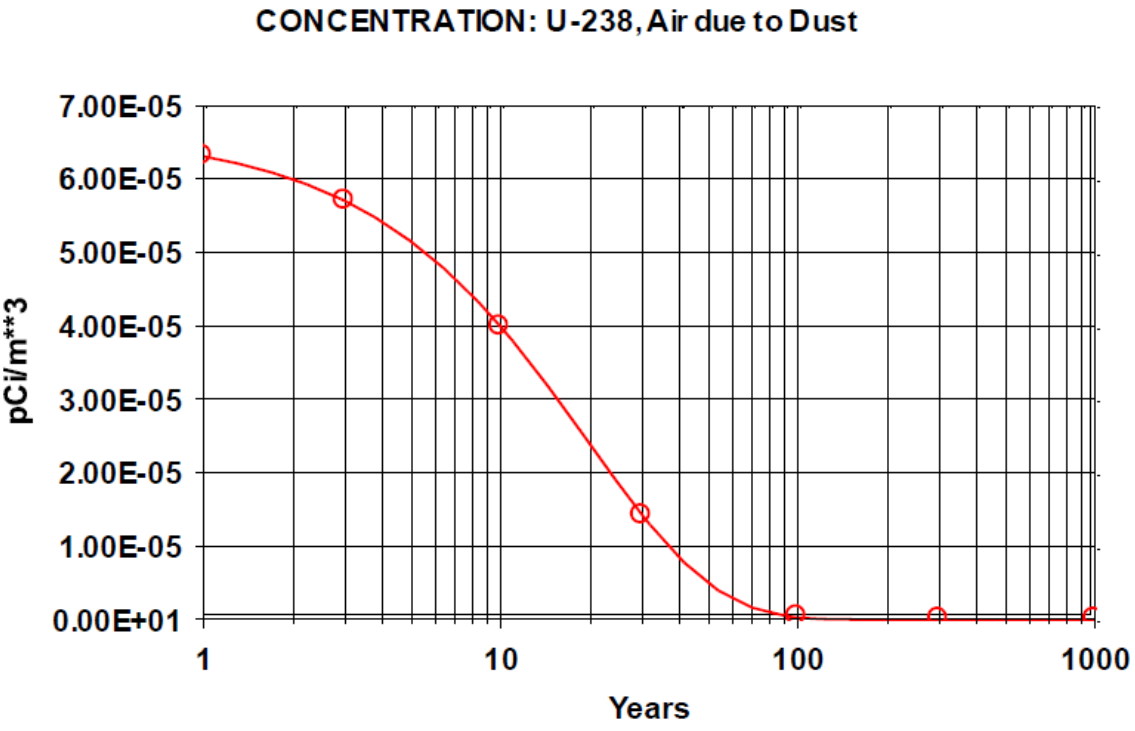

Figure 24 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and contamination zone hydraulic conductivity of 6000 m/y, otherwise using RESRAD 7.0 defaults for resident farmer scenario

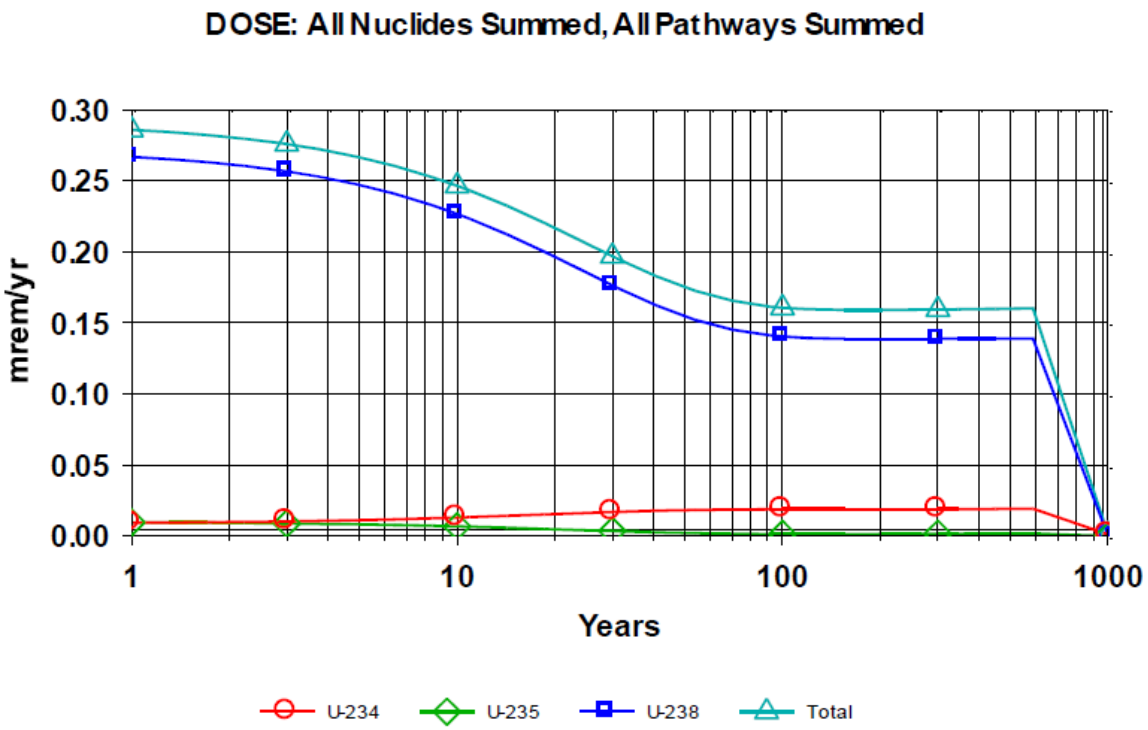

Figure 25 Annual dose vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and average annual wind speed of 1 m/h otherwise using RESRAD 7.0 defaults for resident farmer scenario

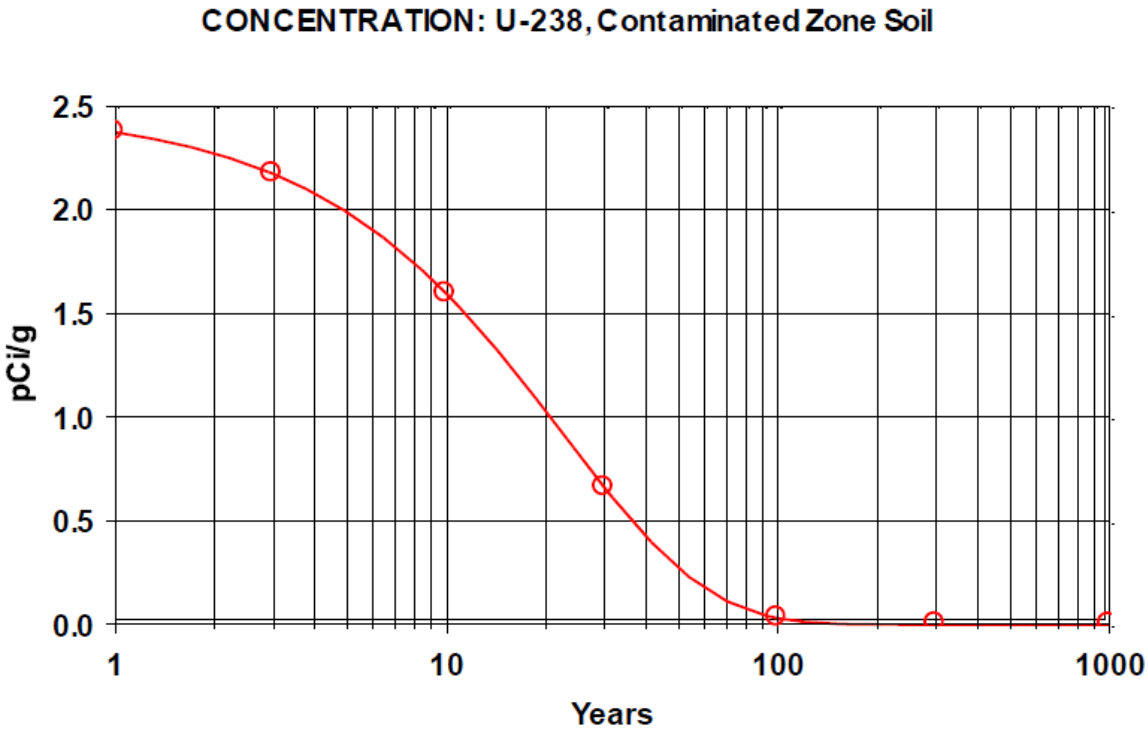

Figure 26 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and average annual wind speed of 1 m/h, otherwise using RESRAD 7.0 defaults for resident farmer scenario

