# AN INNOVATIVE, LOW-TECH APPROACH TO RADIOLOGICAL SCREENING OF ETTP SOILS

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## ABSTRACT

The Model T-100 System developed by PrSM provides an innovative, low-tech, low-cost system that can effectively reduce ambient background field radiation sufficiently so that field radiation detection instruments can distinguish between background soil radiation and soil with uranium contamination at 80 percent of the site remediation level (RL). Three tests were conducted to quantify the unit's ability; 1) background reduction test, 2) laboratory test, and 3) field test. The tests confirmed that the Model T-100 does have sufficient sensitivity to reliably detect soil samples with greater than 80 percent of the 50 pCi/g RL for U-238. Being able to reliably screen soil cores in the field for U-238 has the potential to decrease the amount of off site laboratory analysis by one half leading to a potential cost savings up to $1 million for the currently scoped program.

## INTRODUCTION

This paper presents an analysis by PrSM Corporation (PrSM) of field screening systems for detecting radionuclides in soils at East Tennessee Technology Park (ETTP). Four commercial systems for screening radionuclides in soil sample core were evaluated. One of these systems was selected for further testing and the test results are presented along with conclusions about the system's ability to detect radionuclides at threshold criteria.

## BACKGROUND

In the fall of 2003 Bechtel Jacobs Company LLC (BJC) was awarded the contract for accelerated closure of certain sites on the Department of Energy (DOE) Oak Ridge Reservation (ORR). Included among those sites is the ETTP which is slated for closure by the end of fiscal year 2008. In order to better manage accelerated closure at ETTP, the site has been subdivided into two major zones: Zone 1 consists of approximately 1400 acres of relatively unindustrialized land that surrounds the legacy facilities of ETTP; Zone 2 consists of the approximately 880 acres of industrialized land at ETTP and includes the bulk of the legacy facilities.

The "Record of Decision for Interim Remedial Actions for Selected Contaminated Areas within Zone 1, East Tennessee Technology Park, Oak Ridge, Tennessee" (Zone 1 ROD) (1.) was signed in 2002. The Zone 1 ROD specifies actions to be taken at certain locations in Zone 1 but, for most of Zone 1, the Zone 1 ROD determined that insufficient data are available for decision making. In response to the lack of data, the Zone 1 ROD specifies that a statistically-based soil characterization strategy would be developed to acquire additional data to fill identified data gaps. As a result, the "ETTP Dynamic Verification Strategy and Standard Operating Procedure" (DVS) (2.) was developed in 2003. The DVS presents a broadly encompassing strategy for addressing ETTP soils including guidelines for characterization and the criteria for making the no further action (NFA) determination on parcels of land.

The first practical test of the DVS, the Blair Quarry Pilot Project, was conducted beginning in autumn 2003 and lasting through spring 2004. Under its contract to BJC, PrSM was tasked with conducting field screening of soils for the presence of radionuclides in concentrations above pre-set action levels. Screening action levels were based on the remediation levels (RLs) for radionuclide contaminants of concern (COCs) specified in the Zone 1 ROD. A conclusion drawn from the Blair Quarry Pilot Project was that a cost effective, portable, and shielded detector system is needed for screening soil cores collected during subsequent characterization activities. To meet this end, this document describes the results of laboratory and field testing of the Model T-100 Shield and Ludlum 2221 with 44-17 (2-inch FIDLER) and 44-10 (2-inch by 2-inch NaI) detectors.

## EVALUATION OF THE MODEL T-100 SHIELD

The Model T-100 Shield was developed by PrSM to reduce background radiation during screening of soil cores. The Model T-100 Shield underwent two tests to demonstrate its ability to reduce background radiation sufficiently so that one or both radiation detectors (2-inch FIDLER and 2-inch by 2-inch NaI) could determine if radionuclide COC concentrations exceed RLs.

To test the ability of the Model T-100 Shield to reduce background, 10 separate 30-second counts were taken of the unshielded, ambient outdoor background radiation with each of the detectors (2-inch FIDLER and 2-inch by 2-inch NaI). The mean of the unshielded background counts for the 2-inch FIDLER was 677 counts per minute (cpm) and for the 2-inch by 2-inch NaI it was 3368 cpm. Each detector was then placed in the Model T-100 Shield and 10 30-second counts were taken of the shielded background. The mean of the shielded background counts for the 2-inch FIDLER was 49 cpm, a reduction in background counts by a factor of almost 14. The mean of the shielded background counts for the 2-inch by 2-inch NaI detector was 380 cpm, a reduction in background counts by a factor of almost 9. The results of the background reduction test are presented graphically in Figure 1.

