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Peak Dose Assessment for Proposed DOE-PPPO Authorized Limits

Prepared by
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Prepared for the
U.S. Department of Energy
Portsmouth/Paducah Project Office
Paducah, Kentucky

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FINAL REPORT

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Terms, Acronyms, and Abbreviations

ACL	Administrative Control Level
AL	Authorized Limit(s)
Am-241	americium-241
ANL	Argonne National Laboratory
Ci	curies
Cs-137	cesium-137
CSM	Conceptual Site Model
DOE	U.S. Department of Energy
DOE-PPPO	DOE Portsmouth/Paducah Project Office
EPA	U.S. Environmental Protection Agency
KAR	Kentucky Administrative Regulations
KDWM	Kentucky Division of Waste Management
MCL	Maximum Contaminant Level
mrem	millirem
mrem/yr	millirem per year
Np-237	neptunium-237
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
ORO	Oak Ridge Office
PCB	Polychlorinated Biphenyl
pCi/g	picocuries per gram
PGDP	Paducah Gaseous Diffusion Plant
PRS	Paducah Remediation Services
Pu-238	plutonium-238
Pu-239	plutonium-239
Pu-240	plutonium-240
Pu-241	plutonium-241
RCRA	Resource Conservation and Recovery Act
Tc-99	technetium-99
Th-228	thorium-228
Th-230	thorium-230
Th-232	thorium-232
TSCA	Toxic Substances Control Act
U-234	uranium-234
U-235	uranium-235
U-238	uranium-238
yr	year(s)

ABSTRACT

The Oak Ridge Institute for Science and Education (ORISE), a U.S. Department of Energy (DOE) prime contractor, was contracted by the DOE Portsmouth/Paducah Project Office (DOE-PPPO) to conduct a peak dose assessment in support of the *Authorized Limits Request for Solid Waste Disposal at Landfill C-746-U at the Paducah Gaseous Diffusion Plant* (DOE-PPPO 2011a). The peak doses were calculated based on the DOE-PPPO Proposed Single Radionuclides Soil Guidelines and the DOE-PPPO Proposed Authorized Limits (AL) Volumetric Concentrations available in DOE-PPPO 2011a. This work is provided as an appendix to the *Dose Modeling Evaluations and Technical Support Document for the Authorized Limits Request for the C-746-U Landfill at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (ORISE 2012).

The receptors evaluated in ORISE 2012 were selected by the DOE-PPPO for the additional peak dose evaluations. These receptors included a Landfill Worker, Trespasser, Resident Farmer (onsite), Resident Gardener, Recreational User, Outdoor Worker and an Offsite Resident Farmer. The RESRAD (Version 6.5) and RESRAD-OFFSITE (Version 2.5) computer codes were used for the peak dose assessments. Deterministic peak dose assessments were performed for all the receptors and a probabilistic dose assessment was performed only for the Offsite Resident Farmer at the request of the DOE-PPPO. In a deterministic analysis, a single input value results in a single output value. In other words, a deterministic analysis uses single parameter values for every variable in the code. By contrast, a probabilistic approach assigns parameter ranges to certain variables, and the code randomly selects the values for each variable from the parameter range each time it calculates the dose (NRC 2006). The receptor scenarios, computer codes and parameter input files were previously used in ORISE 2012. A few modifications were made to the parameter input files as appropriate for this effort. Some of these changes included increasing the time horizon beyond 1,050 years (yr), and using the radionuclide concentrations provided by the DOE-PPPO as inputs into the codes. The deterministic peak doses were evaluated within time horizons of 70 yr (for the Landfill Worker and Trespasser), 1,050 yr, 10,000 yr and 100,000 yr (for the Resident Farmer [onsite], Resident Gardener, Recreational User, Outdoor Worker and Offsite Resident Farmer) at the request of the DOE-PPPO. The time horizons of 10,000 yr and 100,000 yr were used at the request of the DOE-PPPO for informational purposes only. The probabilistic peak of the mean dose assessment was performed for the Offsite Resident Farmer using Technetium-99 (Tc-99) and a time horizon of 1,050 yr.

The results of the deterministic analyses indicate that among all receptors and time horizons evaluated, the highest projected dose, 2,700 mrem/yr, occurred for the Resident Farmer (onsite) at 12,773 yr. The exposure pathways contributing to the peak dose are ingestion of plants, external gamma, and ingestion of milk, meat and soil. However, this receptor is considered an implausible receptor. The only receptors considered plausible are the Landfill Worker, Recreational User, Outdoor Worker and the Offsite Resident Farmer. The maximum projected dose among the

plausible receptors is 220 mrem/yr for the Outdoor Worker and it occurs at 19,045 yr. The exposure pathways contributing to the dose for this receptor are external gamma and soil ingestion.

The results of the probabilistic peak of the mean dose analysis for the Offsite Resident Farmer indicate that the average (arithmetic mean) of the peak of the mean doses for this receptor is 0.98 mrem/yr and it occurs at 1,050 yr. This dose corresponds to Tc-99 within the time horizon of 1,050 yr.

1.0: INTRODUCTION

The C-746-U Landfill at the Paducah Gaseous Diffusion Plant (PGDP) was constructed from 1995 to 1997 by DOE for disposal of solid wastes that are not regulated as hazardous waste under the Resource Conservation and Recovery Act (RCRA) Subtitle C or as waste containing Polychlorinated Biphenyls (PCBs) under the Toxic Substances Control Act (TSCA). Construction of the Landfill was needed to continue onsite disposal of certain wastes generated at the PGDP after an older landfill at the PDGP was filled to capacity and closed in accordance with Kentucky requirements.

The C-746-U Landfill is located north of the PGDP and is permitted by the Kentucky Energy and Environment Cabinet, Department for Environmental Protection, Division of Waste Management (KDWM) in accordance with the requirements of its solid waste regulations—401 Kentucky Administrative Regulations (KAR) 48, *Standards for Solid Waste Facilities*—and Subtitle D of RCRA. A cross-section of the Landfill is provided in Figure 1-1. C-746-U Landfill design features described here were excerpted from DOE 2003. Additional details regarding the Landfill design features, current and planned controls for the Landfill, conceptual site model (CSM) and other assumptions which directly influenced the ORISE modeling analyses, are provided in the main ORISE report *Dose Modeling Evaluations and Technical Support Document for the Authorized Limits Request for the C-746-U Landfill at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (ORISE 2012).

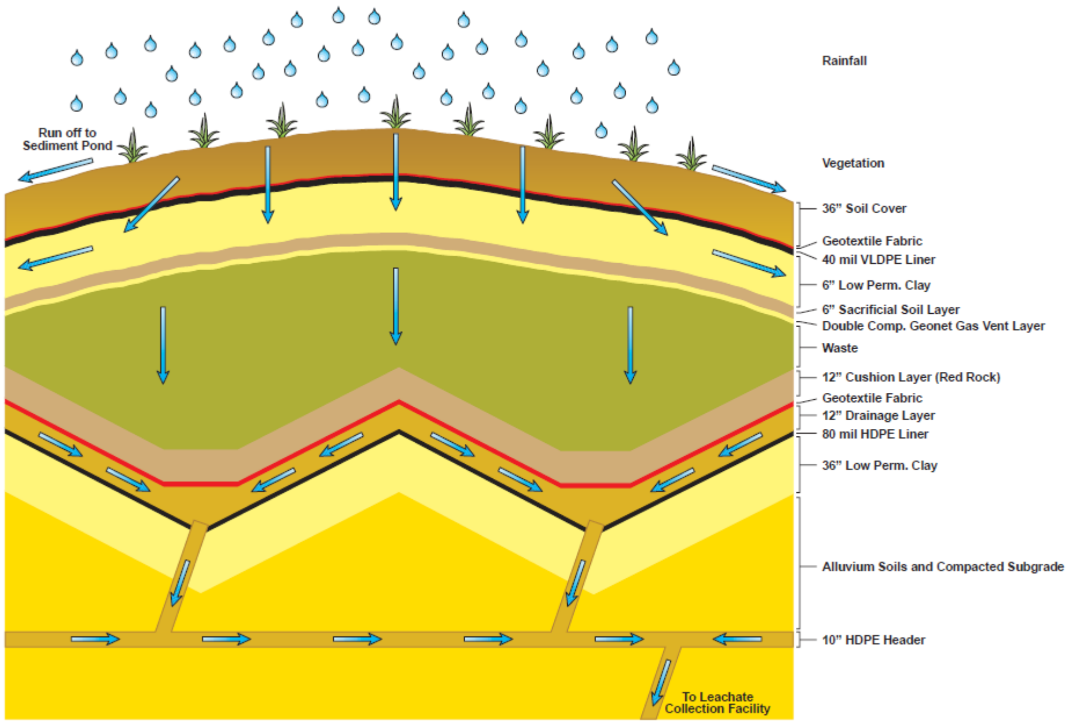

Figure 1–1. C–746–U Landfill Cross–Section (Excerpted from DOE 2003)

The purpose of the analyses presented in this report is to provide deterministic peak dose assessments for seven receptors based on the DOE-PPPO Proposed Single Radionuclide Soil Guidelines and the DOE-PPPO Proposed Authorized Limits as applicable. In addition, a probabilistic peak of the mean dose assessment is provided for only one receptor using the DOE-PPPO Proposed Single Radionuclide Soil Guideline for Tc-99 as selected by the DOE-PPPO. These assessments are conducted in support of the DOE-PPPO *Authorized Limits Request for Solid Waste Disposal at Landfill C-746-U at the Paducah Gaseous Diffusion Plant* (DOE-PPPO 2011a). The RESRAD (Version 6.5) and RESRAD-OFFSITE (Version 2.5) computer codes are used for the analyses. Furthermore, these analyses included a comparison to the 1 mrem/yr (above background) dose constraint and the 100 mrem/yr primary public dose limit (above background) as applicable to each receptor. The 1 mrem/yr (above background) dose constraint is referred to as a "walk-away" dose (Volpe 2001). This target dose constraint is both a DOE field element and a Commonwealth of Kentucky Radiation Health Branch constraint. The 100 mrem/yr is the primary public dose limit (above background) cited in DOE Order 458.1, *Radiation Protection of the Public and the Environment* (DOE 2011).

2.0: MATERIALS AND METHODS

The radionuclide concentrations, receptors and their pertinent assumptions for the analyses presented in this report are included in this section. A detailed description of the targeted radionuclides used, target doses and receptor scenarios is included in ORISE 2012.

2.1 RADIONUCLIDE CONCENTRATIONS

The specific radioactive material quantities in picocuries per gram (pCi/g) associated with individual radionuclides were provided by DOE-PPPO to ORISE. These concentrations (pCi/g) for the individual radionuclides were required as inputs to the modeling codes. Table 2-1 lists the radionuclide concentrations (pCi/g) provided by DOE-PPPO. The concentrations represent the DOE-PPPO Proposed Single Radionuclide Soil Guidelines and DOE-PPPO Proposed Authorized Limits (AL) Volumetric Concentrations for the C-746-U Landfill. Details on the derivation of these DOE-PPPO proposed concentrations are provided in the *Authorized Limits Request for Solid Waste Disposal at Landfill C-746-U at the Paducah Gaseous Diffusion Plant* (DOE-PPPO 2011a).

Table 2–1. DOE–PPPO Proposed Radionuclide Concentrations for the C–746–U Landfill

Radionuclide	PPPO Proposed Single Radionuclide Soil Guidelines (pCi/g)	PPPO Proposed Authorized Limits Volumetric Concentrations (pCi/g)
^{241}Am	35	70
^{137}Cs	19	38
^{237}Np	5.5	11
^{238}Pu	39	78
^{239}Pu	36	72
^{240}Pu	36	72
^{99}Tc	52	104
^{228}Th	4	8
^{230}Th	100	200
^{232}Th	4	8
^{234}U	160	320
^{235}U	6.5	13
^{238}U	160	320

2.2 COMPUTER CODES

Two validated and verified computer codes, developed by Argonne National Laboratory (ANL), were used for the analyses presented in this report.

2.2.1 RESRAD

The RESRAD code was developed by ANL over 20 yr ago and has been updated several times since its introduction. RESRAD is a computer model used to evaluate radiation doses and excess cancer risks to an individual exposed from residual radioactive materials in soil (Yu et al. 2001). The code is recognized by the DOE (e.g., in DOE Order 458.1) for use in dose modeling evaluations.

The RESRAD code was used in this project to model six receptors. These include a Landfill Worker, Trespasser, Resident Farmer (onsite), Resident Gardener, Recreational User and an

Outdoor Worker. The Landfill Worker and the Trespasser were modeled under current (C-746-U Landfill operational period) use scenarios and the other receptors were modeled under future use scenarios (C-746-U Landfill institutional and post-institutional control periods) as modeled in ORISE 2012.

2.2.2 RESRAD-OFFSITE

The RESRAD-OFFSITE dose modeling code was developed much more recently by ANL. RESRAD-OFFSITE is considered by ANL an evolution of RESRAD and is expected to replace RESRAD in the future. RESRAD-OFFSITE uses new models such as a three-dimensional dispersion groundwater flow and radionuclide transport model, a Gaussian plume model for atmospheric dispersion, and a deposition model used to estimate the accumulation of radionuclides in offsite locations and in foods (Yu et al. 2007).

The RESRAD-OFFSITE code evaluates the radiological dose and excess cancer risk to an individual who is exposed while located within or outside the area of initial (primary) contamination. The primary contamination, which is the source of all the releases modeled by the code, is assumed to be a layer of soil. The releases of contaminants from the primary contamination to the atmosphere, to surface runoff, and to groundwater are considered. Unlike RESRAD, RESRAD-OFFSITE can model both onsite and offsite receptors.

The RESRAD-OFFSITE code was used to model the Offsite Resident Farmer under a future use scenario (institutional and post-institutional control periods). Under this scenario, the Offsite Resident Farmer places a well 407 m north from the downgradient edge of the contaminated zone and builds a house, grows crops, and raises livestock near the DOE property boundary. This particular location was selected for consistency with a previously modeled offsite well (DOE 2003).

2.3 PEAK DOSE ASSESSMENT METHODOLOGY

Several peak dose assessments were performed as requested by the DOE-PPPO. The peak doses appearing within the time periods of 70 yr, 1,050 yr, 10,000 yr and 100,000 yr were determined. The codes' input files used for the peak dose assessment are the same input parameter files used for the development of ORISE 2012. The receptors' files were used, and edited as necessary.

The peak doses for all receptors were assessed by deterministic analyses. However, only the Offsite Resident Farmer's dose was assessed by probabilistic analysis to obtain the peak of the mean doses. The Offsite Resident Farmer was the receptor selected by the DOE-PPPO for the probabilistic analysis. The receptor scenario, computer code, and parameter input file previously used by ORISE for the Offsite Resident Farmer's deterministic analysis in ORISE 2012, are used for the probabilistic analysis. Modifications to the input file were made as needed. Although ORISE's deterministic analysis included 13 radionuclides, Tc-99 contributed 100% of the peak dose within the time frame of 1,050 yr and DOE-PPPO requested that the probabilistic analysis be performed using Tc-99 only.

The following approaches were used to evaluate the peak doses for all the receptors by using deterministic analyses.

2.3.1 DETERMINISTIC ANALYSES TO CALCULATE PEAK DOSES FOR ALL RECEPTORS

A deterministic analysis uses a single value for each parameter, resulting in a single dose value (Kamboj et al. 2000). The model computations are performed once using a single set of inputs to produce a single set of deterministic outputs (Yu et al. 2007). The deterministic analyses in this report were conducted to calculate the peak doses for all the receptors.

2.3.1.1 Peak Dose Assessment for Receptors Modeled During the Operational Period

Two peak dose evaluations were performed for the Landfill Worker and the Trespasser using a time horizon of 70 yr. The first evaluation involved using DOE-PPPO Proposed Single Radionuclide Soil Guidelines for each targeted radionuclide as inputs into the codes. The second evaluation involved using DOE-PPPO Proposed AL Volumetric Concentrations for each targeted radionuclide as inputs into the codes (See Table 2-1).

The 70 yr time horizon represents the 20 yr for the Landfill's operational period and an additional 50 yr to begin the analysis as of the year 1960. Selection of 1960 represents a reasonable starting point for the analysis and allows for radioactive ingrowth and decay from that time forward. A time period beyond 70 yr is not applicable for the Landfill Worker or the Trespasser, since these receptors are only modeled while the Landfill is operational. Details on the Landfill's operational period are included in ORISE 2012. The Landfill Worker is considered a plausible receptor and the Trespasser is considered an implausible receptor as indicated in ORISE 2012.

2.3.1.2 Peak Dose Assessment for Receptors Modeled During the Post-Institutional Control Period

Three separate peak dose evaluations were performed for the Resident Farmer (onsite), Resident Gardener, Recreational User, Outdoor Worker and Offsite Resident Farmer using time horizons of 1,050 yr, 10,000 yr and 100,000 yr. These evaluations involved using DOE-PPPO Proposed Single Radionuclide Soil Guidelines for each targeted radionuclide as inputs into the codes (see Table 2-1).

The 1,050 yr time horizon represents the conventional period used in the analyses for soil guideline determinations (1,000 yr) and an additional 50 yr to begin the analysis as of the year 1960. The time frame of 1,050 yr and beyond is applicable to the receptors modeled during the Landfill's post-institutional control period. ORISE did not model the Landfill's institutional control period separately. ORISE did the modeling using the assumptions from the post-institutional control period for the institutional control period and the post-institutional control period. Therefore these two periods were combined into one (the post-institutional control period) as performed in ORISE 2012. Details on these two Landfill control periods are included in ORISE 2012. The Resident Farmer (onsite), and the Resident Gardener are the only two implausible receptors modeled during the post-institutional control period, the other three receptors modeled during this period are considered plausible as indicated in ORISE 2012.

The time horizons of 10,000 yr and 100,000 yr (maximum allowed by the codes) were used at the request of the DOE-PPPO for informational purposes to determine the magnitude of the dose during these time periods.

When increasing the time horizon beyond 1,000 yrs in the RESRAD-OFFSITE code, it is important to have a sufficient number of intermediate time points in the code to capture the variation in the computed fluxes and concentrations. The number of intermediate time points specifies the number of graphic points, affects the precision of the computed results and the smoothness of the output graphic curves (Yu et al. 2007). Therefore, ORISE increased the number of points to 16,384 from 2,048 points (code default number of points). Difficulties with the graphics viewer in RESRAD-OFFSITE were encountered when using 22,000 points —the maximum number of points available in the code. Specifically, it was not possible to view the graphics with 22,000 points. According to an ORISE personal communication with ANL, there may be a limit on the number of points in the graphics program used in RESRAD-OFFSITE.

2.3.2 PROBABILISTIC ANALYSIS TO CALCULATE PEAK OF THE MEAN DOSES FOR THE OFFSITE RESIDENT FARMER

NUREG/CR-6676 (Kamboj et al. 2000) states: "the probabilistic approach uses systematic uncertainty analysis to quantify the uncertainty in dose estimates due to uncertainty in the input parameters. In the probabilistic analysis, a probability distribution is specified for each model input parameter of uncertain value." The probabilistic analysis in this report was conducted to calculate the peak of the mean dose.

2.3.2.1 Peak of the Mean Dose Assessment for the Offsite Resident Farmer

The Offsite Resident Farmer, modeled using the RESRAD-OFFSITE code, was the receptor selected by DOE-PPPO for the probabilistic analysis. The probabilistic dose assessment was performed to determine the peak of the mean doses based on Tc-99 exclusively and demonstrate that the Tc-99 dose meets the constraint of 1 mrem/yr (above background). As requested by DOE-PPPO, ORISE used the following information for the Tc-99 probabilistic analysis:

- The DOE-PPPO Proposed Single Radionuclide Soil Guideline for Tc-99 (i.e., 52 pCi/g) as the input radionuclide concentration.

- The probabilistic inputs and related information were obtained from the DOE-PPPO document entitled: *Probabilistic Risk Assessment Analysis for Establishing the Technetium-99 Single Radionuclide Soil Guideline from the Drinking Water Pathway for the Offsite Resident Farmer for the C-746-U Landfill at the Paducah Gaseous Diffusion Plant, Paducah Kentucky* (DOE-PPPO 2011b). For additional details on the DOE-PPPO probabilistic analysis, refer to DOE-PPPO 2011b. Below is the information obtained from DOE-PPPO 2011b:

  - Parameters, type of distribution and values selected for Probabilistic Analysis.

Parameter	Type of Distribution	Minimum Value	Mode	Maximum Value
Saturated Zone Hydraulic Conductivity (m/yr)	Triangular	27034	38938	67642
Total Porosity of Saturated Zone	Triangular	0.27	0.39	0.54
Effective Porosity of Saturated Zone	Triangular	0.22	0.3	0.35
Distribution Coefficient (K_d) of Contaminated Zone (cm^3/ g)	Triangular	0.1	1	10
Dry Bulk Density of Contaminated Zone (g/cm^3)	Triangular	1.5	1.85	2.5
Unsaturated Zone (5) Effective Porosity	Triangular	0.1	0.25	0.4

  - The rank correlation coefficient used for the total and effective porosities of the saturated zones was 0.9.

  - The number of observations used was 2,000 and the number of repetitions was 3.

As mentioned previously, the probabilistic dose assessment was performed to determine the peak of the mean doses based on the DOE-PPPO Proposed Single Soil Guideline of 52 pCi/g for Tc-99 and to demonstrate compliance with the 1 mrem/yr (above background). During this probabilistic analysis, ORISE encountered difficulties with the RESRAD-OFFSITE code due to insufficient computer memory available for the code to perform the computations. The initial probabilistic run attempted by ORISE was not successfully completed by the code; it provided an output file indicating the errors. The run included all the exposure pathways as identified in ORISE 2012 (i.e., external gamma, inhalation of dust, drinking water, plant, meat, milk, and soil ingestion) and the probabilistic parameters as described previously in this section. The RESRAD-OFFSITE input files used for this initial run, the probabilistic parameters and the error output file generated by the code were submitted to Argonne National Laboratory (ANL) via the "resrad" email address for assistance.

Due to the fact that a standard computer with limited memory was available to run this code at its full potential, ORISE and DOE-PPPO decided that separate probabilistic runs should be performed to prevent computer memory issues. The rationale of doing these separate probabilistic runs was to incorporate changes in each one in order to minimize the number of calculations executed by the code for it to successfully complete the run and still obtain acceptable results. ORISE and DOE-PPPO agreed on maintaining the probabilistic input parameters intact (unchanged). Three probabilistic runs were performed. The first two runs were executed as agreed to with DOE-PPPO. The third run was executed as a confirmatory run as agreed between ORISE and a DOE-PPPO technical consultant. The modifications made for the runs are explained in the points below.

1. For the first probabilistic run, only the exposure pathways by which Tc-99 contributes to the dose were activated. These pathways are drinking water, plant, milk, and meat ingestion as shown by the deterministic analysis within the time frame of 1,050 yr. The external gamma, inhalation of dust, and soil ingestion pathways were deactivated. The deterministic input parameters and probabilistic parameters remained unchanged.

2. For the second probabilistic run, only the pathways by which Tc-99 did not contribute to the dose were activated. These pathways are external gamma, inhalation of dust, and soil ingestion pathways. The drinking water, plant, milk, and meat ingestion pathways were deactivated. The deterministic input parameters and probabilistic parameters remained unchanged.

   The purpose for the first and second runs was to add the results of the peak of the mean doses and determine the dose from all seven pathways.

3. For the third probabilistic run all the pathways (i.e., external gamma, inhalation of dust, drinking water, plant, meat, milk, and soil ingestion) remained activated; however, a deterministic parameter called the "grid spacing for areal integration" in the atmospheric transport model was changed from its default value of 10 meters to a maximum of 500 meters. None of the other deterministic inputs parameters or probabilistic parameters were modified.

