Field Application Results of an Innovative, Low-Tech Instrument for Field Screening of Radioactivity in Soil Samples - 9197

W. Roger Vinson
Restoration Services, Inc

Kenneth M. Skinner
Mid-Atlantic Technology, Research and Innovation Center

Peter A. Salpas
Salpas Consulting

ABSTRACT

The Model T is a simple, low-tech, lead-shielded instrument constructed of off-the-shelf materials and equipment and designed for screening radioactivity along the lengths of 2-inch diameter soil cores in the field. Laboratory and field tests conducted in 2005 demonstrated the Model T's linear response to soils with between 1 and 94 pCi/g of U-238. Based on these tests, Model T screening results have been accepted in lieu of laboratory analyses as demonstrating that radionuclide concentrations in soils at the East Tennessee Technology Park (ETTP) in Oak Ridge, Tennessee are less than their promulgated remediation levels (RLs). Since 2005, the Model T has been deployed in the field in support of the Dynamic Verification Strategy (DVS) soils characterization program in Zone 1 at ETTP. This paper reports on Model T screening results for 505 soil cores and demonstrates that with the application of systematically-derived action levels (ALs), the Model T was able to effectively differentiate between soils with radionuclide concentrations less than RLs and those with concentrations greater than RLs.

Based on Model T screening results, no samples were collected from 329 of the 505 soil cores. A total of 230 samples were collected for laboratory radionuclide analyses from the remaining 176 cores based on Model T screening results, project-specific data needs, and a quality control requirement for random sampling of 20% of the cores regardless of Model T screening results. One hundred fifty samples with Model T screening results less than the AL were analyzed for radionuclides. Analytical results showed that no radionuclide exceeded its RL concentration.

INTRODUCTION

The Model T-100 Core Screening Device, and subsequent Models T-125 and T-150 (all generally referred to as the Model T), is a simple, compact, low-tech instrument designed as a shield against ambient radiation so that 2 inch diameter by 10 feet long soil cores can be screened for radioactivity in the field. Core screening with the Model T is conducted continuously along the length of the core using an off-the-shelf field instrument for detection of low energy radiation (FIDLER). As reported in (1), laboratory and field tests showed that the Model T effectively reduces the influence of background radiation by over 90 per cent.

This paper is the initial report on the performance of the Model T in its application during a soils characterization program in Zone 1 at the East Tennessee Technology Park (ETTP) in Oak Ridge, Tennessee. The Model T's function being evaluated here is whether it can effectively discriminate between soils with radionuclide concentrations less than the remediation levels (RLs) specified in the

Zone 1 Record of Decision (ROD) (2). The importance of this evaluation lies in the fact that Model T screening results that are less than systematically-derived action levels (ALs) are accepted in lieu of laboratory radiological analyses as demonstrating that the concentrations of the primary radiological contaminants in ETTP soils are less than their respective RLs. In addition, Model T core screening results and associated analytical data evaluated in this paper demonstrate the utility of the Model T in being able to determine the depth interval(s) of possible radionuclide contamination.

BACKGROUND

During development of the Dynamic Verification Strategy (DVS) for soils and sediments in Zone 1 at the East Tennessee Technology Park in Oak Ridge, Tennessee (3) it was agreed that radiological screening of soil cores would be accepted in lieu of laboratory analyses as demonstrating that soil radionuclide concentrations are less than RLs specified in the Zone 1 ROD (2). The first attempts at radiological screening of cores in the field, conducted during the Blair Quarry Pilot Project (4) using an unshielded sodium-iodide (NaI) detector, proved unsuccessful owing to the overwhelming influence of background radiation. Several commercial shielded core scanners were evaluated but were rejected based on large capital outlays and perceived problems with mobility. In response to the need for a cost-effective, mobile core screening device, the Model T was constructed by project personnel using off-the-shelf materials and equipment.

The Model T derives its name from its configuration. It is constructed from 10.2 cm (4 inches) diameter Schedule 80 “T” steel pipe approximately 45.7 cm (18 inches) along the length of the “T’s” cross bar and 30.5 cm (12 inches) along the length of the “T’s” leg. 7.6 cm (3 inches), lead-wrapped copper pipe is inserted inside the cross bar and leg of the “T”; the thickness of the lead is approximately 1.3 cm (one-half inch). A 6.4 cm (2.5 inches) diameter hole is cut into the lead-lined PVC pipe inserted in the cross bar of the “T” so that the leg and cross bar of the “T” are unobstructed. Two-inch soil cores are fed through the T’s cross bar at the bottom of the system and the radiation detector is mounted in the upright leg of the T so that the protective covering of the detector is 2 mm from the core when the core is fed through the Model T. The whole system is enclosed in a reinforced wooden box that measures approximately 0.3 m (1 ft) on a side. The weight of the system varies by model number from 45 kg (100 pounds) to 68 kg (150 pounds) (thus, Model T-100, Model T-125, and Model T-150). The size and weight of the Model T make it easily transportable by two people and a hand truck.