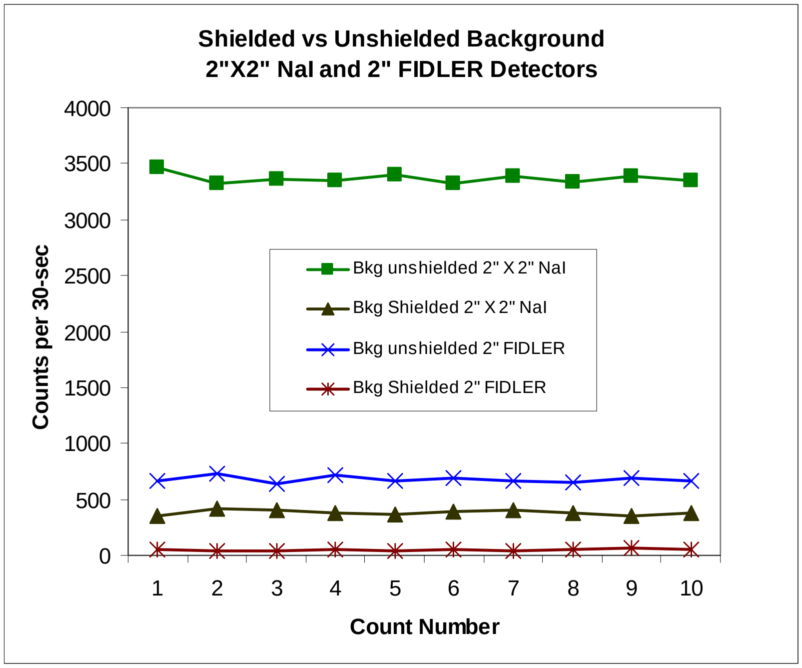


**Fig. 1. Results of the Model T-100 Shield background reduction test.**

It was concluded from the first test that the Model T-100 Shield could significantly reduce background radiation and that further testing was warranted to determine if the field radiation detectors, when combined with the Model T-100 Shield, are sufficiently sensitive to detect radionuclide COCs at concentrations below the RLs.

The sensitivity of the Model T-100 Shield with FIDLER to uranium in soil was tested during controlled laboratory and field experiments. The objective of the tests was to determine the range of shielded FIDLER instrument responses to varying concentrations of uranium in ETTP soils. Uranium was selected for the laboratory and field tests because U-238 is the primary radionuclide of concern among the ETTP soils COCs that were identified in the Zone 1 ROD. When implemented as a field instrument, the goal of the Model T-100 System (i.e., the combined FIDLER and Model T-100 Shield) is to be able to detect U-238 at 80% of its RL. The RL for U-238 is 50 pCi/g, thus the goal is to be able to detect U-238 at 40 pCi/g.

The 2-inch FIDLER was selected as the field radiation detector for the sensitivity test. Several types of radiation surveys conducted during the Blair Quarry Pilot Project showed that the FIDLER provided better response to the low levels of radionuclides in ETTP soils than the 2-inch by 2-inch NaI detector. FIDLER response is comprised of the X-ray energy region of the photon continuum. Nearly every nuclear transition includes an X-ray emission. In addition, when beta and alpha emissions interact with the matrix material (soil in this case), secondary and tertiary photons are generated, many within the FIDLER’s range of detection. In contrast, The 2-inch by 2-inch NaI detector is sensitive mainly to higher energy gamma photons that accompany radioactive decay. Consequently, the 2-inch by 2-inch NaI detector will not “see” a disintegration if it does not emit a high energy gamma photon. As an example, U-238 decays by alpha decay with concomitant emission of a low energy gamma photon to which the 2-inch by 2-inch NaI detector is not sensitive. The presence of U-238 in a soil sample can only be inferred when using the 2-inch by 2-inch NaI detector by detecting the higher energy gamma photons emitted during decay of some U-238 progeny nuclides (primarily Th-234). However, the FIDLER is sensitive to the secondary and tertiary X-rays generated by decay of U-238 and all of its progeny and is therefore more sensitive to the decay of this important radionuclide.

To prepare for the test, uranium certified reference materials (CRMs) were obtained. The CRMs are fully described in Appendix A. Four CRM samples with varying U-238 were used in the laboratory for initial verification of the Model T-100 System's response characteristics. Then a liquid solution of known U-238 was made in the laboratory from a CRM to create six spiked soil samples of known U-238 using soil collected from an existing ETTP project site. The six spiked soil samples were split; one split of each sample was used to evaluate the Model T-100 System in the laboratory and the other split of each sample was used to evaluate the Model T-100 System in the field.