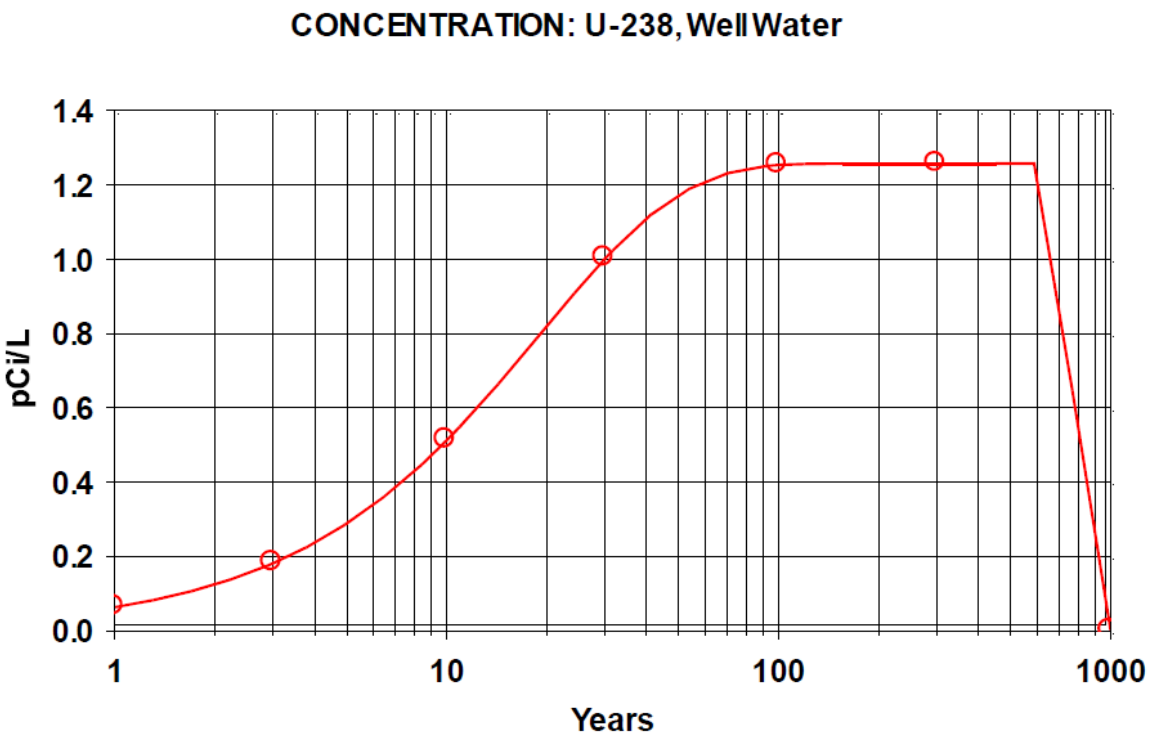

Figure 27 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and annual wind speed of 1 m/h, otherwise using RESRAD 7.0 defaults for resident farmer scenario

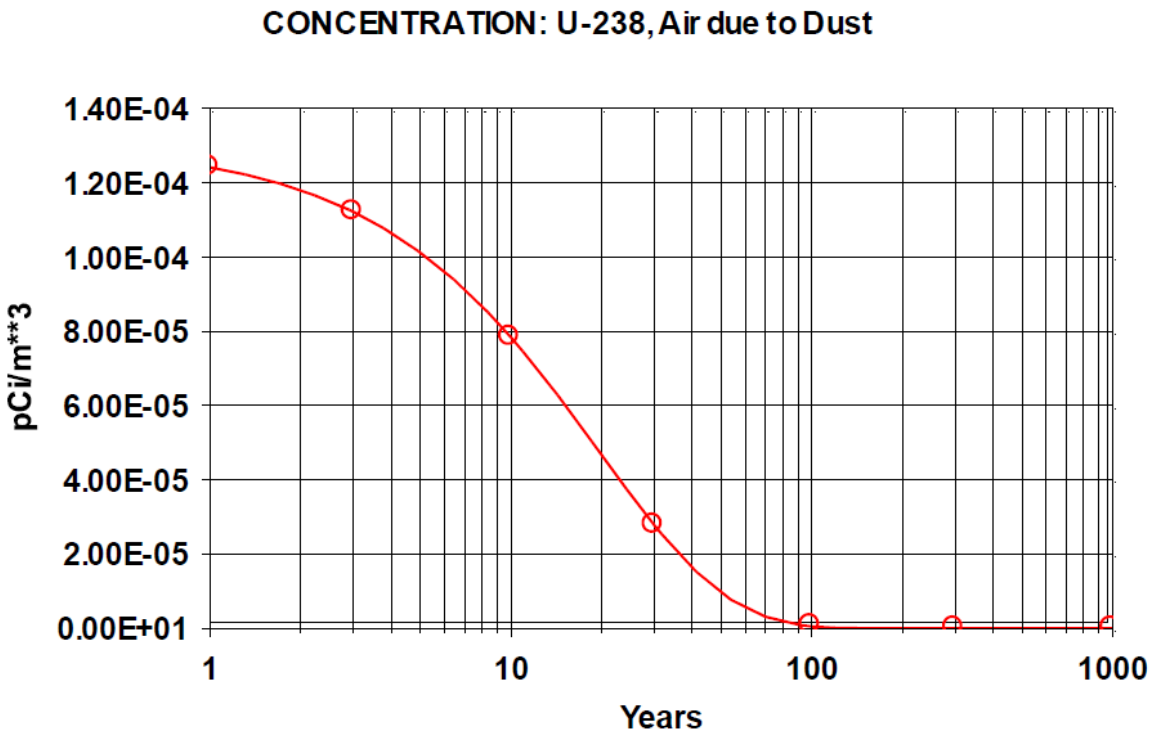

Figure 28 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and annual wind speed of 1 m/h, otherwise using RESRAD 7.0 defaults for resident farmer scenario

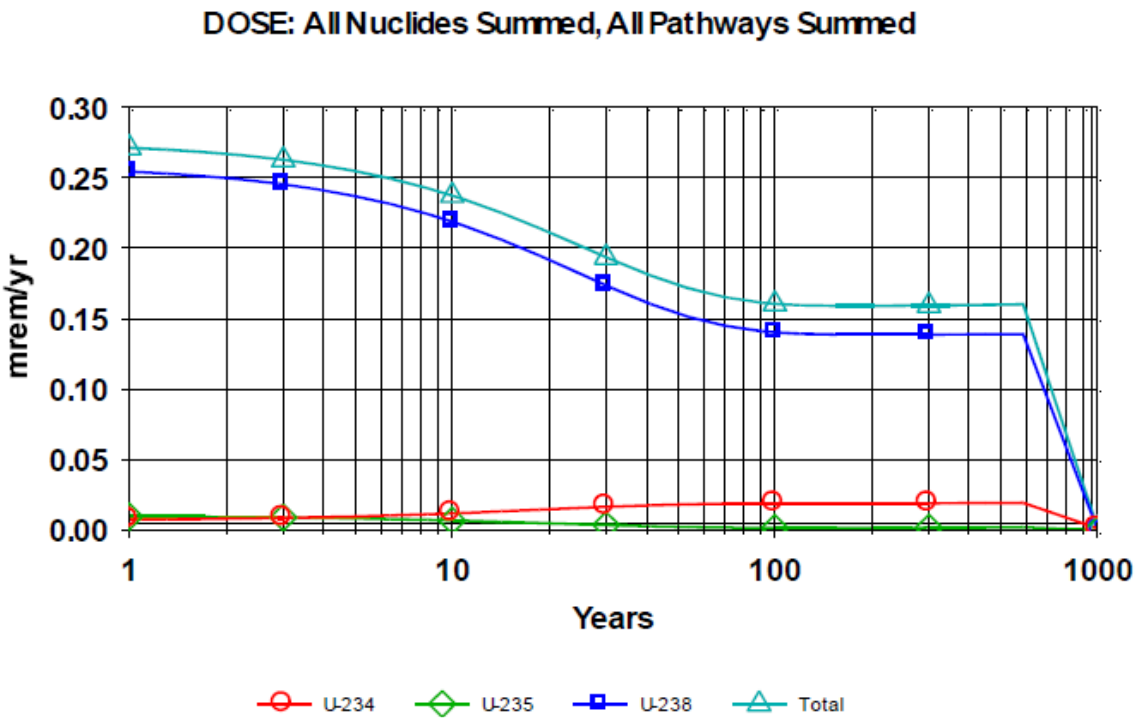

Figure 29 Annual dose vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and average annual wind speed of 10 m/h otherwise using RESRAD 7.0 defaults for resident farmer scenario

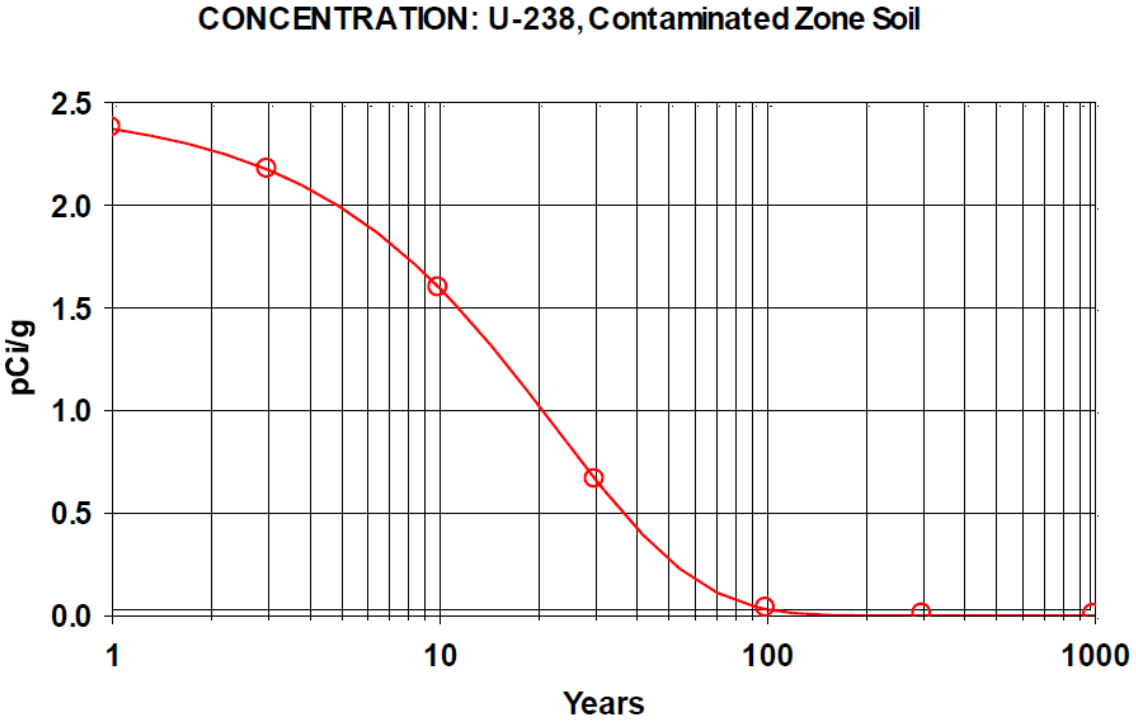

Figure 30 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and average annual wind speed of 10 m/h, otherwise using RESRAD 7.0 defaults for resident farmer scenario

