March 11, 2011

Steve Tarlton
Radiation Management Unit
Hazardous Materials and Waste Management Division
Colorado Department of Public Health and Environment
4300 Cherry Creek Drive South
Denver, Colorado 80246-1530

Subject: Radiological Survey and Dose Assessment Report for Cotter Property near Air Particulate Monitoring Station AS-210

Dear Mr. Tarlton,

Please find the enclosed report entitled "Radiological Survey and Dose Assessment for Cotter Property near Air Particulate Monitoring Station AS-210". This voluntary study was conducted in accordance with the Study Plan approved by the Division. Per the Division's request, Cotter is currently attempting to locate a qualified laboratory for a petrology analysis of material of interest as identified and discussed in this report. Petrology analysis information was not required to complete the radiological characterization and dose assessment objectives as outlined in the Study Plan. Petrology analysis results will be provided to the Division when available.

If you have any questions, please contact me at 719-275-7413 (Ext. 210) or 970-556-1174.

Sincerely,

Randy Whicker

Randy Whicker
Health Physicist, Cotter Corporation

cc: Phil Egidi, CDPHE

Cotter Corporation
Cañon City Mill, P.O. Box 1750, Cañon City, CO 81215-1750 USA

Telephone (719) 275-7413
Fax (719) 275-1669

Radiological Survey and Dose Assessment for Cotter Property near Air Particulate Monitoring Station AS-210

March 11, 2011
Prepared by:

Cotter Corporation (N.S.L.)
Canon City Milling Facility
P.O. Box 1750
Canon City, CO 81215-1750

Table of Contents

Introduction 1

Background 2

Study Objectives and Dose Assessment Approach 6

Radiological Survey Methods 6

- Surface Soil Sampling 6
- Depth Profile Soil Sampling 7
- Laboratory Soil Analyses 8
- Gamma Survey 9

Characterization Results 9

- Gamma Survey Results 9
- Gamma / Soil Radionuclide Correlations 10
- Surface Soil Sampling Results 12
- Depth Profile Soil Sampling Results 14
- Source Material Assessment 15

Dose Assessments 19

- Receptor Scenarios and Parameter Selections 19
- Dose Modeling Results for the School Child Receptor Scenario 20
- Dose Modeling Results for the Recreational Golfer/Jogger Scenario 21
- Dose Modeling Results for the Nearby Resident Scenario 22
- Dose Assessment Implications 23

Summary and Conclusions 25

References 26

Appendix A (Analytical Results for Soil Samples) 28

Appendix B (Soil Depth Profiles: Photo Documentation, Field Notes, Analytical Results) 30

INTRODUCTION

This document provides background, objectives and results from a voluntary environmental study conducted by Cotter Corporation (N.S.L.) (Cotter). Significantly elevated thorium-230 (Th-230) concentrations in soil have been measured on Cotter owned property near air particulate monitoring station AS-210 (Cotter, 2009a). This monitoring station is located near the northwest corner of the Shadow Hills Golf Course (Figure 1). Thorium-230 concentrations in this area have raised questions regarding potential for doses to members of the public in excess of regulatory limits (25 mrem/yr excluding radon). Annual soil sampling at this location began in 1996. Past correspondence between Cotter and the Colorado Department of Public Health and Environment (CDPHE) indicates an agreement that Cotter would retain control and begin air monitoring on this parcel of land, but future earthmoving in this particular area would be prohibited (CDPHE, 1994).

Figure 1: Location of air monitoring station AS-210 and surrounding study area.

There is a small, ephemeral drainage channel that carries surface water runoff to the northeast in this area, and prior to 1994 had prompted construction of a silt fence at the Cotter property boundary to prevent potential offsite migration of elevated material. This document provides background information, an assessment of previous data, and results of a thorough radiological study of the distribution of Th-230, natural uranium (U-nat) and radium-226 (Ra-226) within the triangular shaped study area depicted in Figure 1. The study area involves approximately 5.4 acres. Corresponding radiological dose assessments are also provided. This work was conducted in accordance with the study plan approved by CDPHE (Cotter, 2009b; CDPHE, 2010).

BACKGROUND

Soils near AS-210 have demonstrated a high degree of small-scale spatial variability (within a few feet) with respect to soil Th-230 concentrations (Figure 2). Temporal variability may also occur, but this cannot be adequately demonstrated by existing data as sampling locations have varied by several feet each year. Natural uranium (U-nat) and radium-226 (Ra-226) concentrations in this area have been comparatively consistent in annual samples, and results suggest approximate secular radiological equilibrium with one another (i.e. U-238 and Ra-226 have approximately equal radioactivity concentrations). In most cases, Th-230 occurs at significantly higher radioactivity concentrations relative to U-nat or Ra-226 (Figure 2).

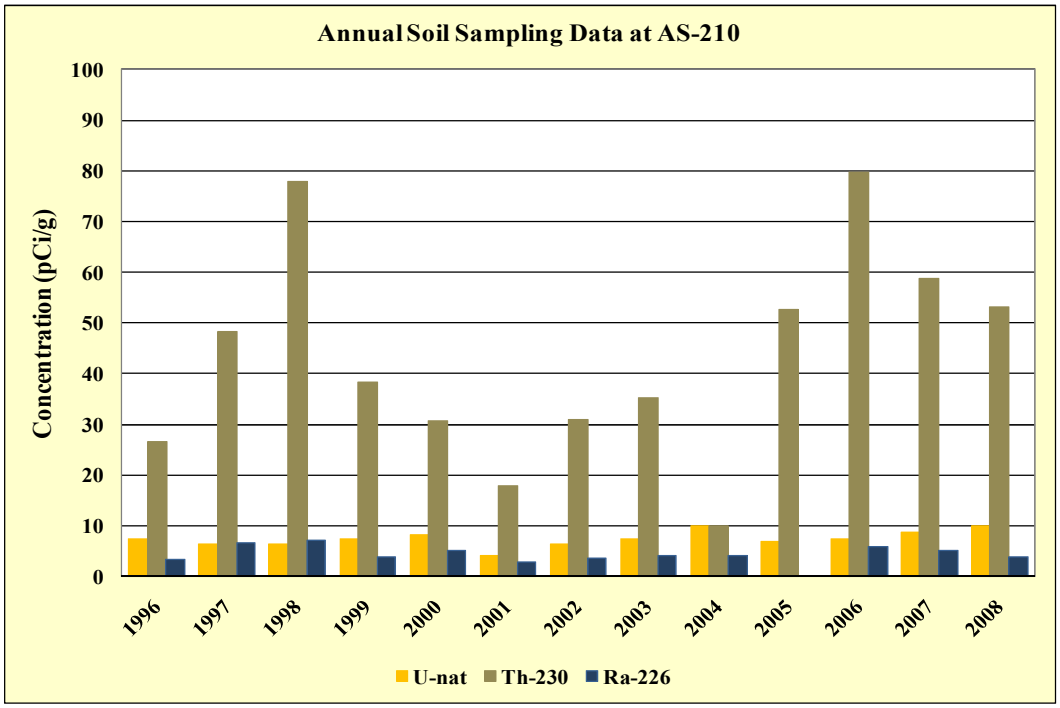


Figure 2: Soil concentrations for U-nat, Th-230, and Ra-226 over time near AS-210.

Potential reasons for disequilibrium between Th-230 and U-nat and Ra-226 at this location could be related to materials historically associated with the mill. Congo raffinate materials were once processed at the Canon City milling facility for their residual uranium content. This material was purchased and processed by Cotter Corporation in the late 1960's and early 1970's. Prior to the additional processing by Cotter, Congo Raffinate was already in a state of radiological disequilibrium between U-238, Th-230, and Ra-226. It was enriched in Th-230 relative to U-nat and Ra-226 as a result of previous extractions of the latter two elements from natural Congo ore.

A similarly high Th-230 enrichment may have been present in Colorado Raffinate materials from previously processed Colorado Western Slope ore. In addition to the pre-existing radiological disequilibrium of various raffinate materials, processing of these and other materials at the Canon City

mill may have contributed to additional enrichment of Th-230 relative to Ra-226 in milling byproduct materials, all of which were ultimately disposed in onsite impoundments as processed tailings.

Given the above factors, soil Th-230/U-nat ratios greater than 0.5, or Th-230/Ra-226 ratios greater than 1 in soil could indicate a radiological signature that is characteristic of historical operations at the Canon City mill. Soil sampling data at various air particulate monitoring stations, collected on an annual basis, were provided in Cotter's annual report for 2008 (Cotter, 2009a) to the CDPHE. These data show a number of concentration ratios that demonstrate a similar radiological signature, particularly at station AS-210 (Figure 3).

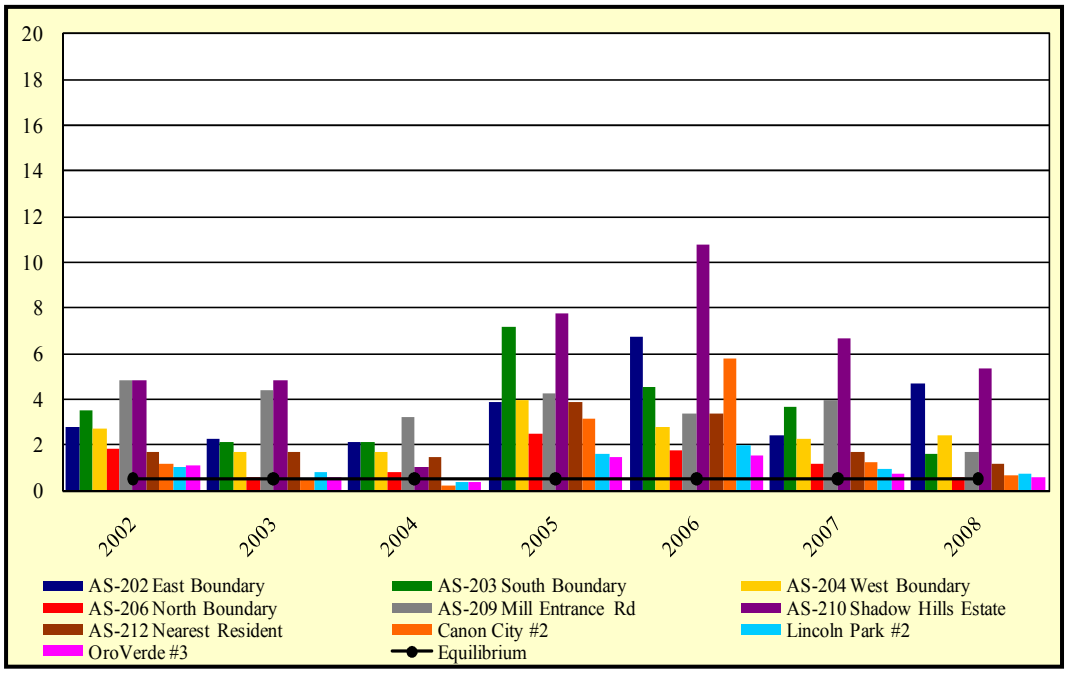


Figure 3: Th-230/U-nat soil concentration ratios for various air particulate monitoring station locations in the vicinity of the Cotter Canon City mill site.

Aside from thorium-enhanced material associated with the mill, there is evidence documented in the June 2000 Final Report to the CDPHE for the Team Track Railroad Transfer Site cleanup (Cotter, 2000) that residues from other historical industrial operations in the area (e.g. coal mining residues, zinc smelter slag, or fly ash from the local power plant) may have been used as road bed material along County Road 143. Discovered during the Team Track cleanup, this material was described as resembling fine coal and "unlike any Cotter mill feed stock in appearance or chemical analysis". This material was significantly elevated in Th-230 concentrations, yet had comparatively little Ra-226 present. If this material was not associated with Cotter, and such material extends to other portions of County Road 143, this would represent an alternate reason for elevated Th-230 signatures within the study area.

Previous soil samples collected within the study area at the silt fence (Figure 4) show that Th-230 concentrations are also elevated, though not as pronounced as those measured in soils near AS-210.

Th/Ra ratios (Figure 5) at the silt fence are also elevated, but again not as pronounced as those measured in soil samples collected near AS-210. These observations suggest that soils near AS-210 with elevated concentrations of Th-230 are a likely source area for down-drainage migration of this material, presumably diluted with lower concentration background soils from adjacent erosional areas.

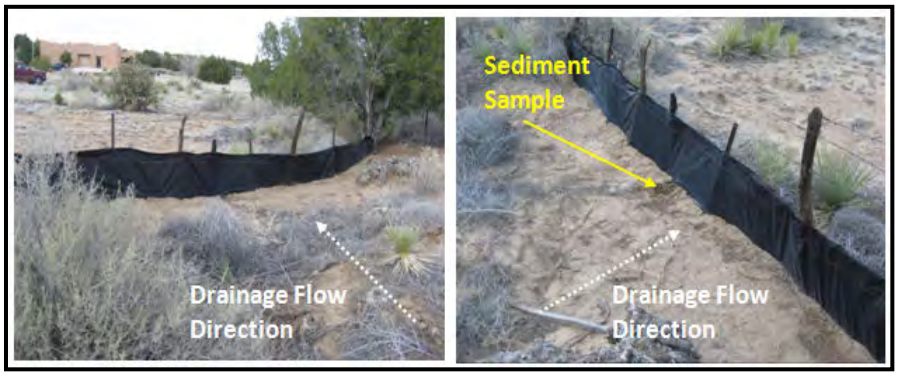


Figure 4: Silt fence in study area with drainage flow direction and sediment sampling location.

