



**RADIATIONS SOLUTIONS, INC.**  
**RS 700 SYSTEM OVERVIEW**  
SET-UP, PARAMETERS, DATA PATH, ANALYSIS

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September 27, 2018



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**ABBREVIATIONS, DEFINITIONS AND EQUATIONS**

AC	Asphalt concrete, commonly called asphalt, is concrete consisting of aggregate rock and a bituminous binder
CoV	Coefficient of Variation = $\frac{\text{Standard Deviation of measurements}}{\text{Average of measurements}}$  Predicted CoV = $\frac{\sqrt{\text{Average of measurements}}}{\text{Average of measurements}}$
cps	Counts per second
GPS	Global positioning system
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCA	Multi-channel analyzer
NaI	Sodium Iodide, doped with Thallium
NIST	National Institute of Standards and Technology
NORM	Naturally occurring radioactive materials
ROI	Radionuclide of Interest, plural ROIs
RS 700	Radiation Solutions, Inc. Mobile Radiation Monitoring System, for gamma and neutron detection only
RSX	Four-liter NAI detector
$\sigma$	Sigma is the standard deviation, Std. Dev. of the measurements of interest.
Std. Dev.	Standard Deviation, $\sigma = \sqrt{\frac{(x_i - \bar{x})^2}{N}}$ where $x_i$ is measurement, $N$ is number of measurements, $\bar{x}$ is the average of measurements.
SU	Survey Unit
UTV	Work /Utility vehicle
Z-score	Statistical measure of how a single measurement compares to the average of all measurements in the data set (Kruglak).  $z_i = \frac{(x_i - \bar{x})}{1\sigma}$ where $\bar{x}$ is the average of measurements, $x_i$ is individual measurement, and $\sigma$ is the standard deviation of all of the measurements.

**EQUIPMENT DESCRIPTION:**

- **RS 700 MOBILE RADIATION MONITORING SYSTEM**

The Radiological Systems, Inc. RS 700 Mobile Radiation Monitoring system is a self-contained spectrometer designed for mobile gamma ray and neutron detection. This system cannot detect alpha or beta particle radiation, and was not configured to detect neutron radiation. The RS 700 system consists of two four-liter sodium iodide doped with thallium (NaI) detectors, a Trimble AgGPS global positioning system (GPS), power sources, vehicle with trailer, RS 701 (or RS 705) console multi-channel analyzer (MCA) and a laptop computer for real-time gamma ray and GPS position monitoring and data collection.



**Figure 1: RS 700 Mapping system (towed array)**



**Figure 2: RS 700 Electronics and detectors on trailer**

The NaI detectors are rectangular prisms, 73.1 cm long by 16.2 cm wide by 17.2 cm high. The detectors are mounted on the underside of the trailer, approximately 27.5 cm from the ground surface and parallel to each other, with a 29 cm separation between the detectors (Hensley). The long axis is in the direction of travel, on the underside of a utility trailer pulled by a small utility vehicle (UTV) pulls the trailer. The NaI detector array on the trailer was towed at a target scan speed of 1 meter per second.

Data from each NaI detector and the GPS was collected on a field laptop computer equipped with the proprietary software and administrative rights necessary to operate the detection equipment. *RadAssist* software, upon selecting “Start Data Recording...” assigned a name, with date and time; to which the surveyor appended a descriptive survey unit name. The data recorded consisted of one-second data collections of region of interest data and spectral data. The number of one-second data sets for each unit surveyed depends on the path length of the scan, which depends on the area of the survey unit, the scan path separation, and the actual scan speed. At the end of the scan, *RadAssist* saved the data in the form of an .rsv file.

For detailed technical specifications, please see the “Technical Basis Document for the CA Radiologic Health Branch, RS 701 Radiation Mapping System,

Radium 226”, written by Mr. Jerry Hensley, CHP, see Appendix A: Technical Basis Document for the CA Radiological Health Branch RS-701 Radiation Mapping System; Radium 226. For clarity, the following radionuclides of interest were renamed, as follows in Table 1: Equivalent Names below:

**Table 1: Equivalent Names**

Technical Basis Document Name	Report Names
TotCount	Range(45-1980)
Uranium	Ra-226(1764)

- **RS 700 SYSTEM COMPONENTS**

The RS 700 System consists of the components found in Table 2: RS 700 System Components.