MODEL T TEST RESULTS SUMMARY

Prior to deployment, it was necessary to demonstrate to the decision makers that the Model T was capable of discerning radionuclide concentrations in excess of their RLs in 2-inch soil cores. For this purpose, three tests were conducted:

1. Background radiation reduction test,
2. Laboratory test, and
3. Field test.

Details of the tests and their results are presented in (1) and are summarized here.

Background Radiation Reduction Test

To quantify the effectiveness of the Model T in reducing the influence of background radiation on the measurement of radiation in soil cores, 10 30-second counts were taken of unshielded ambient radiation using a 2-inch by 2 mm thick FIDLER and a 2-inch by 2-inch NaI detector. The mean unshielded count rate for the FIDLER was 677 counts per minute (cpm) and the mean unshielded count rate for the 2-inch by 2-inch NaI detector was 3368 cpm. Each detector was then placed in the Model T and 10 30-second counts were taken of the shielded ambient radiation and the means were calculated. The resulting mean count rates were 49 cpm for the FIDLER and 380 cpm for the 2-inch by 2-inch NaI detector, a reduction of approximately 90% for both detectors.

Laboratory Test

Seven natural soil samples from an unimpacted area of ETTP with a mean U-238 concentration of 1 pCi/g were spiked with uranium solutions having varying U-238 concentrations ranging from 0 to 93 pCi/g. U-238 was selected for the test because it is the primary radionuclide contaminant at ETTP with a RL of 50 pCi/g. Radiation measurements were made of the seven samples in a laboratory controlled environment using the FIDLER as the radiation detector. The FIDLER was selected over the 2-inch by 2-inch NaI detector because of the lower absolute shielded background count rate and because the FIDLER is sensitive to the secondary and tertiary X-rays generated by the decay of U-238 and its progeny. Tests results showed that the Model T responded linearly to increasing concentrations of U-238. In particular, the laboratory test demonstrated that the Model T made it possible to differentiate soil samples with 40 pCi/g U-238 (i.e., 80% of the U-238 RL) from those with higher concentrations of U-238.

Field Test

The field test of the Model T essentially mimicked the laboratory test except that it was conducted in the field. Radiation measurements of splits from the seven samples used for the laboratory test were made in the field under conditions similar to what was expected for full scale field deployment of the Model T. Field test results also showed a linear response of the Model T to increasing concentrations of U-238. Comparison of the co-variance of the field data to the laboratory data showed that the two data sets vary linearly and are equivalent data sets.

MODEL T FIELD DEPLOYMENT

Soil cores were fed manually through the Model T at a fixed rate of 0.5 m (1.6 ft) per minute. A computer program was written and linked to the FIDLER so that radiation measurements were taken and recorded electronically every 2 seconds. The computer program also converted the elapsed time at which each radiation measurement was taken to the length along the soil core which is equivalent to depth below ground surface (bgs).

Each day that the Model T was used a radiation background was determined by measuring the count rate of a soil core collected from an unimpacted area at ETTP. An action level (AL) for that day was determined by adding 65 cpm to the daily background value. The 65 cpm was empirically determined to be the approximate count rate corresponding 40 pCi/g of U-238 (1). The AL was used during Model T deployment to determine which soil cores required laboratory analysis for radionuclides and which did not. If the AL was exceeded during the initial feed of the core through the Model T, the core was manually inserted back into the Model T and a 1 minute radiation measurement was made at the location of the AL exceedance along the core. If the AL was exceeded during the 1 minute radiation measurement, that segment of the core with the AL exceedance was selected for laboratory radionuclide analysis. If the AL was not exceeded during the initial feed of the core through the Model T, laboratory radionuclide analysis was not required for the core. As a quality control (QC) measure, 20 per cent of the planned sample locations were randomly selected during characterization planning and designated for sampling and laboratory radionuclide analysis.

MODEL T FIELD DEPLOYMENT PERFORMANCE

Here we discuss the performance of the Model T during its field deployment in Zone 1 at ETTP. Table 1 summarizes the data set being addressed in terms of number of Model T core screens conducted and the radionuclide sampling and analysis performed.

Table 1. Model T core screening and sampling summary

Number of sample locations with Model T core screens	Number of sample locations with Model T core screens resulting in no radionuclide analyses	Number of sample locations that were sampled for radionuclide analyses	Number of samples collected for radionuclide analyses
505	329	176	230

Table 1 shows that no samples were collected at 329 of 505 locations based on Model T screening results. Samples were collected from 176 locations based on Model T screening results, QC requirements, or other project-specific requirements and 230 samples were collected for radionuclide analyses from the 176 locations. In fact, 33 sample locations with radionuclide analyses were sampled either 2 or 3 times at discrete positions along their cores. Multiple samples from a given core generally resulted from multiple AL exceedances. Because position along a core corresponds to depth bgs, these locations with multiple samples highlight the enhanced resolution provided by the Model T for determining depths of possible radionuclide contamination.