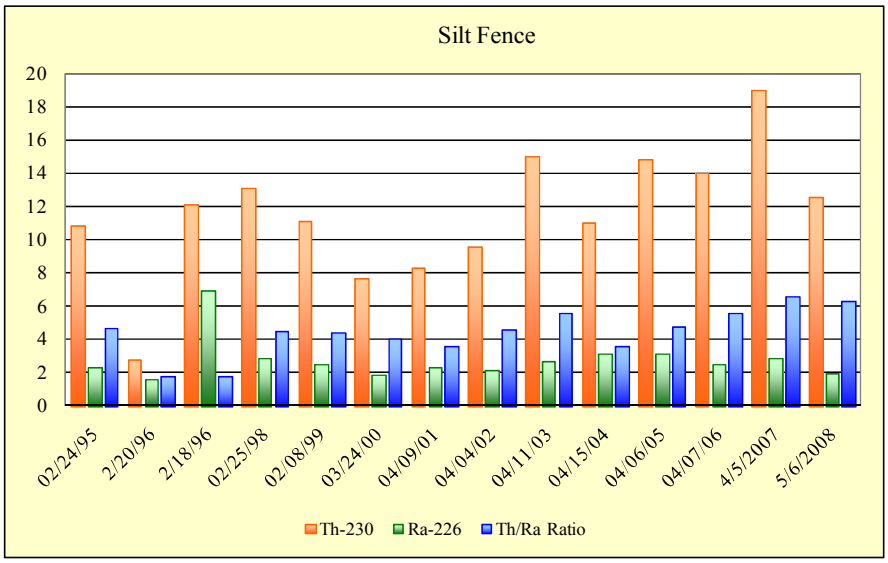


Figure 5: Th-230 and Ra-226 concentrations and Th/Ra ratios at the silt fence.

A radiological risk assessment that included roadside margins of County Road 143 and the mill access road was conducted by MFG Incorporated in 2005 (MFG, 2005a). The results were presented to the Fremont County Independent Outreach Committee (FCIOC) and though significant risks to the public were not found for either area in this study, a voluntary cleanup plan for the access road was developed (MFG, 2005b). As part of the MFG risk assessment, soil samples were collected along County Road 143 (Figure 6, sample locations B1-B4 and C1-C5). Natural uranium, U-238, Th-230, and Ra-226 concentration results for these samples are shown in Table 1.

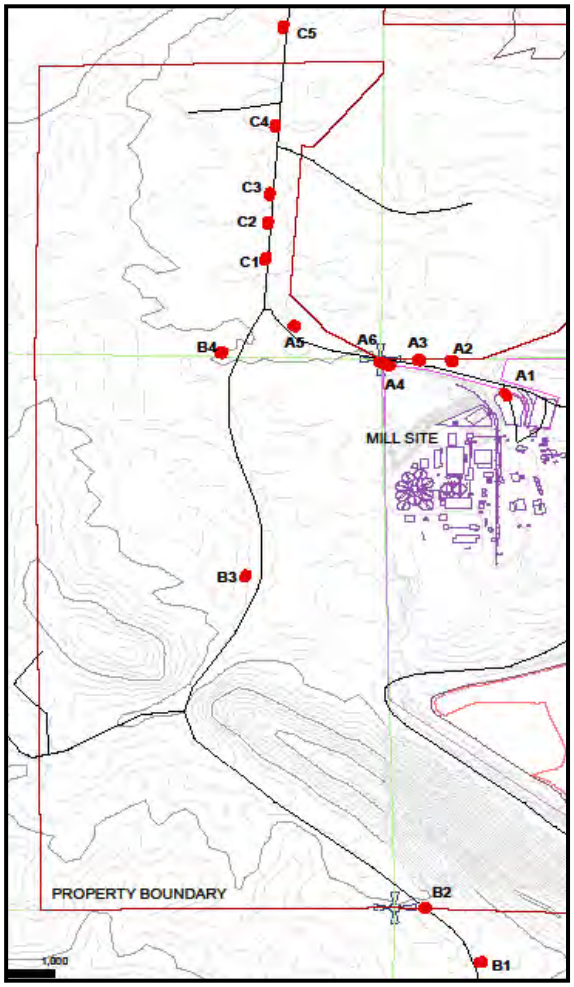


Figure 6: Soil sampling locations from the 2005 roadside risk assessment study.

Table 1: Soil sampling results for County Road 143 locations shown in Figure 6.

Sample ID	Ra-226, pCi/g	Th-230, pCi/g	U, pCi/g	U-238, pCi/g
County Road (background locations)				
B1	0.8	0.2	0.81	0.39
B2	1.2	nd	0.80	0.39
B3	1.6	2	0.92	0.45
B4	2.1	2.4	1.73	0.84
B5	1.4	nd	2.06	1.01
Mean	1.42	1.53	1.27	0.62
County Road (near golf course)				
C1	7.7	24	8.73	4.26
C2	14	22	19.77	9.64
C3	7.1	21	8.39	4.09
C4	5.8	25	5.68	2.77
C5	3.8	9.7	3.57	1.74
Mean	7.7	20	9.21	4.5

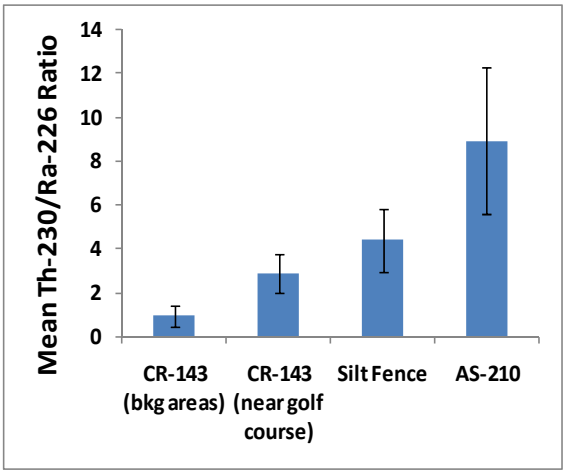


Figure 7: Mean Th/Ra ratios (± 1 std. dev.) for select location categories.

AS-210 is located near a low spot along County Road 143. During precipitation events, surface runoff water has been observed draining down slope from road margins and pooling near this area. A comparison of average Th/Ra ratios (± 1 standard deviation) from relevant areas (Figure 7) suggests that a hydrologic/erosional connection may exist between elevated material along County Road 143, AS-210, and the silt fence. Surface soils may have gradually eroded from the margins along County Road 143 near the golf course and accumulated near AS-210 and at the silt fence. Several potential mechanisms for significantly more concentrated Th-230 levels at AS-210 relative to other areas are discussed in this report.

STUDY OBJECTIVES AND DOSE ASSESSMENT APPROACH

Regardless of the source(s) and genesis of elevated Th-230 in the vicinity of AS-210, Cotter agreed to further investigate radiological levels and distributions in the study area to assess potential doses to members of the public. In accordance with the approved study plan (Cotter, 2009b; CDPHE, 2010), radiological survey work was conducted in the winter and spring of 2010 to characterize the levels and horizontal/vertical distributions of U-nat, Th-230, and Ra-226 in soils across the study area. The primary objective was to produce data necessary for a dose assessment using the DOE computer code RESRAD-OFFSITE (ANL, 2009).

The radiological survey also included a limited investigation of potential local source areas outside of the study area (along the county road margins) which could be responsible for elevated radionuclides near AS-210. The 2005 Roadside Risk Assessment conducted by MFG Incorporated (MFG, 2005a) concluded that elevated radionuclides along the county road margins do not pose significant health risks to members of the public. The maximum modeled dose to plausible receptors was 2.9 mrem/yr (far below the 25 mrem/yr regulatory limit) and based on this result, remediation for radiological health reasons would normally be considered unwarranted. The purpose of this part of the AS-210 study was to assess county road margins with respect to potential sources of radionuclides that may be migrating and accumulating within the study area, and to better understand potential for doses to the public.

Any remedial measures that may be considered as a result of this study will presumably be subject to discussions and approval by the CDPHE and/or Fremont County officials. The easement of County Road 143 is a County issue, and a letter from the CDPHE to Cotter's former Executive Vice President dated Sept. 27, 1994, indicates a written agreement between Cotter and the CDPHE that "earthmoving in the drainage area up-gradient from the silt fence (tract "F" on Appendix D)" is prohibited (CDPHE, 1994). Tract F as described in the 1994 CDPHE letter is the same as the 5.4 acre study area defined for this study.

RADIOLOGICAL SURVEY METHODS

The radiological investigation of the study area included a comprehensive gamma survey along with systematic and judgmental soil sampling. The approach was consistent with characterization survey protocols described in MARSSIM, the Multi-Agency Radiation Survey and Site Investigation Manual (NRC, 2000). The survey team was comprised of radiological investigation experts with decades of experience with similar studies. Standard quality control protocols (e.g. check source QC readings, decontamination between samples to prevent cross-contamination, etc.) were observed for all phases of sample collection and field measurements.

Surface Soil Sampling

Visual Sample Plan (VSP), a public domain software tool developed by Pacific Northwest National Laboratory for the U.S. Department of Energy, was used to create a simple triangular grid sampling

design for surface soils. The number of samples collected was based on anticipated availability of resources with respect to sampling, sample preparation, and laboratory analyses. The sampling grid included 25 surface soil samples, each collected to a depth of 6 inches (Figure 8). Two additional surface samples were collected at locations of potential interest in the immediate vicinity of AS-210. Surface soil sampling was performed February 3 and 4, 2010.

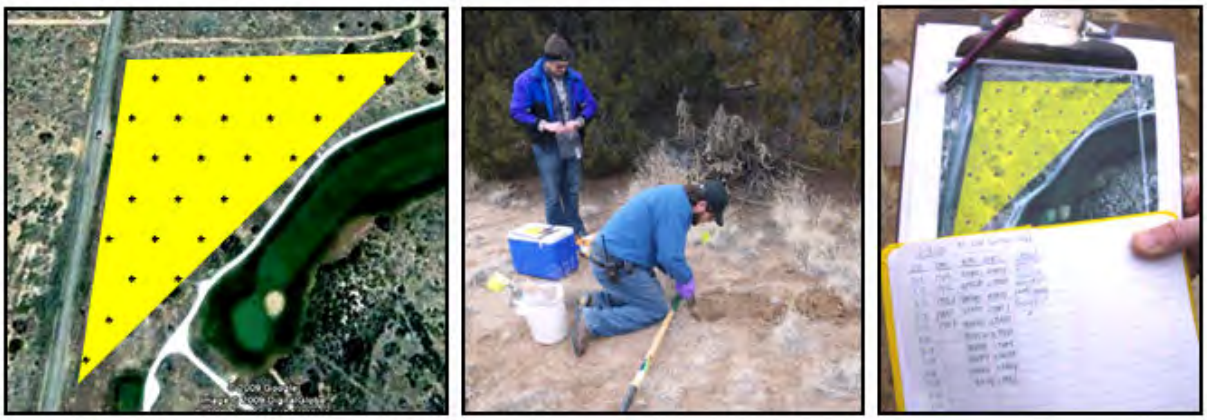


Figure 8: Left: VSP-generated surface soil sampling grid; Center/Right: soil sampling and associated data collection.

Depth Profile Soil Sampling

On January 26, 2010, four separate backhoe trenches were excavated for depth profile sampling (Figure 9), three along the margins of County Road 143 and one in the immediate vicinity of air monitoring station AS-210. Trench locations were selected based on gamma survey information and areas of potential interest with respect to study objectives. Within each trench, depth profile sampling increments were based on gamma readings and visual observations of soil stratification, color and texture (Figure 9).

Figure 9: Left: excavation of trench adjacent to county road (monitoring station AS-210 can be seen in the distance); Right: depth profile next to the county road with visible stratification of soil colors/textures.

Laboratory Soil Analyses

Each soil sample was analyzed by the Cotter Laboratory for gross alpha concentration according to Cotter Laboratory Procedure SOP 5-2 (Cotter, 2006a). A select subset of these samples was also analyzed for Th-230 concentration according to Cotter Laboratory Procedure SOP 5-9 (Cotter, 2006b).

Aliquots of each soil sample were also analyzed for Ra-226 concentration using an analytical screening procedure based on field laboratory methods developed by Whicker et al. (2006). Primary modifications from the gamma spectroscopy methodology referenced above were that a 2”× 2” NaI detector was used, and the analytical calibration curve was based on gross gamma measurements (rather than spectral analysis of specific energy peaks) for soil Ra-226 reference material standards.

Sample aliquots were sealed in special soil counting tins and placed inside of a lead shielded well during gamma counting to greatly reduce background radiation and maximize system sensitivity to Ra-226 and its decay products (Figure 10). Based on previous method-specific assessments of radon ingrowth for site-specific soil samples, a statistical correction was applied to initial counting results to account for the ingrowth of radon-222 and its decay products (at approximate secular equilibrium with Ra-226).

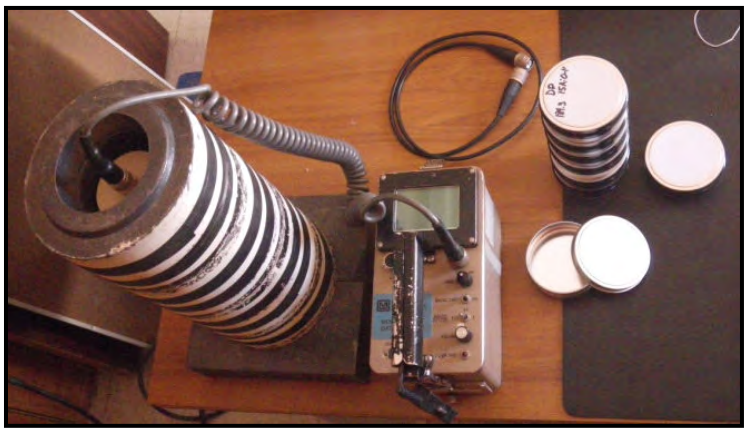


Figure 10: Lead-shielded gamma counting well, NaI detector, and soil sample counting tins.

Because background gamma radiation is not 100% shielded during soil Ra-226 counting, system sensitivity to gammas associated with very low Ra-226 concentrations (near 1 pCi/g) becomes limited and the calibration curve can sometimes result in unrealistically low or even slightly negative values. The practical reporting limit for the method is believed to be about 1 pCi/g. Because this is about the national average for background soils, and because it is relatively uncommon for natural soils to have Ra-226 concentrations lower than this, all calculated estimates falling below 1 pCi/g were automatically assigned a value of 1 pCi/g.