**Table 2: RS 700 System Components**

<b>Manufacturer</b>	<b>Model</b>	<b>Serial Number</b>	<b>Function</b>
Radiations Solutions, Inc.	RS 701	7017	Console
Radiations Solutions, Inc.	RS 705		Console
Radiations Solutions, Inc.	RSX	5121	NaI detector (Det. #1)
Radiations Solutions, Inc.	RSX	5122	NaI detector (Det. #2)
Trimble	Z plus	31534803	GPS antenna
Trimble	AgGPS 332	0225122424	GPS receiver
TrippLite	PV6168	9629AY	Power inverter

Other components for the RS 700 system include detector cables, antenna cable, separate power cables for the RS System and the GPS system, a battery for powering GPS, crossover cable to connect the RS 701 console to the data logging device, RS232 cable for connecting the GPS antenna to the RS 701 console, and data logging device with power cord.

• **RS 700 DATA PATH**

Data file of interest collected by RadAssist was in the form of a *.rsv* file which must be converted for analysis, graphing and mapping. Prior to analysis, the files were transferred from the field computer to a faster laptop, with faster processors and larger random access memory (RAM) memory. Data was backed up on G and H drives. When available, the initial unprocessed data was also burned onto a DVD for archive purposes. File conversion and data analysis path is as follows, for summary of process see Figure 3: RS 700 Data Path:

1. *RSV to RAW File Conversion*-proprietary software tool, part of the RadAssist software package, which formats the data for RadAssist to open and to export. Creates *.RFL* file or files depending on the number of 1-second data sets. These files are placed in the same folder as the original *.rsv* file.
2. *RadAssist*-converts *.RFL* file(s) into a comma-separated-value (*.csv*) file. Spectral data is always collected, but export preferences determine whether it is exported into the (*.csv*) file. This conversion can be performed repeatedly and/or separately for processing spectral data. The number of rows of data is dependent on how many 1-second data collections were made. The largest survey unit file for Hunters Point Parcel D-2 has 6963 rows of data.
  - a. File for mapping consists of 70 columns
  - b. File for spectral data consists of 1094 columns
3. *Excel*-converts *.csv* files to Excel 97-2003 Workbook version *.xls* file for future data analysis and graphing. This Excel version is necessary to be compatible with Surfer 7.0 mapping software.
  - a. For spectral data, the *.csv* file must be converted to Excel Workbook *.xlsx* file. The Excel 97-2003 Workbook does not support enough columns to display all 1094 columns of data.
4. *Excel-RS 700 Analysis Template*- is a workbook created to consolidate and streamline data analysis and graphing. All graphs and calculations are based upon the same set of data, eliminating inconsistent version errors. Macros embedded in the spreadsheet template automate inputting data, separating out GPS failure data, and tailoring the calculation fields and graph parameters to the number of rows in each data set. The workbook is saved with the same name as the original survey file as an Excel Workbook *.xlsx* format to strip out the macros and Visual Basic for Applications (VBA) scripts which are incompatible with *Surfer 7.0*. The file is then re-saved as an *Excel 97-2003 Workbook .xls* format, because the *.xlsx* format is incompatible with *Surfer 7.0*.