Table 2 presents a breakdown of the number of samples with Model T screening results less than the AL and Model T screening results equal to or greater than the AL for the 230 samples that were analyzed for radionuclides.

Table 2. Breakdown of Model T screening results relative to the action level (AL) for the 230 samples with radionuclide analyses

Number of samples with Model T screening results less than the AL	Number of samples with Model T screening results equal to or greater than the AL
150	80

The 150 samples with Model T screening results less than the AL were analyzed for radionuclides either because of the QC requirement for radionuclide sampling and analysis at 20 percent of the planned sample locations or because of other project-specific requirements. Model T and analytical results for these samples provide the data necessary for evaluating whether the Model T was successful in meeting its primary objective of identifying soils with radionuclide concentrations less than RLs. U-238 was selected for field and laboratory testing of the Model T (summarized above) because it is the primary radionuclide contaminant at ETTP. However, the Zone 1 ROD lists six other radionuclides with RLs and it is important to document whether the Model T was successful in screening these radionuclides as well as U-238. Table 3 presents a summary of the Model T screening results and analytical data for all seven radionuclides with Zone 1 RLs in the 150 samples with Model T screening results less than the AL. The Model T results are summarized in Table 3 with the AL Ratio. The AL Ratio is the Model T screening result for the sample divided by the AL. Thus, all AL Ratios in Table 3 are less than 1 because the Model T screening results for the 150 samples being evaluated are all less than the AL. Full reports of the analytical data for the seven radionuclides in Table 3 are presented in (5) and (6).

Table 3. Summary of AL Ratios and analytical data for the seven radionuclides with Zone 1 RLs in the 150 samples with Model T screening results less than the AL

AL Ratio[a] range (unitless)	Cs-137 range (pCi/g)	Np-237 range (pCi/g)	Ra-226 range (pCi/g)	Th-232 range (pCi/g)	U-234 range (pCi/g)	U-235 range (pCi/g)	U-238 range (pCi/g)
	RL = 2	RL = 5	RL = 5	RL = 5	RL = 700	RL = 8	RL = 50
0.49-0.99	0.22-0.89	0.04-0.15	0.24-4.44	0.40-3.27	0.57-30.4	0.04-2.97	0.71-26.7

[a]The AL Ratio is the Model T screening result divided by the AL.

As demonstrated by the information in Table 3, none of the seven Zone 1 radionuclide RLs were exceeded in the 150 samples with Model T screening results less than the AL. However, the maximum Ra-226 concentration (4.44 pCi/g) is almost 90% of the Ra-226 RL (5 pCi/g). The maximum Ra-226 concentration occurs in the same sample as the maximum Th-232 concentration and the AL Ratio for this sample is 0.95. Ra-226 and Th-232, in general, are problematic when evaluated against their RLs because their background concentrations are significant percentages of their RL concentrations (Ra-226 background concentration = 1.25 pCi/g; Th-232 background concentration = 1.95 pCi/g). The problems posed by these relatively high background values was ultimately addressed in the ETTP Zone 2 ROD (7) which says that risk from Ra-226, Th-230, and Th-232 will be evaluated by calculating Ra/Th decay series concentrations and comparing those concentrations to a RL equal to 5 pCi/g. The details of the calculation are presented in (7) but part of the calculation involves subtracting the background concentration of each radionuclide from the analytical results. Although the Zone 1 ROD does not provide for subtraction of background concentrations when evaluating analytical results against RLs, it can be argued that the ETTP input to the maximum concentration Ra-226 concentration is substantially less than the RL. Nevertheless, the analytical results for Ra-226 in the samples with Model T screening results less than the AL raise concerns about the sensitivity of the Model T in discerning Ra-226 at its RL concentration. These concerns are explored more fully below when samples with Model T screening results equal to or greater than the AL are addressed.

Table 4 summarizes the number of samples with Zone 1 radionuclide RL exceedances in the 80 samples with Model T screening results equal to or greater than the AL. Six of the seven radionuclides with RLs had RL exceedances; Np-237 did not exceed its RL in any of the samples.