Gamma Survey

Advanced GPS-based gamma scanning systems with automated electronic data collection have become widely used in the field for radiological assessments (Meyer et al., 2005a; Meyer et al., 2005b; Johnson et al., 2005; Whicker et al., 2008). These systems are consistent with radiological survey guidelines outlined in MARSSIM (NRC, 2000). Associated methods for application of this technology have been refined to meet various analytical objectives and regulatory requirements (Whicker et al., 2008).

Figure 11: Automated backpack scanning.

Cotter has leased special software from Tetra Tech (Fort Collins, Colorado) to enable an automated gamma scanning system. This system, comprised of a GPS receiver and NaI-based gamma detection equipment, was mounted on a backpack for a walking survey of the AS-210 study area (Figure 11). The gamma detector was unshielded and positioned at about 3 feet above the ground surface. Up to 60 individual gamma readings and corresponding GPS measurements per minute were recorded during the survey on a shoulder-harnessed mini-tablet PC, providing a detailed record of gamma exposure rate conditions across the study area.

CHARACTERIZATION RESULTS

Gamma Survey Results

It is appropriate to begin the discussion of radiological characterization results with the gamma survey because it provides the highest spatial density of study area coverage, directly reflects horizontal distributions of Ra-226 concentrations in surface soils, and provided a basis for selection of judgmental soil sampling locations. A frequency histogram of 2,328 individual gamma readings (Figure 12) reveals a lognormal distribution, with a median value of 21.6 µR/hr. This distribution reflects the fact that only small portions of the study area have gamma readings in excess of 28 µR/hr, primarily along the county road margins. A color-coded map of gamma scanning results across the study area, including the margins of County Road 143, is shown in Figure 13.

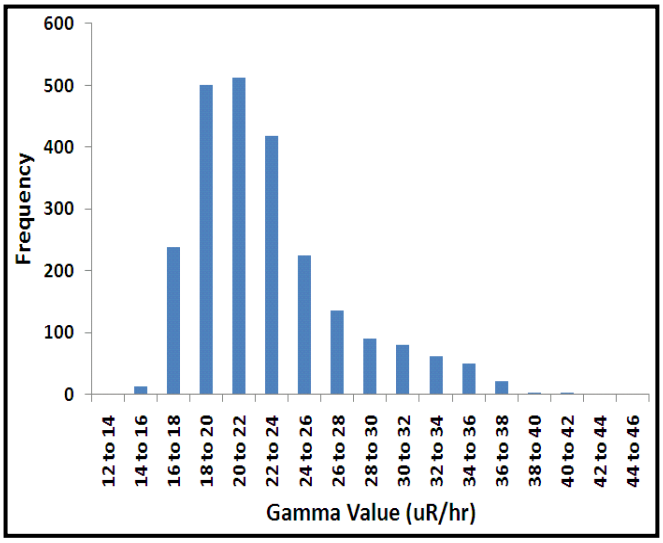


Figure 12: Numeric distribution of gamma exposure rate readings.

Based on the gamma readings shown in Figure 13, a kriging program in ArcGIS® was used to develop continuous estimates of gamma exposure rates across the study area. Kriging is a geostatistical interpolation procedure that fits a mathematical function to a specified number of nearest points within a defined radius to determine an output value for each location. A given "location" is represented by a cell of specified areal dimensions that may or may not include any measured data points. Values closer to the cell are given more weight than values further away, and distances, directions, and overall variability in the data set are all considered in the predictive semivariogram model. Kriging is a useful interpretive tool that can help improve understanding of overall survey results. Kriging results for gamma exposure rates are shown in Figure 14.

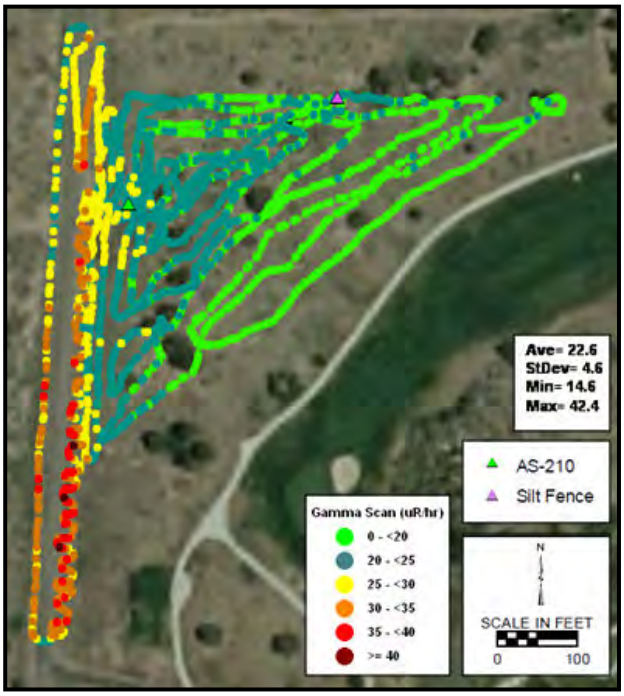


Figure 13: Spatial distribution of individual gamma exposure rate readings.

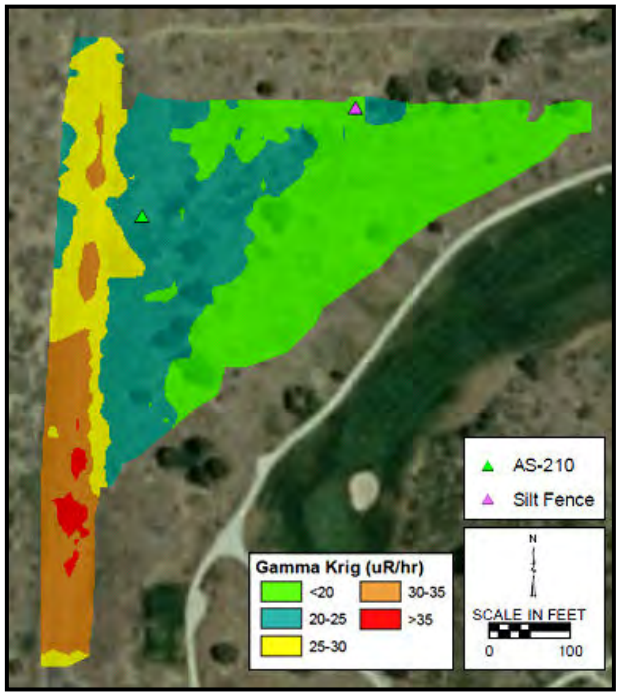


Figure 14: Kriged continuous estimates of gamma exposure rates.

Gamma / Soil Radionuclide Correlations

Gamma survey data were also used to estimate soil Ra-226 concentrations based on a gamma/Ra-226 correlation developed from earlier Roadside Risk Assessment data (Figure 15). Two outlying data points from this data set, believed to be impacted by heterogeneous conditions or gamma shine effects, were excluded from the correlation. After converting individual gamma readings into corresponding estimates of soil Ra-226 concentration, the converted data were kriged to provide continuous estimates of soil Ra-226 across the study area (Figure 16).

Based on 12 years of soil sampling data in the vicinity of AS-210, U-nat and Ra-226 concentrations in local soils, on average, are close to being in radiological equilibrium with one another. A U-nat/Ra226 ratio of about 2 is expected at equilibrium. The average measured U-nat/Ra-226 ratio for these samples was 1.7 (Figure 17), possibly due to slightly greater leaching of U-nat relative to Ra-226. Assuming this mean ratio is representative of soils in the study area, all Ra-226 concentration estimates, including those for direct soil samples as well as those derived from gamma survey readings, were converted into individual estimates of U-nat. Estimates based on gamma survey readings were kriged to provide continuous estimates of soil U-nat concentrations across the study area (Figure 18).

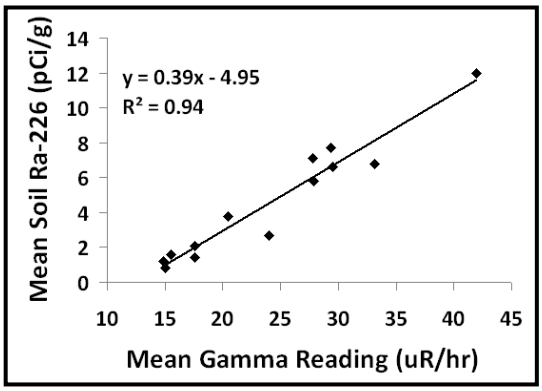


Figure 15: Gamma/Ra-226 correlation based on Roadside Risk Assessment data (MFG, 2005).

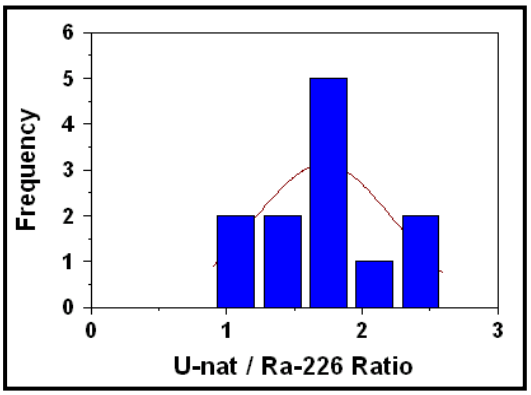


Figure 17: Frequency Histogram of U-nat / Ra-226 ratios in soil samples collected in the vicinity of AS-210 (mean ratio = 1.7).

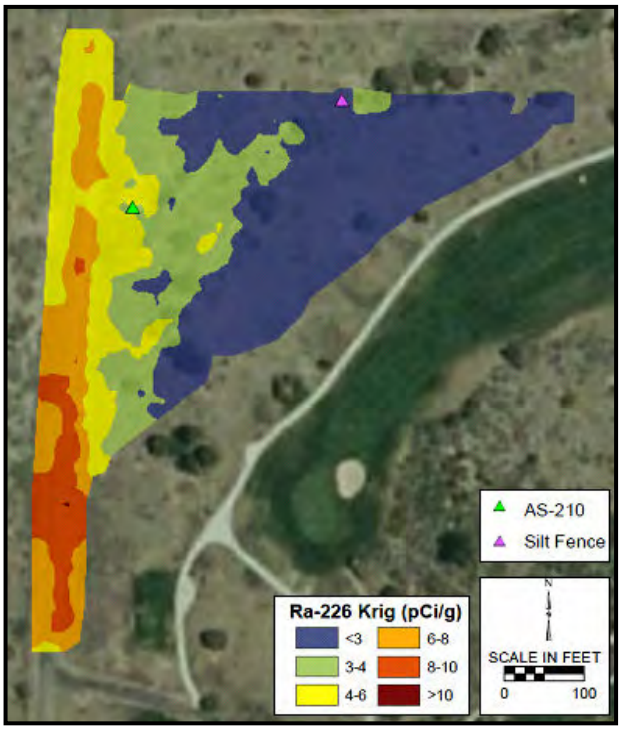


Figure 16: Kriged continuous estimates of Ra-226 concentrations in surface soils based on gamma survey measurements and the gamma/Ra-226 correlation.

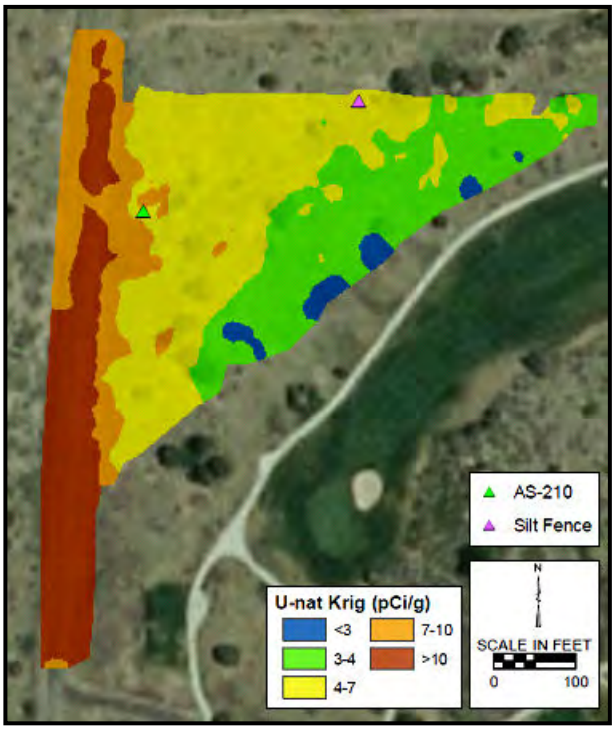


Figure 18: Kriged continuous estimates of U-nat concentrations in surface soils based on gamma survey data, the gamma/Ra-226 correlation, and an equilibrium adjustment factor.

Surface Soil Sampling Results

Summary statistics of analytical results for all surface soil samples collected within the study area (including surface layers collected at depth profile sampling locations) are provided in Table 2. A table of individual analytical results for all samples is provided in Appendix A. Thorium-230 results include a mix of direct laboratory results and statistically estimated values based on a significant non-linear correlation with gross alpha measurements (Figure 19). In cases where direct lab results were available, those results were used for all data analyses provided in this report.

Table 2: Summary statistics for all surface soil samples.

	Surface Soil Concentration (pCi/g)								
Radionuclide	n	Mean	Std Dev	Mode	Median*	75th*	90th*	Min	Max
U-nat	31	3.3	3.7	1.7	1.9	2.8	4.3	1.7	17.3
Th-230	31	8.7	20.1	1.9	2.1	4.3	12.3	0.8	85.8
Ra-226	31	1.9	2.2	1.0	1.1	1.6	2.5	1.0	10.2

**Percentiles*

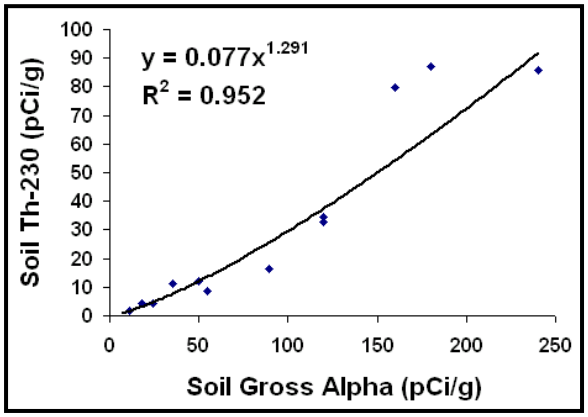


Figure 19: "Best fit" non-linear correlation between gross alpha and Th-230 measurements on 11 samples from the study area.