   ANL provides a report in Yu et al. 2007 describing the processes and code options that affect the execution time when performing probabilistic analysis using the RESRAD-OFFSITE code. The information provided by ANL helps the user to select the conditions and code options that will produce all the desired outputs in the shortest time (Yu et al. 2007). According to Yu et al. 2007, the grid spacing for areal integration parameter is one of a number of parameters used in RESRAD-OFFSITE to improve the accuracy of the calculations and hence influence the computational time. The smaller the value for this parameter the greater the amount of time it takes the code to execute the calculations. From the parameters that could have been modified to reduce the execution time as recommended by ANL, the grid spacing for areal integration was selected, because in this run using only Tc-99, the exposure pathways contributing to the dose are not impacted by the atmospheric transport model. In addition, the presence of the Landfill cap/cover during the time frame of 1,050 yr minimizes or prevents resuspension and subsequent air transport to a location off the Landfill. A sensitivity analysis was performed on this parameter and as expected it demonstrated that the grid spacing for areal integration parameter does not influence the dose.

By increasing the number of meters in the grid spacing for areal integration, the number of calculations performed by the code and hence its execution time was tremendously reduced. This third run can be used as confirmatory run for the first two runs.

3.0: RESULTS AND DISCUSSION

The output results and graphical representations of the peak dose assessments are included in this section. The resultant peak doses were rounded to two significant figures for all receptors unless otherwise noted.

3.1 DETERMINISTIC PEAK DOSE ASSESSMENT FOR RECEPTORS MODELED DURING THE OPERATIONAL PERIOD

The first peak dose assessment involved using the DOE-PPPO Proposed Single Radionuclide Soil Guidelines as input into the codes. The second peak dose assessment involved the use of the DOE-PPPO Proposed AL Volumetric Concentrations as input into the codes and was performed for the Landfill Worker and the Trespasser only.

3.1.1 FIRST ASSESSMENT

The output peak doses for this first evaluation are summarized in Table 3-1. This evaluation involved the use of the DOE-PPPO Proposed Single Radionuclide Soil Guidelines and a time horizon of 70 yr.

Table 3–1. Peak Dose from DOE–PPPO Proposed Single Radionuclide Soil Guidelines

Receptor	Landfill Worker	Trespasser
Target Dose (mrem/yr)	100	100
Peak Dose (mrem/yr)	32	2.1
Time (yr)	70	70

The code generated results that do not approach the DOE's 2,000 mrem/yr Administrative Control level (ACL) for the Landfill Worker or the DOE's 100 mrem/yr public dose limit (above background) for the Trespasser. The peak dose for the Landfill Worker and the Trespasser occurs at 70 yr, which is also the time horizon used for these receptors. Most of the peak dose for these two receptors is attributed to Th-232, Th-230, U-238 and Cs-137. An analysis of additional RESRAD graphics and data shows that the dose attributed to Th-232 and Th-230 is also due to their ingrowth progeny. The exposure pathways contributing to the dose for these receptors are mainly external gamma and soil ingestion.

The following RESRAD graphics were obtained for the Landfill Worker and the Trespasser from the evaluation of the DOE-PPPO Proposed Single Radionuclide Soil Guidelines. Figures 3-1 and 3-3 illustrate the contribution to dose from all targeted radionuclides and pathways. Figures 3-2 and 3-4 illustrate the contribution to the dose from the different component exposure pathways evaluated for these receptors.

LANDFILL WORKER

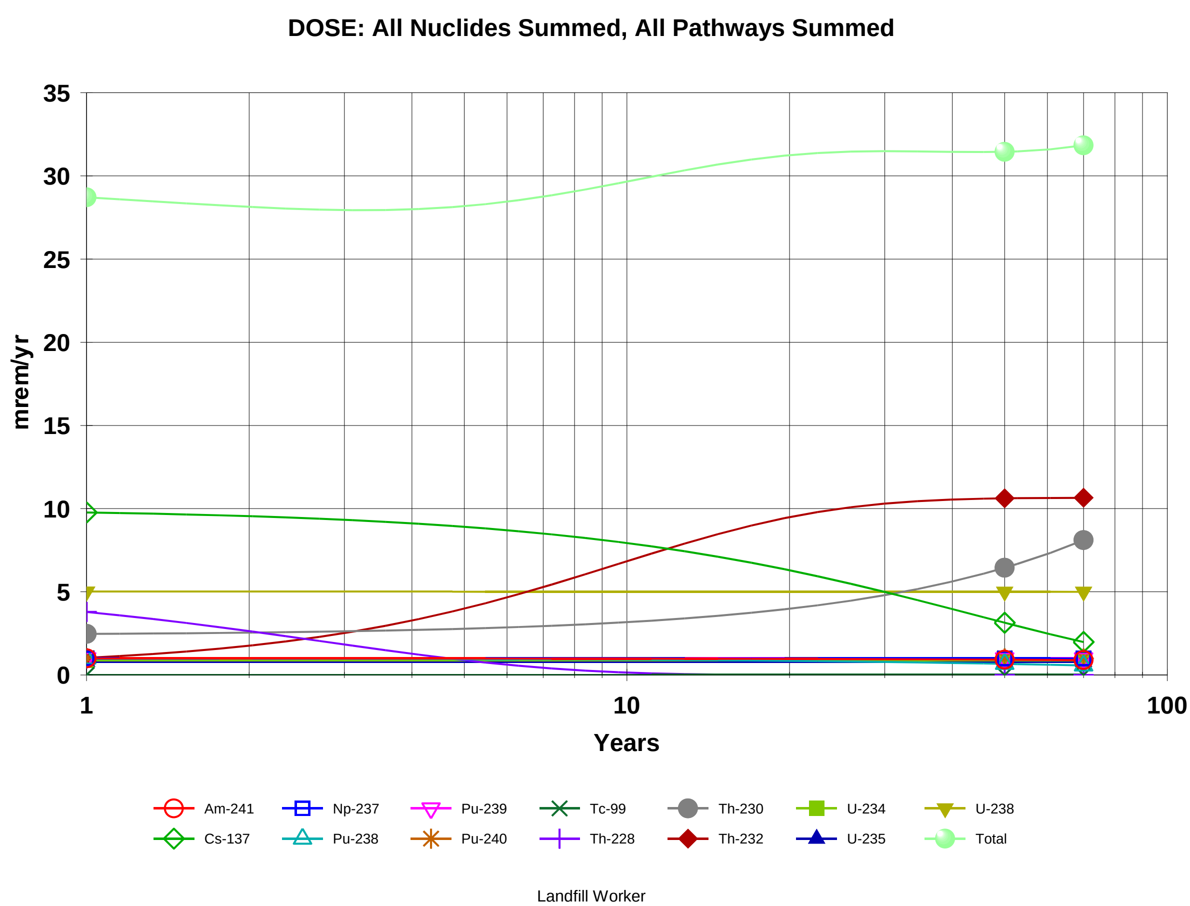

Figure 3–1. Dose to the Landfill Worker from all Selected Targeted Radionuclides and Pathways

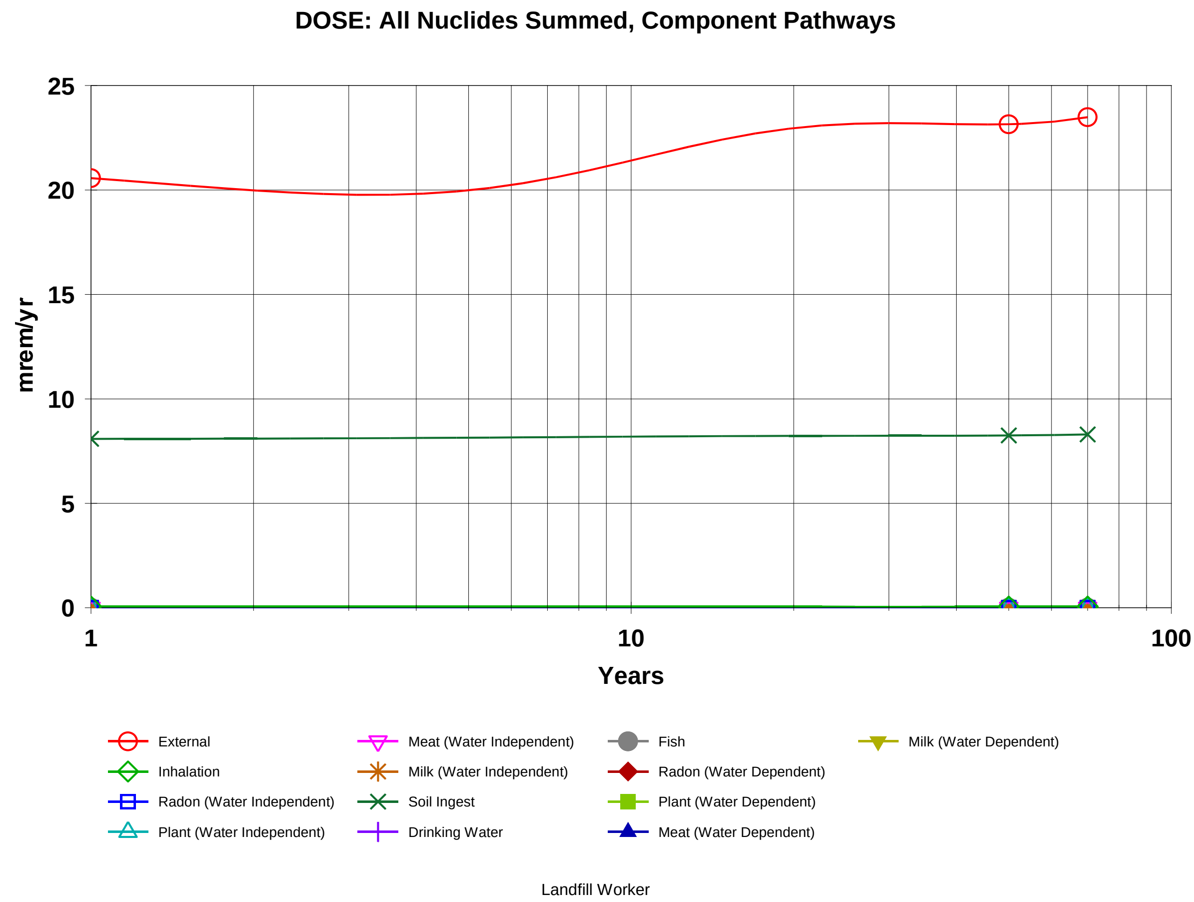

Figure 3–2. Dose to the Landfill Worker by Exposure Pathways

TRESPASSER

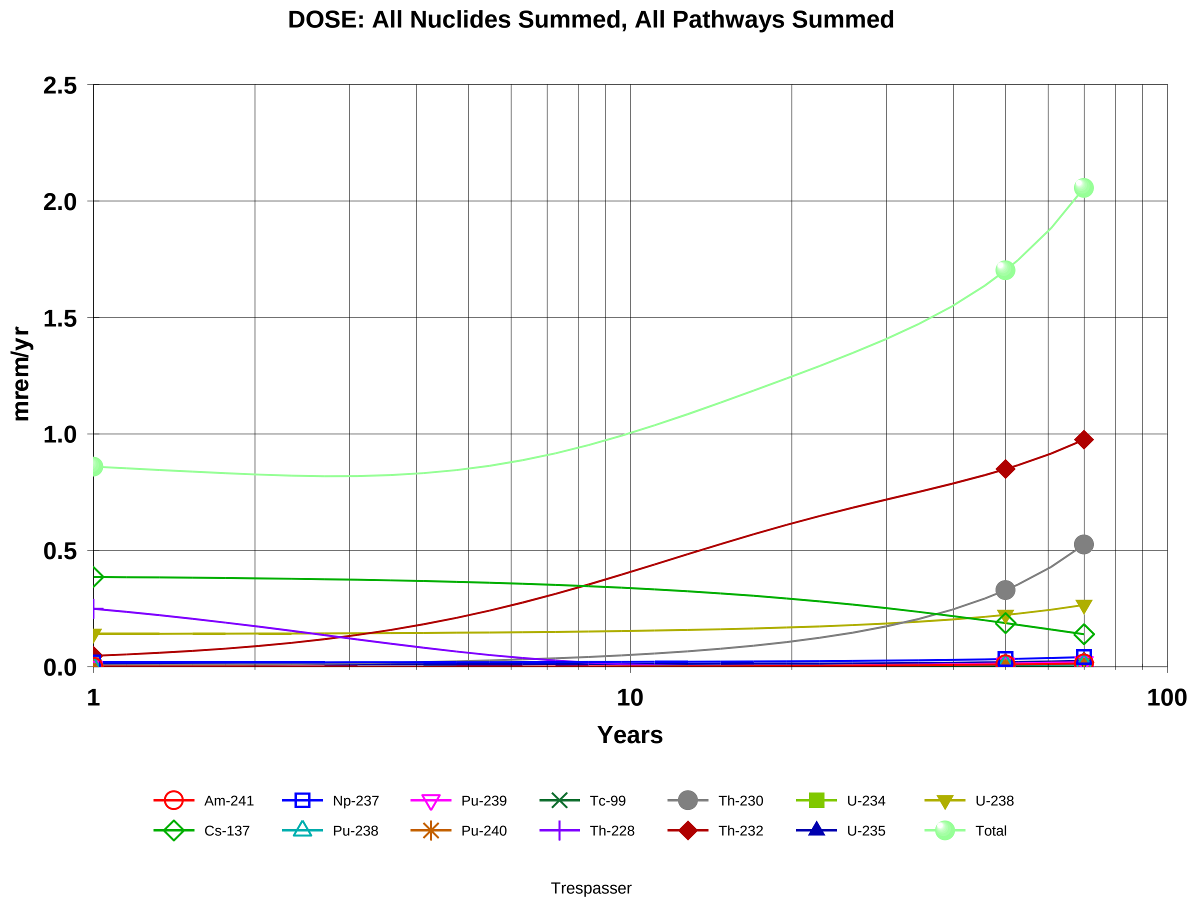

Figure 3–3. Dose to the Trespasser from all Selected Targeted Radionuclides and Pathways

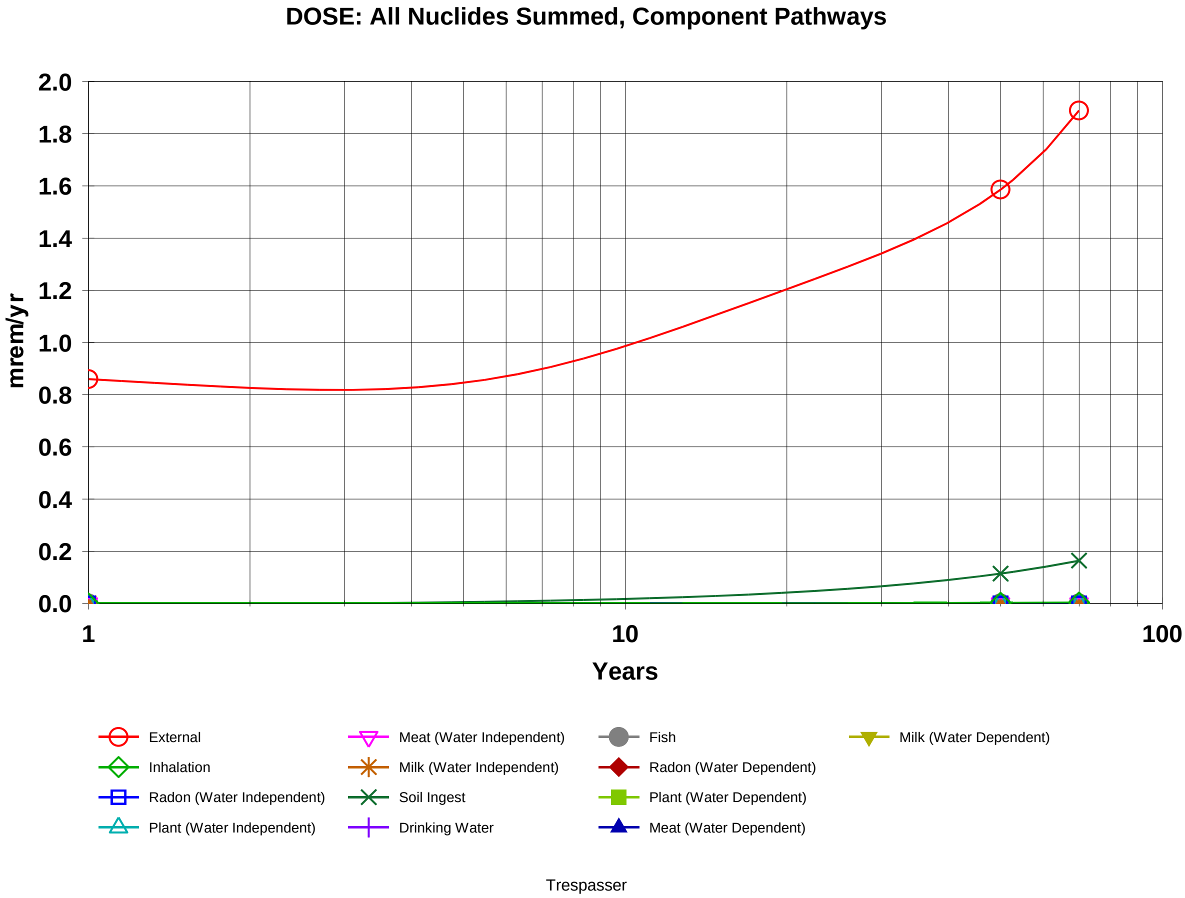

Figure 3–4. Dose to the Trespasser by Exposure Pathways

3.1.2 SECOND ASSESSMENT

The output peak doses for the second evaluation for the Landfill Worker and the Trespasser are provided in Table 3-2. This evaluation involved the use of the DOE-PPPO Proposed AL Volumetric Concentrations and a time horizon of 70 yr.

Table 3–2. Peak Dose from DOE–PPPO Proposed AL Volumetric Concentrations

Receptor	Landfill Worker	Trespasser
Target Dose (mrem/yr)	100	100
Peak Dose (mrem/yr)	64	4.1
Time (yr)	70	70

In this case, the Landfill Worker's dose remains considerably below the DOE's 2,000 mrem/yr ACL and the Trespasser's dose is still noticeably below the DOE's 100 mrem/yr public dose limit (above background). The exposure pathways and radionuclides contributing to these receptors' second evaluation of the peak dose were identical to the ones contributing to the dose in the first evaluation. Figures 3-5 through 3-8 were obtained for the Landfill Worker and the Trespasser from the evaluation of the DOE-PPPO Proposed AL Volumetric Concentrations.

LANDFILL WORKER

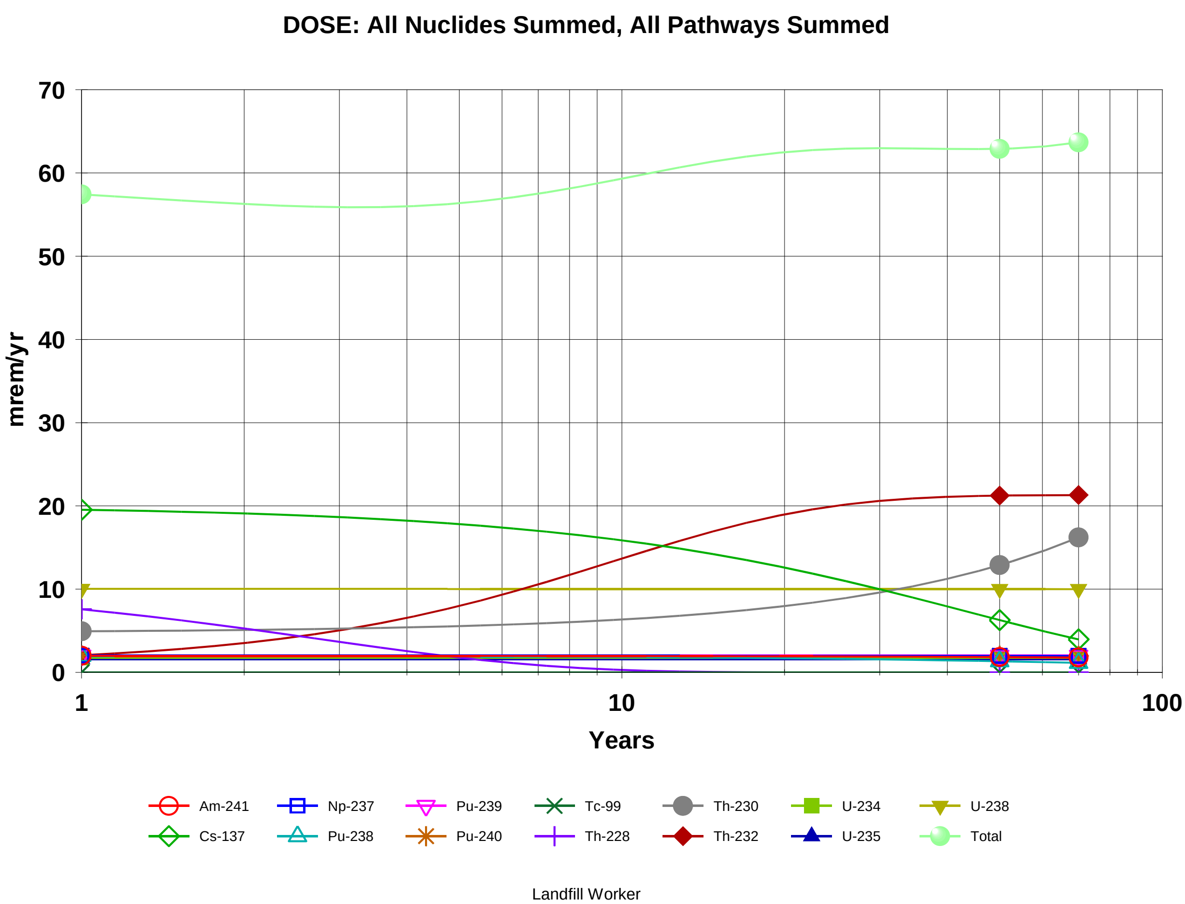

Figure 3–5. Dose to the Landfill Worker from all Selected Targeted Radionuclides and Pathways