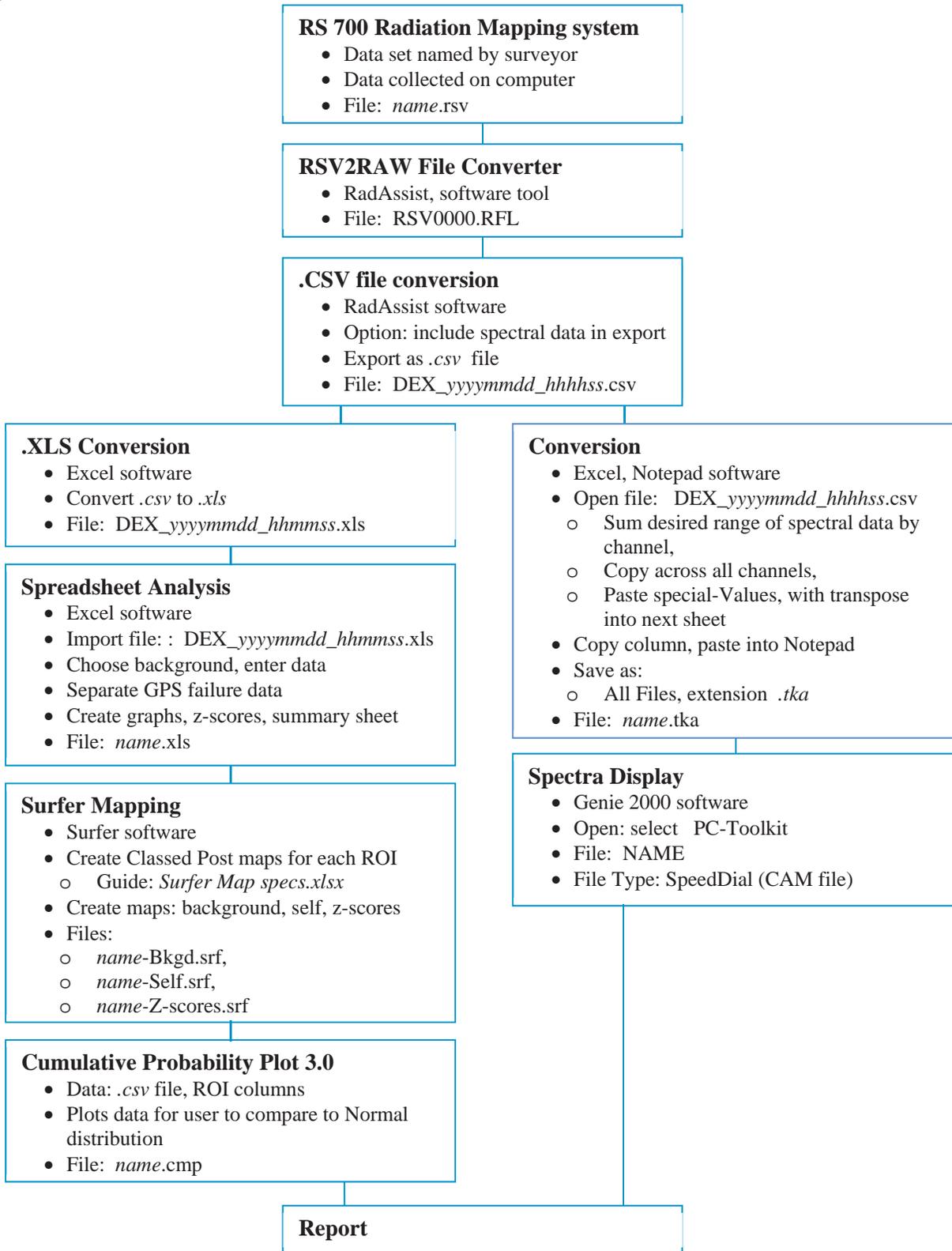


RADIOLOGIC HEALTH BRANCH

RADIOLOGICAL ASSESSMENT UNIT

- a. As part of the analysis, the user inputs values from the chosen background. The effect of a different background data set can easily be evaluated by substituting that background data.
    - b. The data set may be altered to remove data for points outside of the survey unit, such as data collected while turning the vehicle and trailer in outside of a confined survey unit.
    - c. Details on analysis parameters can be found in the following section Analysis Description
5. *Surfer 7.0*-maps the data processed in the Excel workbook
  - a. Quality Assurance/Quality Control (QA/QC) data sets were not mapped
  - b. Background data sets collected while the array was stationary were not mapped.
6. Analysis-*Surfer* maps and the *Excel* worksheet are analyzed for anomalies, such as high count rate points, clusters of elevated measurements which may indicate the need for further investigation.
7. *Cumulative Probability Plot 3.0* software-graphs data and indicates whether measurements for a region of interest of a survey unit lie outside a normal distribution.
8. Report.