With respect to soil Ra-226 results, the degree of agreement between values estimated based on gamma survey measurements, and those based on direct soil sampling, was qualitatively and quantitatively assessed. A comparison of Ra-226 values was considered sufficient to gain an understanding of relative differences in U-nat results from the two characterization methods because estimates of soil U-nat were based on a constant equilibrium correction factor applied to estimates of Ra-226.

Direct measurements of Ra-226 in surface soil samples were plotted on the kriged map of soil Ra-226 concentrations based on gamma survey data (Figure 20). In general there appears to be good spatial agreement between Ra-226 values from each characterization method for most locations, though some significant deviations are apparent at a few locations, namely in areas where gamma survey readings were higher.

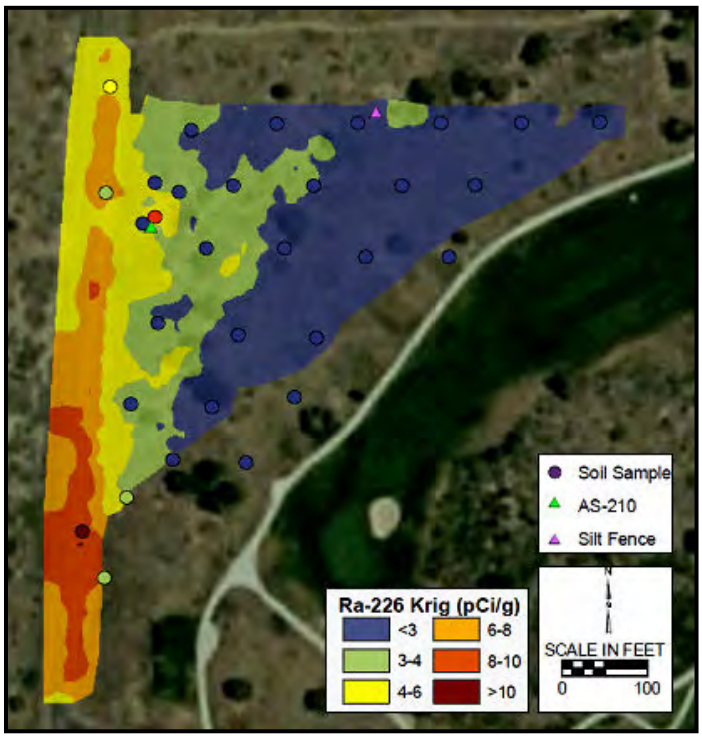


Figure 20: Soil Ra-226 sampling results plotted on the kriged map of Ra-226 concentrations in surface soils based on gamma survey readings (legend color increments apply to both characterization methods).

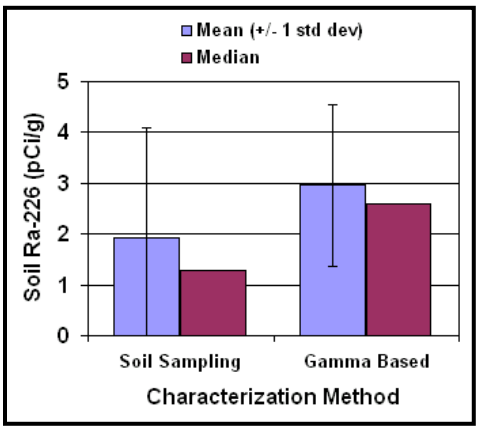


Figure 21: Comparison of mean/median soil Ra-226 values for direct soil sampling versus gamma survey based estimates.

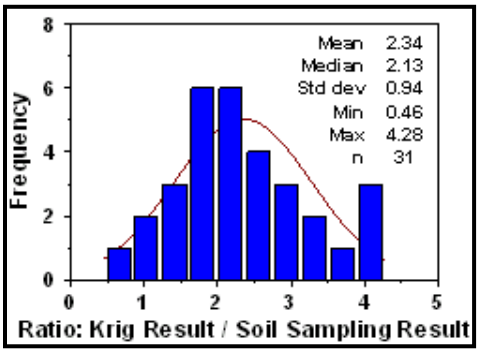


Figure 22: Histogram of the ratios of kriged estimates to soil sampling results for Ra-226 concentrations in surface soils at corresponding locations.

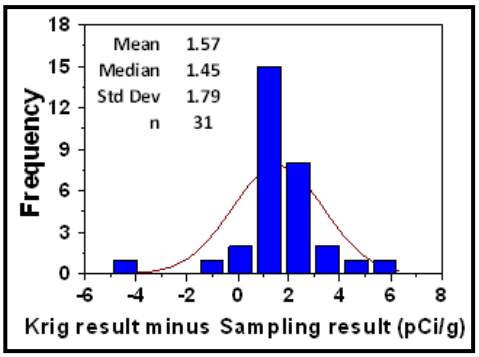


Figure 23: Histogram of actual numeric differences between kriged estimates of Ra-226 and direct soil sampling results at corresponding locations.

Several quantitative indicators of differences in Ra-226 results from each characterization method were assessed. First, general differences with respect to overall characterization of soil Ra-226 across the study area were evaluated. Statistical measures of central tendency (means and medians) for 31 direct soil sampling results were compared with those for 2,328 estimates based on the gamma survey and gamma/Ra-226 correlation (Figure 21). The comparison indicates that gamma based estimates of Ra-226 in surface soils result in a general characterization of the study area that is statistically about 1 pCi/g higher than direct soil sampling results suggest.

Secondly, specific differences between characterization methods were assessed by comparing soil sampling results with Kriged, gamma-based estimates at corresponding locations. The ratio of kriged estimates to soil sampling results indicates that kriged estimates were typically about 2 times higher at individual locations (Figure 22). However, such ratios can be deceiving when concentrations are very low.

The vast majority of soil samples collected across the study area had Ra-226 concentrations near the practical reporting limit of the analytical method (1 pCi/g). At such low concentrations, a small inaccuracy in the gamma/Ra-226 correlation can easily result in predicted Ra-226 concentrations that are double this value (2 pCi/g). In terms of human dose assessments, such small numeric differences in soil concentrations have little practical significance. The average numeric difference between kriged estimate and soil sampling result at corresponding locations was 1.6 pCi/g (Figure 23).

A potential physical reason for differences in values between these characterization methods is related to the nature of gamma radiation and the degree of uniformity in terrestrial sources. A significant degree of small scale spatial variability in soil Ra-226 concentrations (e.g. to within a few feet) can lead to a systematic bias in either method. In this case, soil-bound Ra-226 that migrates by wind erosion can tend to preferentially accumulate around the roots of vegetation. Due to accessibility and practicality issues, exact soil sampling points tend to be biased in favor of locations between vegetative cover.

Conversely, a given gamma survey reading is sensitive to terrestrial emissions from a radius on the order of 5 meters or more at the soil surface, regardless of the degree of variability in soil concentrations within this detector "field of view". There was considerable brush and other vegetation within the study area that limited accessibility for both soil sampling and gamma scanning, but gamma scans are less affected under such conditions in terms of producing representative radiological measurements.

Depth Profile Soil Sampling Results

Depth profile sampling trenches D-1, D-2 and D-3 were each located immediately adjacent to County Road 143, while trench D-4 was located about 50 feet east of the county road and 8 feet north of air monitoring station AS-210. Graphical depth profile results for Th-230 and Ra-226 soil concentrations (Figure 24) indicate that elevated concentrations for these radionuclides are limited to the top 6 inches of the soil profile, with the exception of D-1 which also has slightly elevated concentrations in the 8-15 inch subsurface layer.

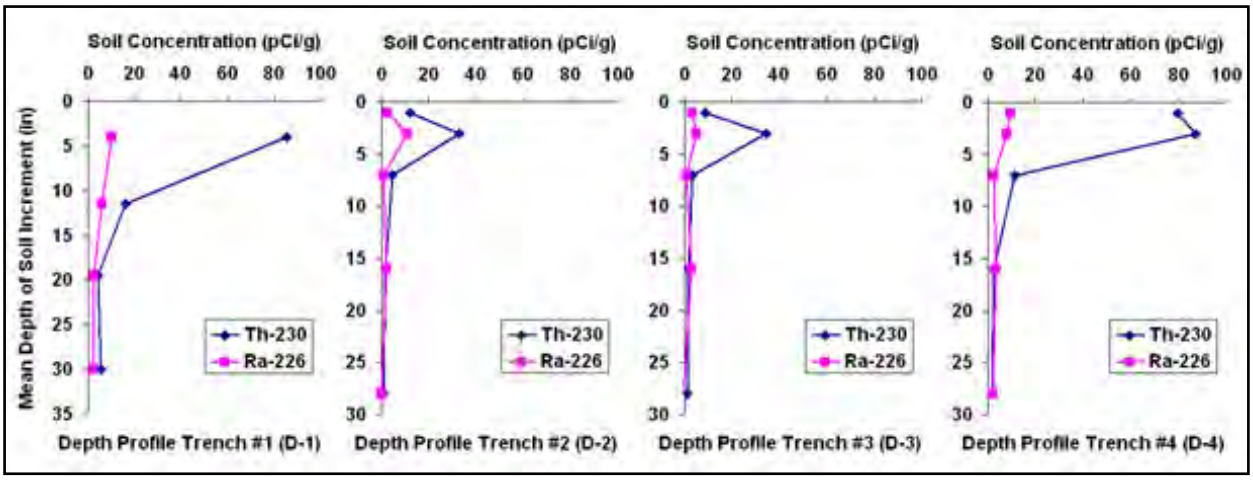


Figure 24: Soil concentration depth profile results for Th-230 and Ra-226. Soil U-nat concentrations are assumed to be about 1.7 times higher than the Ra-226 results based on an assessment of radiological equilibrium between these two radionuclides in local soils.

County road soil profile sampling observations and analytical results provide clear evidence of an association between elevated radionuclide concentrations and non-native material with a distinct black appearance, similar in color and texture to that of degraded asphalt, fine coal, industrial slag, or some other processed material of unknown anthropogenic origin (Figure 25 and Appendix B). Based on depth (2-4 inches), thickness, and observed occurrences near and underneath the county road along considerable stretches of pavement, this layer of material was likely used as road bed or surfacing material at one time.

Figure 25: Photo of soil depth profile sampling trench D-2 showing distinct layers, most notably a thin layer of black material consistent in appearance and texture with degraded asphalt, fine coal, or some other anthropogenic material. Clearly underlying County Road 143, this material also extended laterally several feet from the current edge of the pavement.

Cotter intends to send samples of this radiologically elevated black material to a specialized laboratory for petrology analysis to help identify its origin. According to long time Cotter employees, this material appears similar to that observed underneath and along the margins of the county road during the Team Track cleanup (Cotter, 2000). It is apparent that this material was intentionally placed in large quantities along the county road, and is not a result of spillage from trucks hauling ore, raffinate or other feedstock material in route to the Cotter milling facility.

Source Material Assessment

To help evaluate potential sources of elevated Th-230 at air monitoring station AS-210, soil sampling locations, color-coded to reflect Th-230 concentrations at the soil surface and annotated with location

ID numbers, were plotted on the kriged gamma survey map (Figure 26). The spatial distributions of terrestrial gamma radiation and surface soil Th-230 concentrations (both horizontal and vertical), along with field observations and other relevant information were used for this assessment.

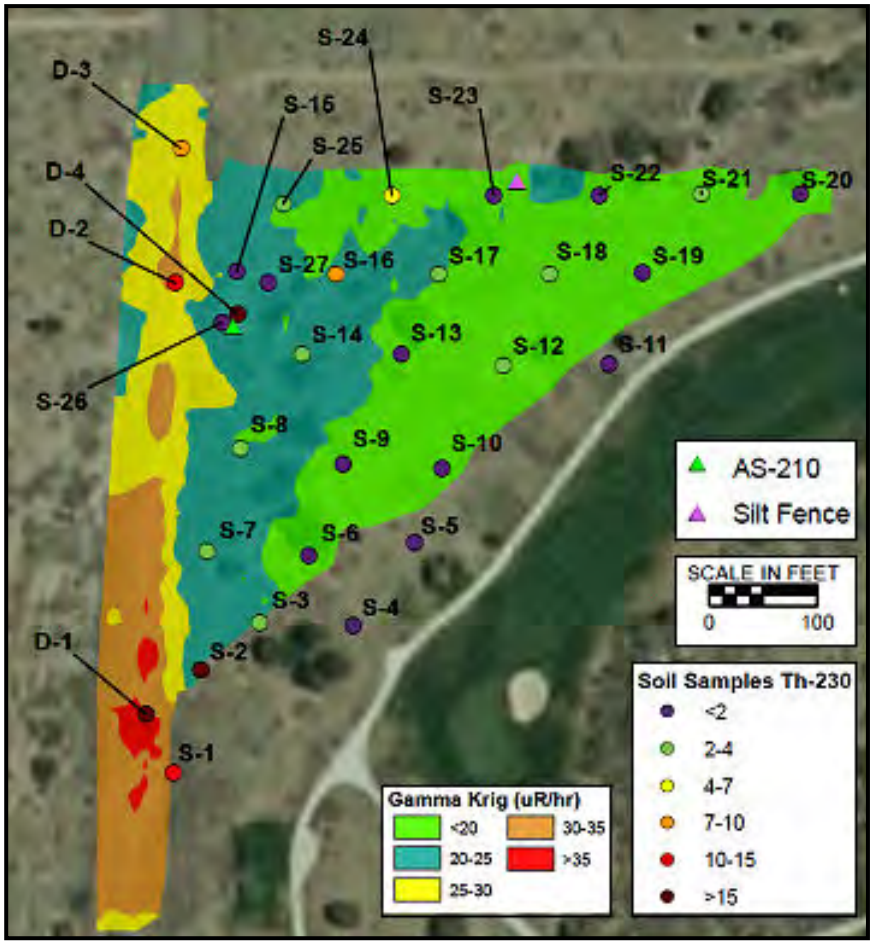


Figure 26: Color-coded Th-230 concentrations in surface soils plotted on the gamma survey map.