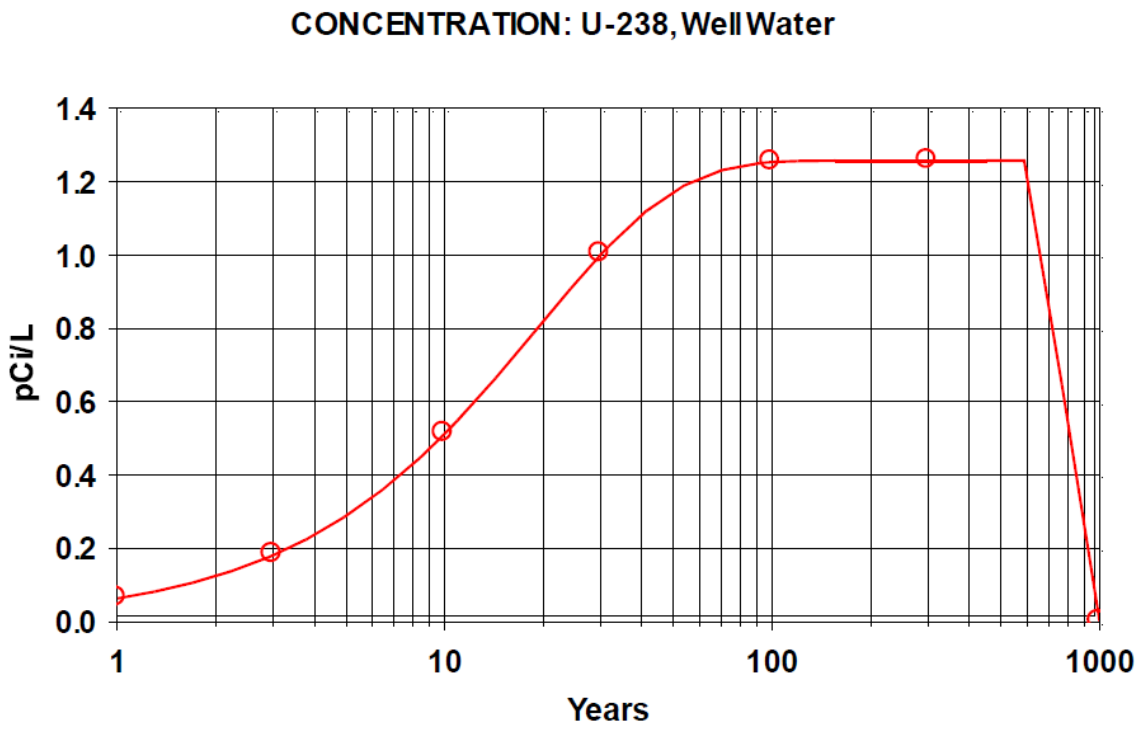

Figure 31 Uranium-238 activity concentration in well water vs. time for bounding value for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and annual wind speed of 10 m/h, otherwise using RESRAD 7.0 defaults for resident farmer scenario

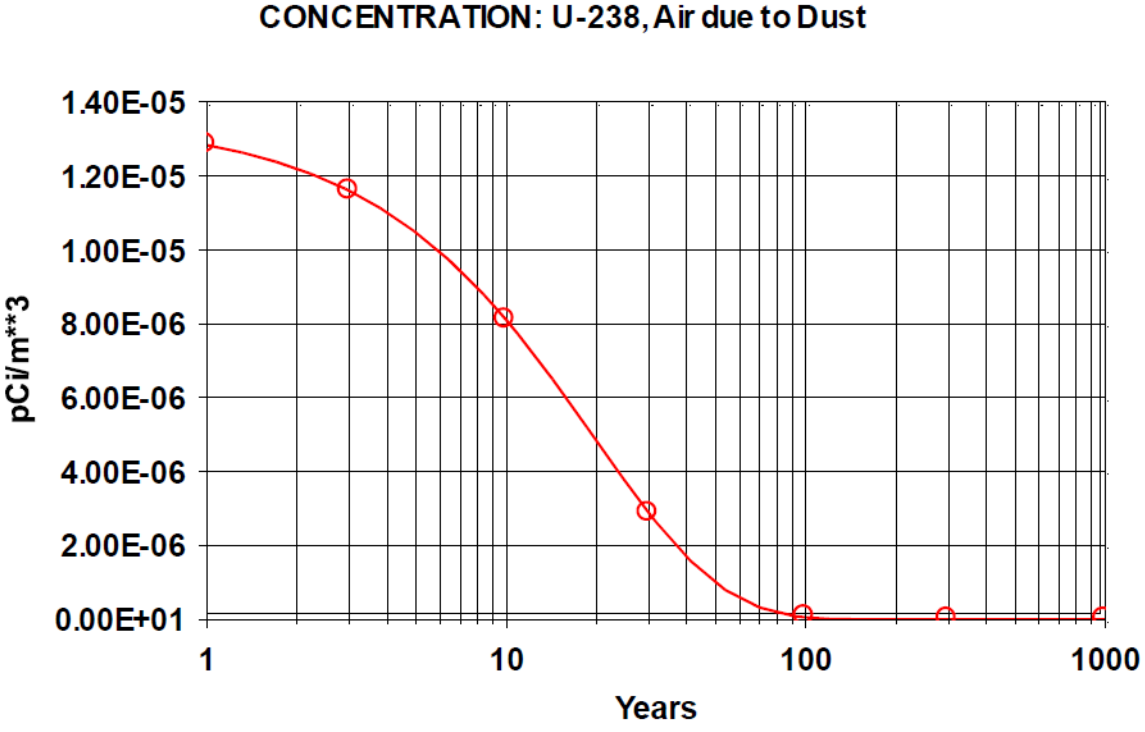

Figure 32 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and annual wind speed of 10 m/h, otherwise using RESRAD 7.0 defaults for resident farmer scenario

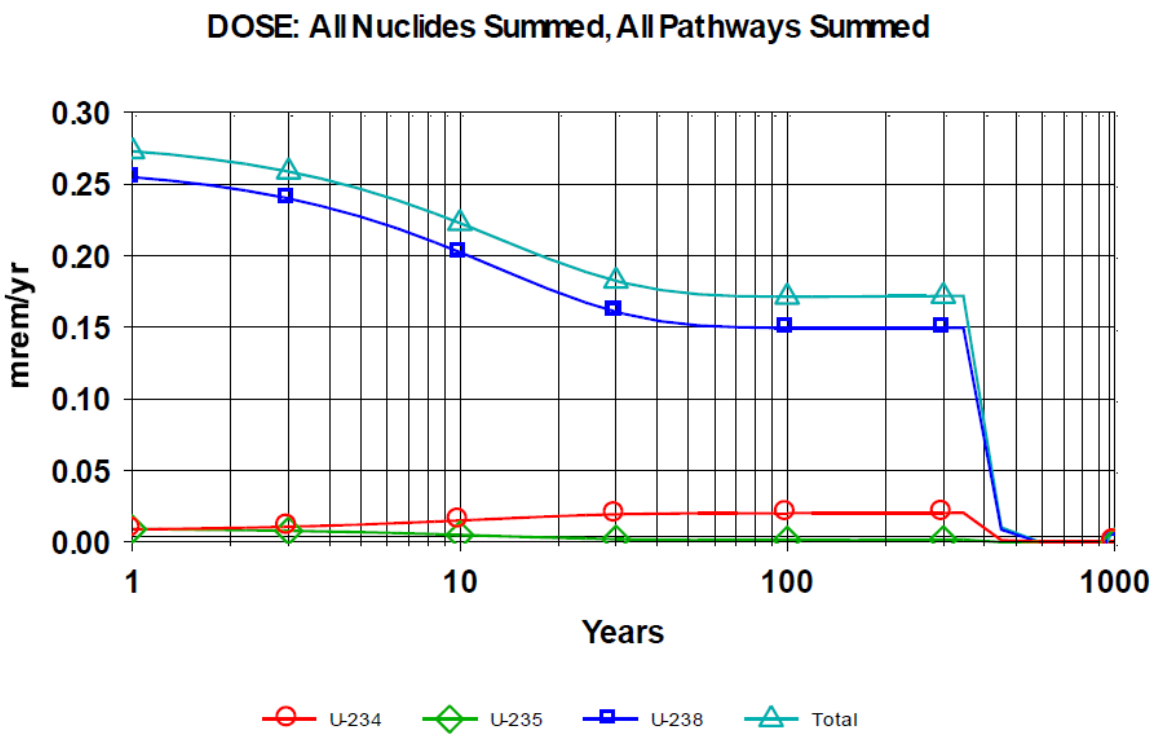

Figure 33 Annual dose vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and average annual precipitation of 2 m otherwise using RESRAD 7.0 defaults for resident farmer scenario