Figure 3: RS 700 Data Path





**ANALYSIS DESCRIPTION**

- **RS 700 RADIATION MAPPING SYSTEM**

Because the radionuclides of concern do not emit gammas, or emit very low energy, low yield gamma radiation (radium-226, 186.2 keV, 3.3% abundance), the higher energy gammas of their progeny are used, for example radium-226 progeny bismuth-214 gammas 609.3 keV (46.3% abundance) and 1764.6 keV (15.8% abundance).

The detection parameters for the RS 700 system were set to measure five windows centered on the gamma emissions of the radionuclides of interest, or one of their more detectable progeny. These windows were named for the ROIs: Potassium, Ra-226(1764), Thorium, Radium (609), and “Range(45-1980)” for the range of gamma-emitting radionuclides detected between 45 keV and 1980 keV. The channel-to-energy conversion is one channel equals 3 keV energy. Table 3: RS 701 Detection Parameters shows the window range for each ROI and the peak of interest.

**Table 3: RS 701 Detection Parameters**

ROI Name	Start Channel	End Channel	Peak of Interest
Range(45-1980)	15	660	Peaks: 45 keV to 1980 keV
Potassium	457	523	1460.8 keV
Ra-226(1764)	553	620	1764.5 keV (Bi-214, progeny of Ra-226)
Thorium	803	937	2614.7 keV (Tl-208, progeny of Th-232)
Ra-226(609)	182	222	609.3 keV (Bi-214, progeny of Ra-226)
Cs-137	183	247	661.6 keV (Ba-137, progeny of Cs-137)

Neither potassium nor thorium are a radionuclides of interest and are considered naturally occurring radioactive materials (NORM), thus these ROIs are used to characterize the variability of the background. The Ra-226(609) and Ra-226(1764) regions are used to evaluate the presence of anthropogenic radium 226, by measurement of the gamma radiation emitted by the radium 226 progeny bismuth 214. The Compton continuum of 1460.8 keV potassium peak contributes to the Ra-226 (609) ROI counts and is not automatically compensated for by the *RadAssist* calibration parameters. Therefore, where elevated Potassium counts are found, the Ra-226 (609) and Cs-137 counts are also expected to be elevated.

Due to the resolution, or peak width, characteristic of NaI (Tl) detectors, and the close proximity of the Ra-226(609) and Cs-137 peaks of interest, there is significant overlap of the ROIs.

The radiological data is associated point-by-point to geographical and temporal information. Radiation Systems, Inc. proprietary software, *RadAssist*, was used to convert collected data from the detector into comma separated values format. The data was then analyzed using *Excel* spreadsheets and *Surfer* (map plotting software). Spectral data was examined using the *Genie 2000* or *Peak Easy* software. Due to the width of the NaI detector peaks, spectral analysis was qualitative rather than quantitative.

Using *Excel* spreadsheets designed for RS 700 data analysis, measurement averages, standard deviations, average plus 2-5 sigmas, z-scores, coefficients of variation for each ROI in each survey unit were calculated. ROI graphs were used to look for clusters of elevated measurements. Ratios of ROIs were compared to evaluate background variability against the primordial radionuclides of interest (potassium and thorium). The functions of the *Excel* spreadsheets based on *RS 700 Analysis Template.xlt* are summarized in Table 4: RS 700 Analysis Template spreadsheet below.