Elevated Th-230 and Ra-226 soil concentrations (and by inference U-nat based on evidence of approximate equilibrium with Ra-226) were found to be present in the same samples, but to different degrees relative to one another. The Th-230 was consistently higher (in disequilibrium) relative to Ra-226. The degree of disequilibrium was most pronounced in near surface soils at depth profile sampling locations D-1 and D-4, and to a lesser extent in samples from the 2-4 inch depth increment layer collected at locations D-2 and D-3 (Figure 24).

The 2-4 inch depth layer at D-2 and D-3 is comprised of the material with the distinct “black asphalt” appearance (Figure 25). Diffuse traces of this same black material were apparent in the top 8 inches of depth profile D-1. Depth profile D-1 appeared disturbed in the upper layers, perhaps a result of easement grading or excavations for installation/maintenance of utility lines along county road margins.

Slightly elevated radionuclide concentrations (particularly Th-230) were also found in the top 6 inches at surface soil sampling locations S-1 and S-2, which are located relatively close to the county road margin in the general vicinity of depth profile sampling location D-1. A thin lens of the black material was also observed within the top 6 inches at sampling location S-1.

Although there were no visible indications of black source material at sampling trench D-4 (next to AS-210), significantly elevated radionuclide concentrations (especially Th-230) were measured in the top 4 inches along with slightly elevated levels in the 4-10 inch subsurface sampling increment. An explanation for significantly higher "enrichment" of Th-230 at locations D-1 and D-4 relative to other locations is likely related to both chemical and physical transport mechanisms.

The soil/water partition coefficient (K_d) for Th-230 is typically orders of magnitude higher than that for Ra-226 and U-nat (ANL, 2009). Mobility of Th-230 is more likely to be dominated by physical transport of particles to which it is sorbed in a solid phase, versus leaching and transport in a liquid phase. Assuming that source material with elevated radionuclides has been subject to decades of percolating precipitation, it stands to reason that Ra-226 and U-nat could have become depleted relative to Th-230 (i.e. Th-230 would appear "enriched"). In addition, if depleted source areas have been subject to physical erosion and transport events (water and/or wind driven erosion), distant locations where this material becomes deposited would include an "enriched" Th-230 signature.

Locations D-1 and D-4 are both subject to percolating water and potential differential leaching, but this may be less true for locations D-2 and D-3 because these samples were collected within inches of the county road pavement. Impermeable pavement reduces or eliminates water infiltration into underlying road bed materials. The pavement and road easement margins are graded to slope away from the center of the road in order to promote surface runoff and avoid pooling on or near the pavement. This presumably reduces the amount of time available for runoff waters to infiltrate near the edge of the pavement.

A related yet possible additional mechanism for unusually high "enrichment" of Th-230 in soils at locations D-1 and D-4 is that if these locations represent zones of accumulation, it is reasonable to assume that water tends to pool in these areas, not only depositing entrained sediment load, but also allowing additional time for infiltration and further leaching of Ra-226 and U-nat relative to Th-230.

The depth profile trench at location D-1 was excavated in a relative low spot a bit further away from the pavement than locations D-2 and D-3, and thus could be a zone of accumulation and enhanced percolation/leaching. This location also corresponds to a small area of elevated gamma readings (Figure 26). The trench at depth profile location D-4 was excavated at a visible bend in the runoff drainage channel next to AS-210, suggesting that this location could also be a zone of accumulation.

Another notable finding is that significantly elevated soil Th-230 was absent from virtually all surface soil samples collected at locations distant from the county road or drainage channel. Moderately elevated Th-230 (7.9 pCi/g) was found at location S-16, which was also sampled within or very close to the

drainage channel about half way between AS-210 and the silt fence (in some areas the drainage is relatively wide and not well channelized or defined). This provides further evidence that elevated radionuclides have migrated from the county road through the drainage channel towards the silt fence.

Finally, it is relevant to consider the spatial pattern of areas with slightly elevated gamma radiation (in the range of 20-25 µR/hr) in relation to proximity to the county road and drainage channel. This pattern reflects a distribution of Ra-226 and its decay progeny resulting from aeolian transport by prevailing winds (generally out of the WNW), water-driven transport along runoff drainage pathways, and related influences of local topography. A conceptual model of postulated radionuclide migration patterns and associated transport mechanisms is depicted in Figure 27.

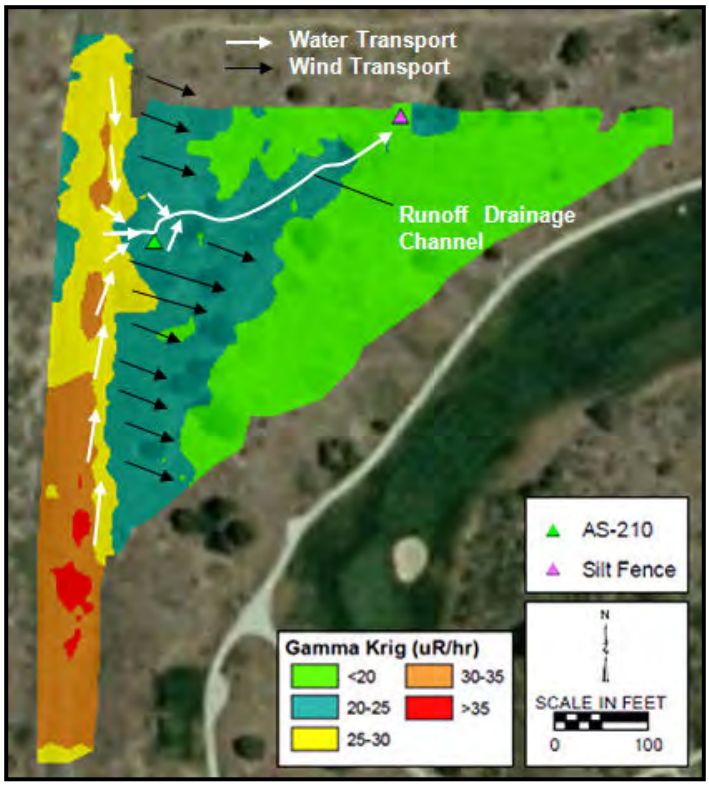


Figure 27: Conceptual model of radionuclide migration patterns and physical transport mechanisms based on gamma data, prevailing wind direction, the drainage channel, and topography.

The above results and observations indicate that the source of elevated radionuclides found at AS-210 resides primarily along the margins of County Road 143. The material with a degraded "black asphalt" appearance is believed to be the primary source, residing underneath and adjacent to the pavement and in some cases extending a bit further away from the roadway easement (e.g. at surface soil sampling location S-1). Over many years (potentially decades), this material may have leached in place (depleting Ra-226 and U-nat), gradually eroded and migrated to the drainage channel near AS-210, and subsequently become subject to further leaching/depletion of Ra-226 and U-nat resulting in higher apparent enrichment of Th-230 relative to other locations with elevated radionuclides.

DOSE ASSESSMENTS

The approved Study Plan (Cotter, 2009b; CDPHE, 2010) called for various dose assessments using radiological characterization data and the RESRAD-OFFSITE computer modeling code (ANL, 2009). The objective was to help determine whether remediation is warranted, and if so, what cleanup criteria would ensure that the regulatory dose limit of 25 mrem/yr (not including radon) to any member of the public will be met.

RESRAD-OFFSITE can be used to model doses to a receptor residing within a zone of contamination, or at a location removed from the contamination. RESRAD-OFFSITE has other advantageous features versus earlier versions of RESRAD, including improved groundwater modeling capabilities, visual mapping tools, comprehensive and versatile graphics utilities, and robust sensitivity/uncertainty analysis features.

Receptor Scenarios and Parameter Selections

Human receptor exposure scenarios for dose assessments included a school child routinely waiting for a school bus near the study area, a golfer or jogger routinely recreating near this area, and a residential scenario for the existing home located just north of the study area (Figure 28). Key model parameter selections for each receptor scenario are provided in Table 3. RESRAD defaults were used for all other model parameters.

Parameter selections were generally based on reasonably conservative assumptions. For example, the area of the modeled contamination zone was set at 3.9 acres based on the possibility that areas with elevated radionuclides in surface soils could have been slightly underestimated due to the potential for a small, vegetation-related sampling bias as previously mentioned. The gamma survey suggests that areas with elevated (above background) radionuclides comprise about 60% of the study area, yet the contamination zone used for dose modeling comprised an area representing about 73% of the study area.

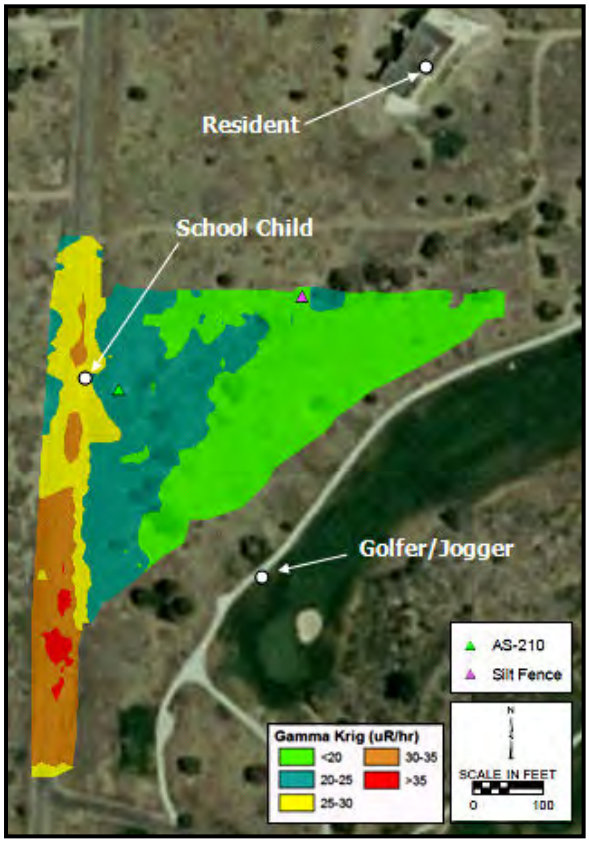


Figure 28: Assumed receptor locations relative to the study area for dose modeling.

In addition, average radionuclide concentrations from surface soil sampling results were used to define the source term within the modeled contaminated zone, yet background concentrations were not

subtracted. This adds further conservatism because background dose is not included in the 25 mrem/yr standard. Because conservative assumptions tend to err on the side of predicting higher doses, it is possible that actual doses to a receptor would be less than those predicted by the modeling.

Table 3: Key model parameter selections and rationale for each receptor dose scenario. RESRAD defaults were used for all other modeling parameters

Model Parameter	Receptor Scenario			Rationale
	School Child	Recreational Golfer/Jogger	Nearby Resident	
OCCUPANCY PARAMETERS				
Modeled Receptor Location	County Road easement adjacent to study area	Golf Course adjacent to study area	Existing residential property north of study area	Plausible average receptor location
Occupancy Frequency	2 hrs/day, 5 days/wk, 50 wks/yr	3 hrs/day, 5 days/wk, 50 wks/yr	14 hrs/day, 365 days/yr	Plausible average receptor time fraction at location
Occupancy Factor (outdoor)	0.06	0.09	0.08	Plausible outdoor time fraction
Occupancy Factor (indoor)	-	-	0.50	Plausible indoor time fraction
CONTAMINATION ZONE PARAMETERS				
Contamination Zone Area (acres)	3.9	3.9	3.9	Approximate size of areas with elevated gamma readings (incl. County Road)
Contamination Thickness (cm)	15	15	15	Based on sampling results
Average U-nat Conc. (pCi/g)	3.3	3.3	3.3	Mean of all surface samples
Average Th-230 Conc. (pCi/g)	8.7	8.7	8.7	Mean of all surface samples
Average Ra-226 Conc. (pCi/g)	1.9	1.9	1.9	Mean of all surface samples
METEOROLOGICAL PARAMETERS				
Wind directions/frequencies	Local STAR data file	Local STAR data file	Local STAR data file	MET data from mill site
Mean Precipitation (m)	0.34	0.34	0.34	Published climate data for Canon City
DOSE PATHWAY SELECTIONS				
External Gamma	Yes	Yes	Yes	Realistic for scenario
Internal Inhalation	Yes	Yes	Yes	Realistic for scenario
Soil Ingestion	Yes	Yes	Yes	Realistic for scenario
Drinking Water	No	No	No	Not realistic for scenario
Plant Ingestion	No	No	No	Not realistic for scenario
Meat Ingestion	No	No	No	Not realistic for scenario
Aquatic Foods	No	No	No	Not realistic for scenario
Radon	No	No	No	Excluded from dose limit

Dose Modeling Results for the School Child Receptor Scenario

Dose modeling results indicate that a child routinely waiting at the edge of the county road for a school bus next to the AS-210 study area would receive a maximum total effective dose equivalent (TEDE) of 0.13 mrem/yr due to average above background concentrations of U-nat (3.3 pCi/g), Th-230 (8.7 pCi/g), and Ra-226 (1.9 pCi/g) residing in the top 15 cm of the soil profile across the study area (Figure 29). The maximum dose rate would be received at time zero, virtually all of which is due to external gamma radiation (Figure 30). Contributions from inhalation or soil ingestion would be negligible.