Following is a summary of the results of the Model T-100 System laboratory sensitivity tests. Laboratory tests were conducted at the Materials and Chemistry Laboratory Inc. (MCL) facilities located at ETTP.

An initial laboratory test of the sensitivity of the Model T-100 System was conducted to determine the type of response the system displayed to varying uranium concentrations in a CRM. The CRM uranium concentrations and the systems responses are presented in Table I.

**Table I. Model T-100 System Response to Varying Concentrations of Uranium in Certified Reference Material**

| | **Total $U_{nat}$ (mg/kg)** | **Estimated $U_{nat}$ activity (pCi/g)[1]** | **Estimated U-238 activity (pCi/g)[2]** | **Instrument response (counts per 30 sec)[3]** |
|---|---|---|---|---|
| Background (unshielded) | 0 | NA | NA | 233 ± 6.1 |
| Background (shielded) | 0 | NA | NA | 29.3 ± 7.6 |
| NBL CRM 101-A (shielded) | 10,070 | 6850 | 3334 | 7098 ± 58 |
| NBL CRM 102-A (shielded) | 1025 | 697 | 339 | 726.3 ± 9.9 |
| NBL CRM 103-A (shielded) | 499.2 | 339 | 165 | 433.0 ± 13 |
| NBL CRM 104-A (shielded) | 98.87 | 67.2 | 33 | 116.3 ± 16 |

[1]Calculated using a specific activity of 0.68 pCi/g – U.
[2]Natural U implies that the U-238 activity is 48.67% of the total U activity (DOE Standard 1136)
[3]Reported results (mean ± 1 SD) for n=3 replicate measurements (each at 0.5-min accumulation interval).

The initial laboratory test of the Model T-100 System showed that the system responded linearly to varying uranium concentrations in CRM.

The next laboratory test was conducted to determine the sensitivity of the Model T-100 System to ETTP soil samples spiked with a range of precisely known uranium concentrations that encompassed 40 pCi/g. To do this, a uranyl nitrate solution was prepared from the CRM and added to a sample of uncontaminated ETTP soil obtained from Blair Quarry. The uranium content of the un-spiked soil was determined to be 4.21 pCi/g by gamma spectroscopy. Aliquots of the spiking solution were added to the soil to create six different samples with the uranium concentrations presented in Table II.

**Table II. Computed Uranium Concentrations Added to Spiked Soil Samples**

| Sample | 1055-11 | 1055-20-7 | 1055-18-3 | 1055-19-4 | 1055-19-5 | 1055-20-6 |
|---|---|---|---|---|---|---|
| U-238 (pCi/g) | 48.13 | 93.40 | 9.24 | 18.79 | 31.40 | 37.48 |
| $U_{nat}$ (total), pCi/g | 98.88 | 191.89 | 18.99 | 38.61 | 64.52 | 77.01 |

The total uranium concentration of each sample was verified by a total activity screen (alpha + beta) performed by liquid scintillation counting of a dissolved aliquot of each sample (Table III). The computed added uranium concentration correlated well ($r^2 > 0.98$) with the liquid scintillation results. An aliquot of un-spiked soil was also analyzed for total activity by liquid scintillation. The liquid scintillation result (13.5 pCi/g total activity) was higher than that previously determined for uranium by gamma spectroscopy (4.3 pCi/g uranium). The uranium data for an un-spiked soil sample (0 pCi/g added) was included in the comparison to the total activity screen (13.5 pCi/g total activity) and is included in the correlation coefficient of the two data sets.

**Table III. Total Activity Screening Results for Spiked Soil Samples**

| Sample | Total $U_{nat}$ added (pCi/g) | Total activity screen results (pCi/g) | |
|---|---|---|---|
| | | Result | Uncertainty[1] |
| 04-0832 | 0.00 | 13.5 | 3 |
| 1055-18-3 | 18.99 | 26 | 3.5 |
| 1055-19-4 | 38.61 | 46 | 4.5 |
| 1055-20-6 | 64.52 | 67 | 5 |
| 1055-20-6 | 77.01 | 82 | 6 |
| 1055-20-6 (duplicate) | 77.01 | 70.5 | 5 |
| 1055-11 | 98.88 | 96.5 | 6.5 |
| 1055-11 (duplicate) | 98.88 | 110.5 | 7 |
| 1055-20-7 | 191.89 | 179 | 9 |

[1]Uncertainty is estimated as two standard deviations of the computed results for the counting data (i.e., 95% confidence interval).