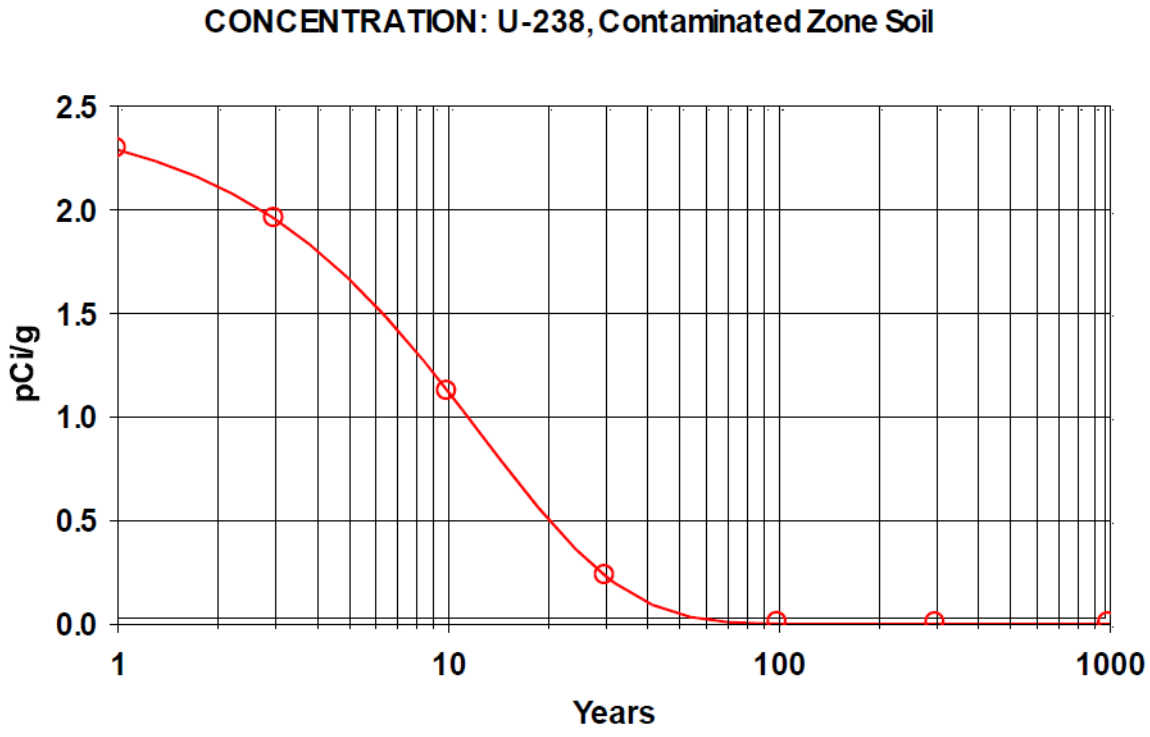

Figure 34 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and average annual precipitation of 2 m, otherwise using RESRAD 7.0 defaults for resident farmer scenario

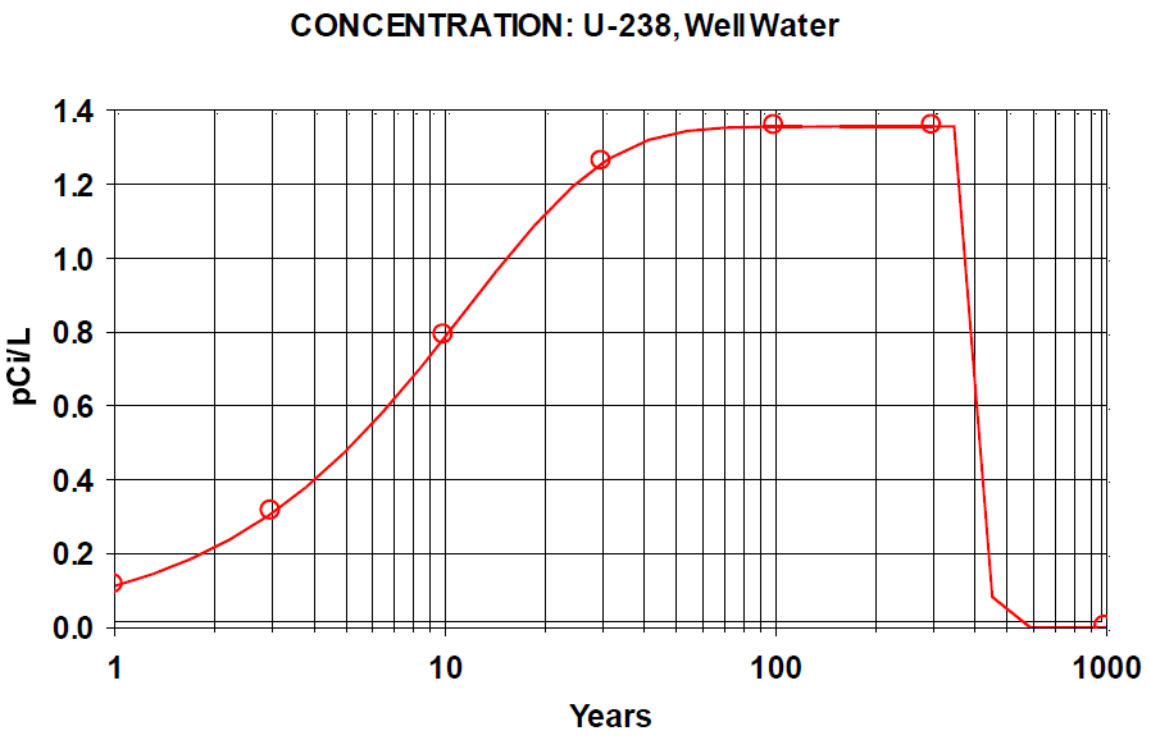

Figure 35 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and annual precipitation of 2 m, otherwise using RESRAD 7.0 defaults for resident farmer scenario

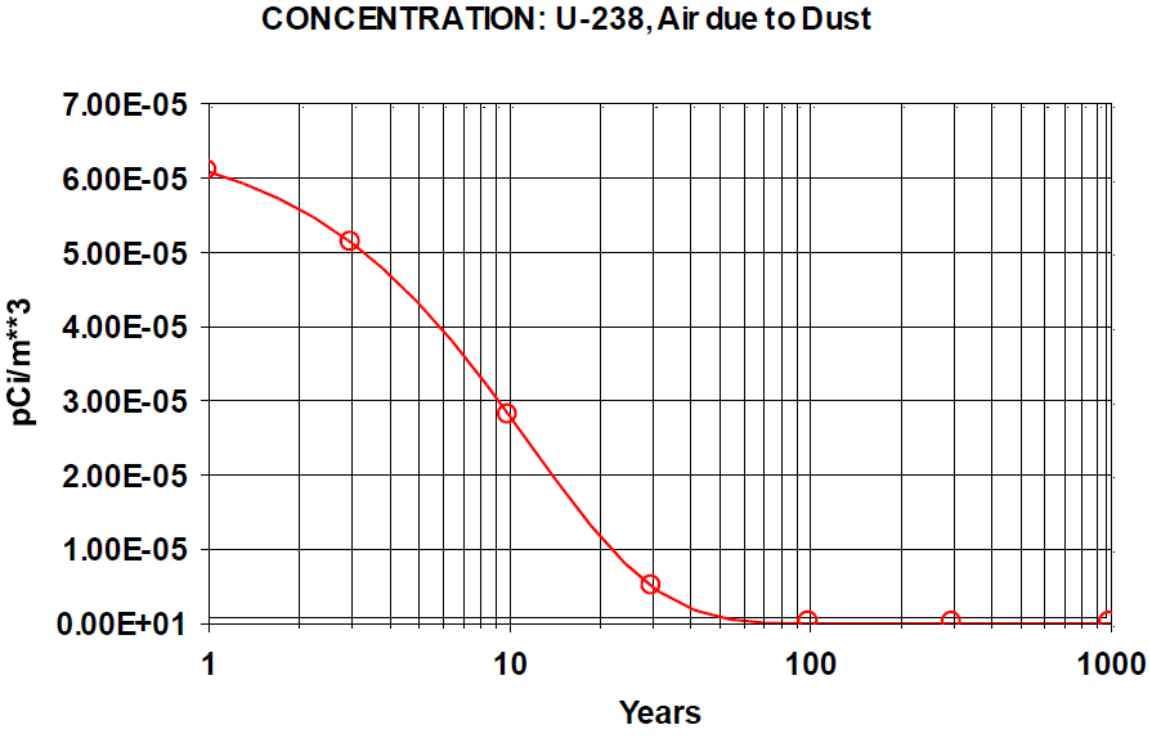

Figure 36 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area and annual precipitation of 2 m, otherwise using RESRAD 7.0 defaults for resident farmer scenario