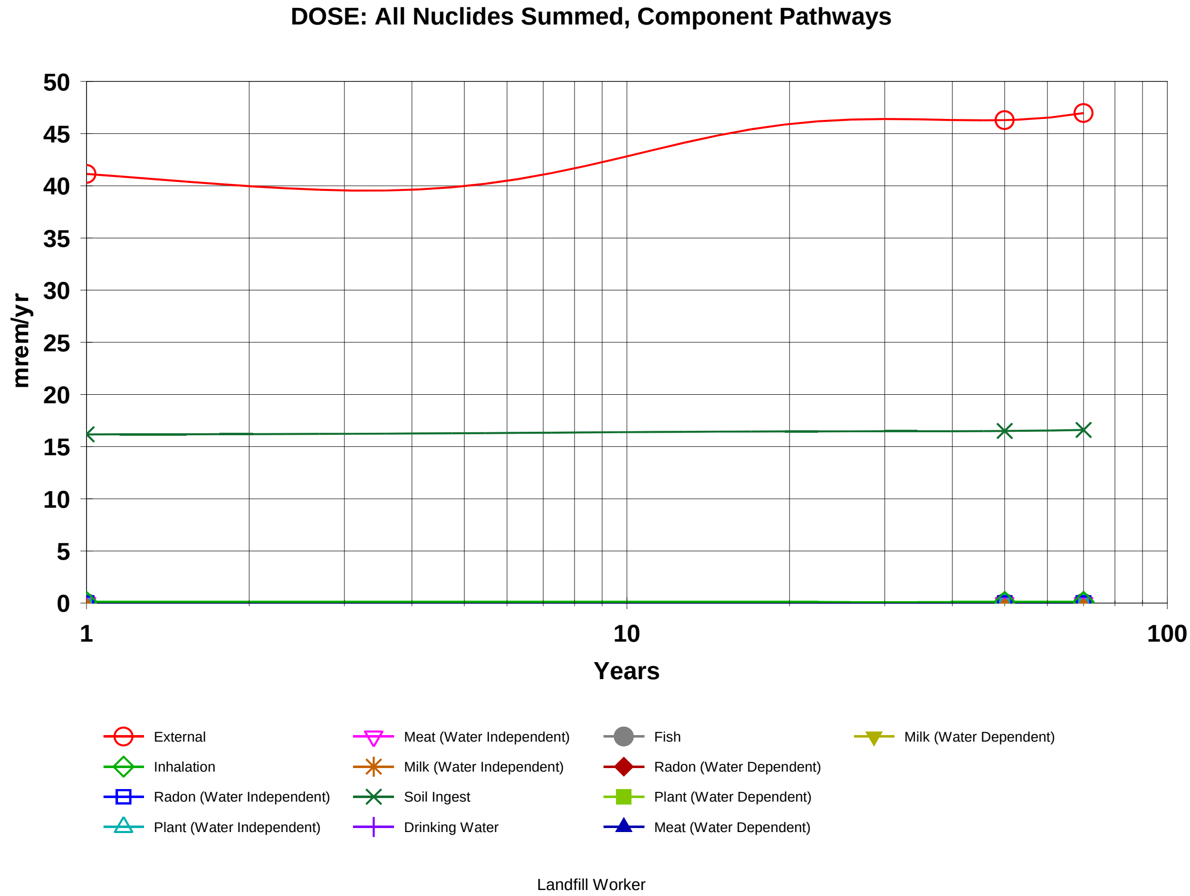

Figure 3–6. Dose to the Landfill Worker by Exposure Pathways

TRESPASSER

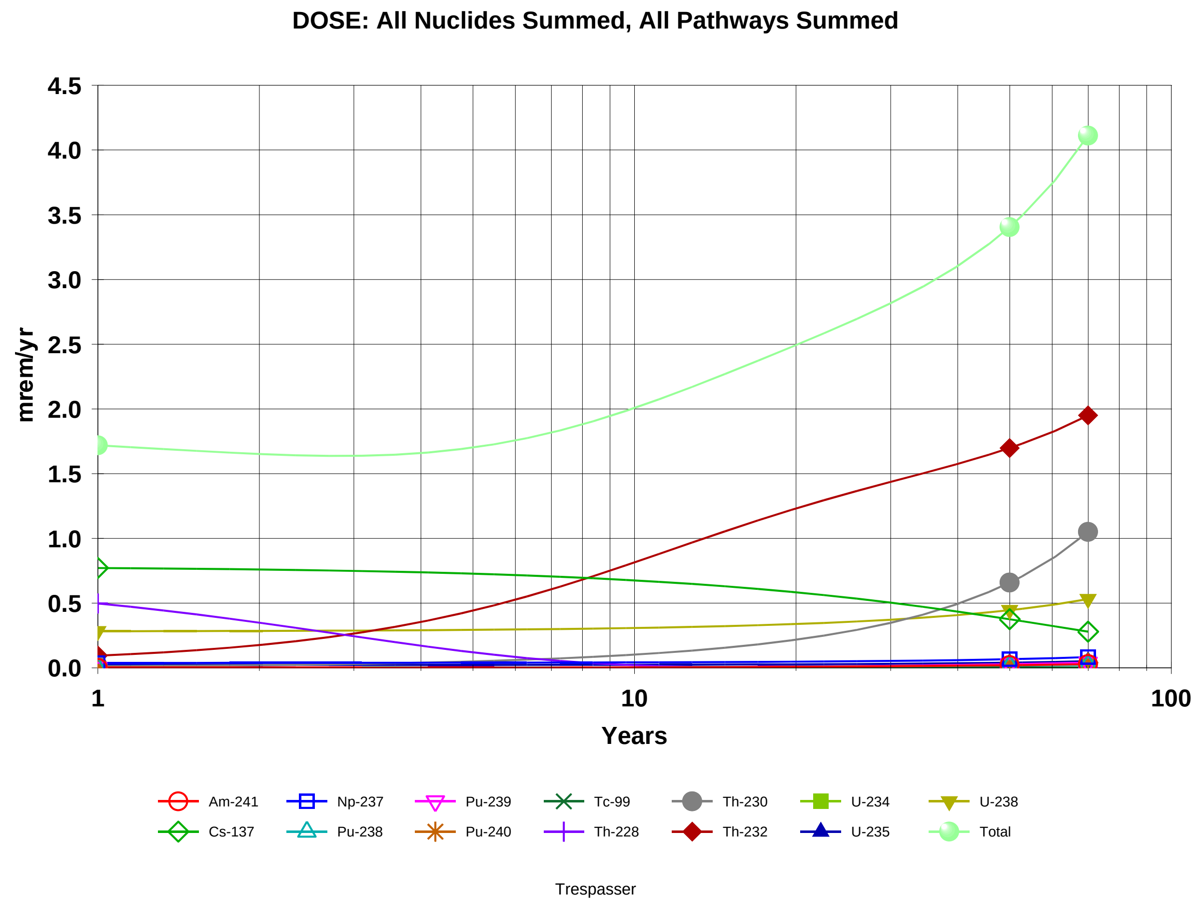

Figure 3-7. Dose to the Trespasser from all Selected Targeted Radionuclides and Pathways

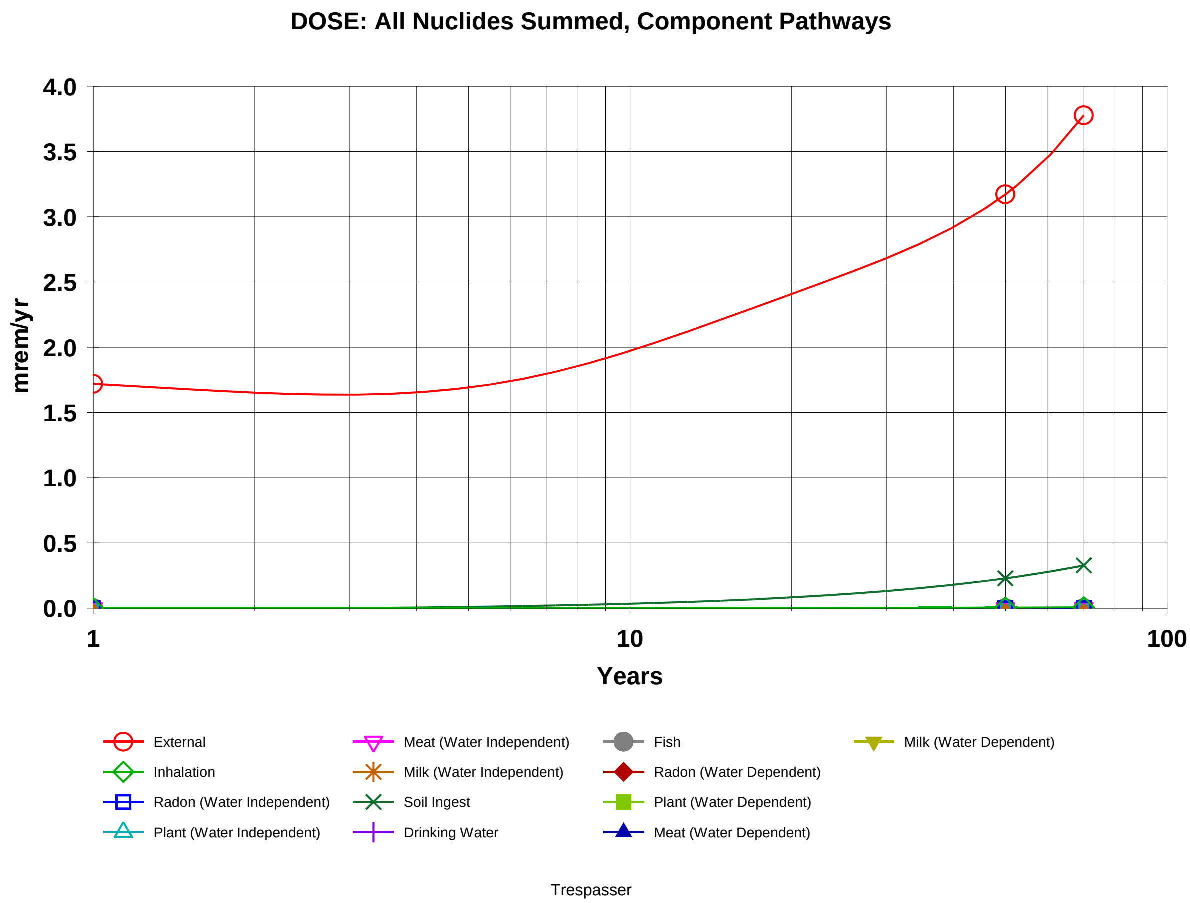

Figure 3–8. Dose to the Trespasser by Exposure Pathways

3.2 DETERMINISTIC PEAK DOSE ASSESSMENT FOR RECEPTORS MODELED DURING THE POST-INSTITUTIONAL CONTROL PERIOD.

Three separate peak dose evaluations were performed for the Resident Farmer (onsite), Resident Gardener, Recreational User, Outdoor Worker and Offsite Resident Farmer using the DOE-PPPO Proposed Single Radionuclide Soil Guidelines and time horizons of 1,050 yr, 10,000 yr and 100,000 yr. It is important to emphasize that the time horizons of 10,000 yr and 100,000 yr (maximum allowed by the codes) were used at the request of the DOE-PPPO for informational purposes to determine the magnitude of the dose during these time periods.

3.2.1 FIRST ASSESSMENT

The results for the first evaluation using a time horizon of 1,050 yr are summarized in Table 3-3.

Table 3–3. Peak Doses from DOE–PPPO Proposed Single Radionuclide Soil Guidelines

Receptor	Resident Farmer (onsite)	Resident Gardener	Recreational User	Outdoor Worker	Offsite Resident Farmer
Target Dose (mrem/yr)	100	100	1	1	1
Peak Dose (mrem/yr)	21	7	0.001	0.003	1.9
Time (yr)	425.2 ± 0.9	1,050	1,050	1,050	772

The codes generated results that do not exceed the DOE's 100 mrem/yr primary public dose limit (above background) for the Resident Farmer (onsite), Resident Gardener, Recreational User, and Outdoor Worker. However, the result obtained for the Offsite Resident Farmer exceeds the DOE field element and Commonwealth of Kentucky Radiation Health Branch "walk away" dose constraint of 1 mrem/yr (above background).

RESIDENT FARMER (ONSITE)

The peak dose for the Resident Farmer (onsite) occurs at 425.2 ± 0.9 yr when using a time horizon of 1,050 yr. As depicted in Figures 3-9 and 3-10, this receptor's dose is due to Tc-99 through the drinking water, milk and plant ingestion pathways with the maximum dose occurring at 425.2 ± 0.9 yr. The meat ingestion pathway also contributes to the dose; however, the dose contribution is less than 1%. This receptor is considered an implausible receptor as indicated in ORISE 2012.

The following RESRAD graphics correspond to the Resident Farmer (onsite) using a time horizon of 1,050 yr.

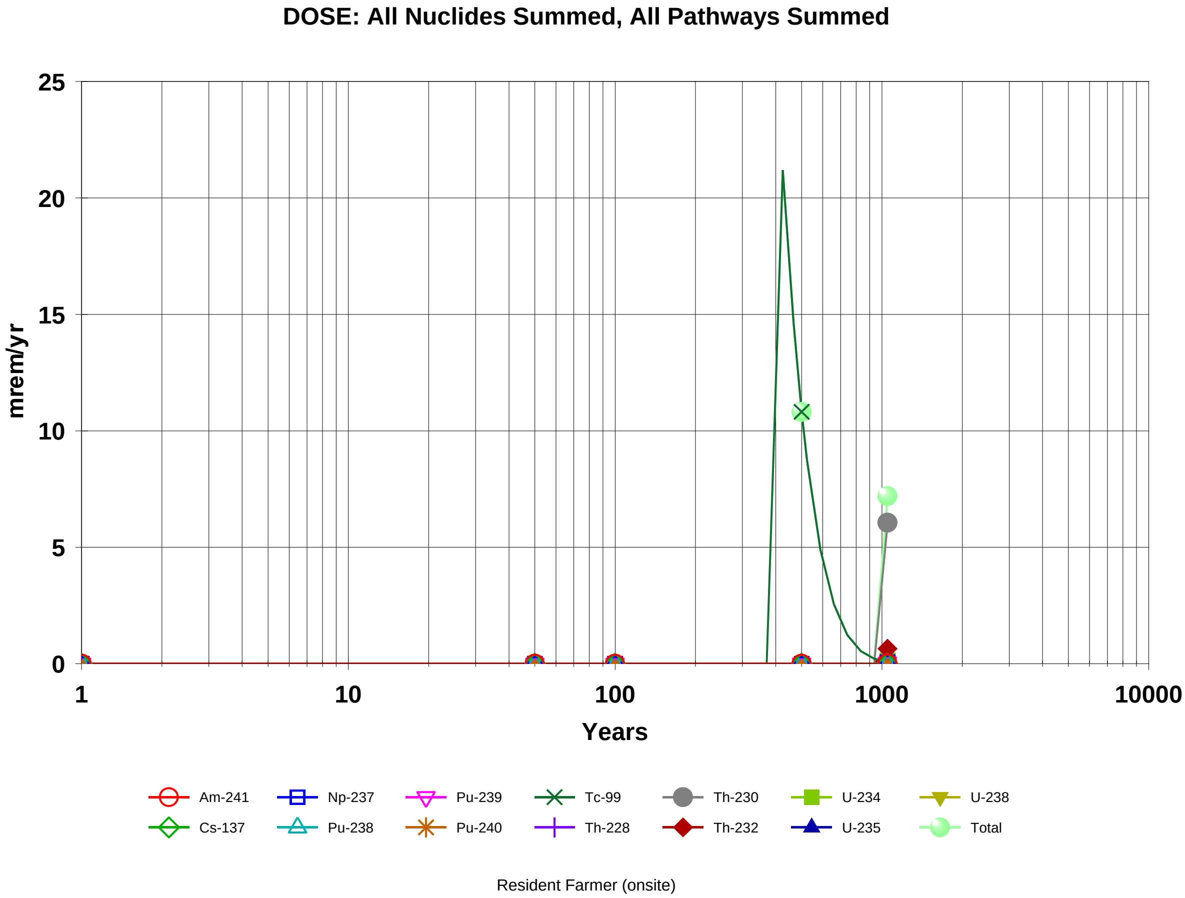

Figure 3–9. Dose to the Resident Farmer (onsite) from all Selected Targeted Radionuclides and Pathways

The sharp peak for Tc-99 may be caused by an artifact in the code; however, the reason why this occurred is not clearly understood. Further investigation and assistance by the developers of the RESRAD code are required to explain the rapid increase and decrease of this peak.

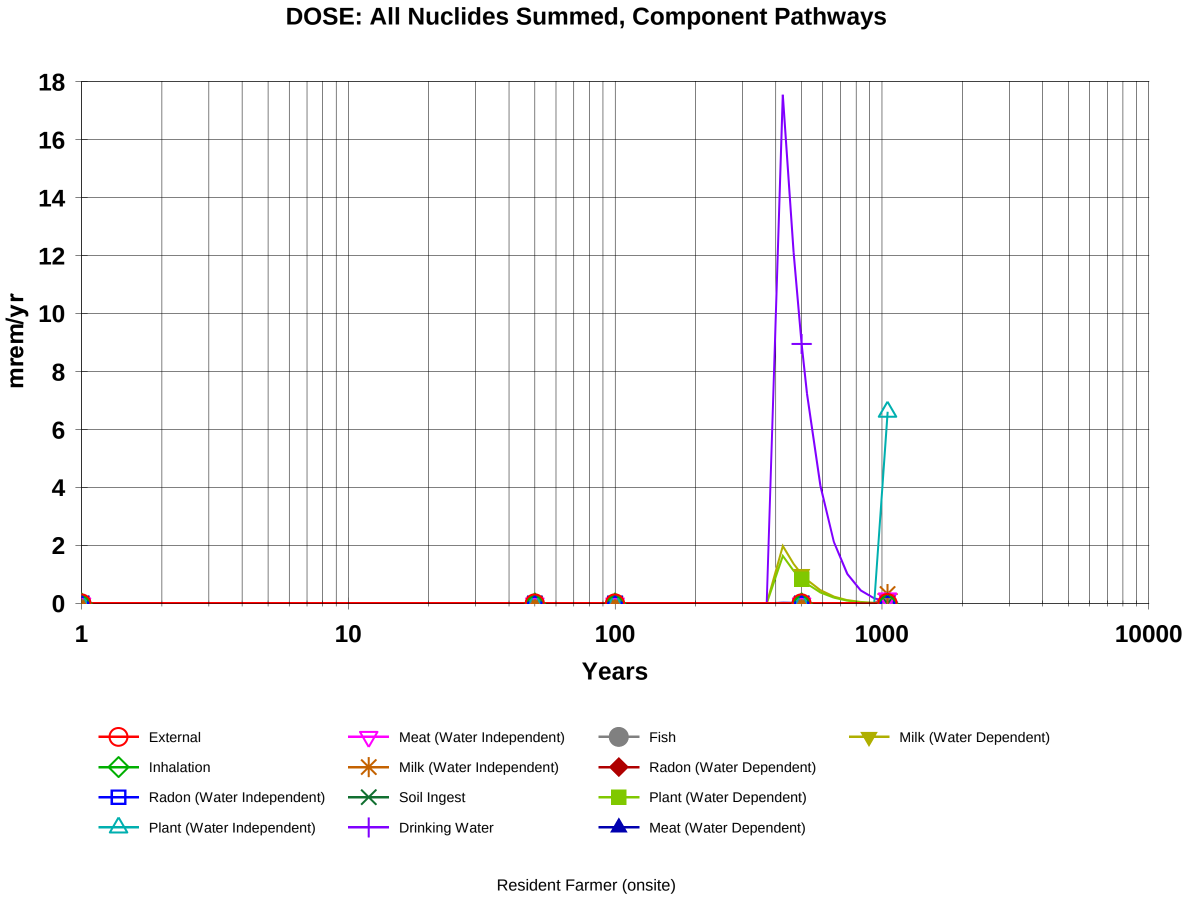

Figure 3–10. Dose to the Resident Farmer (onsite) by Exposure Pathways

RESIDENT GARDENER

The peak dose for the Resident Gardener occurs at 1,050 yr which is same as the time horizon used in this evaluation. As depicted in Figures 3-11 and 3-12, this receptor's dose is due to Th-230 and Th-232 through the plant ingestion pathway. This receptor is considered an implausible receptor as indicated in ORISE 2012.

The following RESRAD graphics correspond to the Resident Gardener using a time horizon of 1,050 yr.

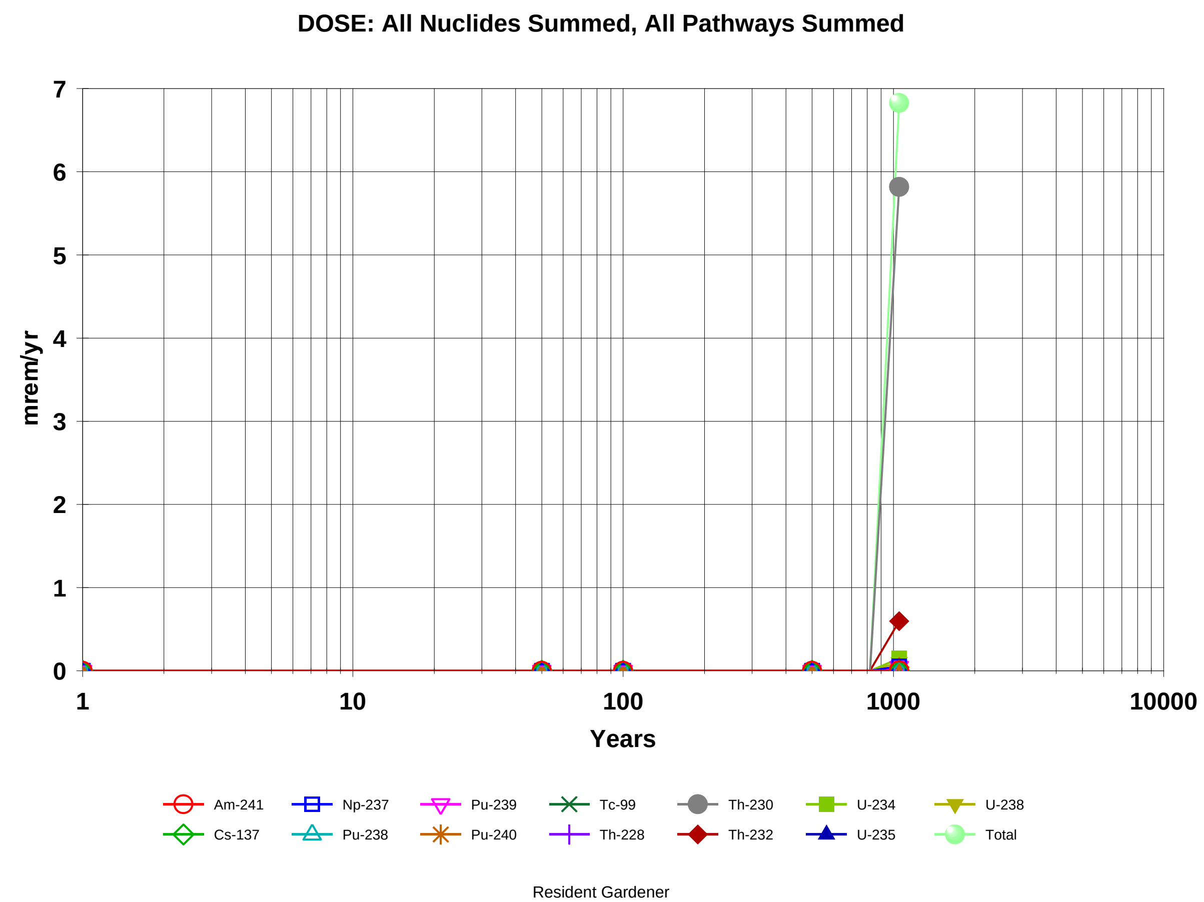

Figure 3–11. Dose to the Resident Gardener from all Selected Targeted Radionuclides and Pathways

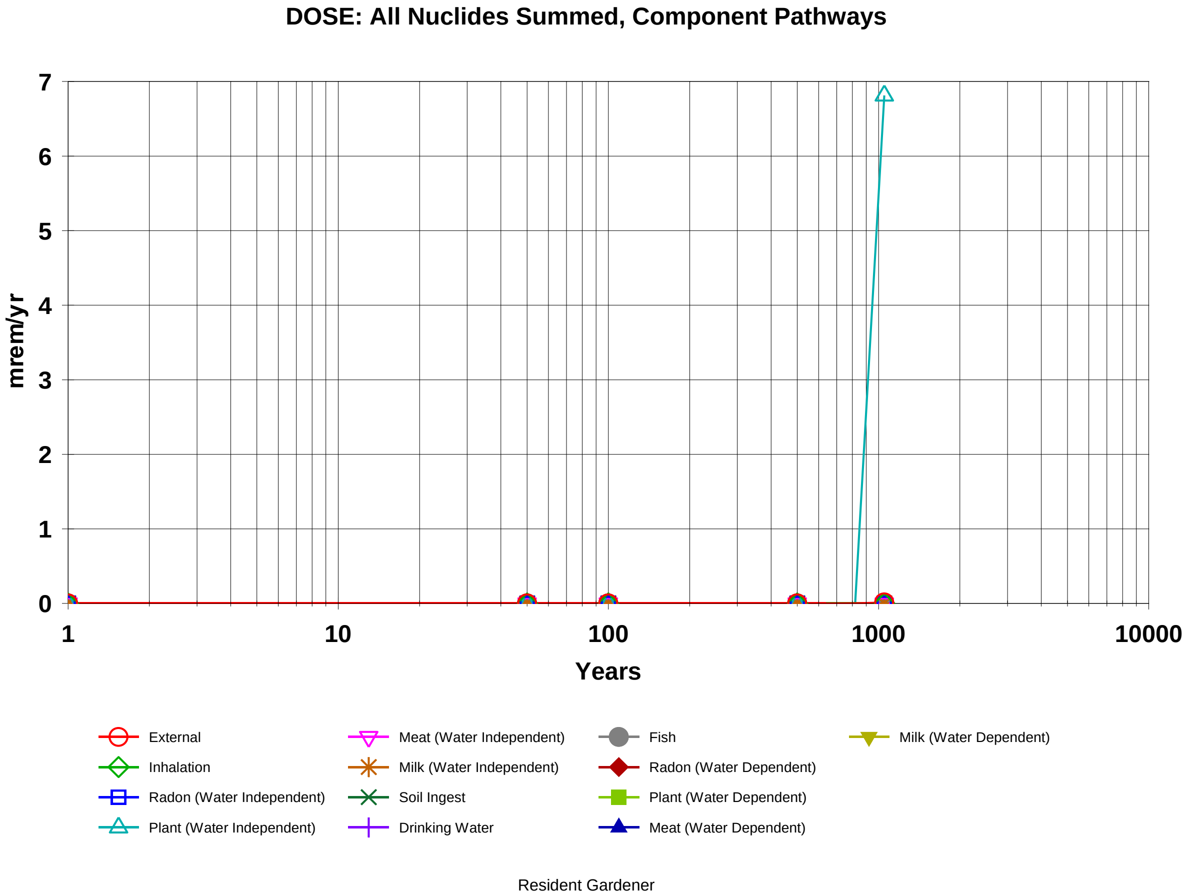

Figure 3–12. Dose to the Resident Gardener by Exposure Pathways

RECREATIONAL USER

The peak dose for the Recreational User occurs at 1,050 yr which is same as the time horizon used in this evaluation. As depicted in Figures 3-13 and 3-14, this receptor's dose is due to Th-230 and Th-232 through the external gamma pathway. This receptor is considered a plausible receptor as indicated in ORISE 2012.