Aliquots of spiked soil preparations (described in Table III) were packed into plastic soil core sampling sleeve sections (~ 15.2-cm length by 4.24-cm internal diameter). Packed soil was sandwiched between ~ 2.4-cm Styrofoam disc sections, giving a central packed soil zone length ~ 10.7-cm (compare to a Model T-100 System detector tube diameter ~ 6.7-cm). End caps were glued onto the assembled tube using PVC cement. In this manner, moisture within the soil cannot escape. Soil within the active measurement zone was tamp packed to an average density of (1.25 $\pm$ 0.04) g/cm$^3$. Two series of packed soil columns (A and B) were prepared for each of the spiked soil compositions; Series A columns were used for the Model T-100 System laboratory tests, Series B columns were also used for testing the Model T-100 System in the laboratory then were transmitted to PrSM personnel for field testing.

On June 28, 2004, PrSM staff brought the Model T-100 System to MCL for evaluation versus the prepared uranium activity reference specimens. The Model T-100 System was modified to have more shielding than in the unit previously used for the initial measurements. Data are presented in Table IV and depicted graphically on Figure 2.

**Table IV. Model T-100 System Laboratory Response to Soil Column Reference Specimens**

| Sample | $U_{nat}$ (total) added pCi/g[1] | U-238 added pCi/g | System response (mean cpm)[2] | | |
|---|---|---|---|---|---|
| | | | Series A | Series B | Median |
| No sample | 0 | 0 | | | 47.5 (± 5.5) |
| 1055-24-1 | 0 | 0 | 82.67 (± 9.1) | 85.33 (± 14.6) | 84.00 (± 17.2) |
| 1055-24-3 | 18.99 | 9.24 | 110.67 (± 9.4) | 115.00 (± 12.1) | 112.83 (± 15.4) |
| 1055-19-4 | 38.61 | 18.79 | 127.67 (± 14.6) | 129.67 (± 15.6) | 128.67 (± 21.4) |
| 1055-19-5 | 64.52 | 31.4 | 151.67 (± 11.9 ) | 148.33 (± 10.1) | 150.00 (± 15.6) |
| 1055-20-6 | 77.01 | 37.48 | 172.00 (± 17.1) | 163.67 (± 2.5) | 167.83 (± 17.2) |
| 1055-11 | 98.88 | 48.13 | 162.67 (± 11.0) | 191.00 (± 7.0) | 176.83 (± 13.0) |
| 1055-20-7 | 191.89 | 93.4 | 251.33 (± 2.5) | 256.67 (± 11.7) | 254.00 (± 11.9) |

[1]See Table III.
[2]Tabulated response is mean and one standard deviation for three (3) 1-min readings, all made at a single position along the column.

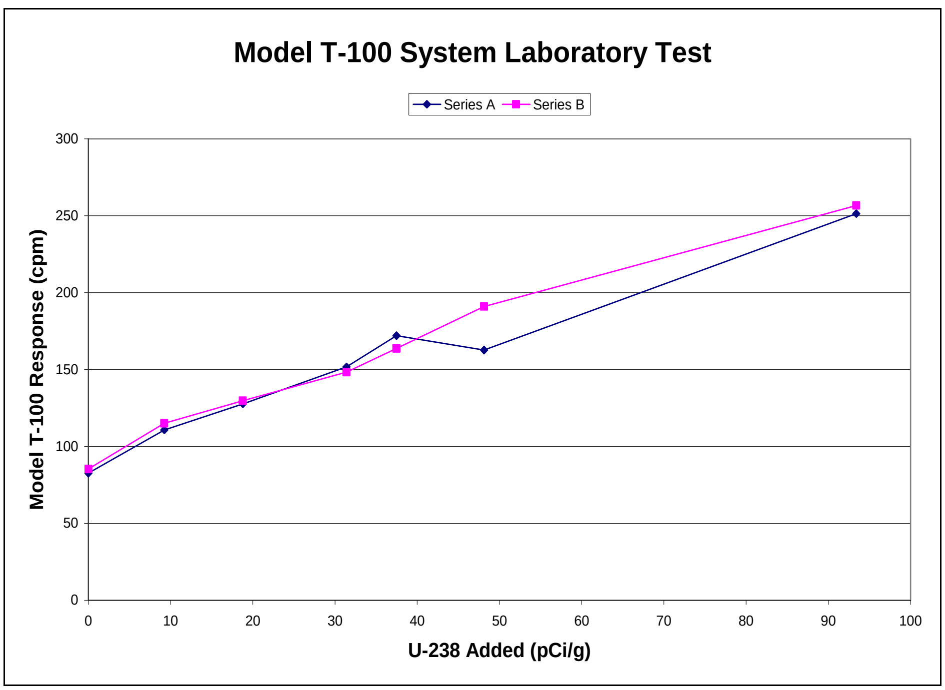


**Fig. 2. Model T-100 System laboratory response to reference soil columns.**

See Table IV for raw data. Regression analysis for combined data (Series A and B):