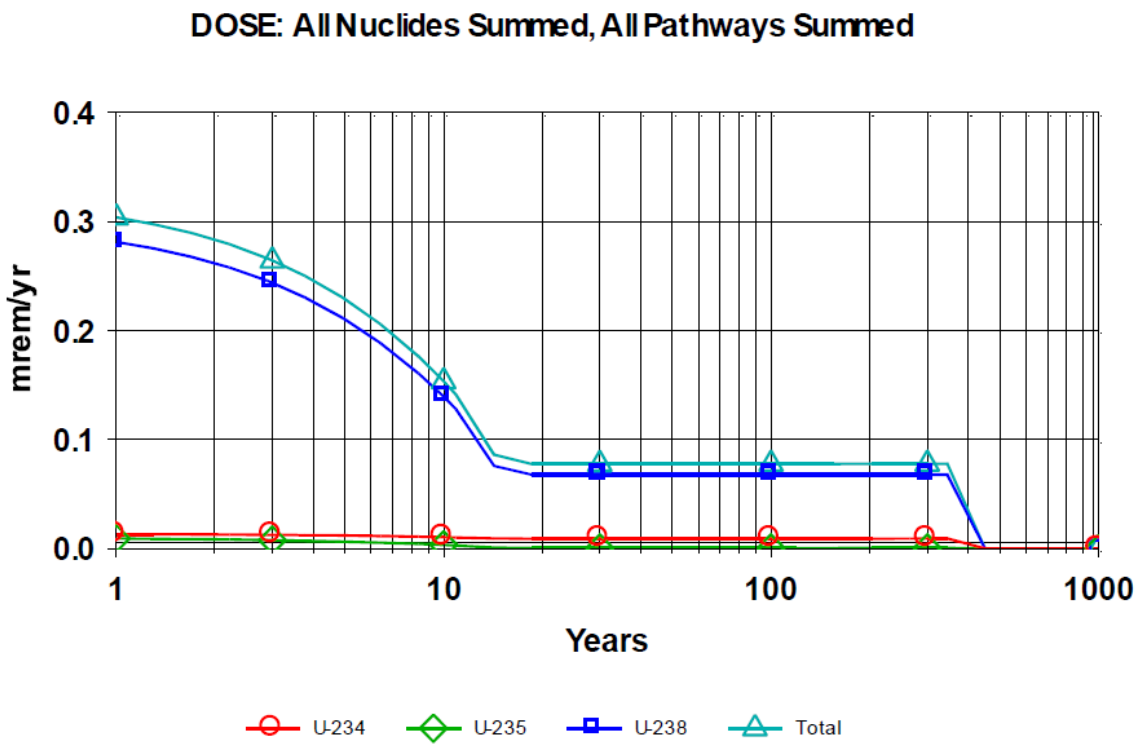

Figure 37 Annual dose vs. time from 9700 M101 DU rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area with several bounding environmental parameters using RESRAD 7.0 for the resident farmer scenario

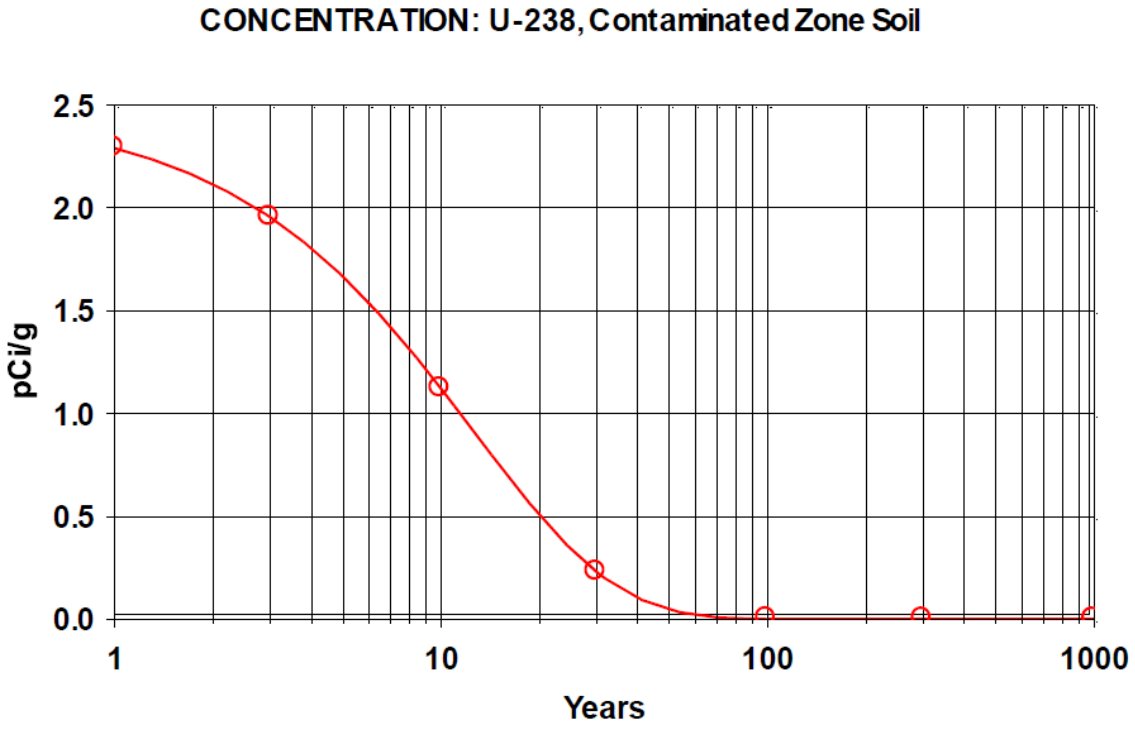

Figure 38 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area with several bounding environmental parameters using RESRAD 7.0 for the resident farmer scenario

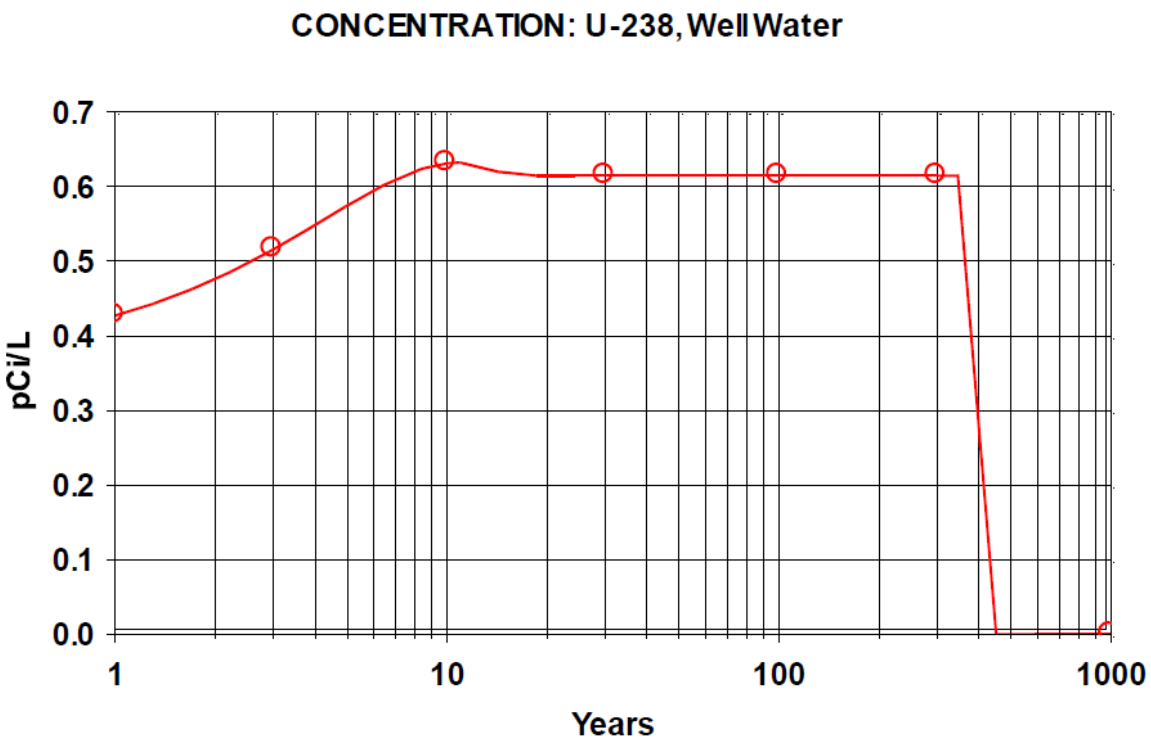

Figure 39 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area with several bounding environmental parameters using RESRAD 7.0 for the resident farmer scenario