Table 4: RS 700 Analysis Template spreadsheet

Sheet Name	Sheet Function
Summary	Raw Data: data drawn from Raw Data and GPS Failure Data sheet; Predicted CoV calculated directly, Avg. and Std. Dev. used by Z-scores. Z-scores: data drawn from Z-scores sheet Ratios: data drawn from Ratios sheet Background: data entry (background Average and background Std. Dev.) used by Net Graph Data, Color Separate,
Summary-Self Bkgd	This worksheet summarizes data from "Self-Background data", analyzes and compares "Raw Data" to 2, 3 and 4 sigma reject averages and standard deviations.
DEX ...	Data imported from RadAssist
Imported Data	Data sheet for exported data from RadAssist, copied from data sheet (DEX ...).
Raw Data	Contains all detector data, minus GPS failure Data. ROI Graphs, Z-scores calculations and graph, Ratio calculations and graphs, and Summary calculations are based upon this data set. Macro extracts GPS Failure data and places in the GPS Failure Data sheet.
GPS Failure Data	Holding place for GPS failure data removed from "DEX ..." and "Raw Data" sheets. Data contained in this sheet is included in calculation of average and standard deviations for each region of interest.
Graph Data	Automatically imported from Raw data, automatically calculates Average, Std. Deviation, +2 sigma, -2 sigma, +3 sigma, -3 sigma for each ROI based upon data set values. Automatically imports Background average and Background Std. Dev. from data input on "Summary" sheet. Automatically calculates Average +2 sigma, Average-2 sigma, Average +3 sigma, Average-3 sigma from Background Std. Dev.
ROI Graphs	Graphs generated from Graph Data sheet, using data set average and Std. Dev.
ROI Graphs, Bkgd Sigmas	Graphs generated from Graph Data sheet, Background and Std. Dev. from data input on "Summary" sheet. Sigmas are calculated using Background Std. Dev. entered in "Summary" sheet.
Z-scores	Automatically calculated, binned and graphed, this data is used in Surfer maps
Net Graph Data	Point-by-point subtracts the background the user inputs into Summary and automatically generated Background, Std. Deviation (of Background), +2 sigma (of Background), -2 sigma, +3 sigma, -3 sigma for each ROI based on Background data entered by the user.
Net Graphs	Graphs generated from Net Graph Data sheet.
Ratios	Data is pulled from Raw Data, calculated automatically and graphed automatically
Color Separate	This worksheet is for producing color separation layers for each ROI for graphing in Surfer. Separation parameters are set from user entered background average and standard deviation for each ROI.
Self-Background Data	This worksheet is for producing self-background Averages and Standard deviations based on rejecting data greater than 2, 3 or 4 sigma. Results are summarized in the worksheet: "Summary-Self Bkgd"
OPhub	Necessary for macro use
OPlog	Detailed log of macro actions; necessary for macro use
OPstore	Necessary for macro use



- **Z-SCORES**

Z-scores are a unit-less measure of each measurement's deviation from the average, divided by the standard deviation of the measurements of that survey unit. Z-scores were calculated separately for each survey unit and for each ROI. A greater Z-score number indicates a measurement farther from the mean of the measurements for the survey unit and ROI.



# Radiation Solution RS-701 Mobile Radiation Monitoring System: Operation Procedure

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# Radiation Solution RS-701 Mobile Radiation Monitoring System Operation Procedure

## Section 1: Initial Setup

1. Remove detectors (2 each), RS-701 control box, detector cables (2 each), GPS (1 each), Ethernet crossover cable, and power connector (12 VDC or 110 VAC) from kits.
2. Visually inspect for damage
3. Connect detector cable #1 to RS-701 control box **DET 1** and detector #1 connector (Serial number 5121)  
Note: Each end of the detector cable has a different gender – only connect to appropriate connector.
4. Repeat step #3 for detector #2 (Serial number 5122)
5. Connect GPS antenna to “**GPS**” connector on RS-701 control box
6. Connect power supply cable (110 VAC or 12 VDC as applicable) to RS-701 control box **POWER** connector.  
Note: white wire on 12 VDC is *hot* and the black wire is neutral