The following RESRAD graphics correspond to the Recreational User using a time horizon of 1,050 yr.

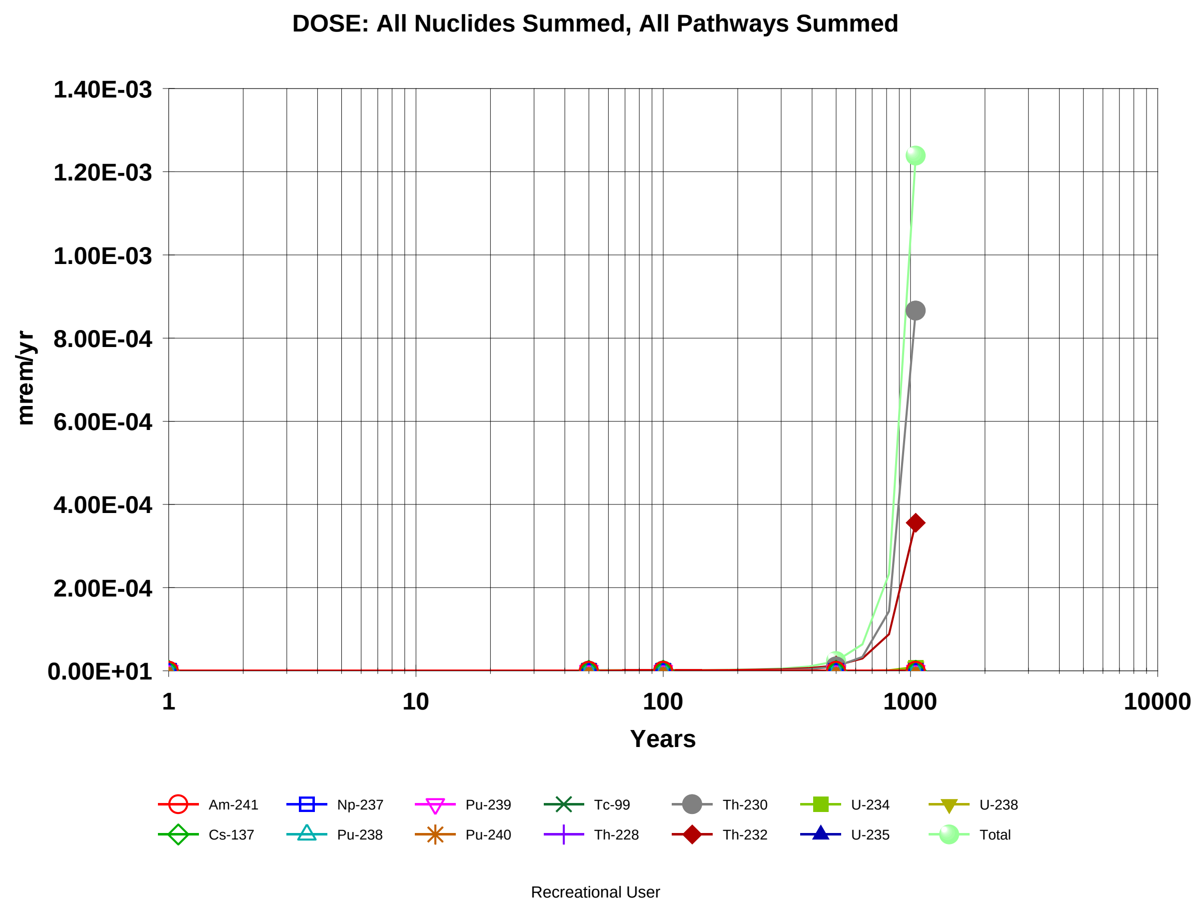

Figure 3–13. Dose to the Recreational User from all Selected Targeted Radionuclides and Pathways

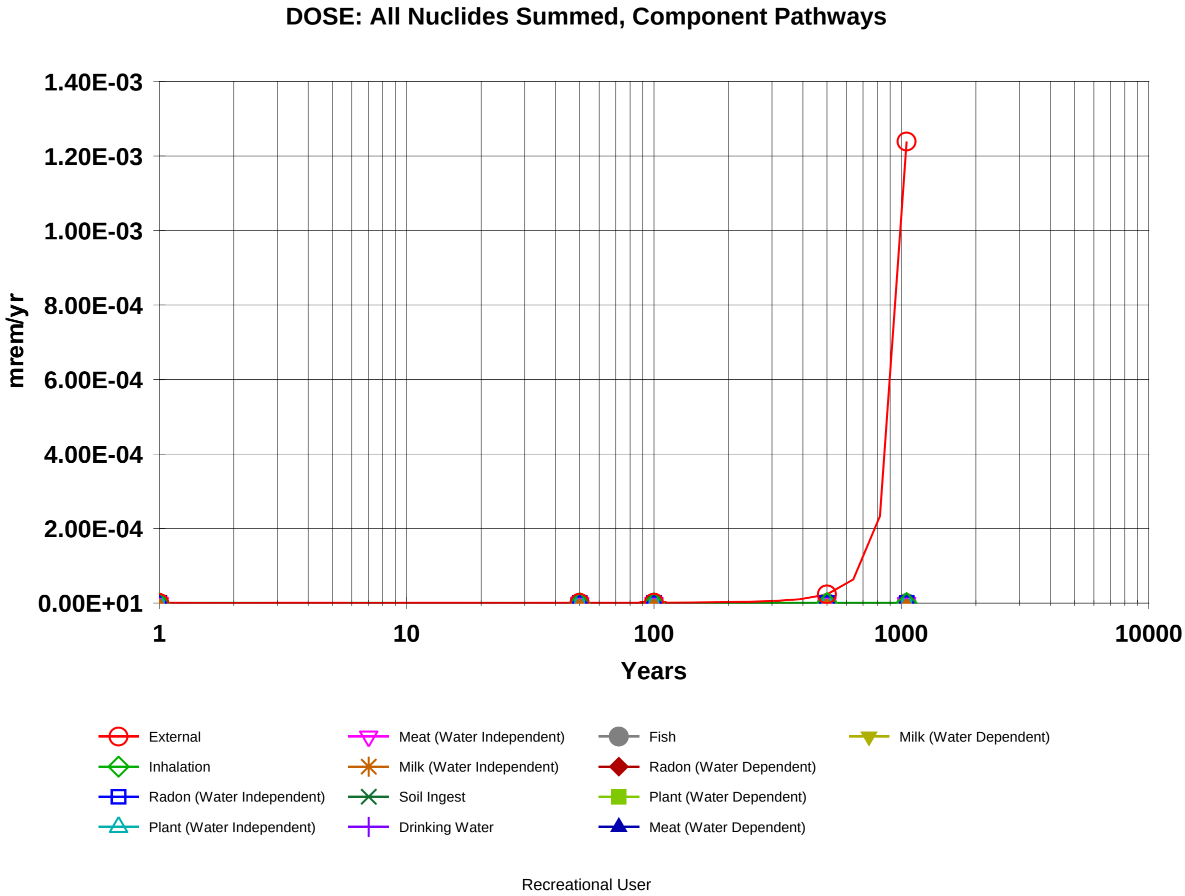

Figure 3–14. Dose to the Recreational User by Exposure Pathways

OUTDOOR WORKER

The peak dose for the Outdoor Worker occurs at 1,050 yr which is same as the time horizon used in this evaluation. As depicted in Figures 3-15 and 3-16, this receptor's dose is due to Th-230 and Th-232 through the external gamma pathway. This receptor is considered an implausible receptor as indicated in ORISE 2012.

The following RESRAD graphics correspond to the Outdoor Worker using a time horizon of 1,050 yr.

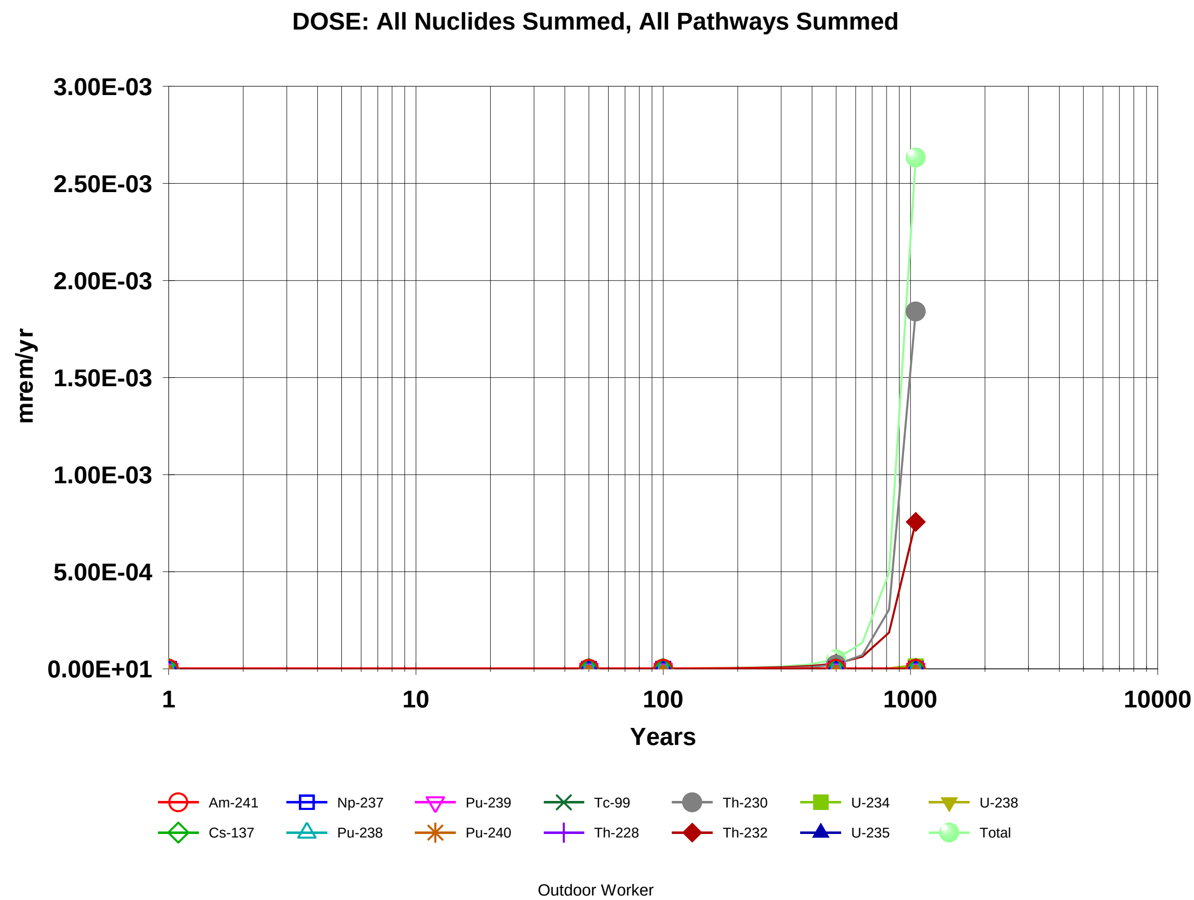

Figure 3–15. Dose to the Outdoor Worker from all Selected Targeted Radionuclides and Pathways

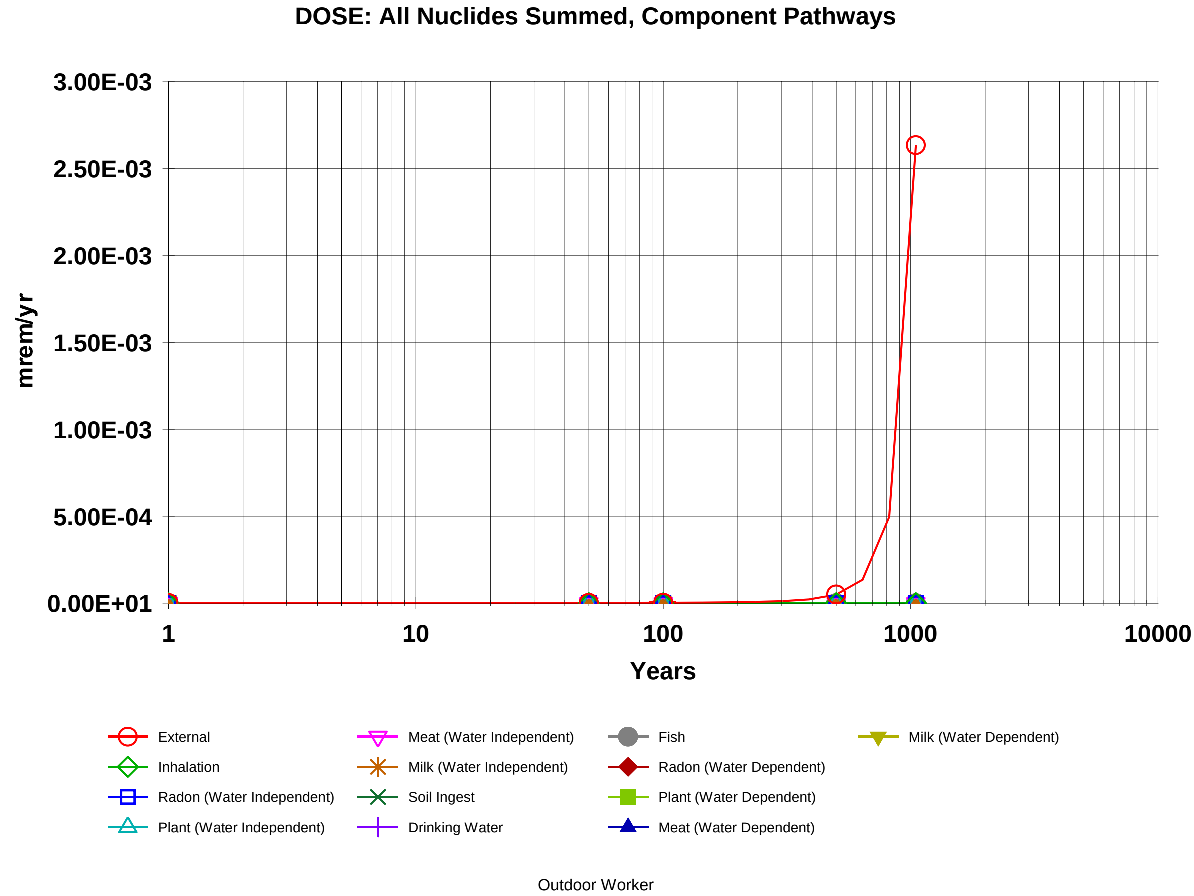

Figure 3–16. Dose to the Outdoor Worker by Exposure Pathways

OFFSITE RESIDENT FARMER

The peak dose for the Offsite Resident Farmer occurs at 772 yr when using a time horizon of 1,050 yr. As depicted in Figures 3-17 and 3-18, this receptor's dose is also due entirely to Tc-99 through the drinking water, plant and milk ingestion pathways. The meat ingestion pathway also contributes to the maximum dose; however, the contribution from this pathway is 0.1%. However, it could be assumed that the dose derives from drinking water, plant, and milk ingestion pathways due to the fact that the meat ingestion pathway contribution is miniscule.

The following RESRAD-OFFSITE graphics correspond to the Offsite Resident Farmer using a time horizon of 1,050 yr.

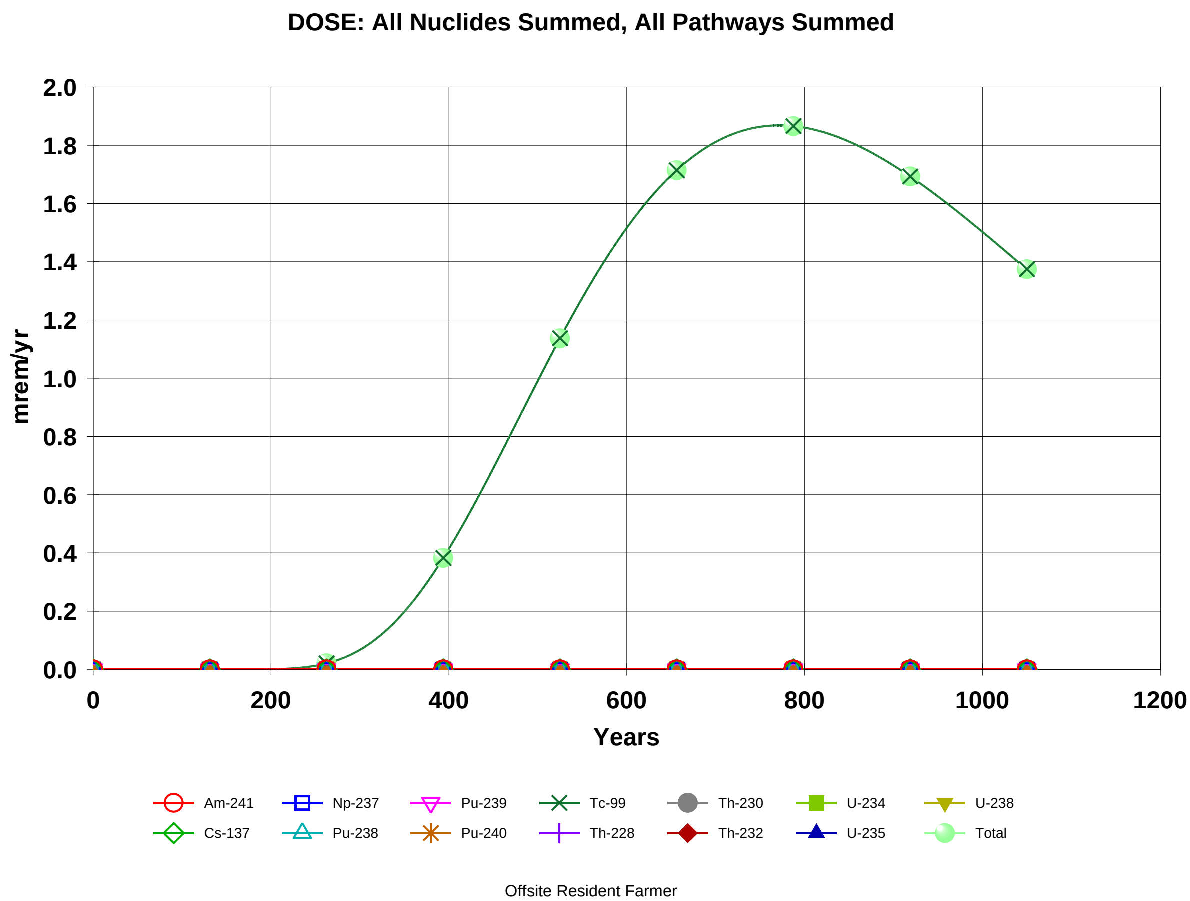

Figure 3–17. Dose to the Offsite Resident Farmer from all Selected Targeted Radionuclides and Pathways

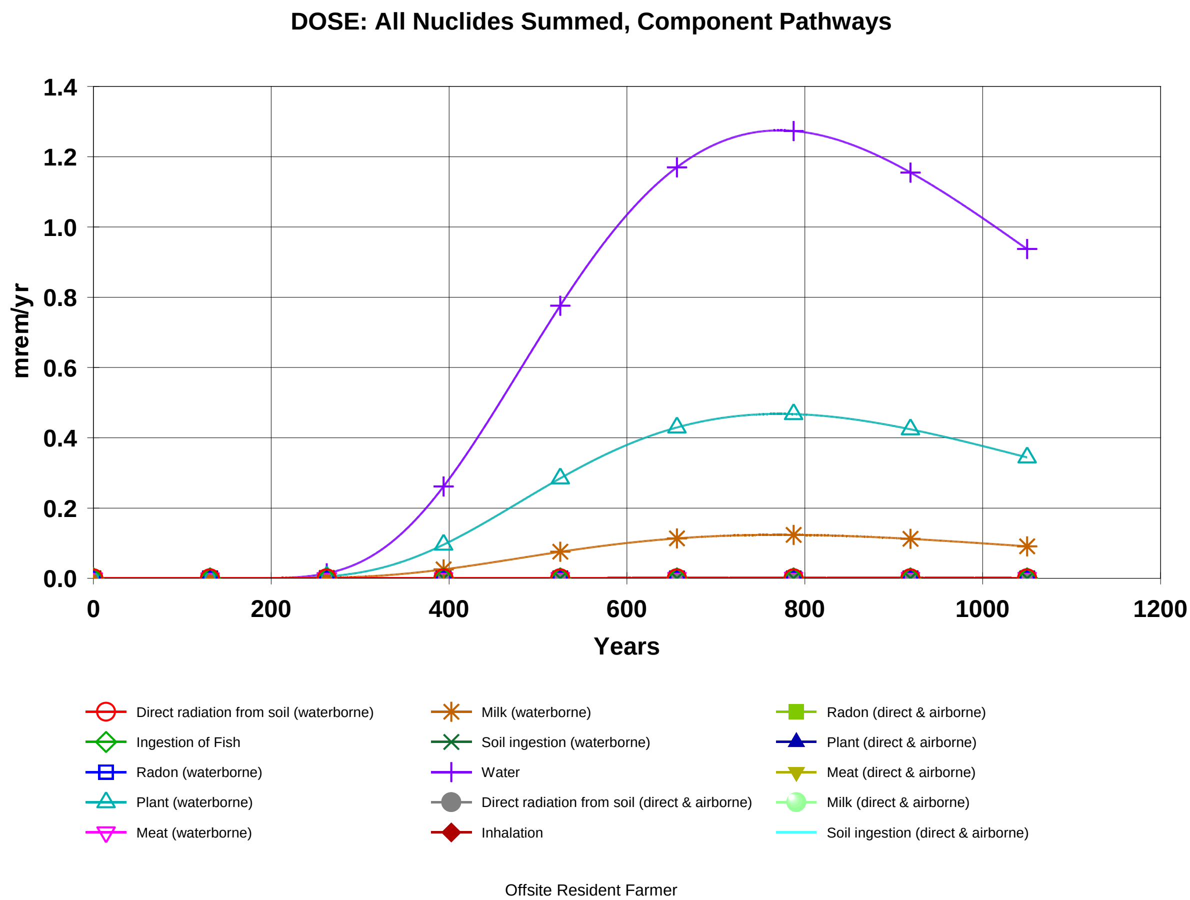

Figure 3–18. Dose to the Offsite Resident Farmer by Exposure Pathways

This receptor is considered plausible in ORISE 2012. The Tc-99 dose to this receptor is worthy of further discussions. Table 3-4 includes a breakdown of the 1.9 mrem/yr total dose for this receptor from Tc-99. Figure 3-19 is also included to exclusively show the contribution of each pathway to the total Tc-99 dose as a function of time.