$$y = 1.7118x + 93.552;\ R^2 = 0.9765. \quad \text{(Eq.1)}$$

Figure 2 shows that the nonspecific Model T-100 System response correlates well with the added uranium activity for the reference soil specimens. Both total activity screening results (Table III) and the Model T-100 System responses (Table IV) are strongly correlated with the total uranium activity added to the soil, it is to be expected that total activity screening results and Model T-100 System responses would also correlate with one another.

The Model T-100 System was tested on the Series B reference soil specimens at K-1070-F on June 28, 2004. Three field tests were conducted. The first field test was conducted to generate data for comparison to the laboratory data for the Model T-100 System response to the Series B soil column reference specimens. The second field test was conducted to test the uranium distribution homogeneity in the Series B soil column reference specimens. The third test was conducted to determine if longer count times enhanced the sensitivity of the Model T-100 System to the 40 pCi/g of U-238 threshold.

For comparison to laboratory results, soil column reference specimens were inserted into the Model T-100 System with no preferred orientation and three 1-minute counts were conducted on each sample in the field. The means of the three counts for each sample are presented in Table V; the data from Table V are depicted graphically on Figure 3.

**Table V. Model T-100 System Field Response to Series B Soil Column Reference Specimens. – 1 Minute Counts With Random Column Orientation**

| Sample | U (total) added, pCi/g | U-238 added pCi/g | Mean 1-minute counts (cpm) | Range (cpm) |
|---|---|---|---|---|
| No sample | 0 | 0 | 72 | 67 – 74 |
| 1055-24-1 | 0 | 0 | 97 | 83 – 107 |
| 1055-24-3 | 18.99 | 9.24 | 133 | 123 – 150 |
| 1055-19-4 | 38.61 | 18.79 | 130 | 123 – 141 |
| 1055-19-5 | 64.52 | 31.4 | 168 | 164 – 172 |
| 1055-20-6 | 77.01 | 37.48 | 159 | 147 – 178 |
| 1055-11 | 98.88 | 48.13 | 189 | 184 – 197 |
| 1055-20-7 | 191.89 | 93.4 | 240 | 237 - 243 |