## Section 2: Initial QA/QC Setup

1. System is operational when all LEDs on RS-701 console are green.
2. Perform initial background setup.
  - a. Find location(s) where QA/QC tests may be performed multiple times each day. Location should be flat, no sources of elevated radioactivity, and easy to drive UTV and detector each day.
  - b. Mark location using paint or flags.
  - c. Remove all check sources (minimum of 20 feet away).
  - d. Note start time and stop time.
  - e. Allow system to collect a minimum of 300 seconds of data without sources present.
  - f. Calculate average background value using 300 seconds of data from the Cs-137 region of interest (ROI).
  - g. Calculate standard deviation value using 300 seconds of data from the Cs-137 ROI.
3. Perform initial Cs-137 source measurements.
  - a. Remove all sources except 1  $\mu\text{Ci}$  Cs-137 point source. This source does not require NIST traceability but the same source should be used throughout the data collection.
  - b. Place the Cs-137 source on the cart at location noted on frame. All QA/QC measurements will require placing the source at this same position.
  - c. Note start and stop time on log.
  - d. Collect minimum 300 seconds of source data.

# Radiation Solution RS-701 Mobile Radiation Monitoring System Operation Procedure

- e. Calculate average background value using 300 seconds of data from the Cs-137 ROI.
- f. Calculate one, two, and, three standard deviation values using 300 seconds of new data from the Cs-137 ROI.

## Section 3: Operation

1. Set up computer to communicate with RS-701 system
  - a. Turn on computer
  - b. Set IP address of computer as follows – this requires administrator access (page 39 of manual)
    - i. Click **START** on lower left of screen
    - ii. Click **SETTINGS**
    - iii. Click **NETWORK SETTINGS**
    - iv. Under LAN or High-Speed Internet, click **LOCAL AREA CONNECTION**
    - v. Under the General tab, select **PROPERTIES**
    - vi. Click **INTERNET PROTOCOL (TCP/IP)** – will highlight
    - vii. Click on **PROPERTIES**
    - viii. Under the General tab, select **USE THE FOLLOWING IP ADDRESS:**
      1. Input the following IP address: **192.168.1.100**
      2. Input the following Subnet mask: **255.255.255.0**
      3. Input the following Default gateway: **192.168.1.1**
    - ix. Click on **OK**
2. Connect Ethernet Cross-Over cable to RS-701 Control box **DATA** position and the other end in the computer Ethernet connector.
3. Press the silver button on the RS-701 console and *hold* until the LEDs on console illuminate.
  - a. *Yellow* lights for the detector indicate the detectors are performing an automatic gain adjustment (aka energy calibration) – no radioactive sources are required.
  - b. *Red* light indicates an error.
  - c. *Purple* light indicates startup.
  - d. *Green* light indicates all is OK.
4. Select **RADASSIST** icon (or Start, Programs, RSI, and RadAssist)
5. Connect RadAssist to computer
  - a. Select **FILE**
  - b. Select **CONNECT TO DEVICE...**

## Radiation Solution RS-701 Mobile Radiation Monitoring System Operation Procedure

- c. Under **DIRECT CONNECTION** tab,
  - i. Select **RS-701 PROTOCOLS** displayed,
  - ii. Select **CONNECT**.

Note: Device is RS-701 System Console and IP address of RS-701 is 192.168.1.149

6. System is operational when all LEDs on RS-701 console are *green*.
7. Perform QA/QC test. This should be performed at the start and end of each run. No more than 3 hours of data collection should occur between background and source tests.
  - a. QA/QC tests should occur in the same physical location, if practical.
  - b. Collect background data file by removing all sources of radiation. Note start and stop time on log. Allow system to collect a minimum of 180 seconds of data.
  - c. Place ~ 1 uCi Cs-137 point source at location noted on cart. The source does not require NIST traceability but the *same* source should be used for survey duration.
    - i. Note start and stop time on log.
    - ii. Allow system to collect a minimum of 180 seconds of data with the source in position.
  - d. Net source data should be within  $2\sigma$  of the initial net cps. Project health physicist (HP) may approve up to  $3\sigma$  deviation on a case by case basis.
8. Start collecting data on laptop by selecting **FILE** and **START DATA RECORDING**. Choose file name and storage location. Note start time.  
Note: System will automatically collect data without a computer.
9. At the end of data collection, select **FILE** and **STOP DATA RECORDING...**
10. To retrieve data in the RS-701 console, select **DEVICE** and **REQUEST ALL EVENTS**, chose file name and save in predetermined location.
11. To turn system off
  - a. Select **FILE** and **STOP DATA RECORDING...** if still collecting.
  - b. Exit out of RadAssist
  - c. Press and hold silver **POWER** button on back of RS-701 console until lights on the console turn off.
12. Disconnect cables
13. Change computer IP address to **OBTAIN AN IP ADDRESS AUTOMATICALLY**, using Step #7
14. Setup baud rate equal to 38,400 on RS-701 Com-1 for external GPS, on RS-701 **DEVICE PARAMETERS** tab on RadAssist program