Table 3–4. Exposure Pathways and Doses Contributing to the Tc–99 Dose for the Offsite Resident Farmer

Exposure Pathway	Dose (mrem/yr)*	Percentage contributing to the total dose
Drinking water	1.275	68%
Ingestion of Plants	0.4681	25%
Ingestion of Milk	0.1239	6.6%
Ingestion of Meat	0.001403	0.1%

*Note: These dose results are not rounded to two significant figures in order to show a more accurate dose contribution by each pathway.

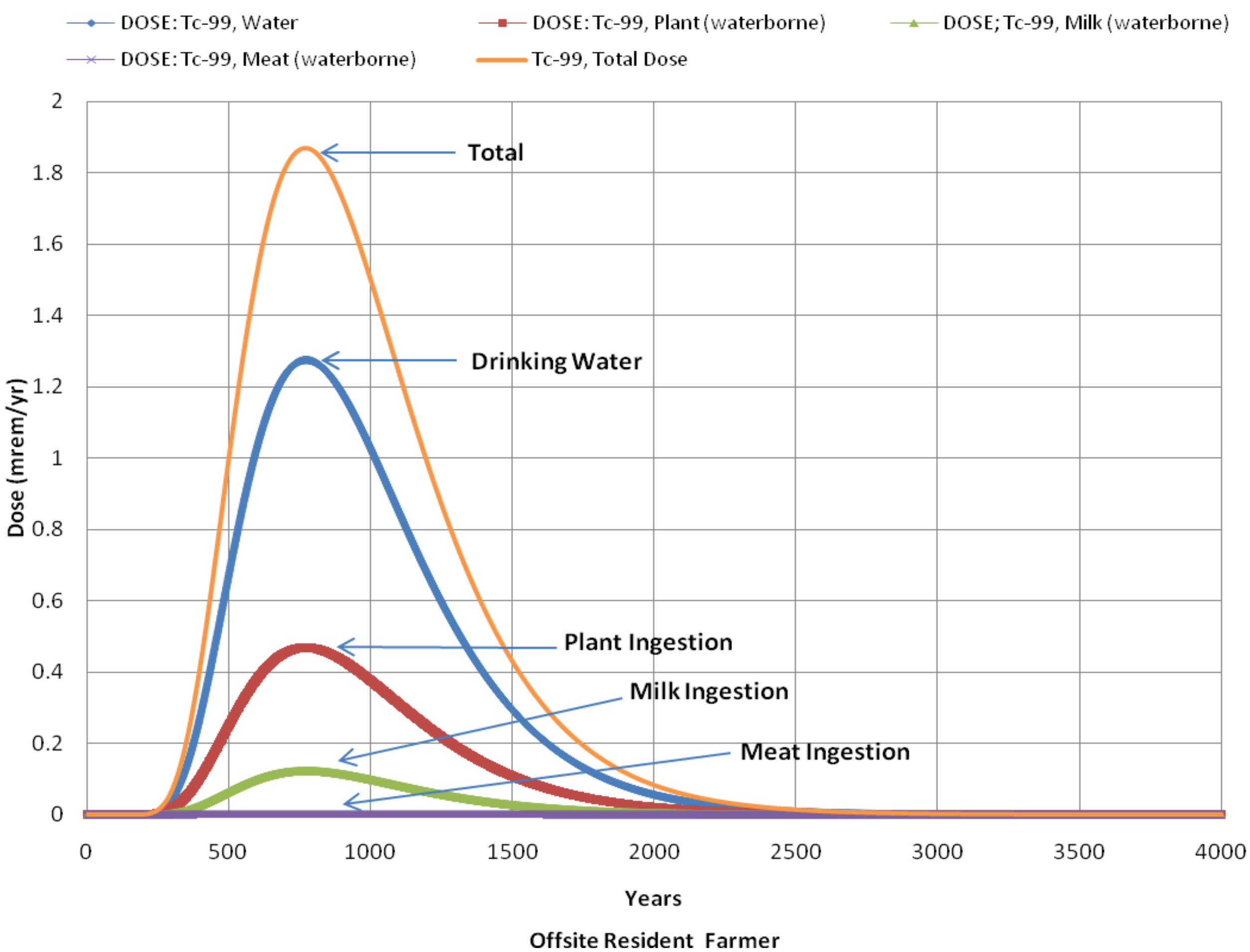

Figure 3–19. Tc–99 Dose by Contributing Exposure Pathway

The dose from drinking water predicted by the deterministic analysis is above the 1 mrem/yr (above background) dose constraint, but it is less than the EPA's 4 mrem/yr MCL for beta particle and photon radioactivity from man-made radionuclides, such as Tc-99, in public drinking water supplies (40 CFR 141.66 (d) and 401 KAR 8:550 Section 1). Contributions to total dose from the other pathways modeled (e.g., plant, milk and meat consumption), were negligible and peaked at 0.59 mrem/yr.

3.2.2 SECOND ASSESSMENT

The results for the second evaluation using a time horizon of 10,000 yr are summarized in Table 3-5.

Table 3–5. Peak Doses from DOE–PPPO Proposed Single Radionuclide Soil Guidelines

Receptor	Resident Farmer (onsite)	Resident Gardener	Recreational User	Outdoor Worker	Offsite Resident Farmer
Target Dose (mrem/yr)	100	100	1	1	1
Peak Dose (mrem/yr)	2,700	2,400	95	220	2.2
Time (yr)	10,000	10,000	10,000	10,000	10,000

The peak doses for all the receptors exceed the 1 mrem/yr dose constraint (above background) and the 100 mrem/yr primary public dose limit (above background). In addition, these peak doses occur at 10,000 yr which is also the time horizon used in these analyses.

RESIDENT FARMER (ONSITE)

The main radionuclides contributing to the peak dose for the Resident Farmer (onsite) (in descending order) are Th-230, U-234, Th-232, U-238, U-235, Np-237, Pu-239 and Pu-240. As depicted in Figure 3-20 the majority of the dose derives from Th-230. The ingrowth progeny of Th-230, specifically Ra-226 and Pb-210, are the actual contributors to most of the peak dose. The exposure pathways contributing to the peak dose are ingestion of plants, external gamma, and ingestion of milk, meat and soil. These pathways are depicted in Figure 3-21.

The following RESRAD graphics correspond to the Resident Farmer (onsite) using a time horizon of 10,000 yr.

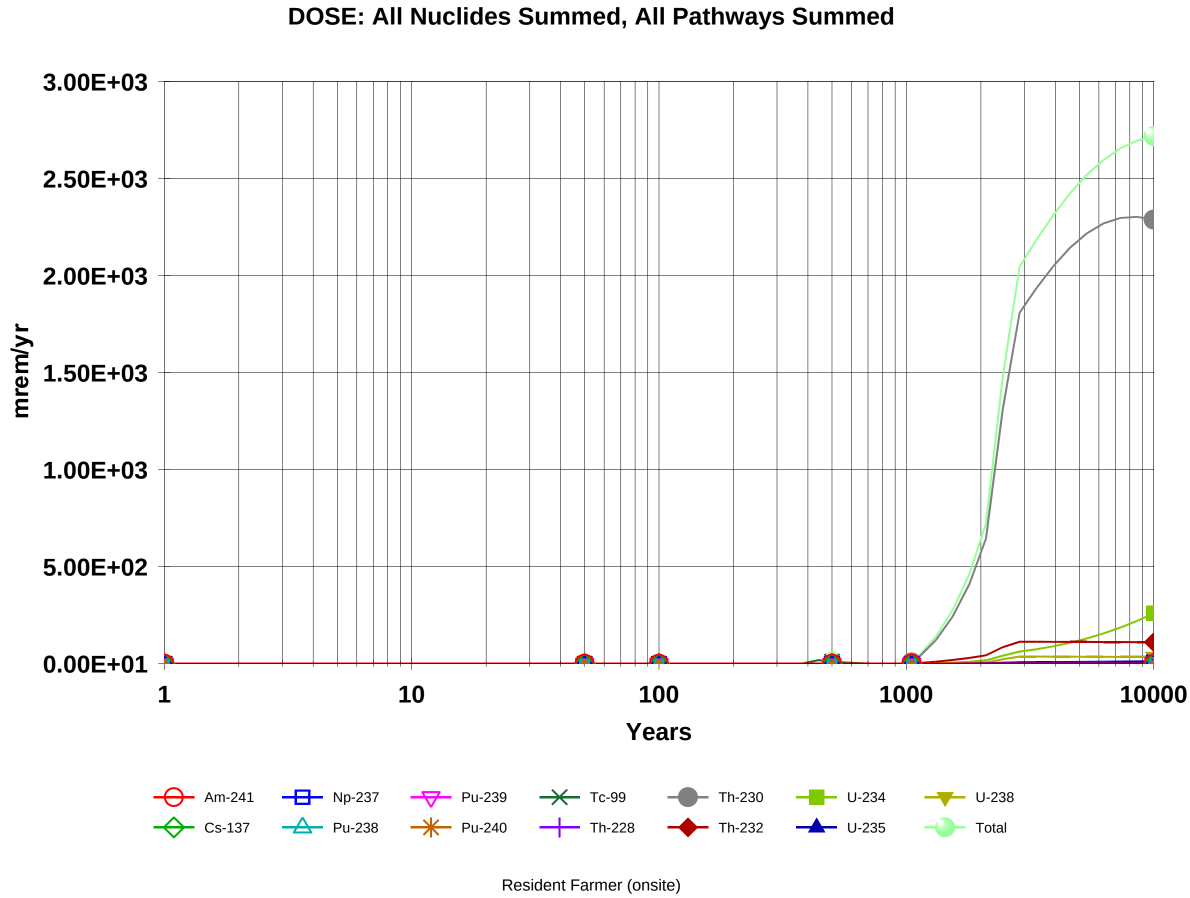

Figure 3–20. Dose to the Resident Farmer (onsite) from all Selected Targeted Radionuclides and Pathways

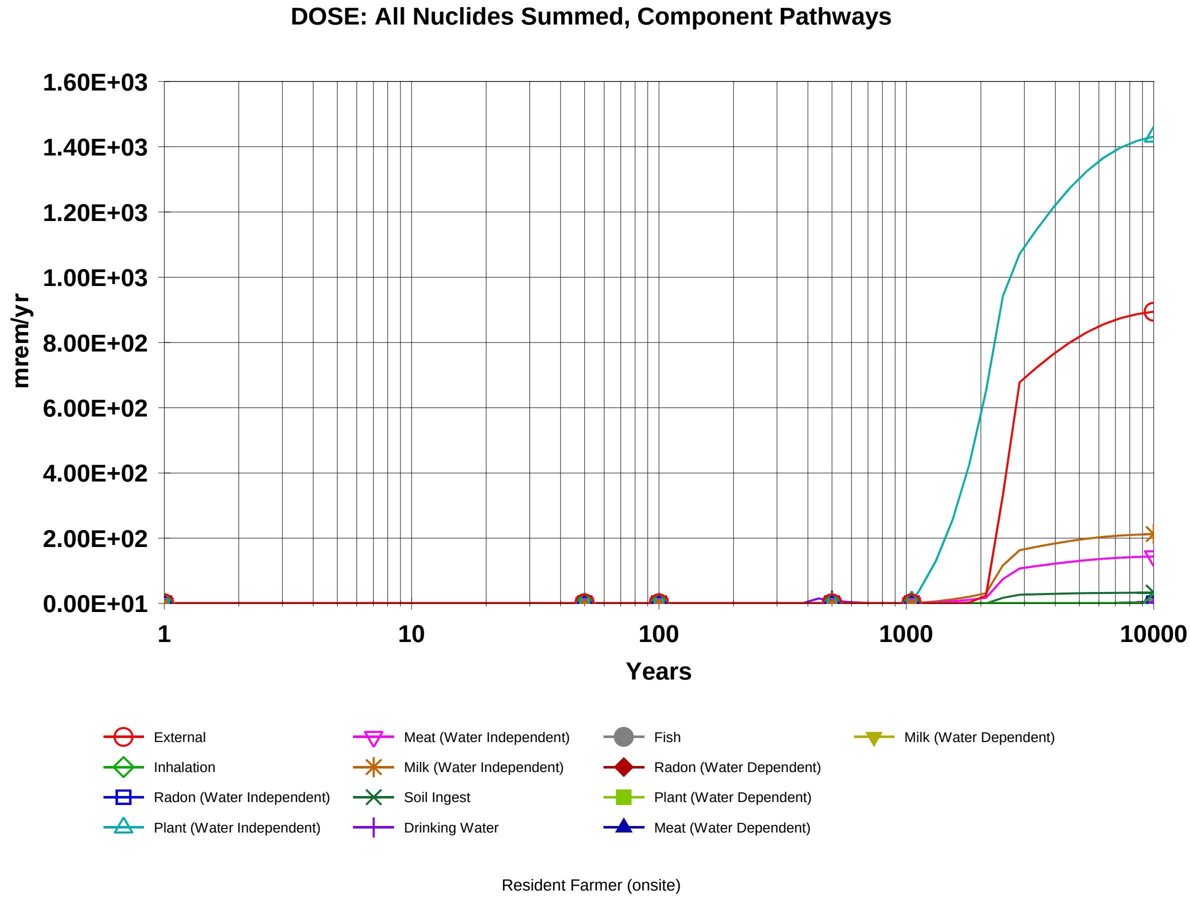

Figure 3–21. Dose to the Resident Farmer (onsite) by Exposure Pathways

RESIDENT GARDENER

The principal radionuclides contributing to the peak dose for the Resident Gardener (in descending order) are Th-230, U-234, Th-232, U-238, U-235, Pu-239, Np-237 and Pu-240. As depicted in Figure 3-22 the majority of the dose derives from Th-230. The ingrowth progeny of Th-230, specifically Ra-226 and Pb-210, are the actual contributors to most of the peak dose. The exposure pathways contributing to the peak dose are ingestion of plants, external gamma, and ingestion of soil. These pathways are depicted in Figure 3-23.

The following RESRAD graphics correspond to the Resident Farmer (onsite) using a time horizon of 10,000 yr.

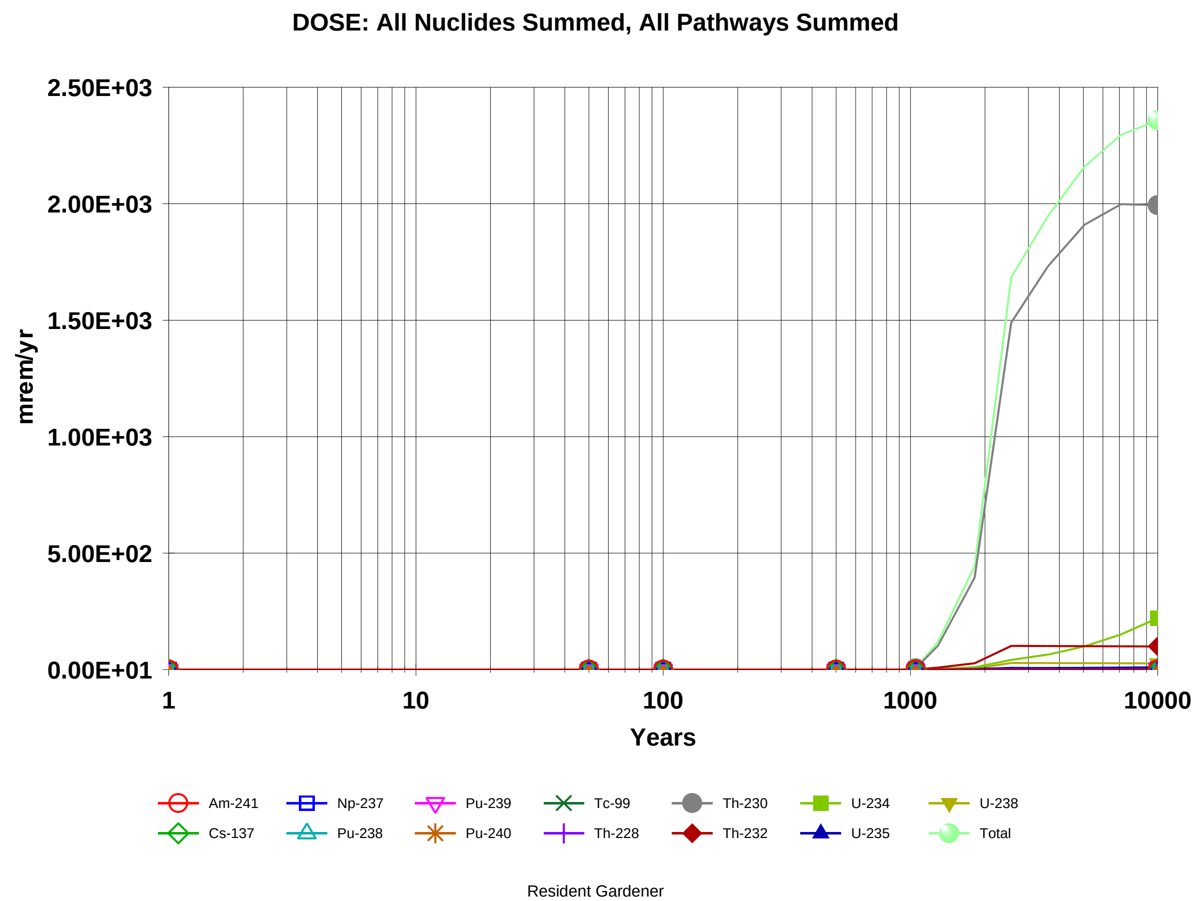

Figure 3–22. Dose to the Resident Gardener from all Selected Targeted Radionuclides and Pathways

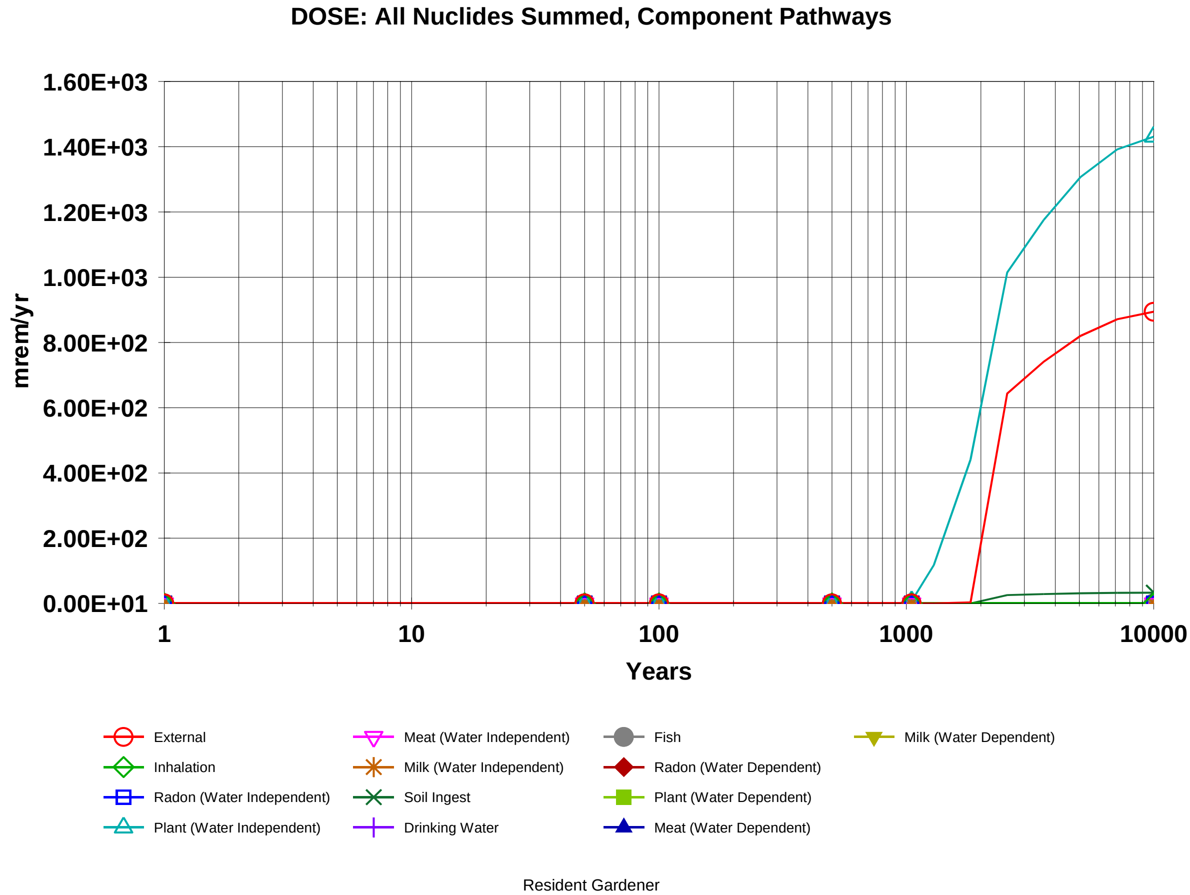

Figure 3–23. Dose to the Resident Gardener by Exposure Pathways

RECREATIONAL USER

The peak dose for the Recreational User derives (in descending order) from Th-230, U-234, Th-232, U-238, U-235, Np-237, Pu-239 and Pu-240 through the external gamma and soil ingestion pathways as depicted in Figures 3-24 and 3-25.

The following RESRAD graphics correspond to the Recreational User using a time horizon of 10,000 yr.