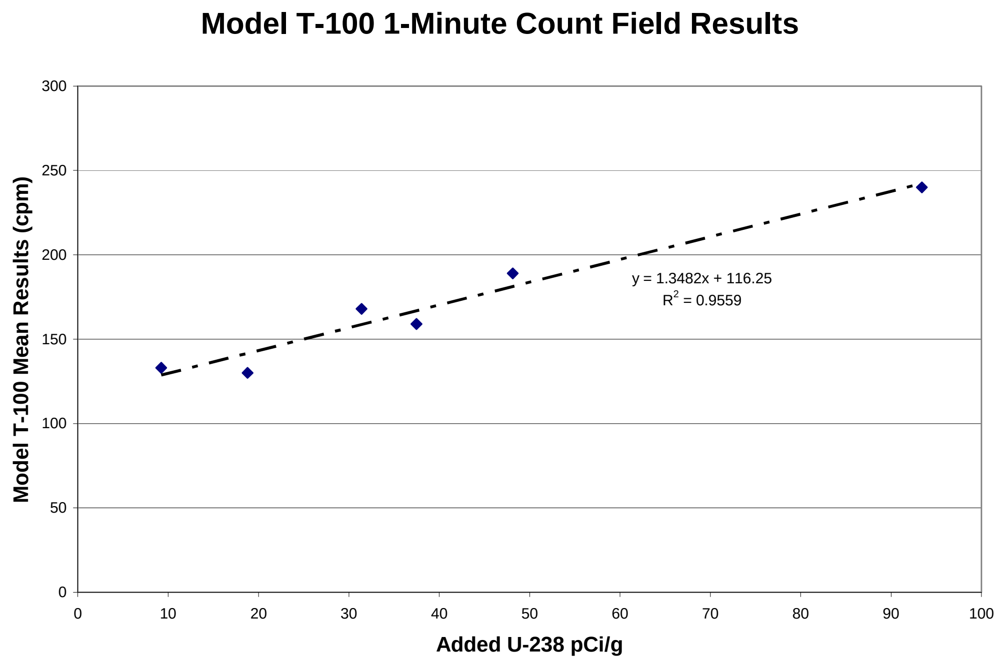


**Fig. 3. Model T-100 System field response to Series B reference soil columns.**[a]

Figure 3 shows that the mean values of the three 1-minute counts of the soil column reference specimens vary linearly with the concentration of uranium added to the spiked sample. However, the value for the counts of Series B sample 1055-19-4 (38.61 pCi/g added $U_{nat}$) was 3 cpm less than that for Series B sample 1055-24-3 (18.99 pCi/g added $U_{nat}$) (Table V). This result is in contrast to the Series A sample results (Table IV) which showed that the median value for 1055-19-4 was ~16 cpm greater than that for 1055-24-3. This apparently anomalous result of the field test was investigated during the subsequent two field tests of the Model T-100 System.

Figure 4 presents a comparison of the co-variance of field data (Table V) to laboratory data (Table IV) for the Series B soil column reference specimens. This chart demonstrates that the two data sets vary linearly and are equivalent data sets. For both data sets, the Model T-100 System response to the reference soil specimens is approximately 1.5 counts per pCi/g of U-238. The clean soil response is in the 95 to 100 cpm range.

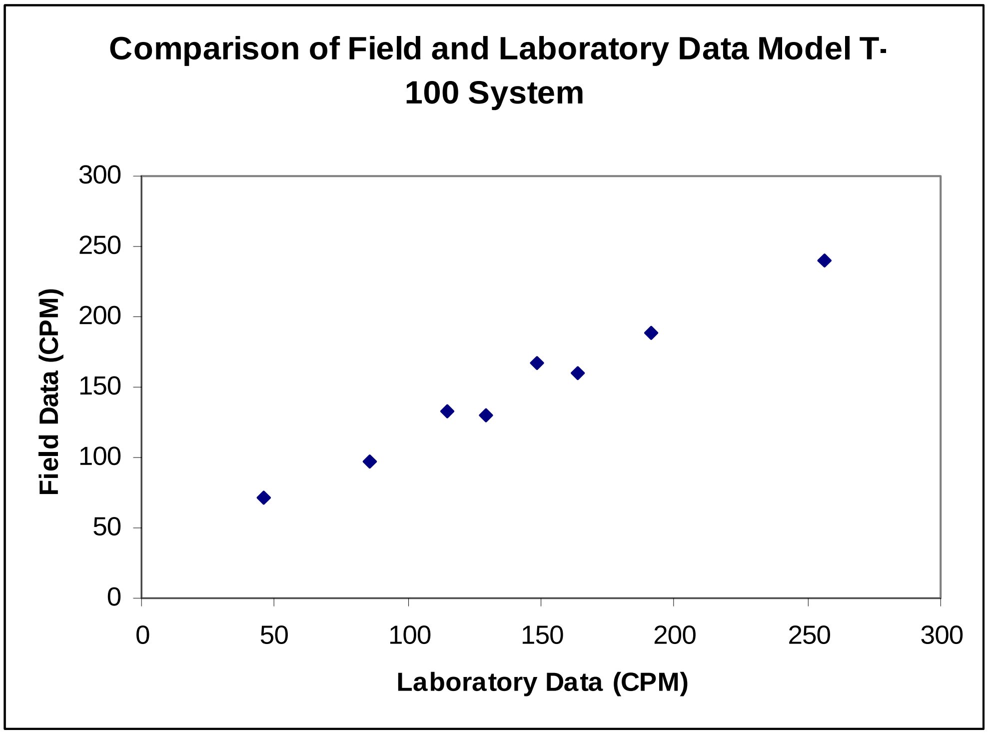


**Fig. 4. Comparison of the Model T-100 System laboratory and field results.[b]**

Uranium distribution in the Series B soil column reference specimens was also tested in the field. An important issue for this test was the observation made during the first field test that sample 1055-19-4 had a lower count rate than sample 1055-24-3 even though the concentration of added uranium was higher. In preparing the background soil sample for spiking, the soil was sieved so that smaller gravel and vegetation (< ¼ inch) was included to provide a realistic degree of heterogeneity to the sample. The uranium spiking solution is expected to have distributed to the soil grains and pores, binding to the humic material and the iron-containing minerals within the soil matrix but not to the gravel in the soil matrix. Therefore, the distribution of gravel in the soil column reference specimens is expected to have an effect on the distribution of uranium in the columns. Uranium distribution homogeneity was tested by making an initial reference point mark on each soil column (Quadrant 1) then successively turning each soil column 90 degrees and marking each successive quadrant (Quadrants 2 through 4). Three 1-minute counts were made on each quadrant of each soil column in the Model T-100 System. Table VI presents the averages of the three 1-minute counts for each quadrant.