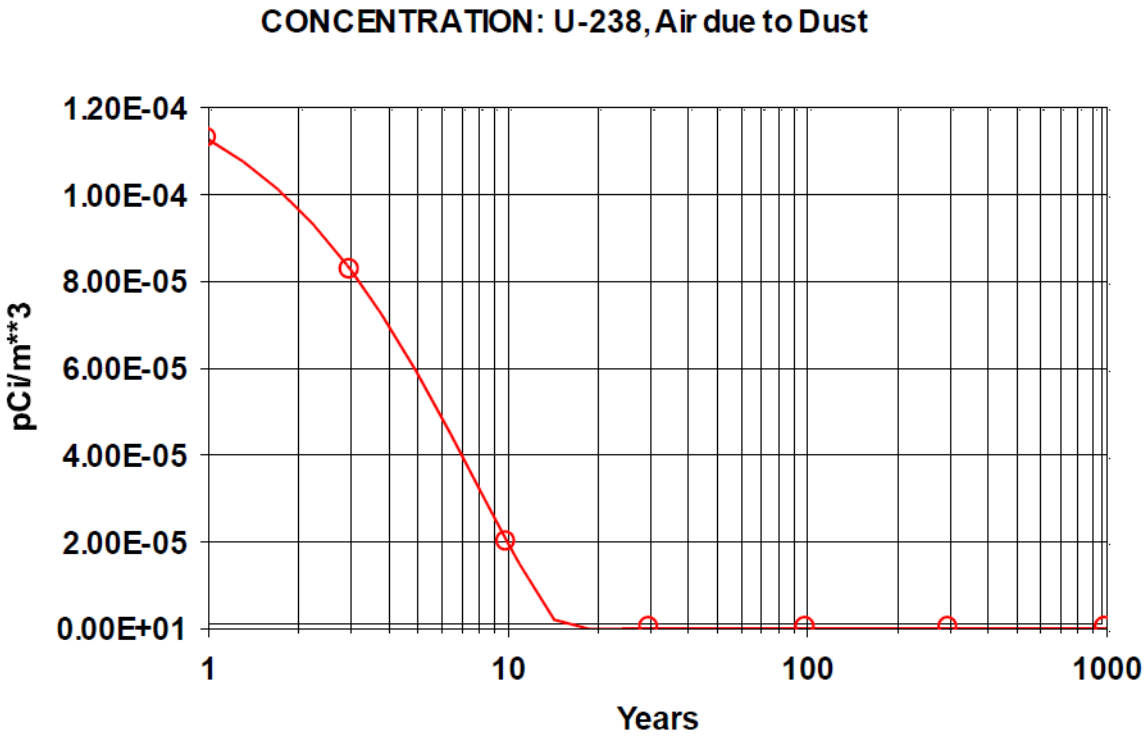

Figure 40 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a one square kilometer impact area with several bounding environmental parameters using RESRAD 7.0 for the resident farmer scenario

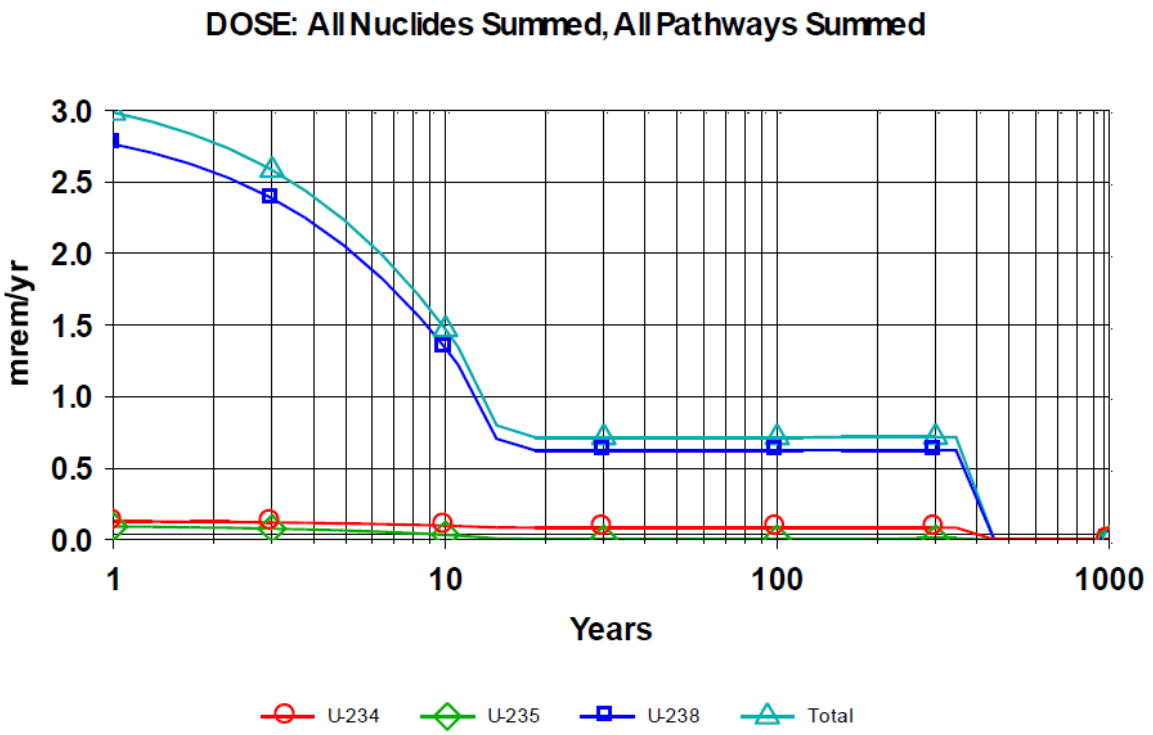

Figure 41 Annual dose vs. time for DU from 9700 M101 DU rounds evenly dispersed in top 15 cm of soil in a 0.1 square kilometer impact area with several bounding environmental parameters using RESRAD 7.0 for the resident farmer scenario

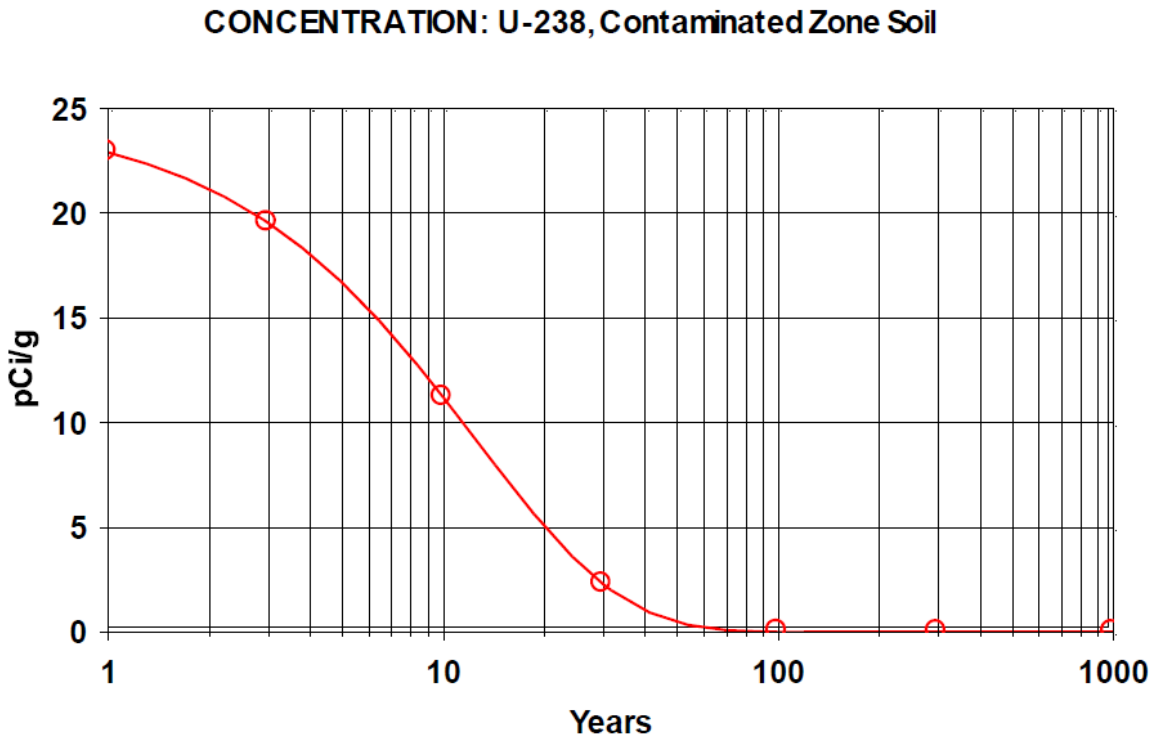

Figure 42 Uranium-238 activity concentration in impact area soil vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a 0.1 square kilometer impact area with several bounding environmental parameters using RESRAD 7.0 for the resident farmer scenario

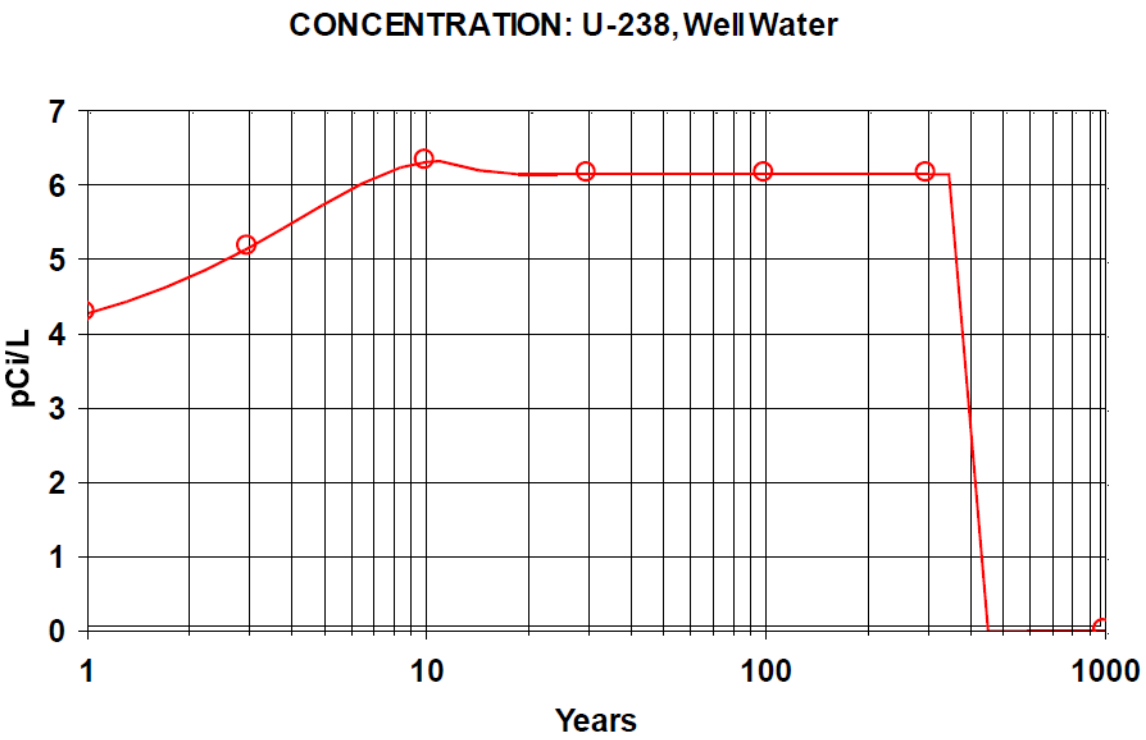

Figure 43 Uranium-238 activity concentration in well water vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a 0.1 square kilometer impact area with several bounding environmental parameters using RESRAD 7.0 for the resident farmer scenario