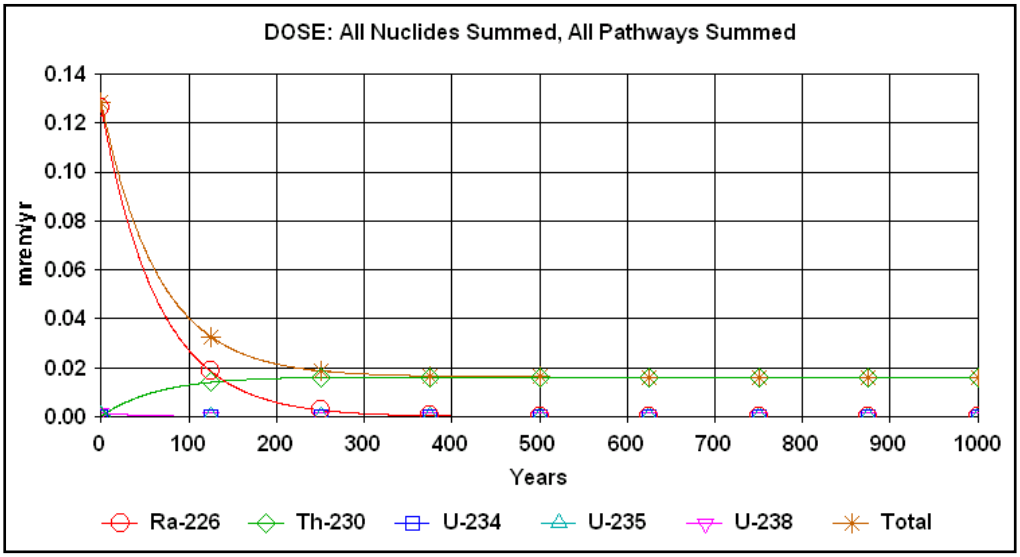


Figure 29: Dose modeling results by radionuclide for the school child receptor scenario.

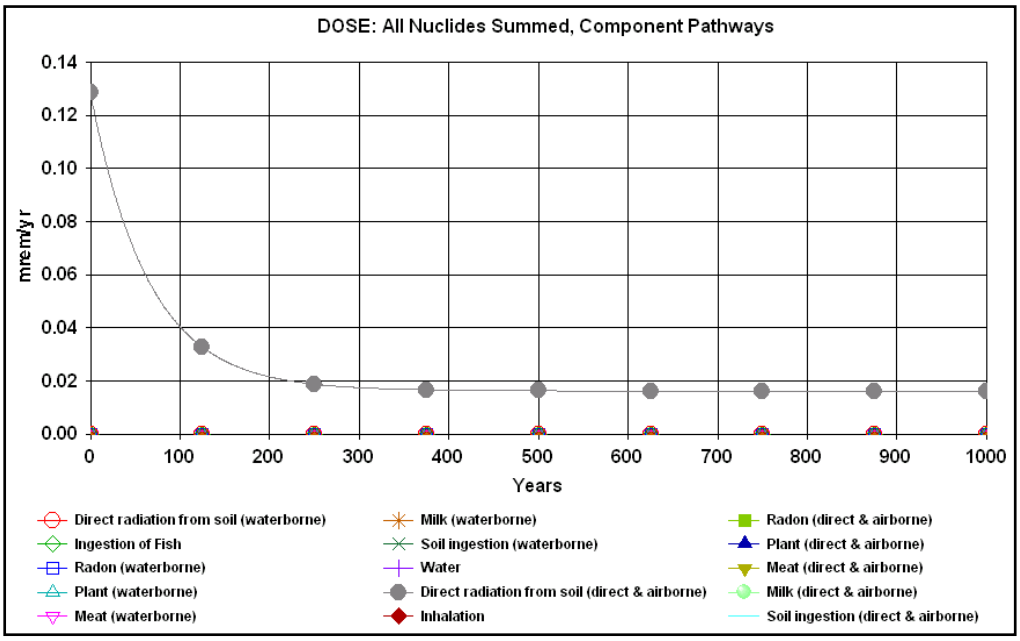


Figure 30: Dose modeling results by component pathway for the school child receptor scenario.

Dose Modeling Results for the Recreational Golfer/Jogger Scenario

Dose modeling results indicate that a golfer or jogger routinely recreating at the golf course next to the AS-210 study area would receive a maximum TEDE of about 0.026 mrem/yr due to average above background concentrations of U-nat (3.3 pCi/g), Th-230 (8.7 pCi/g), and Ra-226 (1.9 pCi/g) residing in the top 15 cm of the soil profile across the study area (Figure 31). The maximum dose rate would be received at time zero, virtually all of which is due to external gamma radiation (Figure 32). Contributions from inhalation or soil ingestion would be negligible.

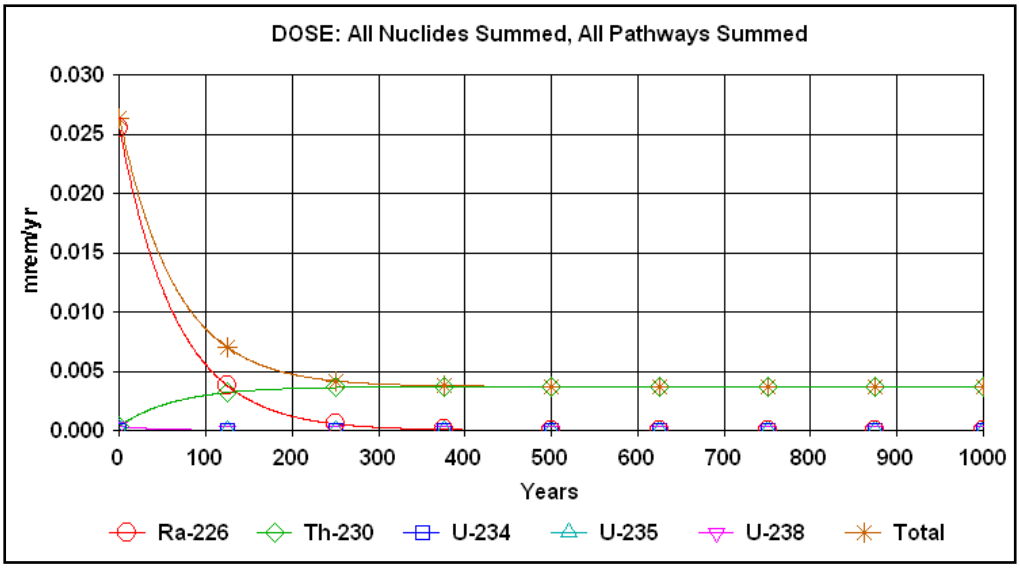


Figure 31: Dose modeling results by radionuclide for the golfer/jogger receptor scenario.

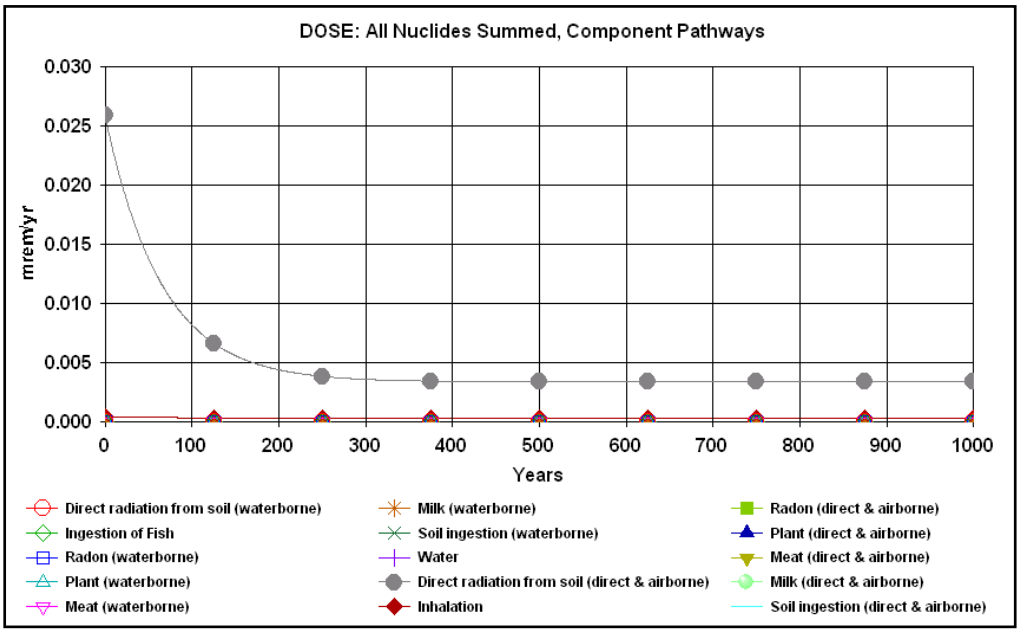


Figure 32: Dose modeling results by component pathway for the golfer/jogger receptor scenario.

Dose Modeling Results for the Nearby Resident Scenario

Dose modeling results indicate that a resident living at the current nearest residence just north of the AS-210 study area would receive a maximum TEDE of about 0.015 mrem/yr due to average above background concentrations of U-nat (3.3 pCi/g), Th-230 (8.7 pCi/g), and Ra-226 (1.9 pCi/g) residing in the top 15 cm of the soil profile across the study area (Figure 33). The maximum dose rate would be received at time zero, most of which is due to external gamma radiation (Figure 34). Relative contributions from inhalation would be very small, and from soil ingestion essentially zero.

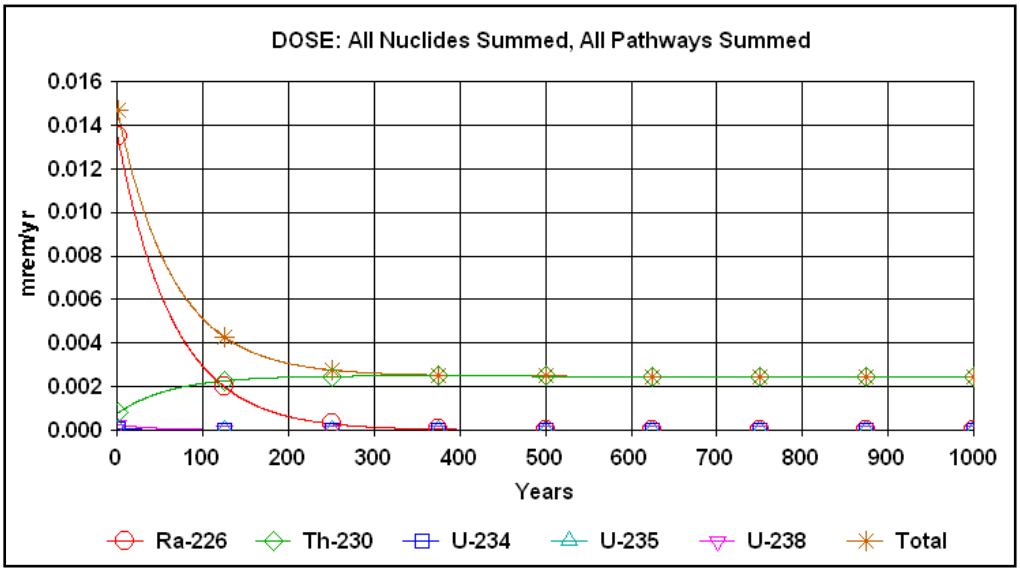


Figure 33: Dose modeling results by radionuclide for the nearby resident receptor scenario.

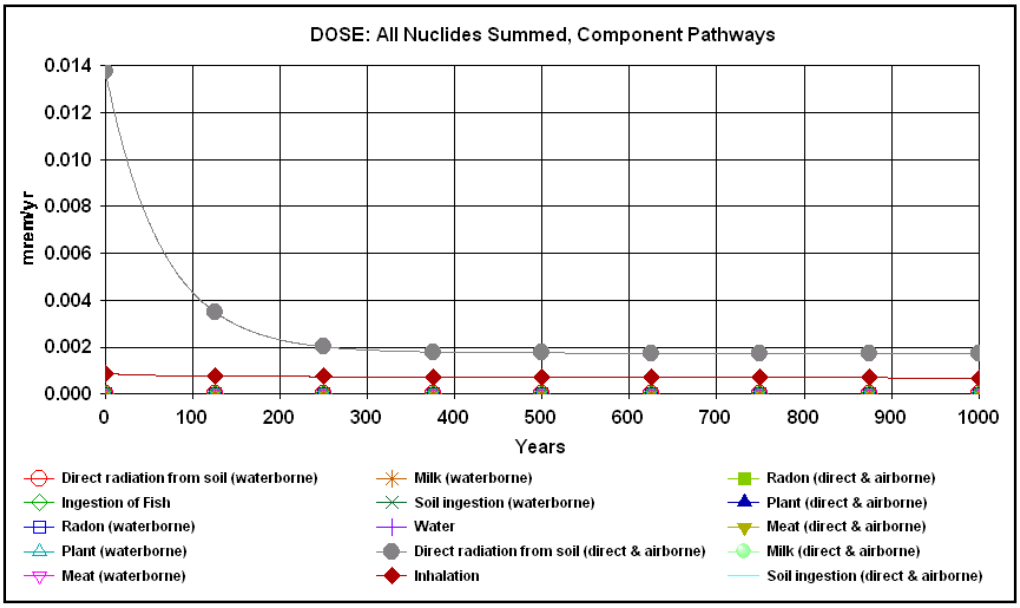


Figure 34: Dose modeling results by component pathway for the nearby resident receptor scenario.

Dose Assessment Implications

Each of the modeled receptor scenarios indicate that potential doses to any member of the public from above background concentrations of radionuclides in portions of the AS-210 study area, including the margins of Count Road 143, are exceedingly small. Of the three receptor scenarios, a child routinely waiting for a school bus at the county road adjacent to the study area would be expected to receive the highest dose, yet the modeled dose for this receptor (0.13 mrem/yr) was two orders of magnitude lower than the 25 mrem/yr regulatory limit.

External gamma radiation is likely to be the dominant pathway for most realistic receptor scenarios, yet average soil Ra-226 concentrations and associated gamma radiation in the study area are low. Thorium-230 concentrations in surface soils are significantly elevated at sampling locations D-1 (near AS-210) and D-2 (near the access road to the golf course), but the evidence indicates that the extent of these areas is very small. To assess whether these small areas by themselves pose significant radiological risks to members of the public, an alternate (secondary) dose assessment was performed.

The secondary dose assessment again involved the school child receptor scenario, but in this case a much smaller contamination zone (100 m^2) located in next to monitoring station AS-210 was modeled (Figure 35). The top 15 cm of the soil profile was set equal to soil surface concentrations measured at sampling location D-4 (U-nat = 15.8 pCi/g, Th-230 = 79.6 pCi/g, and Ra-226 = 9.3 pCi/g). All other modeling parameters remained the same. The maximum dose to the school child under this scenario was 0.024 mrem/yr, due almost entirely to the external gamma pathway. This result indicates that the small areas of significantly elevated Th-230 at sampling locations D-1 and D-4 pose very little risk with respect to external or internal dose pathways.