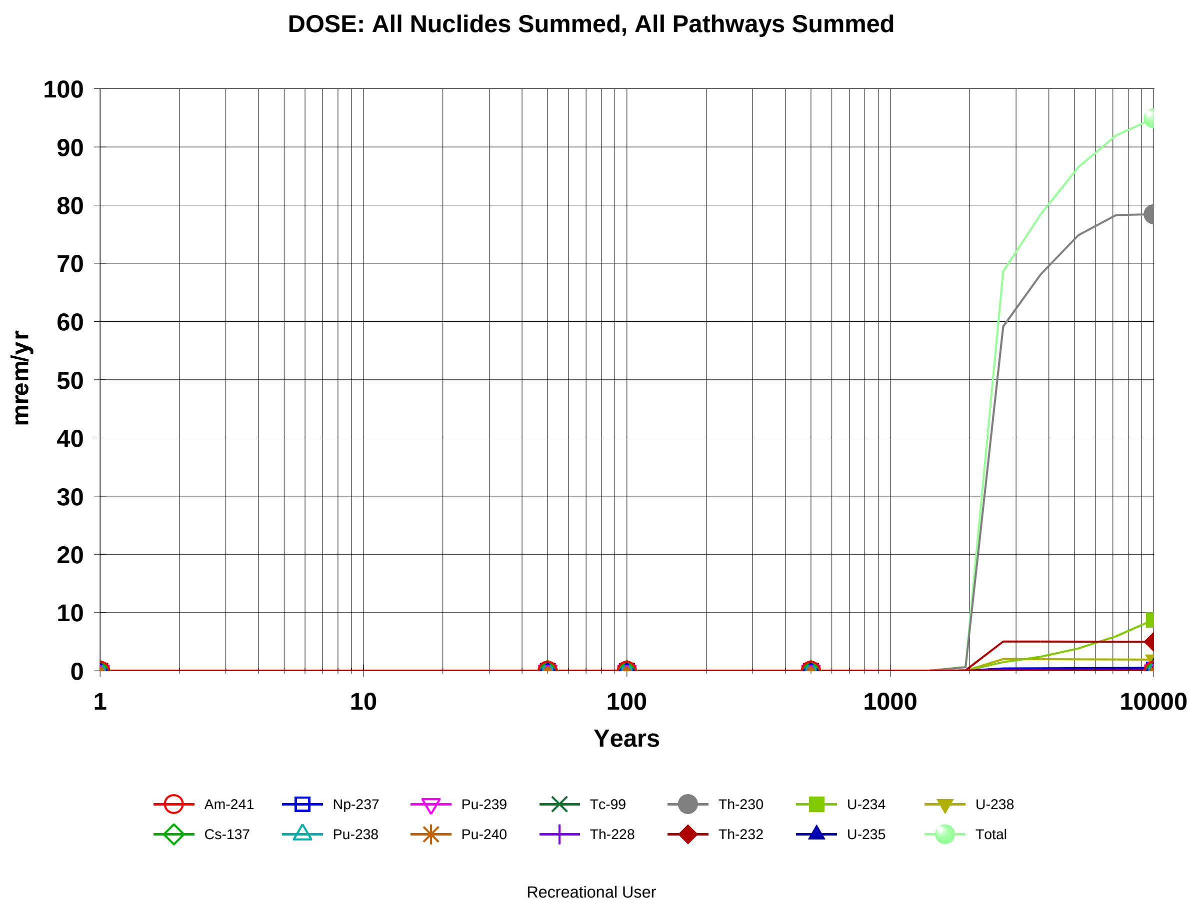

Figure 3–24. Dose to the Recreational User from all Selected Targeted Radionuclides and Pathways

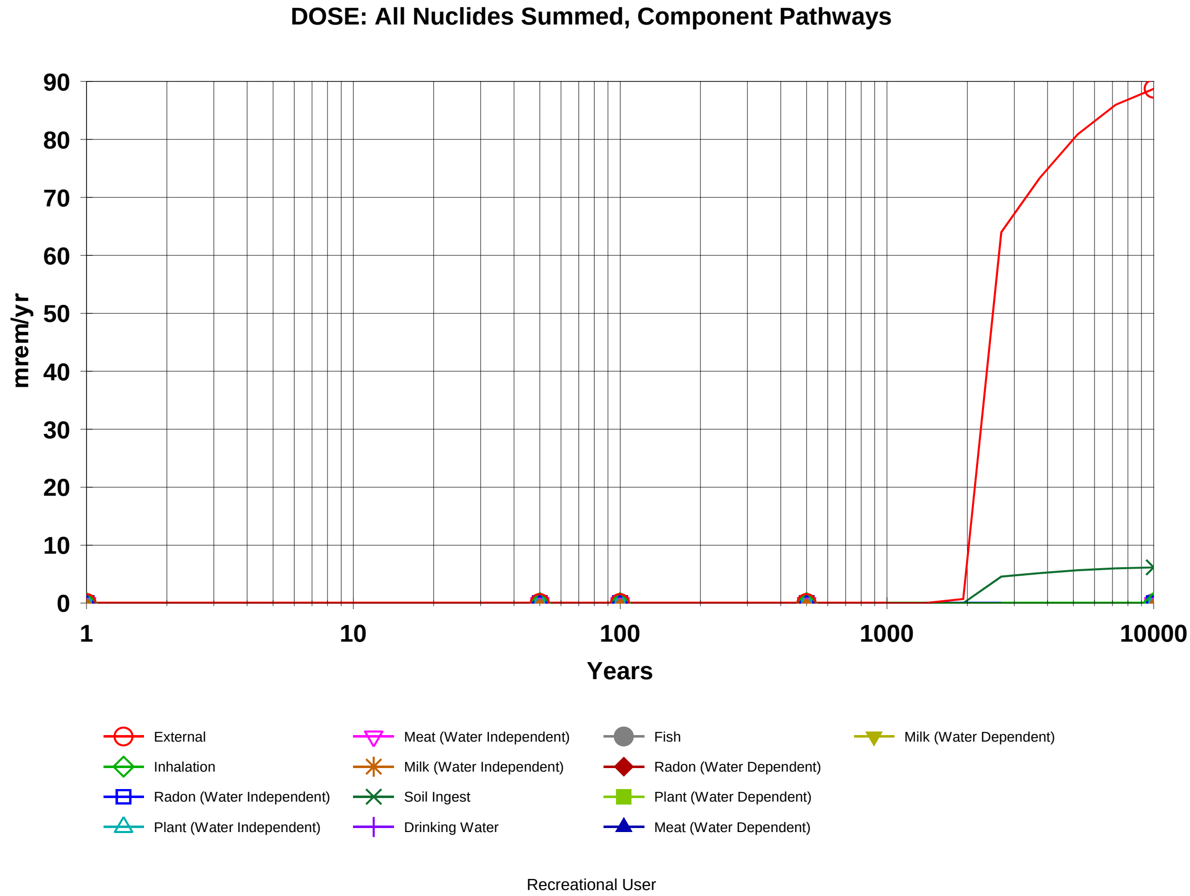

Figure 3–25. Dose to the Recreational User by Exposure Pathways

OUTDOOR WORKER

The radionuclides contributing to the peak dose of the Outdoor Worker (in descending order) are Th-230, U-234, Th-232, U-238, U-235, Pu-239, Np-237, and Pu-240. The majority of the dose derives from Th-230 as depicted in Figure 3-26. The ingrowth progeny of Th-230, specifically Ra-226 and Pb-210, are the actual contributors to most of the peak dose. The exposure pathways contributing to the peak dose are external gamma and soil ingestion as depicted in Figures 3-27.

The following RESRAD graphics correspond to the Outdoor Worker using a time horizon of 10,000 yr.

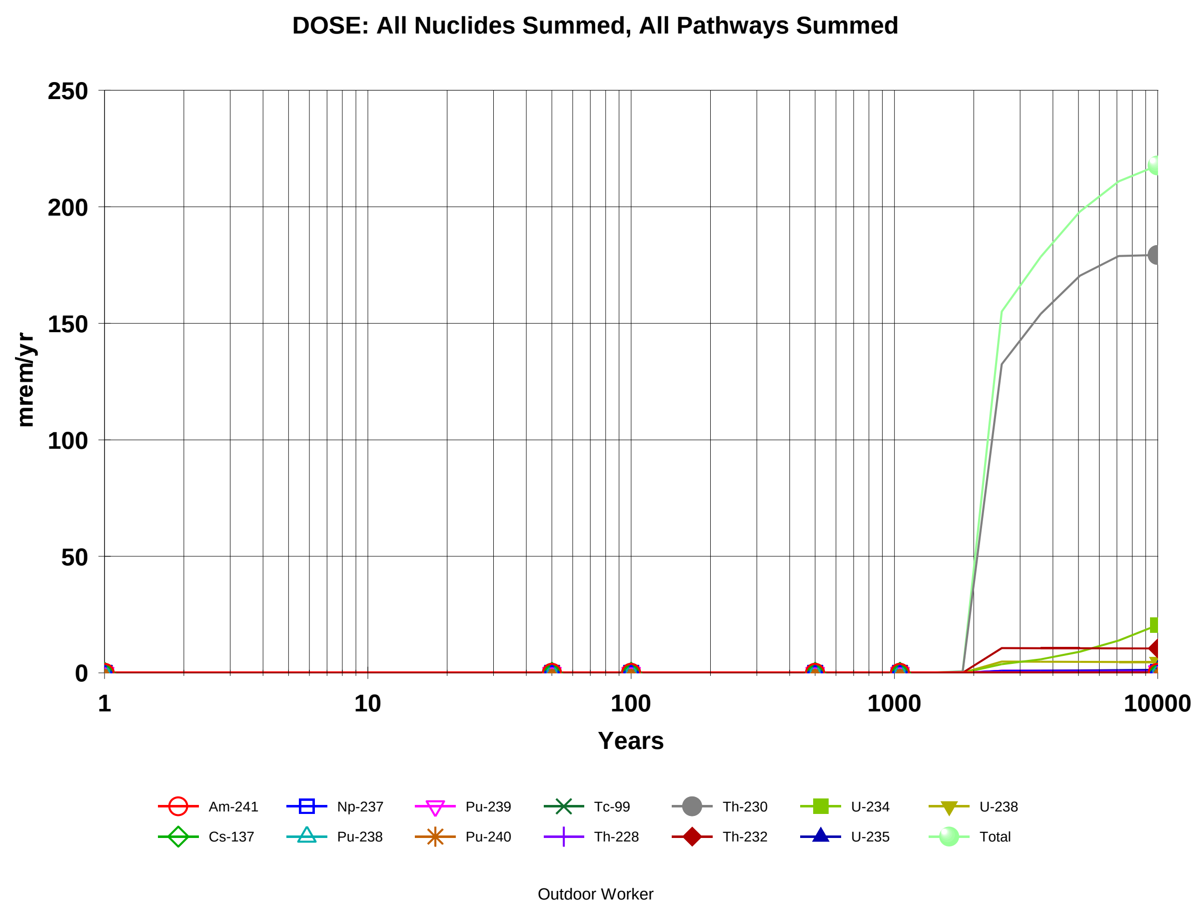

Figure 3–26. Dose to the Outdoor Worker from all Selected Targeted Radionuclides and Pathways

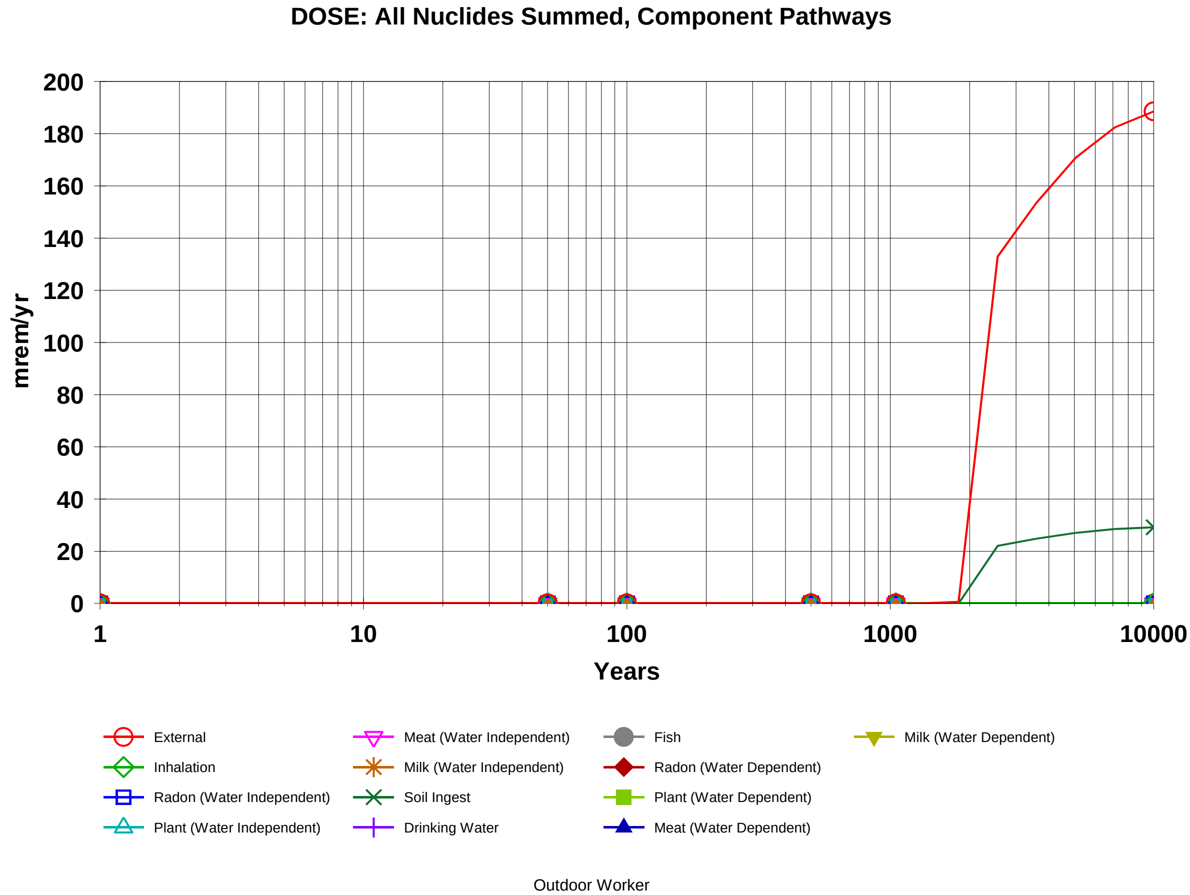

Figure 3–27. Dose to the Outdoor Worker by Exposure Pathways

OFFSITE RESIDENT FARMER

For this second assessment, when using a time horizon of 10,000 yr, the peak dose result for the Offsite Resident Farmer is no longer attributed to Tc-99. In this second assessment, the dose from Tc-99 starts disappearing at approximately 2,500 yr as demonstrated in Figure 3-28. However, the highest dose registered by the code is 2.2 mrem/yr and it occurs at 10,000 yr. The dose contribution derives from Np-237, the ingrowth progeny of Th-230 (i.e., Ra-226), U-234 (i.e., Ra-226), Th-232 (i.e., Th-228 and Ra-228) and the parent U-238 with a small contribution from its ingrowth progeny (i.e., Ra-226). The ingrowth progeny are not depicted in Figure 3-28, this figure only depicts the parent radionuclides as the contributors to the dose. However, a review of additional RESRAD-OFFSITE graphics and data indicates that the contribution to the dose from Th-230, U-234 and Th-232 originates from their ingrowth progeny. The principal exposure pathways by which these radionuclides contribute to the dose are drinking water external gamma and plant ingestion. A considerable portion of this dose, about 1.29 mrem/yr, results from Np-237 through the drinking water and plant ingestion pathways. The remaining dose is attributed to the ingrowth progeny of Th-230, U-234, Th-232 and the parent U-238 through the external gamma pathway. Figure 3-29 shows the exposure pathways by which the dose is created.

It is of interest to DOE-PPPO to know how this offsite receptor receives dose through the external gamma pathway indicated by the “direct radiation from soil (direct & airborne)” curve as illustrated in Figure 3-29. The dose initially appears at approximately 2,750 yrs. By this time the model has eroded the Landfill cover to the extent that the primary contamination is uncovered and it is emitting direct radiation to the receptor. The primary contamination area in the model (91,000 m^2) is considerably large; therefore, this receptor is receiving radiation dose at the dwelling area, agricultural areas, and pastures directly from the Landfill. In addition, this receptor spends 1/3 of the time outside. The direct gamma radiation dose predicted by the code is less than 1 mrem/yr.

The following RESRAD graphics correspond to the Offsite Resident Farmer using a time horizon of 10,000 yr.

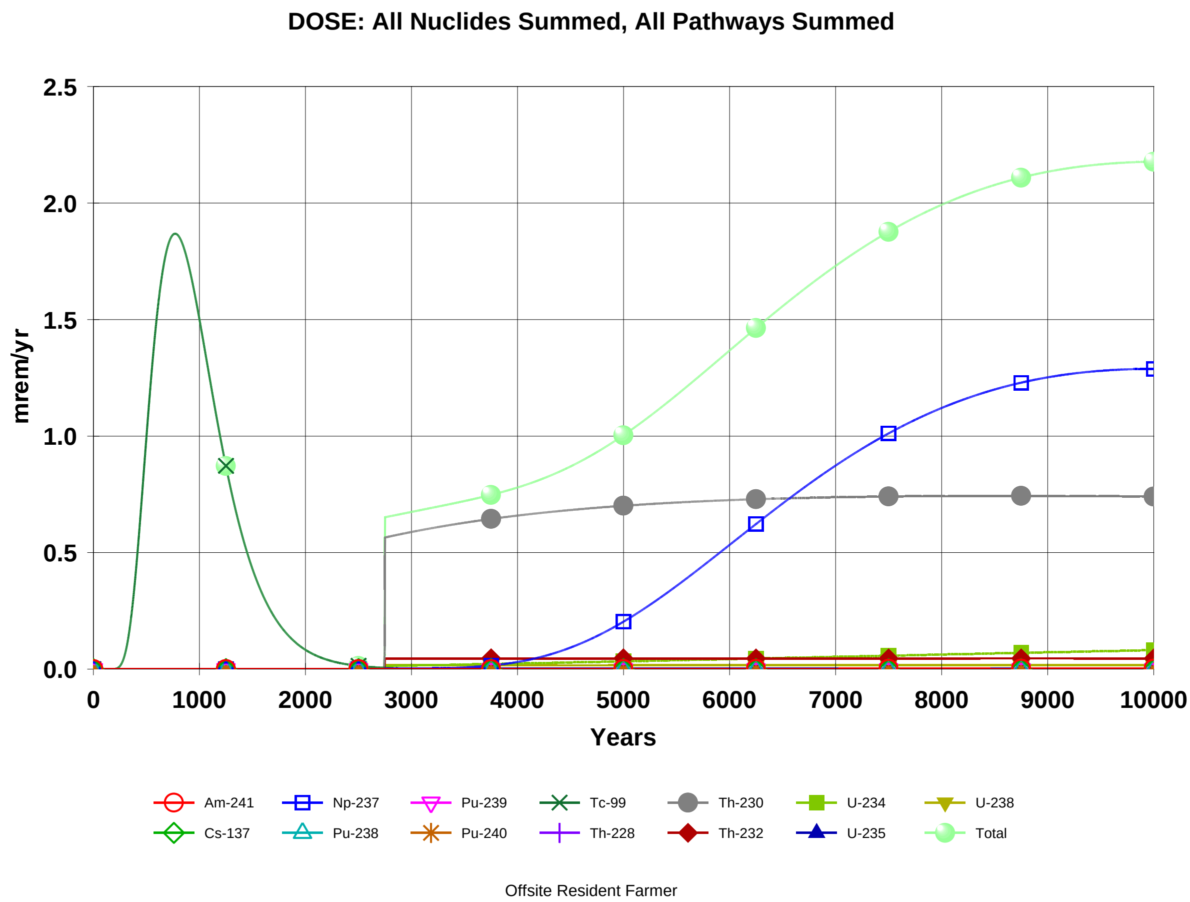

Figure 3–28. Dose to the Offsite Resident Farmer from all Selected Targeted Radionuclides and Pathways

A step increase for Th-230 can be identified in Figure 3-28 which may have been caused by an artifact in the code, however, the reason why this occurred was not clearly understood. While this step increase did not impact the results of the ORISE evaluation, ORISE recommends that further investigation and assistance by the developers of RESRAD-OFFSITE be provided to DOE to resolve this nuance in the code's graphical results.

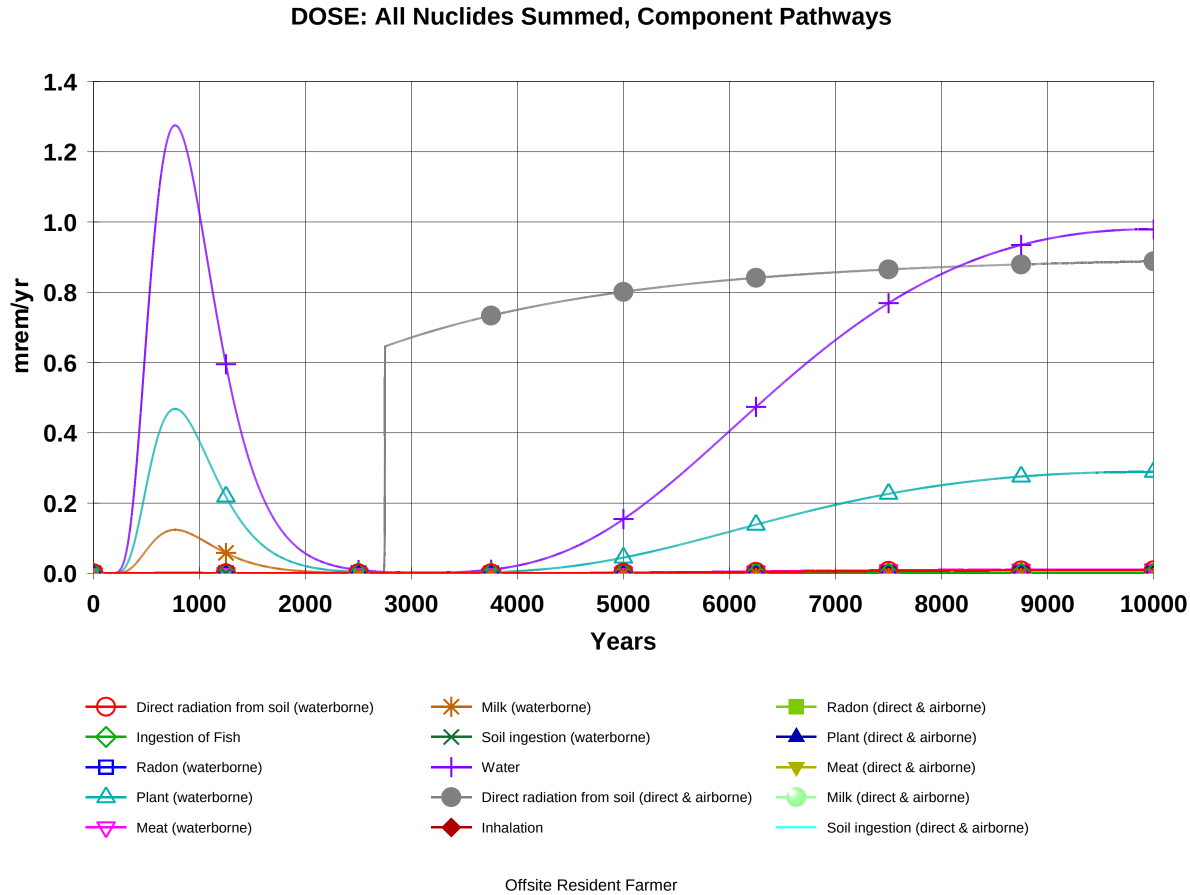

Figure 3–29. Dose to the Offsite Resident Farmer by Exposure Pathways

3.2.3 THIRD ASSESSMENT

The results for the third and last deterministic peak dose evaluation using a time horizon of 100,000 yr (maximum allowed by the code) are included in Table 3-6.

Table 3–6. Peak Doses from DOE–PPPO Proposed Single Radionuclide Soil Guidelines

Receptor	Resident Farmer (onsite)	Resident Gardener	Recreational User	Outdoor Worker	Offsite Resident Farmer
Target Dose (mrem/yr)	100	100	1	1	1
Peak Dose (mrem/yr)	2,700	2,400	96	220	2.2
Time (yr)	12,773	12,931	19,739	19,045	10,065

In this third assessment, the highest projected doses among all the time frames evaluated were obtained by extending the time frame to 100,000 yr. Similar to the second assessment, the results exceed the 1 mrem/yr constraint (above background) and the 100 mrem/yr public dose limit (above background). In addition, the radionuclides and pathways contributing to each receptor's peak doses are the same as those identified in the second peak dose assessments.

RESIDENT FARMER (ONSITE)

The maximum dose for the Resident Farmer (onsite) occurs at 12,773 yr and the dose is mostly due to Th-230, Th-232, U-234, U-235 and U-238 as depicted in Figure 3-30. A considerable fraction of the maximum dose derives from Th-230 and this third evaluation shows the complete peak for Th-230 in Figure 3-30. A review of additional RESRAD graphics and data reveals that the ingrowth progeny of Th-230, specifically Ra-226 and Pb-210, are the actual contributors to most of the peak dose. The exposure pathways contributing to the peak dose are ingestion of plants, external gamma, and ingestion of milk, meat and soil. These pathways are depicted in Figure 3-31.

The following RESRAD graphics correspond to the Resident Farmer (onsite) using a time horizon of 100,000 yr.