Table 4. Summary of the number of samples with radionuclide RL exceedances in the 80 samples with Model T screening results equal to or greater than the AL

	Cs-137	Ra-226	Th-232	U-234	U-235	U-238
Number of RL exceedances	4	4	4	4	13	26

Overall, there were radionuclide RL exceedances in 34 of the 80 samples that were collected in response to Model T screening AL exceedances, approximately 43%. The greatest number of RL exceedances is for U-238 (Table 4), consistent with U-238 being the primary radionuclide of concern at ETTP. All of the

U-234 and U-235, one of the Cs-137, none of the Ra-226, and three of the Th-232 RL exceedances occur in samples with U-238 RL exceedances. Furthermore, the Cs-137, Ra-226, and Th-232 RL exceedances that did not occur in the samples with U-238 RL exceedances occurred in eight different samples.

One of the benefits of using the Model T for core screening is the enhanced resolution it provides in being able to discern discrete zones of radionuclide contamination in the subsurface. Multiple samples were collected from discrete sections of soil cores at 11 sample locations because of Model T screening AL exceedances. Nine samples from four different sample locations had radionuclide RL exceedances. Five samples from two sample locations had U isotope RL exceedances and one of these samples also had a Th-232 RL exceedance, two samples from one location had Cs-137 RL exceedances, and two samples from one location had Th-232 RL exceedances and one of these samples also had U isotope RL exceedances.

It was noted above that, although there were no RL exceedances in the samples with Model T screening results less than the AL, the maximum Ra-226 concentration in these samples was approximately 90% of the Ra-226 RL which is close enough to the RL to raise concerns regarding the Model T's sensitivity to Ra-226. The data for the samples with Model T screening results equal to or greater than the AL shed some light on these concerns. Among these samples there are four Ra-226 RL exceedances ranging in concentration from 5.19 to 6.5 pCi/g with associated AL ratios ranging from 1.1 to 2.3. All of the Ra-226 RL exceedances occur in samples with no other RL exceedances; therefore, it can be concluded that the elevated Ra-226 concentrations were, at a minimum, significant contributors to the Model T screening AL exceedances. In particular, the Model T was sensitive to the minimum Ra-226 RL exceedance which is only 4% greater than the its 5 pCi/g RL.

CONCLUSION

The Model T Core Screening Device has been proven to be capable of identifying soils with radionuclide concentrations less than their ETTP Zone 1 RLs. Analytical results for 150 samples whose Model T screening results were less than the AL showed that no sample had radionuclide concentrations greater than their RLs. The Ra-226 concentration in one of these samples was 90% of the RL concentration but its Model T screening result was 95% of the AL and analytical results for samples with Model T screening results equal to or greater than the AL showed that the Model T was sensitive enough to identify a sample with Ra-226 at a concentration only 4% above the RL.

Field deployment has demonstrated that the Model T is an effective tool for identifying discrete zones of possible radionuclide contamination in subsurface soils. The enhanced understanding of the subsurface distribution of radionuclides provided by the Model T may prove to be a benefit for remedial action planning. Once radiological contamination has been identified, use of the Model T can provide the depth boundary of elevated radioactivity thereby obviating the need for additional sampling and analysis.

Field deployment of the Model T has also shed some light on the nature of radionuclide contamination at ETTP. Based on the analytical results from 80 samples with Model T screening results greater than the AL and associated RL exceedances, it is concluded that the uranium isotopes are co-contaminants. No other radionuclides with Zone 1 RLs are co-contaminants with either uranium or the other radionuclides with RLs.

REFERENCES

1. McDaniel, D., R. Vinson, K. Skinner, P. Salpas, and W. Bostic (2005) *An Innovative, Low-Tech Approach To Radiological Screening of ETTP Soils*, Proceedings of Waste Management 2005, Tucson, Arizona.

2. *Record of Decision for Interim Remedial Actions for Selected Contaminated Areas within Zone 1, East Tennessee Technology Park, Oak Ridge, Tennessee* (DOE/OR/01-1997&D2) U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.

3. *ETTP Dynamic Verification Strategy and Standard Operating Procedure* (DOE/OR/01-2063&D1) U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.

4. *Blair Quarry Project Technical Memorandum, East Tennessee Technology Park, Oak Ridge, Tennessee - Volume 1,Main Text - and Volume 2, Appendices A-G, December, 2004* (DOE/OR/01-2181&D1) U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.

5. *Phased Construction Completion Report for the Duct Island Area and K-901 Area in Zone 1, East Tennessee Technology Park, Oak Ridge, Tennessee* (DOE/OR/01-2261&D2) U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.

6. *Phased Construction Completion Report for the K-1007 Ponds Area and the Powerhouse North Area in Zone 1 at East Tennessee Technology Park, Oak Ridge, Tennessee* (DOE/OR/01-2294&D2) U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.

7. *Record of Decision for Soil, Buried Waste, and Subsurface Structure Actions in Zone 2, East Tennessee Technology Park, Oak Ridge, Tennessee* (DOE/OR/01-2161&D2) U.S. Department of Energy, Office of Environmental Management, Oak Ridge, TN.