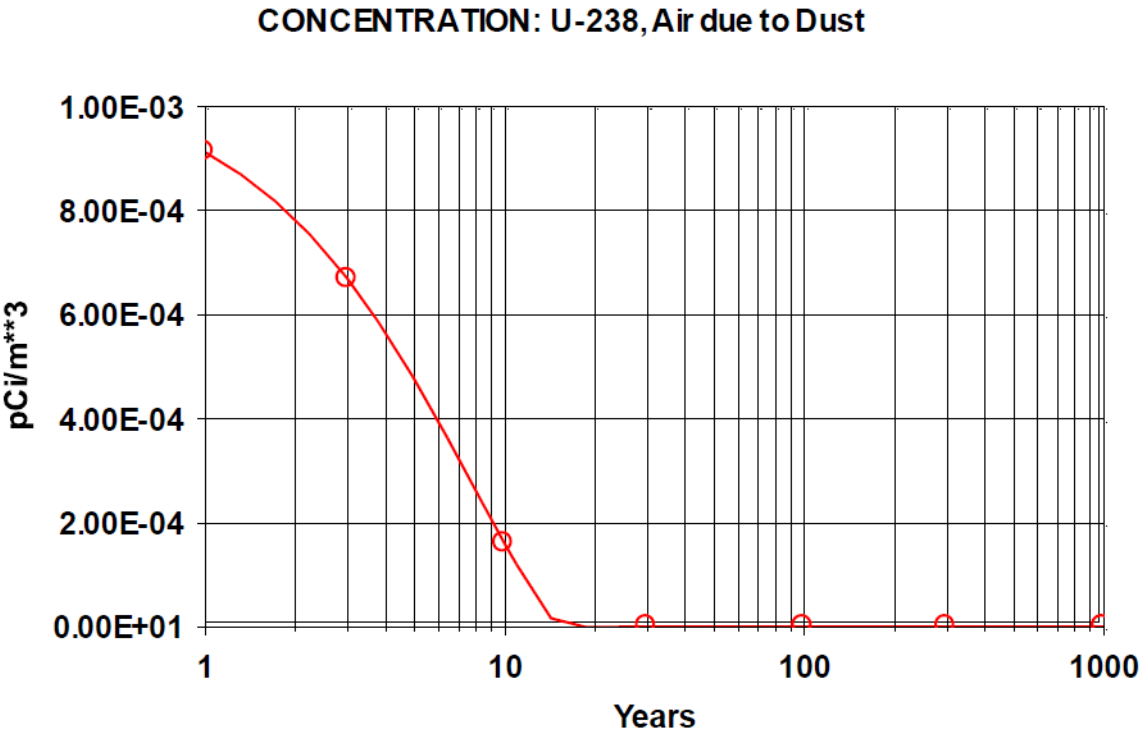

Figure 44 Uranium-238 activity concentration in air over impact area vs. time for DU from 9700 M101 rounds evenly dispersed in top 15 cm of soil in a 0.1 square kilometer impact area with several bounding environmental parameters using RESRAD 7.0 for the resident farmer scenario

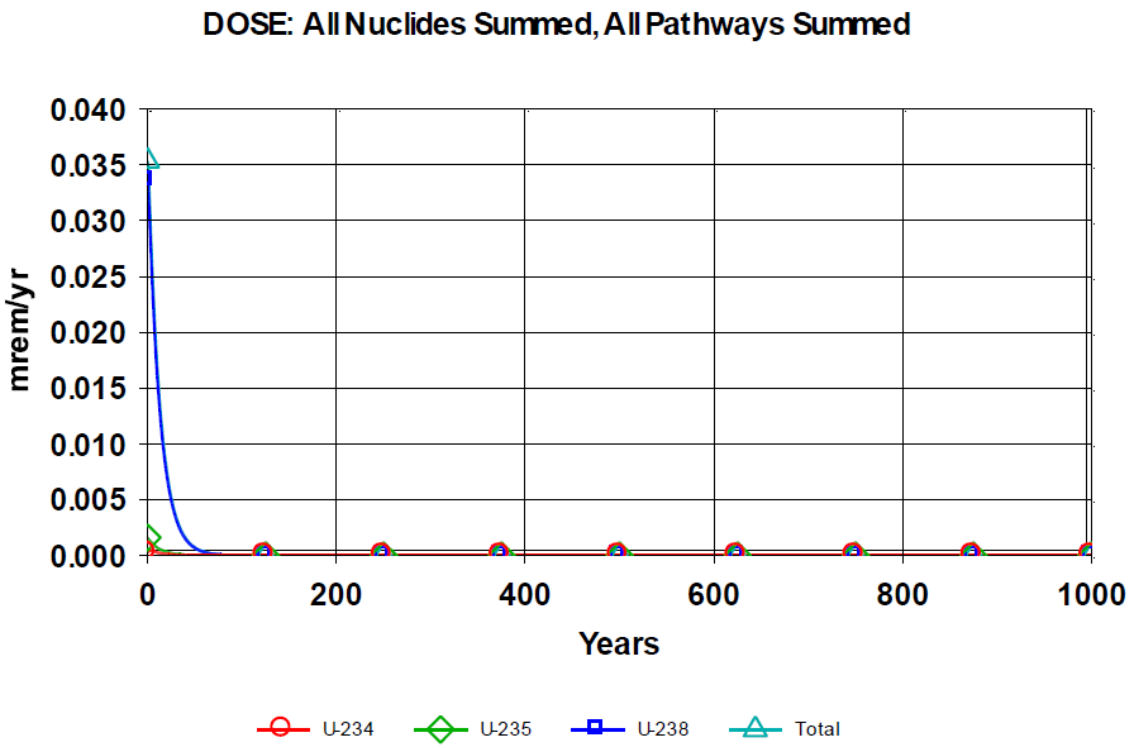

Figure 45 Annual dose vs. time from 9700 M101 DU rounds evenly dispersed in top 15 cm of soil in a 1 square kilometer impact area with default parameters using RESRAD-OFFSITE 3.1 for the scenario of resident farmer 1 km away from the contaminated site

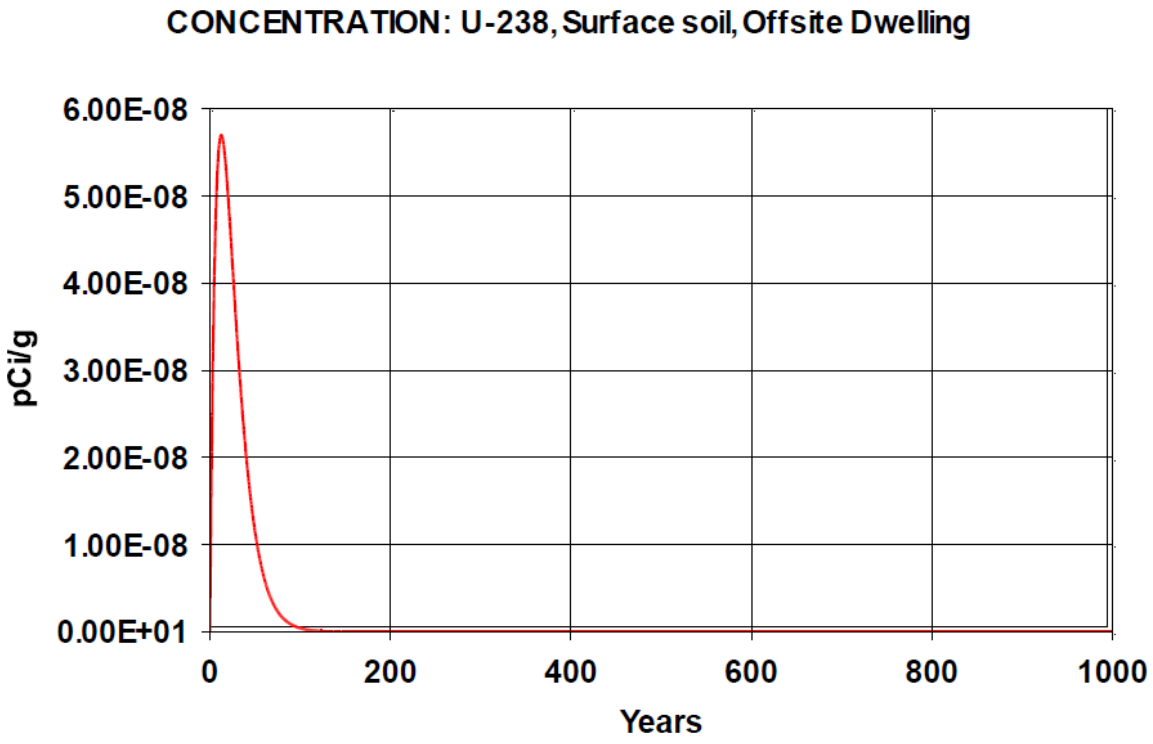

Figure 46 Uranium-238 activity concentration in offsite dwelling surface soil from 9700 M101 DU rounds evenly dispersed in top 15 cm of soil in a 1 square kilometer impact area with default parameters using RESRAD-OFFSITE 3.1 for the scenario of resident farmer 1 km away from the contaminated site