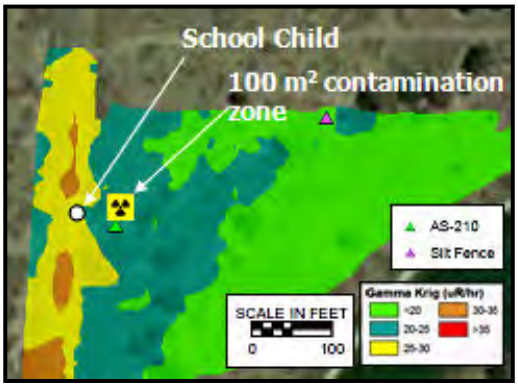


Figure 35: Alternate dose modeling layout for school child receptor scenario.

With respect to the source of elevated radionuclides in portions of the study area, the evidence indicates that the deteriorated "black asphalt" subsurface layer of the soil profile near the county road is primarily responsible. In situ, this material poses little potential for radiological doses to members of the public. The black source material is unlikely to have been associated with the mill, and regardless of genesis, this study revealed no scientific justification for remedial action in terms of radiological health considerations. Any remedial measures involving excavation and removal, particularly on a scale large enough to remove most or all of this material, could pose significantly greater potential for doses to workers and the public as large amounts of the material would be disturbed, mobilized and transported, potentially increasing availability for internal dose pathways and spreading material to other areas.

Should future needs for roadway or utility improvements, repairs, or maintenance require limited soil excavations along the easement of County Road 143 in this area, it may be appropriate for applicable County agencies to notify workers of the presence of this black material. Although there is very low potential for such workers to receive doses greater than a small fraction of the regulatory limit, simple precautions such as dust suppression within and around excavations, along with washing hands before eating or drinking, would further minimize any potential for worker doses via inhalation or ingestion pathways. Such preventative measures would be simple to implement, protective for both radiological and non-radiological issues, and would be consistent with "as low as reasonably achievable" (ALARA) principles.

SUMMARY AND CONCLUSIONS

This study involved a comprehensive and intensive radiological survey of gamma exposure rates and soil radionuclide concentrations across the AS-210 study area and the adjacent margins of County Road 143. Gamma exposure rates are relatively low (mean = 22.6 µR/hr, max = 42.4 µR/hr). Associated Ra-226 concentrations in surface soils are also low, averaging 1.9 pCi/g among 31 direct soil samples and 3 pCi/g among 2,328 gamma survey readings converted to Ra-226 estimates based on the gamma/Ra-226 correlation.

Isolated occurrences of significantly elevated Th-230 concentrations at the soil surface (on the order of 80-90 pCi/g) are extremely limited in areal extent, confined to two discrete locations (D-1 and D-4). The estimated combined extent of these areas is about 200 m^2 or less within the 5.4 acre study area (less than 1 % of areas surveyed). The average Th-230 concentration in surface soils across the study area was 8.7 pCi/g. While used in the primary dose assessments, this mean value represents an inflated indication of general soil levels due to anonymously high results at locations D-1 and D-4. Median (50th percentile) and mode (most probable) values for Th-230 in surface soils across the study area were close to background levels (2.1 and 1.9 pCi/g respectively).

Because dose modeling assumptions were consistently conservative, dose assessment results for the three primary receptor scenarios, each of which indicated extremely small potential for doses, are considered conservative. An additional (secondary) dose assessment to specifically model potential doses from the small area of higher radionuclide concentrations actually measured in the immediate vicinity of air monitoring station AS-210 (location D-4), also indicated negligible dose risks to members of the public.

The evidence indicates that the degraded “black asphalt” subsurface layer of the soil profile near the county road is the primary source of elevated radionuclides near AS-210. Differential leaching and depletion of U-nat and Ra-226 relative to Th-230, along with erosional transport mechanisms, may play a role in the disequilibrium of Th-230 with other radionuclides. In situ, the black source material poses little potential for radiological doses to members of the public. Because this material appears to have been intentionally placed at one time as roadbed or surfacing material for the county road, and is unlike any mill feedstock material in appearance, it is unlikely to have been associated with the mill.

Given the thorough nature of this investigation and consistent indications of extremely low potential for radiological doses or health risks associated with the AS-210 study area or the county road, Cotter believes that further surveys, studies or consideration of remedial action are unwarranted. Per the previous request from CDPHE, Cotter intends to submit samples of the black source material for petrology analysis assuming a qualified lab can be identified. Results will be reported to CDPHE when available.

REFERENCES

ANL (Argonne National Laboratory). 2009. RESRAD-OFFSITE computer code, Version 2.5, August 15, 2007. Developed under joint sponsorship of the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission for site-specific dose assessment of residual radioactivity. Environmental Sciences Division, Argonne National Laboratory.

CDPHE (Colorado Dept. Public Health and Environment). 1994. Letter from Robert M. Quillin of the CDPHE to Rich Ziegler of Cotter regarding "Division Authorization of Transfer of Title" which pertained to Cotter radioactive materials license conditions which were impacted by a negotiated land swap between the Shadow Hills Golf Course and Cotter Corporation.

CDPHE (Colorado Dept. Public Health and Environment). 2010. Letter from Steve Tarlton of CDPHE to John Hamrick of Cotter approving Cotter's "Radiological Survey Plan and Dose Assessment Approach for Evaluation of Cotter Property near Air Particulate Monitoring Station AS-210". Letter dated March 3, 2010.

Cotter Corporation. 2000. Final Report, June 2000: Team Track Railroad Transfer Site Radioactive Contamination Cleanup. Accepted by the CDPHE, July 14, 2000.

Cotter Corporation. 2006a. Procedure 5-2: Gross Alpha and Beta measurements of Soil, Water, and Other Matrices. 11/26/06.

Cotter Corporation. 2006b. Radiochemical Procedure for Radium-226/224, Isotopic Thorium, Isotopic Uranium, Polonium-210 and Lead-210. 12/7/06.

Cotter Corporation. 2009a. Environmental and Occupational Performance Report, ALARA Review and Annual Report on Remedial Action Plan Activities for Calendar Year 2008. June, 2009. Radioactive Materials License No. 369-01, Amendment 45-50. Cotter Corporation, Canon City, Colorado, June 30, 2009.

Cotter Corporation. 2009b. Radiological Survey Plan and Dose Assessment Approach for Evaluation of Cotter Property near Air Particulate Monitoring Station AS-210. November 4, 2009.

Johnson, J.A. Meyer, H.R., and Vidyasagar, M. 2006. Characterization of Surface Soils at a Former Uranium Mill. Operational Radiation Safety. Supplement to Health Physics, Vol. 90, February, 2006.

Meyer, R.; Shields, M.; Green, S. 2005a. A GPS-based system for preliminary or remedial action gamma scanning. American Nuclear Society Topical Meeting on Decommissioning, Decontamination, & Reutilization. Denver, Colorado, August 7-11, 2005.

Meyer, R.; Shields, M.; Green, S.; Johnson, J. 2005b. A GPS-based system for radium/uranium contamination gamma scanning. Uranium Mining and Hydrogeology IV. Broder J. Merkel, Andrea Hasche-Berger (Editors). Uranium in the Environment, conference proceedings, Freiberg, September 2005.

MFG, Inc. (MFG). 2005a. Assessment of Potential Dose to Members of the Public from Materials Along Roads Near the Cotter Corporation Cañon City Milling Facility. May 25, 2005.

MFG, Inc. (MFG). 2005b. Cotter Access Roadside Soil Cleanup Plan. November, 2005.

NRC (U.S. Nuclear Regulatory Commission). 2000. Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM). Revision 1.

Whicker, R.; Whicker, M.; Johnson, J.; and Meyer, H. 2006. Mobile Soils Lab: On-site Radiological Analysis Supporting Remedial Activities. Health Physics. Operational Radiation Safety. 91(2) Supplement 1:S24-S31, August.

Whicker, R.; Cartier, P.; Cain, J.; Milmine, K.; Griffin, M. 2008. Radiological Site Characterizations: Gamma Surveys, Gamma/Ra-226 Correlations and Related Spatial Analysis Techniques. Operational Radiation Safety, Health Physics, Vol. 95 (Supplement 5): S180-S189; November, 2008

APPENDIX A

Analytical Results for Soil Samples

Sample ID	Sample Depth (in)	Sample Date	U-nat (pCi/g)	Ra-226 (pCi/g)	Th-230 (pCi/g)	Notes
S-1	0-6	2/3/2010	3.6	2.1	12.3	1-inch thick Black "asphalt" layer @ 2 inches below surface
S-2	0-6	2/3/2010	4.2	2.5	16.2	Slight reddish layer @ 2 inches below surface
S-3	0-6	2/3/2010	1.7	1.0	3.7	Sandy clay, uniform appearance with depth, Hard/frozen at depth
S-4	0-6	2/3/2010	1.8	1.1	1.0	Sandy clay, uniform appearance with depth, Hard/frozen at depth
S-5	0-6	2/3/2010	3.2	1.9	0.8	Sandy clay, uniform appearance with depth, Hard/frozen at depth
S-6	0-6	2/3/2010	1.9	1.1	1.4	Sandy clay, uniform appearance with depth, Hard/frozen at depth
S-7	0-6	2/3/2010	2.0	1.2	2.5	Sandy clay, uniform appearance with depth, Hard/frozen at depth
S-8	0-6	2/3/2010	1.7	1.0	3.2	Sandy clay, uniform appearance with depth, Hard/frozen at depth
S-9	0-6	2/3/2010	1.7	1.0	1.9	Sandy clay, uniform appearance with depth
S-10	0-6	2/3/2010	1.9	1.1	1.0	Sandy clay, uniform appearance with depth
S-11	0-6	2/4/2010	1.7	1.0	0.9	Sandy clay, uniform appearance with depth
S-12	0-6	2/4/2010	1.7	1.0	2.1	Sandy clay, uniform appearance with depth
S-13	0-6	2/4/2010	1.9	1.1	1.7	Sandy clay, uniform appearance with depth
S-14	0-6	2/4/2010	1.8	1.1	2.3	Sandy clay, uniform appearance with depth
S-15	0-6	2/4/2010	1.7	1.0	0.8	Sandy clay, uniform appearance with depth
S-16	0-6	2/4/2010	2.4	1.4	7.6	Sandy clay, uniform appearance with depth
S-17	0-6	2/4/2010	2.7	1.6	2.1	Sandy clay, uniform appearance with depth
S-18	0-6	2/4/2010	2.8	1.7	2.8	Sandy clay, uniform appearance with depth
S-19	0-6	2/4/2010	1.7	1.0	1.9	Sandy clay, uniform appearance with depth
S-20	0-6	2/4/2010	2.7	1.6	0.8	Sandy clay, uniform appearance with depth
S-21	0-6	2/4/2010	1.8	1.1	3.4	Sandy clay, uniform appearance with depth
S-22	0-6	2/4/2010	1.7	1.0	1.4	Sandy clay, uniform appearance with depth
S-23	0-6	2/4/2010	1.7	1.0	1.5	Sandy clay, uniform appearance with depth
S-24	0-6	2/4/2010	2.6	1.5	4.9	Sandy clay, uniform appearance with depth
S-25	0-6	2/4/2010	1.7	1.0	3.2	Sandy clay, uniform appearance with depth
S-26	0-6	2/4/2010	1.7	1.0	1.5	Drainage channel just up gradient (WSW) of AS-210 station
S-27	0-6	2/4/2010	1.9	1.1	1.9	Drainage channel just down gradient (NE) of AS-210 station
AS-210-D-1A	0-8	1/26/2010	17.3	10.2	85.8	Disturbed, heterogeneous topsoil
AS-210-D-1B	8-15	1/26/2010	10.2	6.0	16.2	Red layer ("Red Dog" appearance), apparent elevated gammas
AS-210-D-1C	15-24	1/26/2010	4.3	2.5	4.1	Sandy Clay, Uniform appearance with depth
AS-210-D-1D	24-36	1/26/2010	3.6	2.1	5.7	Sandy Clay, Uniform appearance with depth
AS-210-D-2A	0-2	1/26/2010	4.3	2.5	11.9	Disturbed, heterogeneous topsoil
AS-210-D-2B	2-4	1/26/2010	18.5	10.9	33.0	2-inch thick Black "asphalt" layer, up to 12" from edge of pavement
AS-210-D-2C	4-10	1/26/2010	1.7	1.0	4.4	Sandy red layer ("Red Dog" appearance)
AS-210-D-2D	10-22	1/26/2010	3.4	2.0	1.5	Sandy Clay, Uniform appearance with depth
AS-210-D-2E	22-34	1/26/2010	1.7	1.0	0.9	Sandy Clay, Uniform appearance with depth
AS-210-D-3A	0-2	1/26/2010	6.0	3.5	8.7	Disturbed, heterogeneous topsoil
AS-210-D-3B	2-4	1/26/2010	8.2	4.8	34.5	2-inch thick Black "asphalt" layer, up to 12" from edge of pavement
AS-210-D-3C	4-10	1/26/2010	1.7	1.0	3.2	Sandy red layer ("Red Dog" appearance)
AS-210-D-3D	10-22	1/26/2010	4.9	2.9	1.6	Sandy Clay, Uniform appearance with depth
AS-210-D-3E	22-34	1/26/2010	1.7	1.0	1.0	Sandy Clay, Uniform appearance with depth
AS-210-D-4A	0-2	1/26/2010	15.8	9.3	79.6	Sandy Clay, Uniform appearance with depth
AS-210-D-4B	2-4	1/26/2010	13.1	7.7	87.2	Sandy Clay, Uniform appearance with depth
AS-210-D-4C	4-10	1/26/2010	4.3	2.5	11.1	Sandy Clay, Uniform appearance with depth
AS-210-D-4D	10-22	1/26/2010	5.4	3.2	2.5	Sandy Clay, Uniform appearance with depth
AS-210-D-4E	22-34	1/26/2010	3.6	2.1	1.5	Sandy Clay, Uniform appearance with depth