**Table VI. Results of the Series B Soil Column Reference Specimen Uranium Homogeneity Field Test with the Model T-100 System – 1 Minute counts**

| Sample | $U_{nat}$ added (pCi/g) | U-238 added (pCi/g) | Model T-100 System Mean Counts of Series B Columns (CPM) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Quadrant 1 | Quadrant 2 | Quadrant 3 | Quadrant 4 | Δ High-Low | PHA |
| 1055-24-1 | 0 | 0 | 113 | 113 | 100 | 94 | 19 | 105 |
| 1055-24-3 | 18.99 | 9.24 | 101 | 107 | 101 | 112 | 5 | 105 |
| 1055-19-4 | 38.61 | 18.79 | 133 | 105 | 122 | 137 | 32 | 124 |
| 1055-19-5 | 64.52 | 31.4 | 144 | 143 | 143 | 135 | 9 | 141 |
| 1055-20-6 | 77.01 | 37.48 | 146 | 142 | 144 | 146 | 4 | 144 |
| 1055-11 | 98.88 | 48.13 | 169 | 172 | 169 | 177 | 8 | 172 |
| 1055-20-7 | 191.89 | 93.4 | 220 | 223 | 243 | 248 | 28 | 233 |

PHA = predicted homogeneous average, i.e., average of the 4 quadrants.

The results of the homogeneity experiment (Table VI) show that the soil columns display variable heterogeneous responses with respect to their radioactivity with differences between high- and low-count quadrants ranging from 4 cpm to 32 cpm. Of particular importance is the sensitivity of the Model T-100 system to 40 pCi/g added $U_{nat}$. The initial field test indicated that the count rate for sample 1055-19-4 was less than that for sample 1055-24-3 when the opposite result was expected. The results of the homogeneity test (Table VI) show that the two samples can be clearly differentiated in the proper direction depending on which quadrant of 1055-19-4 is counted or by looking at the average value of the four quadrants (PHA) for each sample. The difference between the maximum count rate from 1055-19-4 and the minimum count rate from 1055-24-3 is +36 cpm, whereas the difference between the minimum count rate of 1055-19-4 and the maximum count rate of 1055-24-4 is -5 cpm. Alternatively, the difference between the PHAs of the two samples is 17 cpm. The minimum detectable activity using 1-minute counts appears from Table VI to be ~19 pCi/g added $U_{nat}$, i.e., the Model T-100 System was unable to distinguish between sample 1055-24-1 (0 pCi/g added uranium) and sample 1055-24-3 (18.99 pCi/g added $U_{nat}$). However, it is good to note that higher up the response curve at 80 pCi/g $U_{nat}$ (~40 pCi/g U-238 threshold) the response is clear and reliable.

Part of the heterogeneous responses observed in Table VI can be attributed to counting statistics, but for the columns exhibiting the larger differences between high and low counts (e.g., 1055-24-1, 1055-19-4, 1055-20-7), sample heterogeneity cannot be ruled out as a contributing factor. To test the effect of longer count times on the Model T-100 System’s sensitivity, three 5-minute counts were taken of each sample’s quadrant whose 1-minute average was closest to the sample’s PHA. Results are presented in Table VII where they are compared to the 1-minute counts for each sample quadrant (Table VI) and the sample’s PHA (Table VI).

**Table VII. Mean Model T-100 System Results for 5-minute Counts of Series B Column Quadrants with 1-minute Count Rates Nearest to the Sample’s Predicted Homogeneous Average (PHA)**