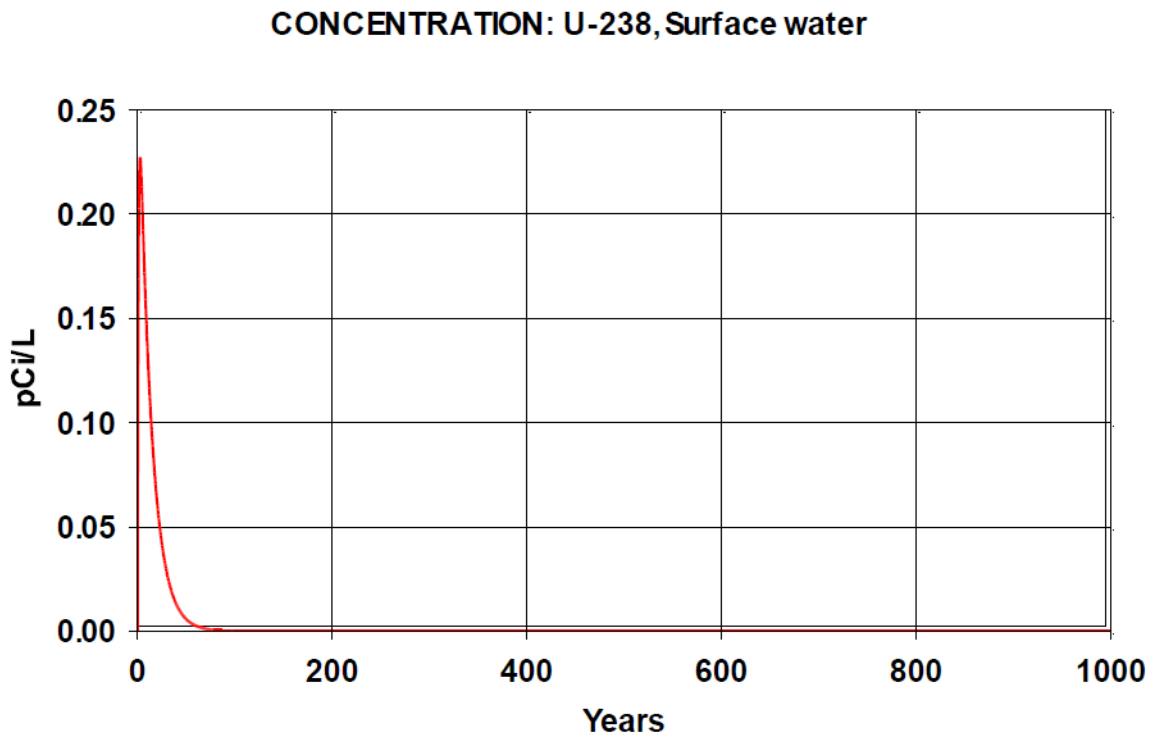

Figure 47 Uranium-238 activity concentration in offsite surface water from 9700 M101 DU rounds evenly dispersed in top 15 cm of soil in a 1 square kilometer impact area with default parameters using RESRAD-OFFSITE 3.1 for the scenario of resident farmer 1 km away from the contaminated site

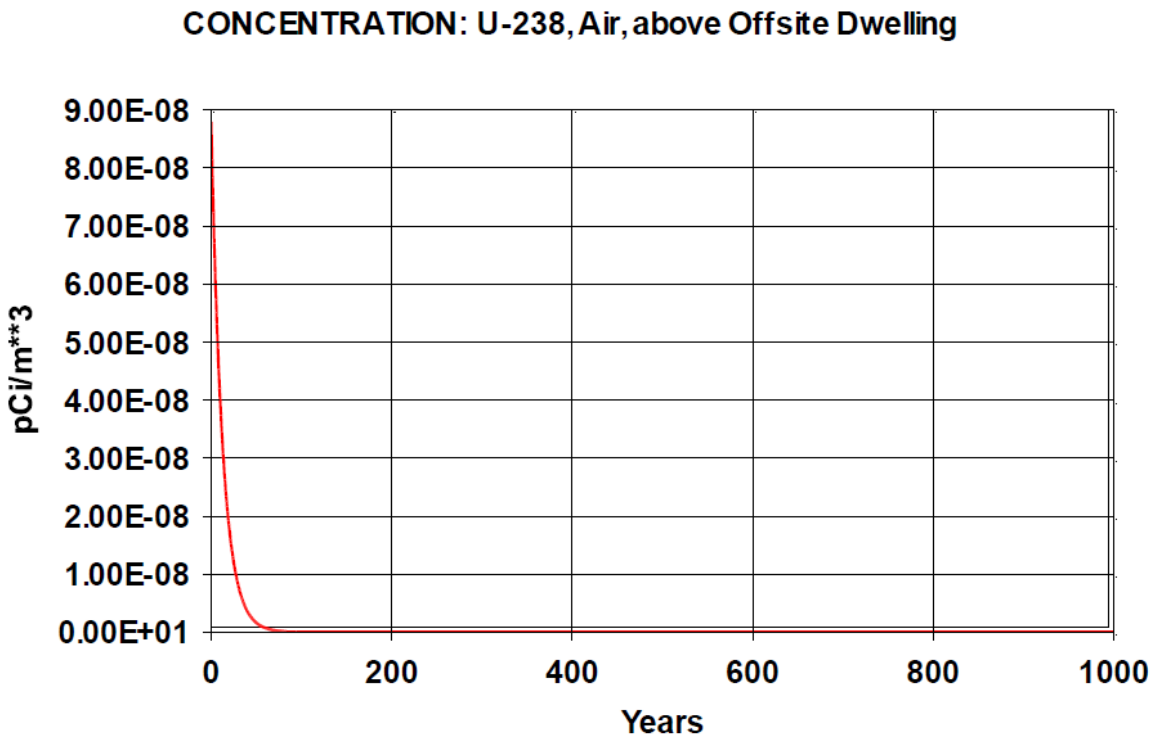

Figure 48 Uranium-238 activity concentration in air above offsite dwelling for 9700 M101 DU rounds evenly dispersed in top 15 cm of soil in a 1 square kilometer impact area with default parameters using RESRAD-OFFSITE 3.1 for the scenario of resident farmer 1 km away from the contaminated site

Attachments[18]

1. RESRAD report for the baseline 1000 M101 rounds in 1 km^2 scenario
2. RESRAD report for the 9700 M101 rounds in 1 km^2 resident farmer bounding scenario
3. RESRAD report for the 9700 M101 rounds in 1 km^2 resident farmer bounding scenario (Water table 7.5 cm below ground surface)
4. RESRAD report for the 9700 M101 rounds in 1 km^2 resident farmer bounding scenario (contaminated zone erosion rate = 0.01 m/y = 1 cm/y)
5. RESRAD report for the 9700 M101 rounds in 1 km^2 resident farmer bounding scenario (contaminated zone total porosity = 0.6)
6. RESRAD report for the 9700 M101 rounds in 1 km^2 resident farmer bounding scenario (contaminated zone hydraulic conductivity = 6000 m/y)
7. RESRAD report for the 9700 M101 rounds in 1 km^2 resident farmer bounding scenario (average annual wind speed = 1 m/s)
8. RESRAD report for the 9700 M101 rounds in 1 km^2 resident farmer bounding scenario (average annual wind speed = 10 m/s)
9. RESRAD report for the 9700 M101 rounds resident farmer bounding scenario (average annual total precipitation = 2 m)
10. RESRAD report for the 9700 M101 rounds in 1 km^2 resident farmer bounding scenario (set of bounding environmental parameters)
11. RESRAD report for the 9700 M101 rounds in 0.1 km^2 resident farmer bounding scenario (set of bounding environmental parameters)
12. RESRAD-OFFSITE report for 9700 M101 rounds in 1 km^2 farmer residing one kilometer from contaminated site, default parameters[19]

[18] RESRAD provides five parts for its report following each calculation run: Part I, Mixture Sums and Single Radionuclide Guidelines; Part II, Source Terms, Factors, and Parameters for Individual Pathways; Part III, Intake Quantities and Health Risk Factors; Part IV, Concentration of Radionuclides; and Part V, Dose from Radionuclide at Point of Action. The total number of pages in these five parts is more than 673 pages, so the eleven full reports consist of more than 7400 pages. Anyone using RESRAD can produce these reports, so they are provided in electronic form only, rather than including paper copies with the submission.

[19] RESRAD-OFFSITE provides three parts for its report following each calculation run: Part I, Mixture Sums and Single Radionuclide Guidelines; Part II, Health Risk Factors; and Part III, Dose from Radionuclide at Point of Action. Anyone using RESRAD-OFFSITE can produce this report, so it is provided in electronic form only, rather than including a paper copy with the submission.