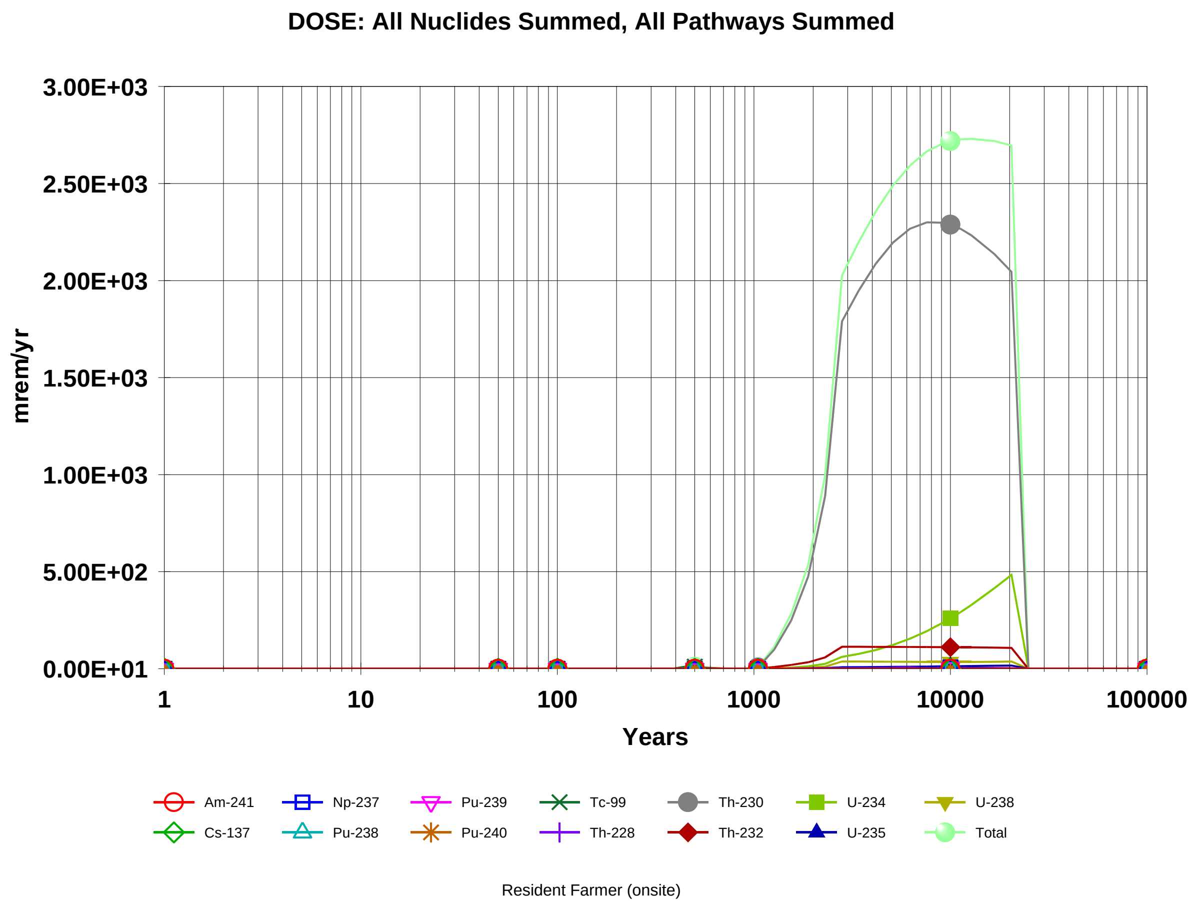

Figure 3–30. Dose to the Resident Farmer (onsite) from all Selected Targeted Radionuclides and Pathways

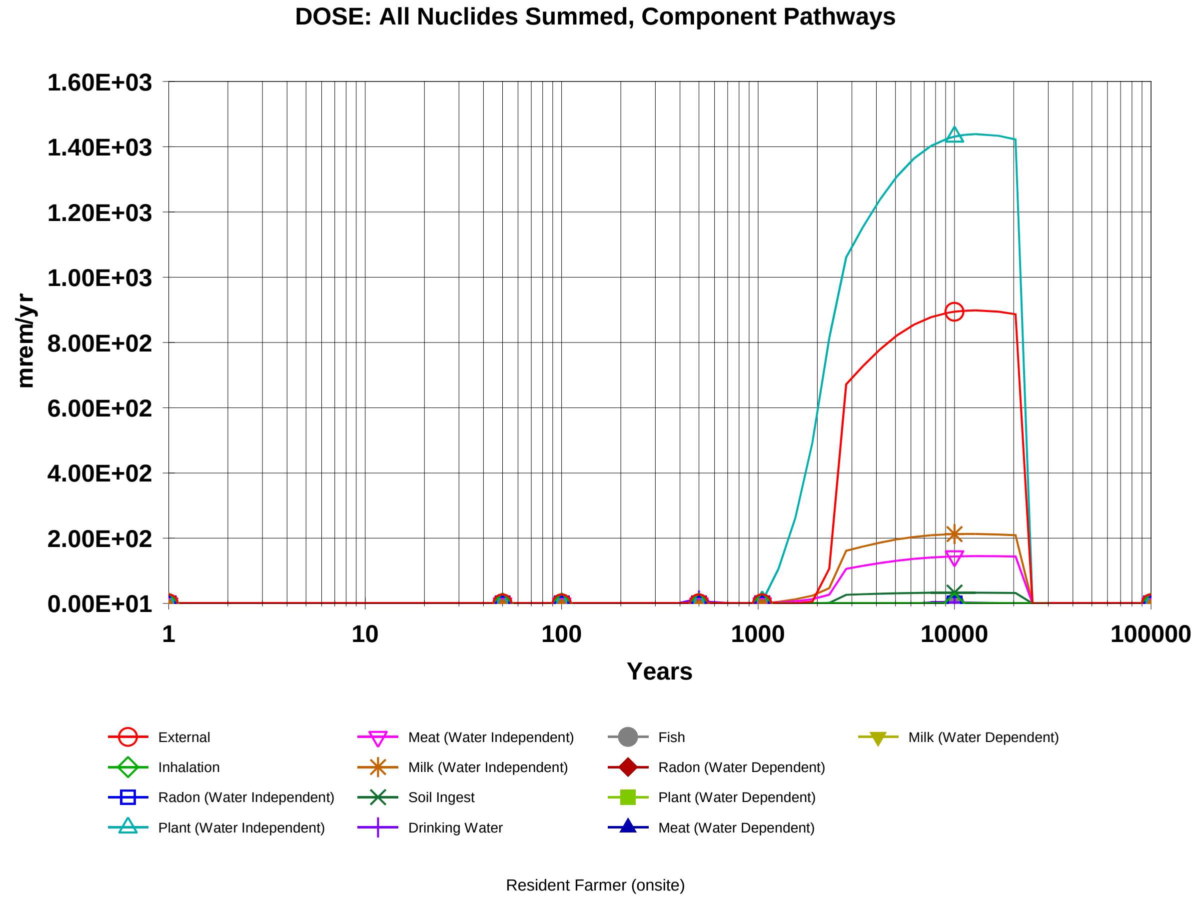

Figure 3–31. Dose to the Resident Farmer (onsite) by Exposure Pathways

RESIDENT GARDENER

As in the second assessment, the third peak dose for the Resident Gardener results mainly from Th-230, U-234, Th-232, U-238, U-235, Pu-239, Np-237 and Pu-240. Figure 3-32 illustrates that almost all of the dose derives from Th-230. The ingrowth progeny of Th-230, particularly Ra-226 and Pb-210, are the actual contributors to the majority of the peak dose. The exposure pathways contributing to the peak dose are ingestion of plants, external gamma, and ingestion of soil. These pathways are depicted in Figure 3-33.

The following RESRAD graphics correspond to the Resident Gardener using a time horizon of 100,000 yr.

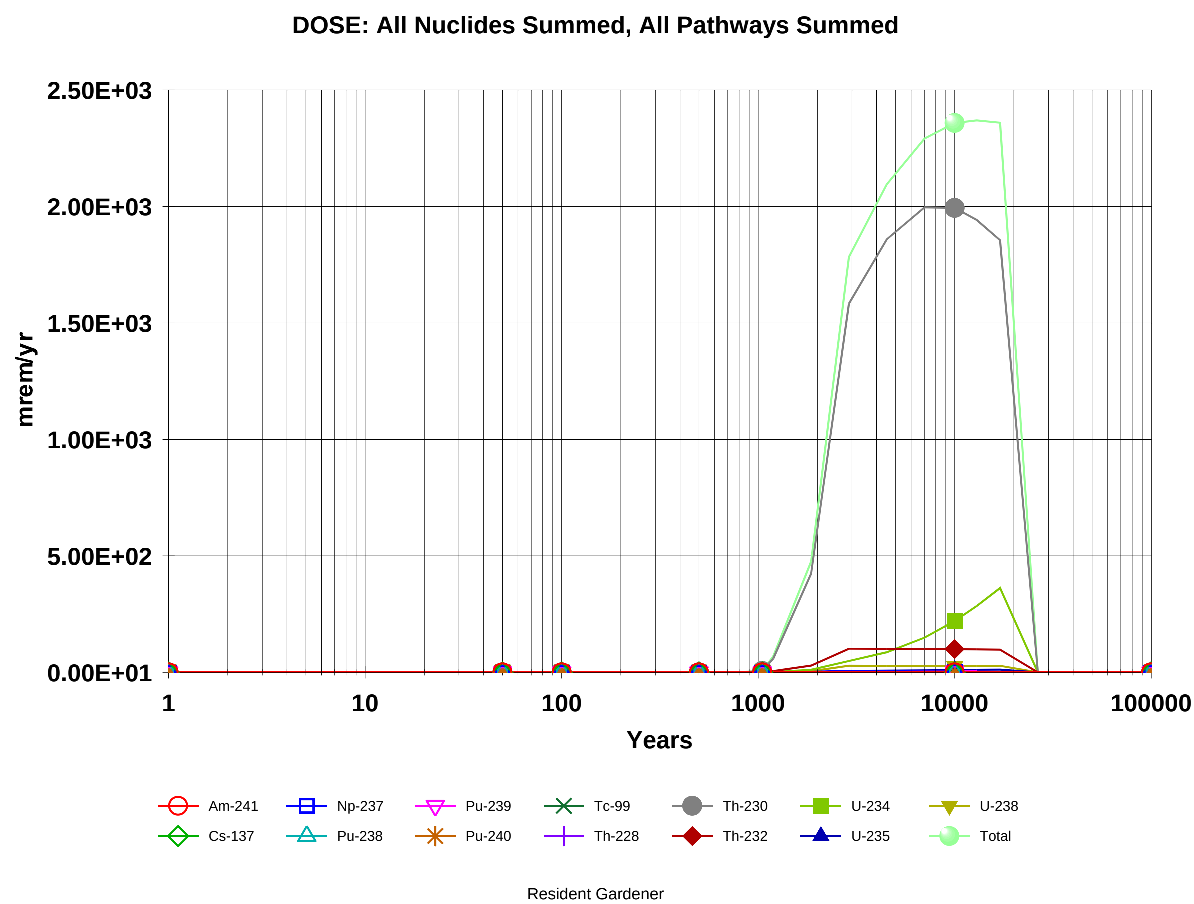

Figure 3–32. Dose to the Resident Gardener from all Selected Targeted Radionuclides and Pathways

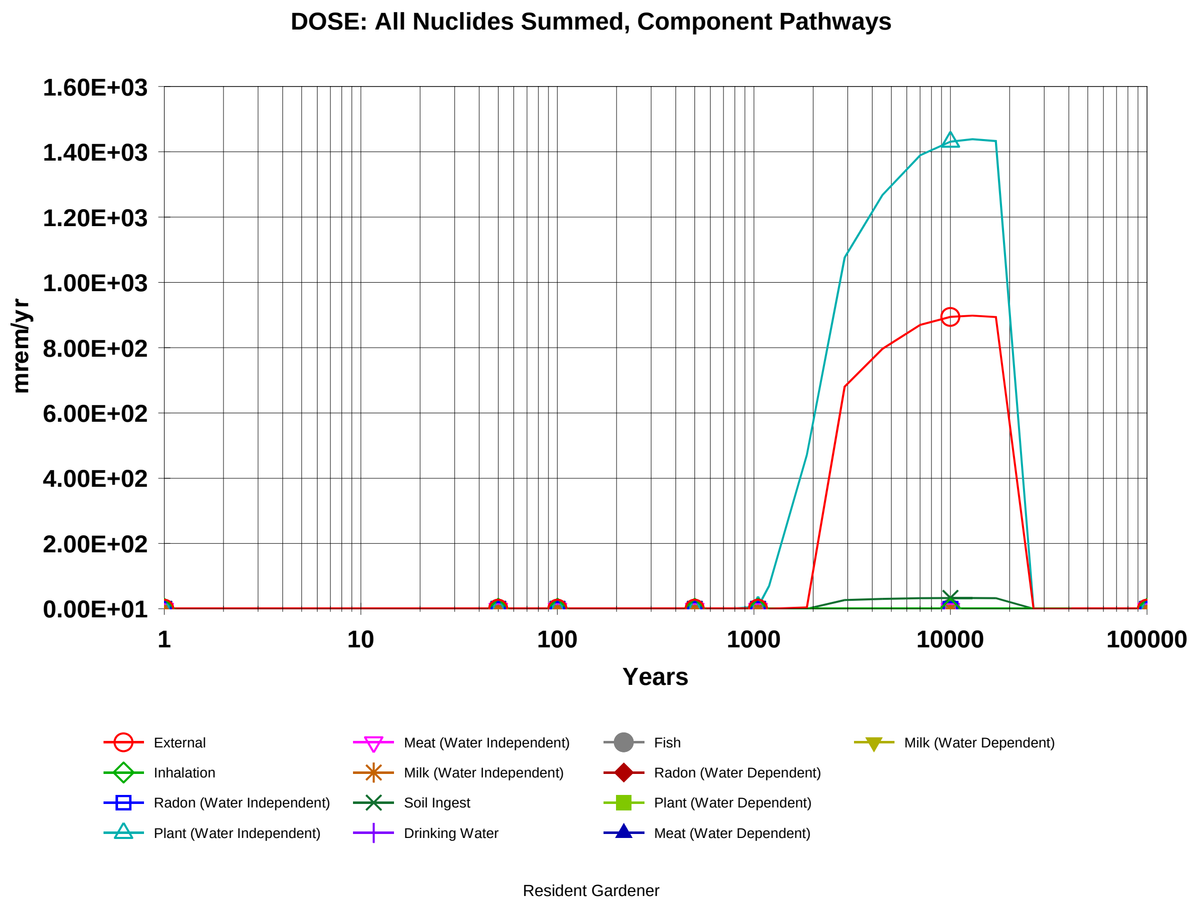

Figure 3–33. Dose to the Resident Gardener by Exposure Pathways

RECREATIONAL USER

This third peak dose assessment shows that the dose for the Recreational User results once again from Th-230, U-234, Th-232, U-238, U-235, Np-237, Pu-239 and Pu-240. Similar to the Resident Farmer (onsite) and the Resident Gardener, the principal contributor to this receptor's dose in this assessment is Th-230 as shown in Figure 3-34. The dose is attributed to the external gamma and soil ingestion pathways as depicted in Figure 3-35.

The following RESRAD graphics correspond to the Recreational User using a time horizon of 100,000 yr.

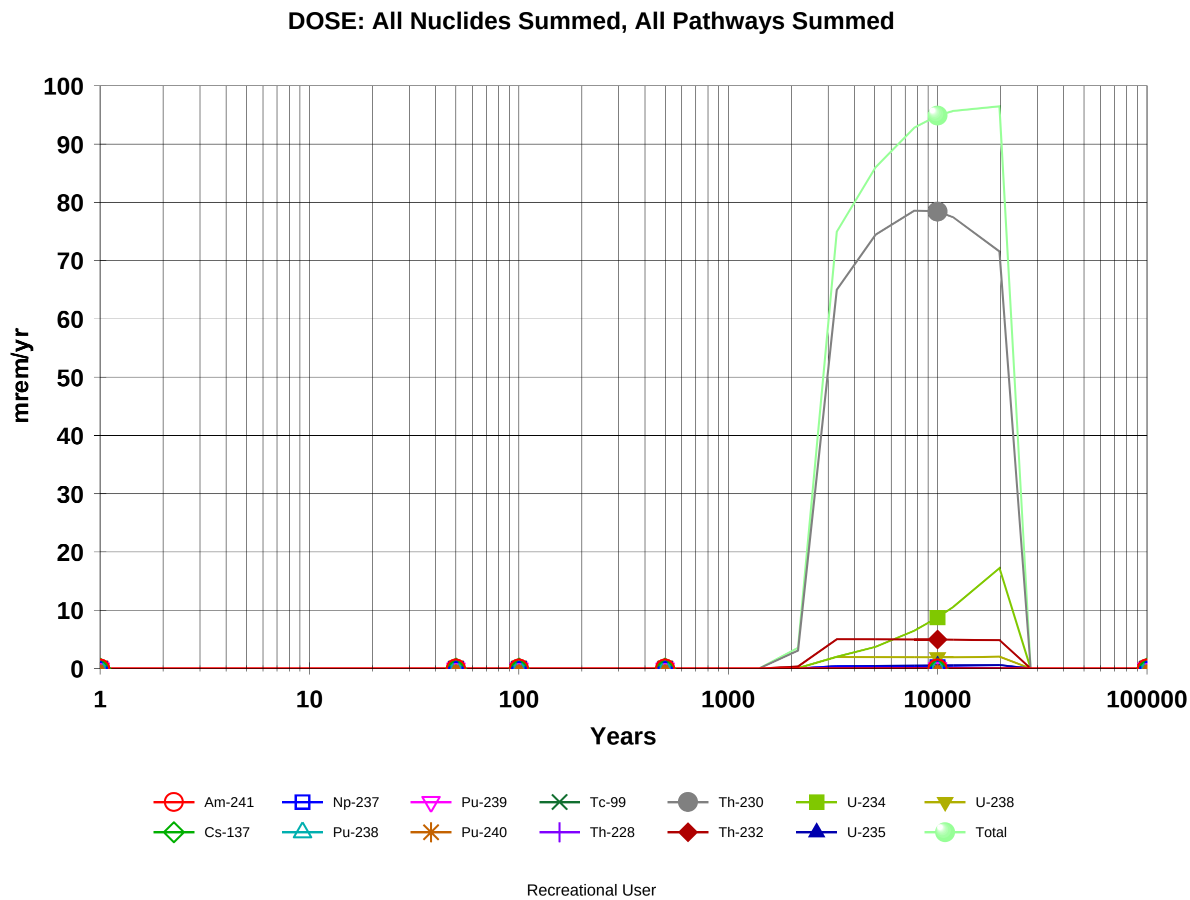

Figure 3–34. Dose to the Recreational User from all Selected Targeted Radionuclides and Pathways

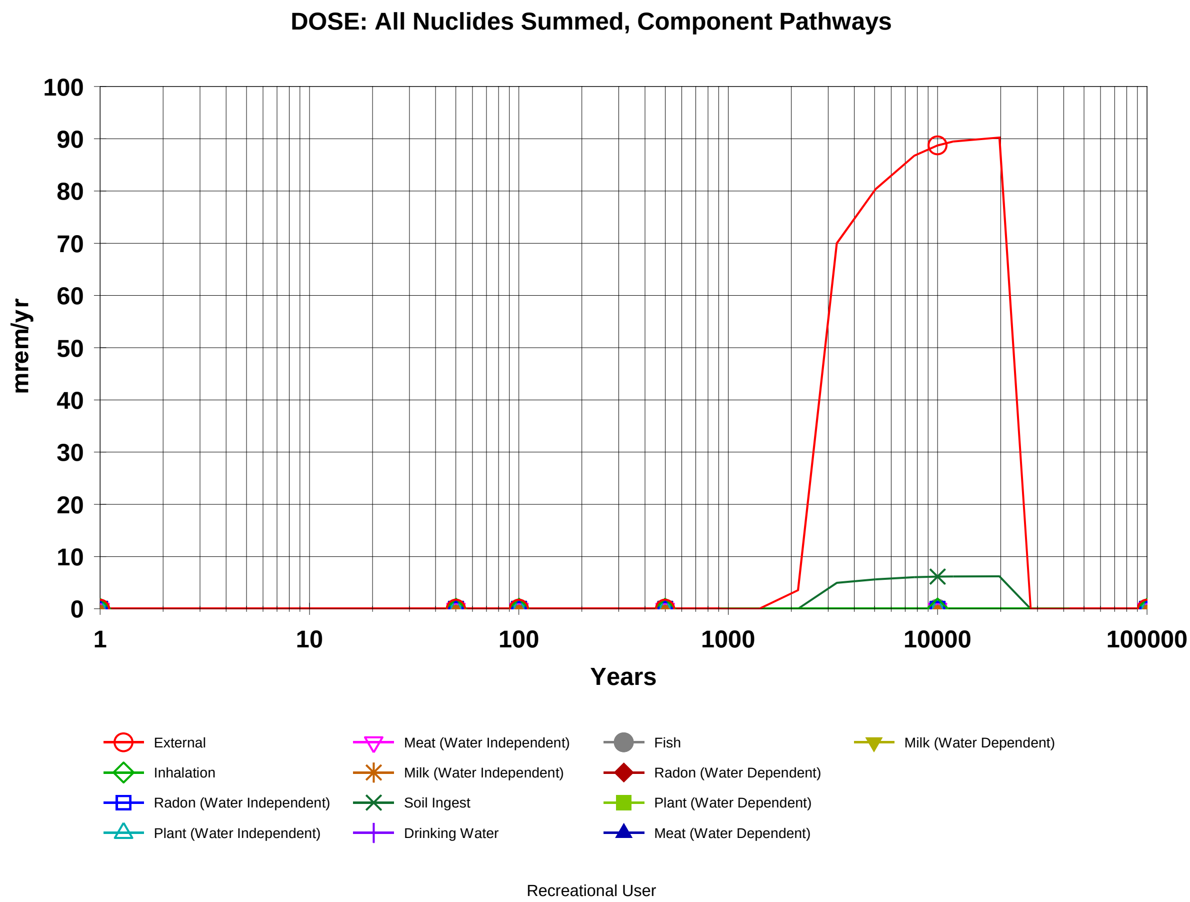

Figure 3–35. Dose to the Recreational User by Exposure Pathways

OUTDOOR WORKER

The peak dose calculated for the Outdoor Worker in this third evaluation results from Th-230, U-234, Th-232, U-238, U-235, Pu-239, Np-237, and Pu-240. The dose primarily derives from Th-230 as depicted in Figure 3-36. The ingrowth progeny of Th-230, in particular Ra-226 and Pb-210, are the actual contributors to most of the peak dose. The exposure pathways contributing to the peak dose are external gamma and soil ingestion as depicted in Figures 3-37.

The following RESRAD graphics correspond to the Outdoor Worker using a time horizon of 100,000 yr.