Font Color = measured value below practical reporting limit for analytical method, value set equal to practical reporting limit

Font Color = value determined by laboratory analysis (all other values estimated from statistical relationships with alternate measured data)

APPENDIX B

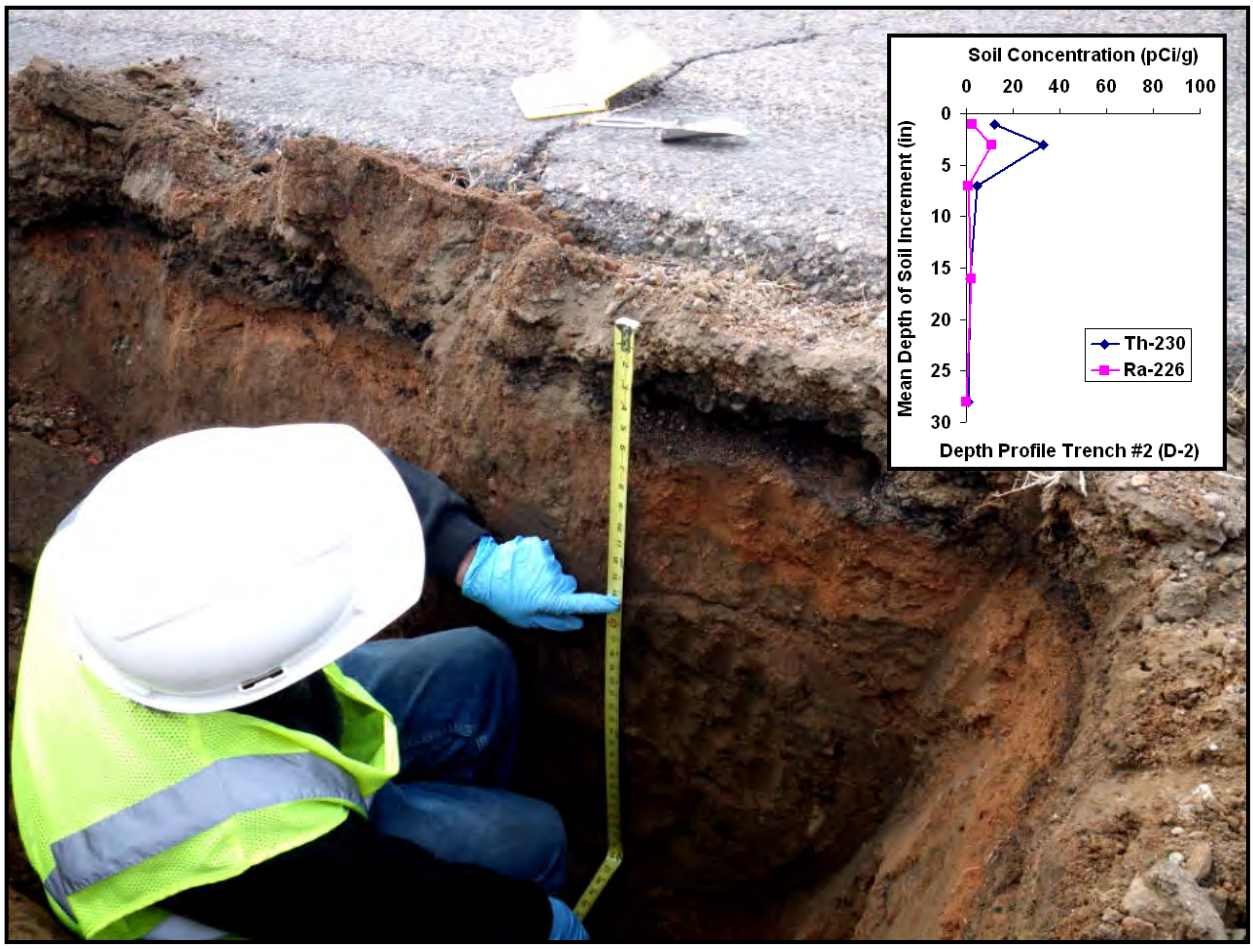
Soil Depth Profiles:
Photo Documentation, Field Notes, Analytical Results

Depth Profile D-1

Layer	Depth (in)	Mean Depth (in)	Ra-226 (pCi/g)	Th-230 (pCi/g)	Description
D-1A	0-8	4	10.2	85.8	Disturbed, heterogeneous, slight diffuse signs of black material
D-1B	8-15	11.5	6.0	16.2	Red layer ("Red Dog" appearance), apparent elevated gammas
D-1C	15-24	19.5	2.5	4.1	Sandy Clay, Uniform appearance with depth
D-1D	24-36	30	2.1	5.7	Sandy Clay, Uniform appearance with depth

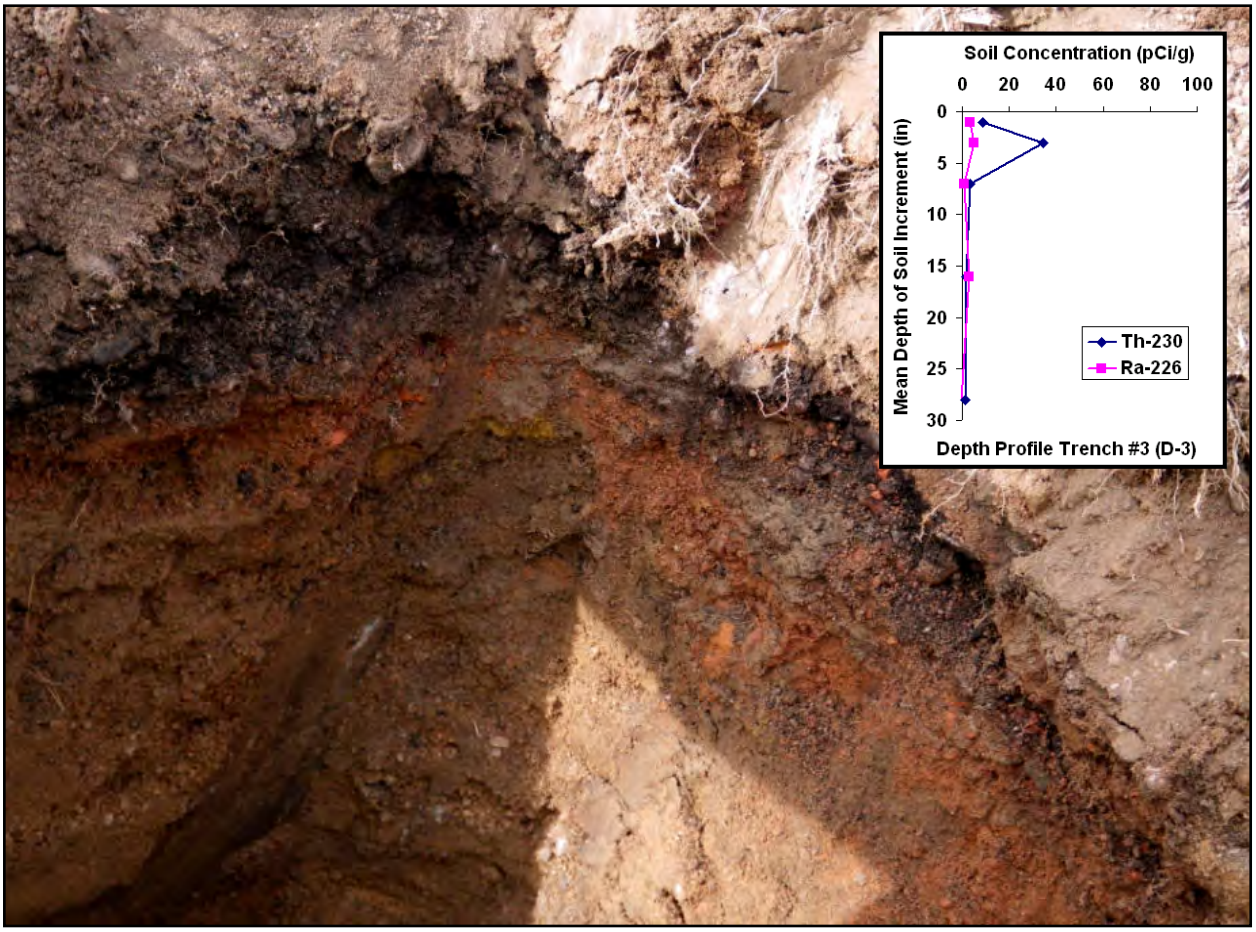
Depth Profile D-2

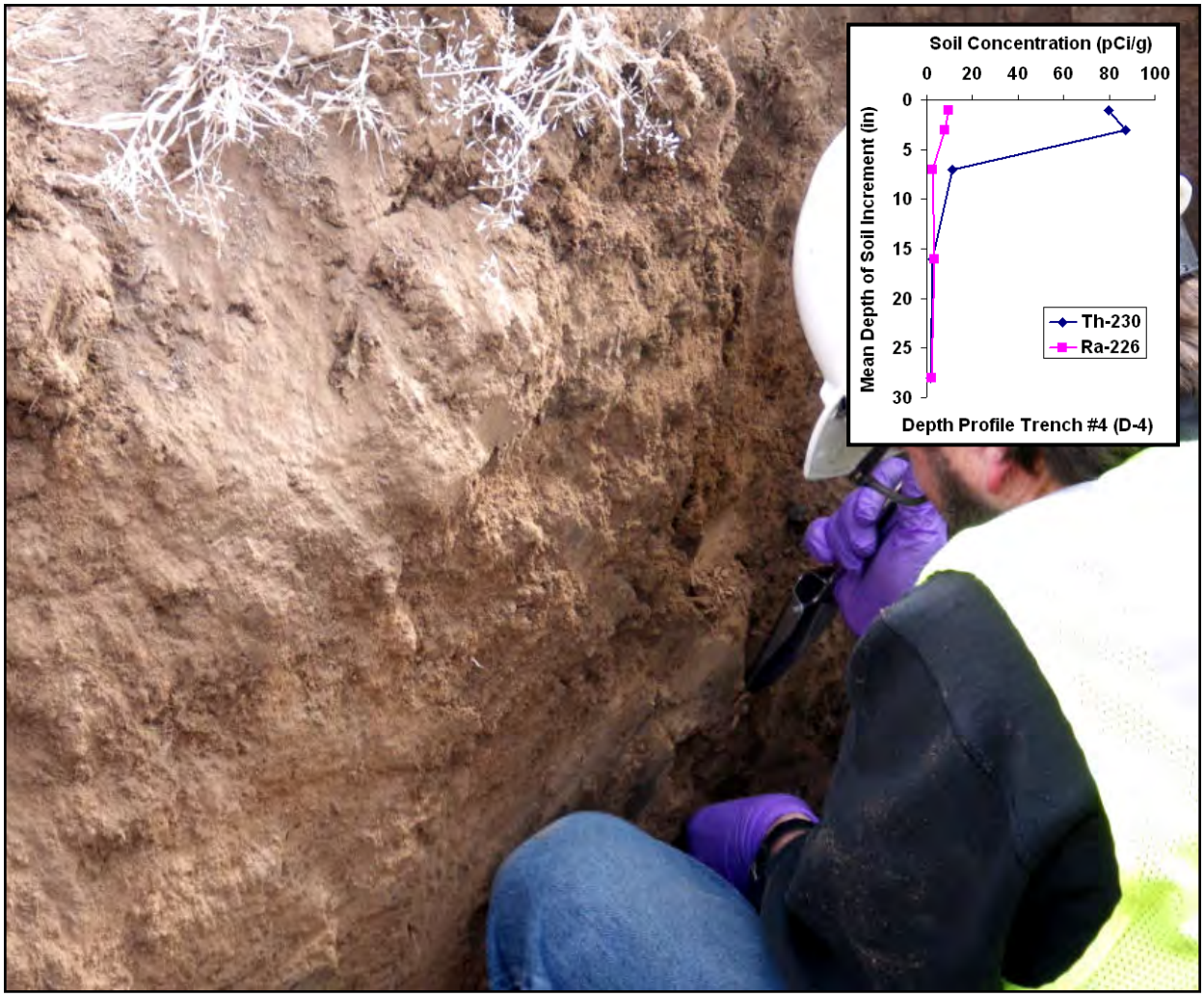
Layer	Depth (in)	Ra-226 (pCi/g)	Th-230 (pCi/g)	Description
D-2A	0-2	2.5	11.9	Disturbed, heterogeneous topsoil
D-2B	2-4	10.9	33.0	2-inch thick Black "asphalt" layer, up to 12" from edge of pavement
D-2C	4-10	1.0	4.4	Sandy red layer ("Red Dog" appearance)
D-2D	10-22	2.0	1.5	Sandy Clay, Uniform appearance with depth
D-2E	22-34	0.1	0.9	Sandy Clay, Uniform appearance with depth



Depth Profile D-3

Layer	Depth (in)	Ra-226 (pCi/g)	Th-230 (pCi/g)	Description
D-3A	0-2	3.5	8.7	Disturbed, heterogeneous topsoil
D-3B	2-4	4.8	34.5	2-inch thick Black "asphalt" layer, up to 12" from edge of pavement
D-3C	4-10	0.9	3.2	Sandy red layer ("Red Dog" appearance)
D-3D	10-22	2.9	1.6	Sandy Clay, Uniform appearance with depth
D-3E	22-34	-0.4	1.0	Sandy Clay, Uniform appearance with depth



Depth Profile D-4

Layer	Depth (in)	Ra-226 (pCi/g)	Th-230 (pCi/g)	Description
D-4A	0-2	9.3	79.6	Sandy Clay, Uniform appearance with depth
D-4B	2-4	7.7	87.2	Sandy Clay, Uniform appearance with depth
D-4C	4-10	2.5	11.1	Sandy Clay, Uniform appearance with depth
D-4D	10-22	3.2	2.5	Sandy Clay, Uniform appearance with depth
D-4E	22-34	2.1	1.5	Sandy Clay, Uniform appearance with depth