| Sample | U (total) added, pCi/g | U-238 added (pCi/g) | 5-minute counts (cpm) | | Quadrant 1-minute counts (cpm) | | Sample PHA (cpm) |
|---|---|---|---|---|---|---|---|
| | | | Mean | Range | Mean | Range | |
| 1055-24-1 – Quadrant 3 | 0 | 0 | 96 | 95 - 97 | 100 | 87 – 101 | 105 |
| 1055-24-3 – Quadrant 2 | 18.99 | 9.24 | 105 | 102 - 110 | 107 | 99 – 112 | 105 |
| 1055-19-4 – Quadrant 3 | 38.61 | 18.79 | 118 | 116 – 122 | 122 | 111 – 131 | 124 |
| 1055-19-5 – Quadrant 2 | 64.52 | 31.4 | 148 | 144 – 151 | 143 | 141 – 146 | 141 |
| 1055-20-6 – Quadrant 3 | 77.01 | 37.48 | 147 | 144 – 150 | 144 | 133 – 151 | 144 |
| 1055-11 – Quadrant 2 | 98.88 | 48.13 | 171 | 163 – 176 | 172 | 170 – 176 | 172 |
| 1055-20-7 – Quadrant 3 | 191.89 | 93.4 | 231 | 227 - 238 | 243 | 233 – 250 | 233 |

Table VII shows that increasing count times has a positive effect on the Model T-100 System’s sensitivity. By increasing the count times from 1 minute to 5 minutes the range in counts, though still variable, has decreased from a maximum of 20 cpm to a maximum of 13 cpm, respectively, and the range exceeds 10 cpm in only two 5-minute count samples, down from five 1- minute samples.

The Model T-100 System is also more sensitive to a lower minimum detectable activity with 5-minute counts than with 1-minute counts.

The 5-minute count data in Table VII shows that the mean counts for sample 1055-19-5 (64.52 pCi/g added $U_{nat}$) are greater than those for the sample with next highest added uranium concentration, 1055-20-6 (77.01 pCi/g added $U_{nat}$). The difference in the added uranium concentration between these two samples is 12.49 pCi/g. Regression of the 5-minute count data in Table VII shows that this corresponds to a count rate difference of 7.5 cpm, well within the variability of the ranges for the 5-minute counts. All other samples differ in their added uranium concentrations by a minimum value of 19.62 pCi/g (difference between samples 1055-24-3 and 1055-19-4) which corresponds to a count rate of 12.7 cpm, at the upper limit of the ranges for the 5-minute counts.

## CONCLUSIONS

The desired sensitivity of near-term application of the Model T-100 System is to be able to demonstrate a statistically significant response for U-238 activity that is 80% of the 50 pCi/g RL, or 40 pCi/g. Laboratory and field testing has shown that the Model T-100 System does have sufficient sensitivity to reliably detect soil samples with total nonspecific activity greater than the 40 pCi/g RL for U-238. From Figure 2, U-238 activity of 40 pCi/g (or 80 pCi/g total $U_{nat}$) corresponds to a Model T-100 System response in the field of ~145 cpm, or 73 cpm above the instrument response with no sample present (as estimated from the data in Tables V and VI.

It is unlikely that all of the activity in a sample will be due to U-238, either directly or indirectly, as every field sample will contain other natural nuclides in varying quantities that can be contributors to total activity. The first step in the field will be to gather a sample thought to come from undisturbed areas and record Model-T System response. This shall serve as the initial base line. As more samples are analyzed a clear response curve may become apparent, and the base line adjusted to reflect the natural range of the soils. We can assume the baseline includes 1 pCi/g of U-238, plus other natural components.

To set an action level, of 39 pCi/g U-238 (40 less the average normal content of 1 pCi/g) the initial set-point should be 65 cpm above the base line response of the Model T-100 System. This is derived from the slope of the curves in Figure 4 that suggests a response of ~1.5 counts per pCi/g U-238.

The Model T-100 System's sensitivity can be enhanced by using longer count times initially. The field test demonstrated increased system sensitivity at all concentrations for 5-minute count times as compared to 1-minute count times. The longer count times lowered the system's minimum detectable activity to near soil background values (i.e., 0 pCi/g added uranium) and enhanced the system's sensitivity to the 40 pCi/g of U-238 threshold.

The effects of sample heterogeneity were demonstrated during the field test of the Series B samples. It is expected that natural sample heterogeneity will be much greater than that observed in laboratory-prepared samples because of the larger grain sizes expected in many natural samples. Natural sample heterogeneity in field samples can be addressed by rotating sample cores and making multiple counts of the same section but in different orientations. An average value of the multiple counts provides an adequate cross sectional analysis of each sample that closely approximates the sample's homogeneous value.

## FOOTNOTES

[a] See Table V for raw data.

[b] See Tables IV and V for raw data. Regression analysis for the two data sets:
$y = 0.8089x+33.61$; $R^2 = 0.9803$.

## REFERENCES

1. 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) (Zone 1 ROD).

2. ETTP Dynamic Verification Strategy and Standard Operating Procedure (DOE/OR/01-2063&D1) (DVS).