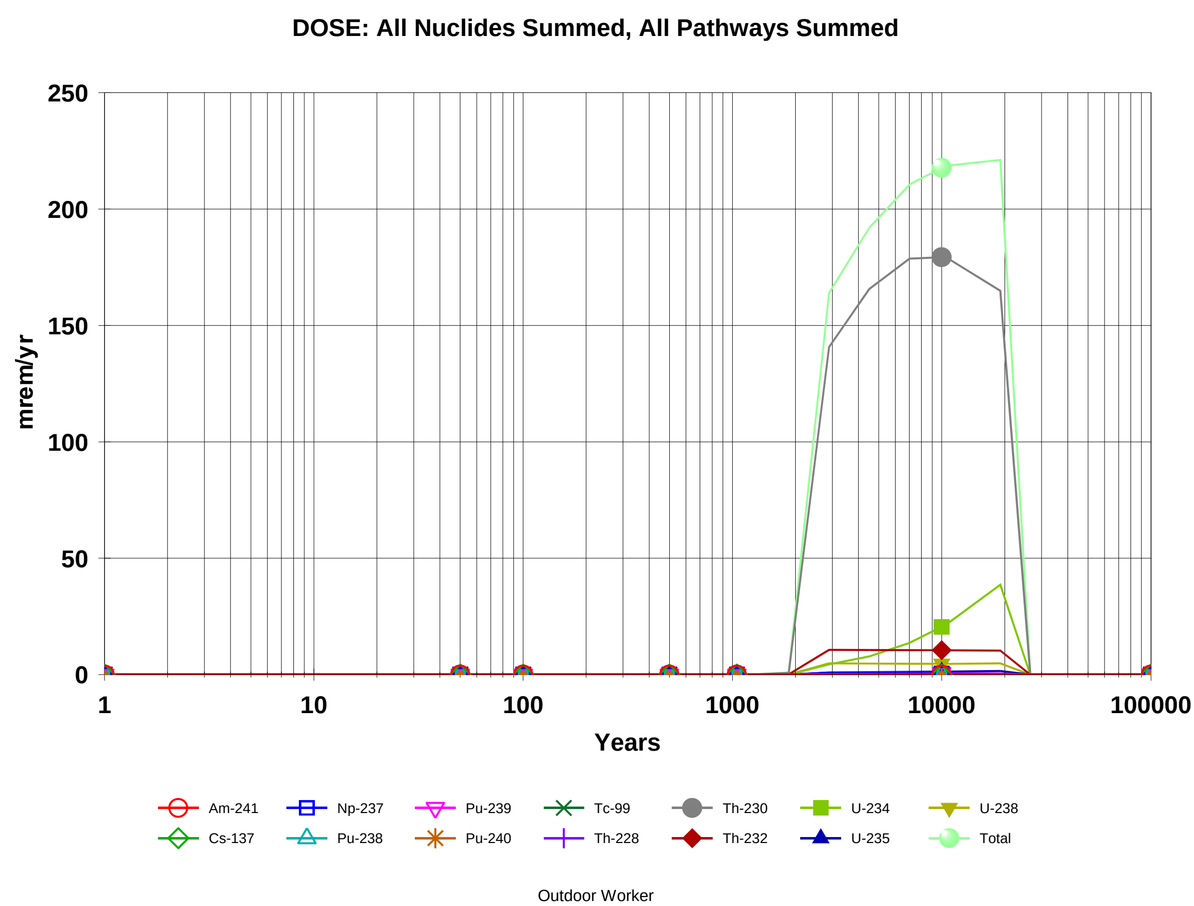

Figure 3–36. Dose to the Outdoor Worker from all Selected Targeted Radionuclides and Pathways

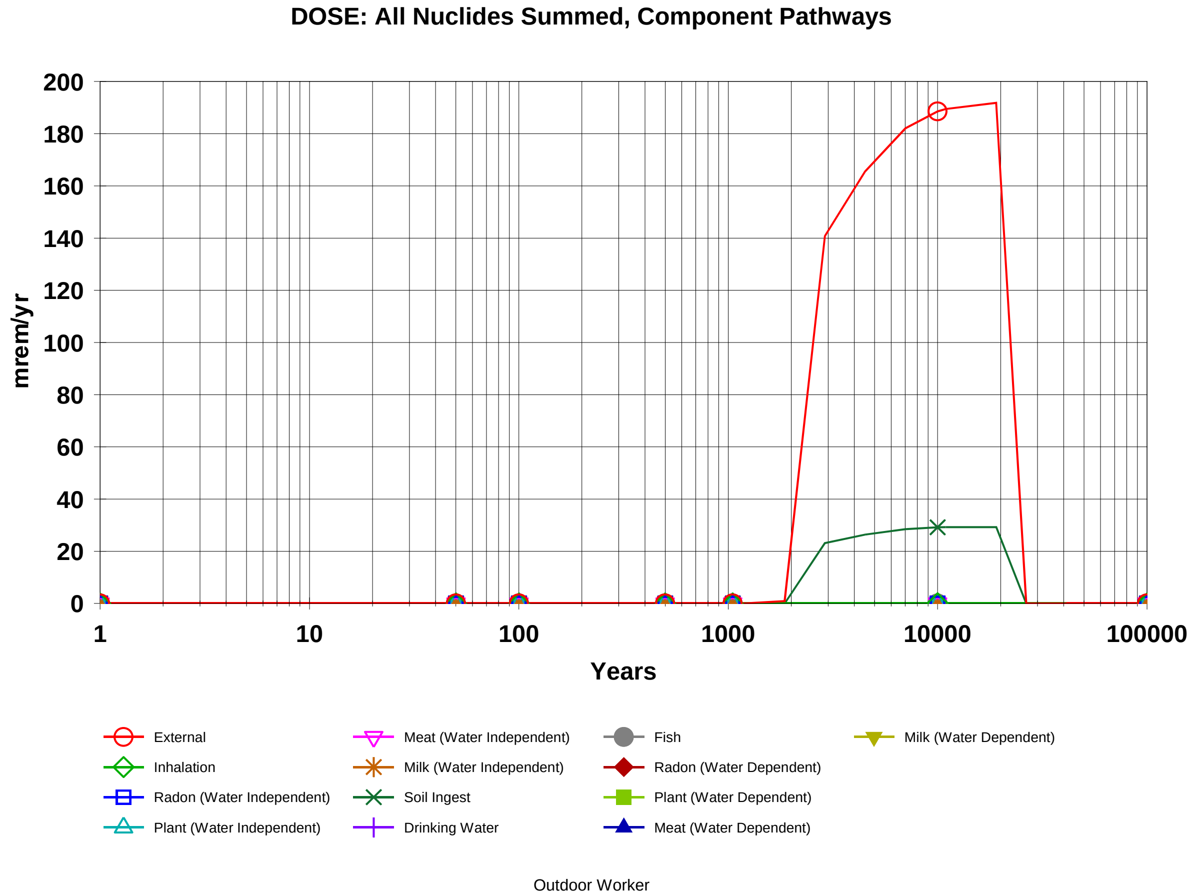

Figure 3–37. Dose to the Outdoor Worker by Exposure Pathways

OFFSITE RESIDENT FARMER

The maximum dose for the Offsite Resident Farmer occurs at 10,065 yr for the maximum time horizon evaluated (i.e., 100,000 yr). The peak dose captured by the code in this third assessment is 2.2 mrem/yr and is attributed to Np-237, the ingrowth progeny of Th-230 (i.e., Ra-226), U-234 (i.e., Ra-226), Th-232 (i.e., Th-228 and Ra-228), and the parent U-238. The Tc-99 dose is not captured by the RESRAD-OFFSITE code when using 16,384 points for a time horizon of 100,000 yr. Therefore, it is not shown in Figures 3-38 or 3-39.

The receptor received the dose through the same radionuclides and exposure pathways as explained earlier in the second assessment. Figure 3-38 and 3-39 illustrate the dose by radionuclides and the dose by exposure pathways, respectively.

The following RESRAD-OFFSITE graphics correspond to the Offsite Resident Farmer using a time horizon of 100,000 yr.

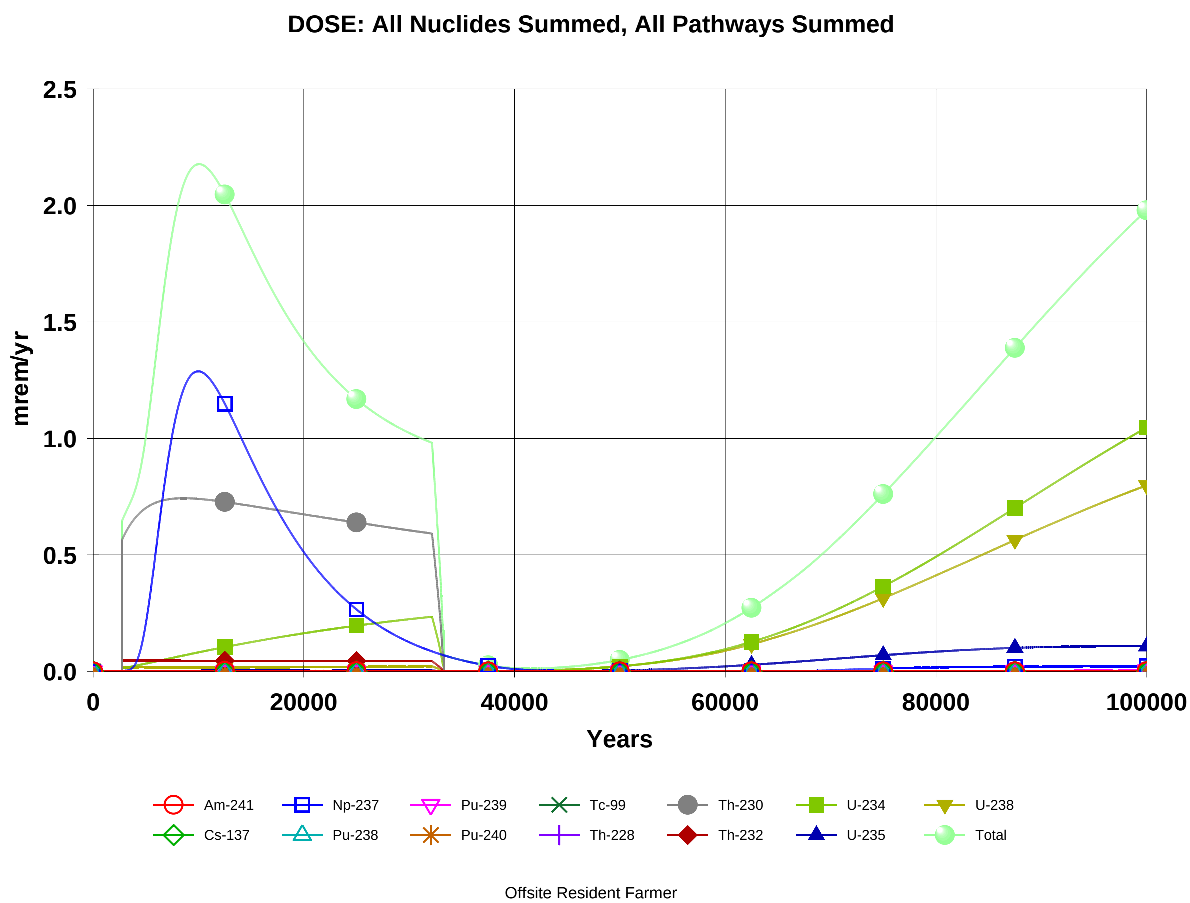

Figure 3–38. Dose to the Offsite Resident Farmer from all Selected Targeted Radionuclides and Pathways

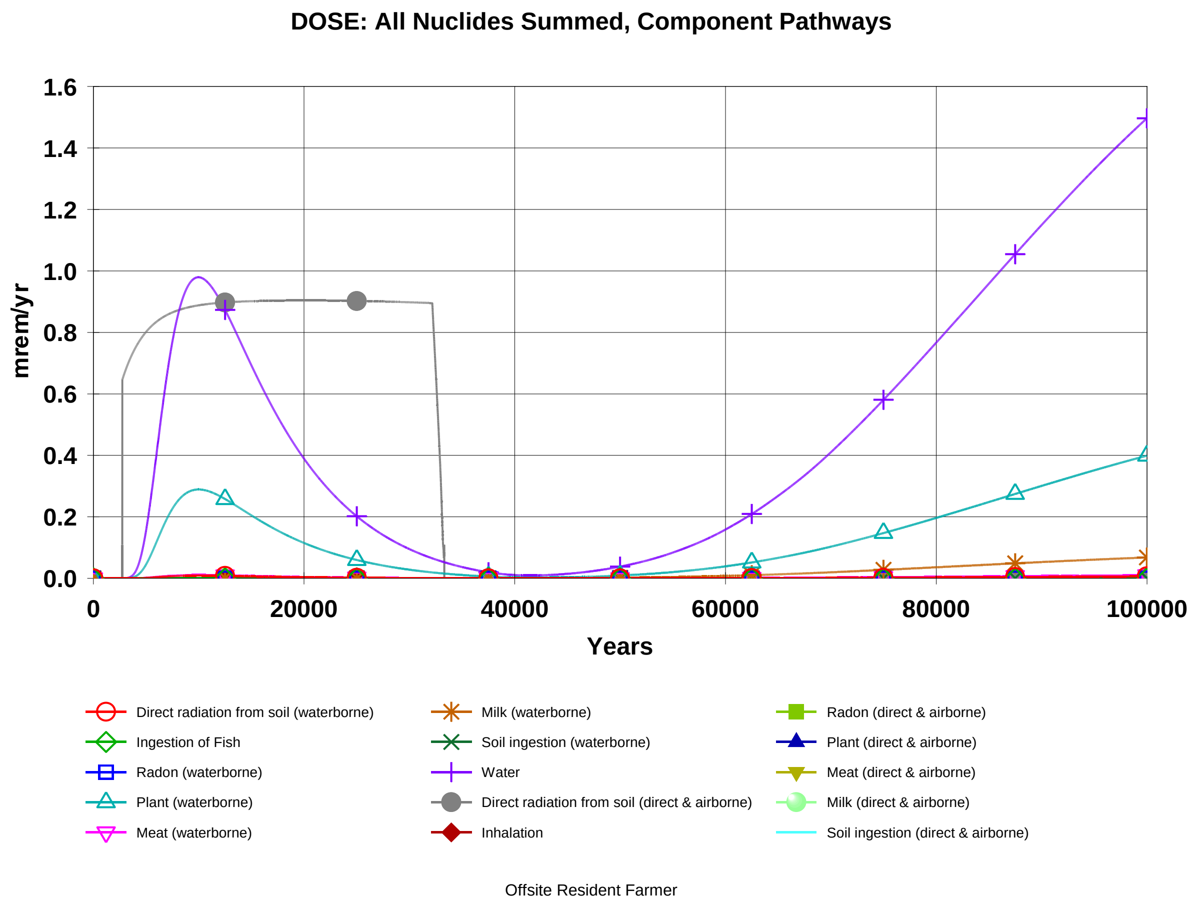

Figure 3–39. Dose to the Offsite Resident Farmer by Exposure Pathways

In summary, the maximum dose predicted among all receptors and time horizons corresponds to the Resident Farmer (onsite), 2,700 mrem/yr, although this receptor is considered implausible due to future planned controls for the C-746-U Landfill. The highest dose projected among the plausible receptors is 220 mrem/yr and it corresponds to the Outdoor Worker. Section 3.4 includes a summary of the results.

Appendices A and B include the reports generated by the codes called "Summary Reports" (RESRAD) and "Parent Dose Reports" (RESRAD-OFFSITE).

3.3 PROBABILISTIC PEAK OF THE MEAN DOSE ASSESSMENT FOR THE OFFSITE RESIDENT FARMER

As requested by the DOE-PPPO, a probabilistic analysis was performed only for the Offsite Resident Farmer using Tc-99 in order to determine the peak of the mean doses and demonstrate compliance with the dose constraint of 1 mrem/yr (above background). The analysis was performed using Tc-99 exclusively and a time horizon of 1,050 yr. The decision was made by DOE-PPPO to include the Tc-99 radionuclide for probabilistic analysis and exclude the other 12 radionuclides, since 100% of the peak dose within the time frame of 1,050 yr derives from Tc-99 as demonstrated in the deterministic run. Additional probabilistic analyses using a time horizon of 10,000 yr or 100,000 yr were not performed. Since the Tc-99 was the only radionuclide modeled, and the deterministic analysis revealed that the peak dose for Tc-99 occurs at 772 yr and the dose from Tc-99 is almost gone at approximately 2,500 yr, additional analyses using time horizons beyond 1,050 yr were not necessary.

Prior to discussing the probabilistic analysis results, it is of interest to state that the Tc-99 peak dose result via deterministic analysis within the time frame of 1,050 yr was 1.9 mrem/yr (as shown in Table 3-1). However, 68% (1.275 mrem/yr) of this peak dose results from the drinking water pathway. The dose from this pathway is above the 1 mrem/yr (above background) constraint, but it is well below the 4 mrem/yr Maximum Contaminant Level (MCL)[1, 2] for beta particle and photon radioactivity established for public drinking water by the Environmental Protection Agency (EPA) in 40 CFR 141.66, *National Primary Drinking Water Regulations.* In addition, the probabilistic dose assessment demonstrates that the dose over all the pathways considered meets the 1 mrem/yr (above background) and consequently the EPA's 4 mrem/yr MCL.

ORISE used information provided by the DOE-PPPO as described in Section 2.3.2.1 for the Tc-99 probabilistic dose analysis provided as part of this effort. Details on the DOE-PPPO Tc-99 probabilistic analysis are provided in DOE-PPPO 2011b. The results for the three probabilistic runs described in Section 2.3.2.1 of this document are presented as follows.

3.3.1 FIRST RUN

The first probabilistic run was performed with only four exposure pathways (i.e., drinking water, plant, milk, and meat ingestion pathways) activated out of a total of seven pathways as identified in ORISE 2012. The other three pathways (i.e., external gamma, inhalation of dust, and soil ingestion) were deactivated. No other modifications were made. Table 3-7 summarizes the results.

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[1] 40 CFR 141.66 (d) *MCL for beta particle and photon radioactivity.* (1) The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water must not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem/year (mrem/year).

[2] 401 KAR 8:550. Radionuclides. Section 1. A community water system shall meet the requirements for radionuclides in accordance with 40 C.F.R. 141.25, 141.26, 141.55, and 141.66.

Table 3–7. Peak of the Mean Doses for the First Probabilistic Run Using the DOE–PPPO Proposed Single Radionuclide Soil Guideline for Tc–99

Receptor	Offsite Resident Farmer			
Pathways Activated	Drinking Water, Plant, Milk, and Meat Ingestion			
Target Dose (mrem/yr)	1			
	Repetition			Average (Arithmetic Mean) of the Peak of the Mean Doses (mrem/yr)
	1	2	3	
Peak of the Mean Dose (mrem/yr)[a]	0.9793	0.9773	0.9772	0.98[b]
Time of Peak of the Mean Dose (yr)	1,050	1,050	1,050	

a. The peak of the mean dose results are not rounded to two significant figures to show the actual code output.

b. The average (arithmetic mean) of the peak of the mean doses is rounded to two significant figures.

The peak of the mean doses obtained through the drinking water, plant, milk, and meat ingestion pathways meet the target dose constraint of 1 mrem/yr (above background). The average (arithmetic mean) of the peak of the mean doses calculated by ORISE was 0.98 mrem/yr.

3.3.2 SECOND RUN

The second probabilistic run was the reverse of the first run. It was performed with only three exposure pathways (i.e., external gamma, inhalation of dust, and soil ingestion) activated out of a total of seven pathways. The other four pathways (i.e., drinking water, plant, milk, and meat ingestion) were deactivated. No other modifications were made. Table 3-8 summarizes the results.

Table 3–8. Peak of the Mean Doses for the Second Probabilistic Run Using the DOE–PPPO Proposed Single Radionuclide Soil Guideline for Tc–99

Receptor	Offsite Resident Farmer			
Pathways Activated	External Gamma, Inhalation of Dust, and Soil Ingestion			
Target Dose (mrem/yr)	1			
	Repetition			Average (Arithmetic Mean) of the Peak of the Mean Doses (mrem/yr)
	1	2	3	
Peak of the Mean Dose (mrem/yr)[a]	1.651E-06	1.648E-06	1.647E-06	0.00[b]
Time of Peak of the Mean Dose (yr)	1,050	1,050	1,050	

a. The peak of the mean dose results are not rounded to two significant figures to show the actual code output.

b. The average (arithmetic mean) of the peak of the mean doses is rounded to two significant figures.

The peak of the mean doses obtained via the external gamma, inhalation of dust, and soil ingestion pathways are practically 0 mrem/yr. There is no noticeable contribution from these pathways to the Tc-99 dose.

By adding the first and second probabilistic runs, it can be demonstrated that the peak of the mean doses from all seven pathways evaluated meet the 1 mrem/yr dose constraint (above background). Table 3-9 includes the combined results for these two runs.

Table 3–9. Peak of the Mean Doses for the First and Second Probabilistic Run Using the DOE–PPPO Proposed Single Radionuclide Soil Guideline for Tc–99

Receptor	Offsite Resident Farmer			
	Repetition			Average (Arithmetic Mean) of the Peak of the Mean Doses (mrem/yr)
	1	2	3	0.98[b]
Peak of the Mean Dose (mrem/yr)[a]	0.9793	0.9773	0.9772	
Time of Peak of the Mean Dose (yr)	1,050	1,050	1,050	

a. The peak of the mean dose results are not rounded to two significant figures to show the actual code output.

b. The average (arithmetic mean) of the peak of the mean doses is rounded to two significant figures.

These results show that peak of the mean doses obtained in the first run are not impacted by the second run. Therefore, the peak of the mean doses and their average (arithmetic mean) meet the dose constraint of 1 mrem/yr.

3.3.3 THIRD RUN

The third probabilistic run was performed with all seven exposure pathways (i.e., external gamma, inhalation of dust, drinking water, plant, milk, meat and soil ingestion) activated. The only other modification made was increasing the size of the grid spacing for areal integration from 10 to 500 meters as described in Section 2.3.2.1. Table 3-10 summarizes the results.

Table 3–10. Peak of the Mean Doses for the Third Probabilistic Run Using the DOE–PPPO Proposed Single Radionuclide Soil Guideline for Tc–99

Receptor	Offsite Resident Farmer			
Pathways Activated	External Gamma, Inhalation of Dust, Drinking Water, Plant, Milk, Meat and Soil Ingestion,			
Grid spacing for areal integration	500 meters			
Target Dose (mrem/yr)	1			
	Repetition			Average (Arithmetic Mean) of the Peak of the Mean Doses (mrem/yr)
	1	2	3	
Peak of the Mean Dose (mrem/yr)[a]	0.9794	0.9773	0.9772	0.98[b]
Time of Peak of the Mean Dose (yr)	1,050	1,050	1,050	

a. The peak of the mean dose results are not rounded to two significant figures to show the actual code output.

b. The average (arithmetic mean) of the peak of the mean doses is rounded to two significant figures.

The results of this run are almost identical to those obtained in the first run. The only negligible difference is the peak of the mean dose result for repetition 1. The result for repetition 1 in the first run was 0.9793 mrem/yr and in the third run was 0.9794 mrem/yr. However, when rounded to two significant figures (i.e., 0.98 mrem/yr) they are essentially the same number. This third run confirms that the approach used for the first two runs is acceptable by providing comparable results.

Appendix C contains the code's deterministic ("Parent Dose Reports") and uncertainty analyses output reports for the three runs.

3.4 SUMMARY OF RESULTS

This section includes a summary of the projected highest doses obtained via deterministic and probabilistic analyses. Table 3-11 summarizes the highest doses projected by the RESRAD codes through deterministic analyses for all receptors and among all time horizons (i.e., 70 yr, 1,050 yr, 10,000 yr and 100,000 yr). The peak dose results in Table 3-11 are rounded to two significant figures.

Table 3–11. Summary of Deterministic Results for Projected Highest Doses for all Receptors Among all Time Horizons

Receptors	Implausible			Plausible			
	Trespasser	Resident Farmer (onsite)	Resident Gardener	Recreational User	Outdoor Worker	Offsite Resident Farmer	Landfill Worker
Target Dose	100 mrem/yr			1 mrem/yr			100 mrem/yr
Peak Dose (mrem/yr)	4.1[a]	2,700[b]	2,400[b]	96[b]	220[b]	2.2[b]	64[a]
Time (yr)	70	12,773	12,931	19,739	19,045	10,065	70
Exposure Pathways Contributing to each Receptor's Dose (in descending order of contribution to dose if more than one is listed)	External gamma, and soil ingestion	Plant ingestion, external gamma, milk, meat and soil ingestion	Plant ingestion, external gamma, and soil ingestion	External gamma, and soil ingestion	External gamma, and soil ingestion	Drinking water, plant and milk ingestion	External gamma, and soil ingestion

a. The peak dose was calculated based on the DOE-PPPO Proposed AL Volumetric Concentrations and a 70 yr time frame.

b. The peak dose was calculated based on the DOE-PPPO Proposed Single Radionuclide Soil Guidelines and a 100,000 yr time frame.

The highest projected deterministic dose for the Landfill Worker and the Trespasser are attributed to Th-232, Th-230 and their ingrowth progeny.

The highest projected deterministic doses for the Resident Farmer (onsite), Resident Gardener, Recreational User and the Outdoor Worker resulted primarily from the ingrowth progeny of Th-230 (i.e., Ra-226 and Pb-210). On the other hand, the maximum projected deterministic dose for the Offsite Resident Farmer resulted mainly from Np-237 and the ingrowth progeny of Th-230 (i.e., Ra-226).

Finally, for the probabilistic analysis the average (arithmetic mean) of the peak of the mean doses obtained was 0.98 mrem/yr at 1,050 yr from Tc-99 for the Offsite Resident Farmer.

4.0: REFERENCES

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ATTACHMENT A: RESRAD SUMMARY REPORTS

ATTACHMENT B: RESRAD-OFFSITE PARENT DOSE REPORTS

ATTACHMENT C: RESRAD-OFFSITE PARENT DOSE REPORTS AND UNCERTAINTY ANALYSIS REPORTS FOR THE TC-99 RUNS