# Radiation Solution RS-701 Mobile Radiation Monitoring System Operation Procedure

## Section 4: Instructions for Using Surfer (field mapping)

1. Retrieve raw data from Rad Mapping system (RMS) by inserting USB memory stick to RS-701 console. Data will be automatically downloaded when a memory stick is inserted. The LED on RS-701 will stop flashing when data is downloaded.
2. Copy files to directory on computer hard drive.
3. Open RadAssist program by selecting **RADASSIST** icon.
4. Select **RAW DATA PROCESSING TAB** at bottom on program.
5. Select folder icon (Load raw files from a given folder).
6. Select show loaded files icon.
7. Select files required to be processed.
8. Select data that will be processed by highlighting on screen – include QA/QC data if applicable. Use times referenced on scale.
9. Select arrow with green background icon
10. Exported Data Range screen - Data range should be **SELECTED DATA**, then **NEXT**
11. Export Data Format screen - Output format should **CSV** and **OPEN FILE AFTER THE EXPORT**
12. Sample time format should be **UTC YYYY/MM/DD/HH:MM:SS**, data format CSV Export Options - should be **LLA WGS84 COORDINATES**, only **OUTPUT ROIS** selected, then **NEXT**.
13. Ignore Errors screen – do not select anything, then **NEXT**.
14. Virtual Detector Configuration screen – select Virtual Detector 1 and Detector Pack 1 only detectors 1 and 2 should be selected, then **FINISH**.
15. Export Done, select **OK**
16. Save CSV file according to project specifics.
  - a. Column I = longitude,
  - b. Column J = latitude,
  - c. Column K =elevation,
  - d. Column Q through XXX is the radiation reading in counts per second (cps) for each named ROI.
17. Open the Surfer program by double clicking on the **SURFER** icon.
18. Create a classed post map by performing the following steps:
  - a. Select **MAP / POST MAP**, and then **NEW CLASSED POST MAP**.
  - b. Open XXXXXX.csv file. XXXXXX is the file you want to plot.
  - c. From the Classed Post Map Properties **General** tab, select the following:
    - i. X Coord: Column I,
    - ii. Y Coord: Column J,
    - iii. Z Value: Column Q or higher.

## Radiation Solution RS-701 Mobile Radiation Monitoring System Operation Procedure

- d. From the *Classed Post Map Properties Labels* tab, use all default values.
  - e. From the *Classed Post Map Properties Classes* tab, the number of classes should be 3 and the binning method should be equal number. Change classes as follows:
    - i. Class 1 upper value to the “average + 2 $\sigma$ ”.
    - ii. Class 2 lower value to the “average + 2 $\sigma$ ” and the upper value to the “average + 3 $\sigma$ ”.
    - iii. Class 3 lower value to the “average + 3 $\sigma$ ” and the upper value to the highest integer on the survey.
    - iv. Note: It is preferable to use, a light green equal arm cross “+” symbol for values up to the “average + 2 $\sigma$ ”. For values between background + 2 $\sigma$  and background + 3 $\sigma$  use a dark yellow triangle “▲”. For values greater than “average + 3 $\sigma$ ”, it is preferable to use a red dot “●”.
19. Select **Apply** and then **OK** when complete.
20. Save file by selecting **File, Save As**, and then XXXXXX.srf. XXXXXX is the name of the original file.

**TECHNICAL BASIS DOCUMENT**  
**CA RADIOLOGIC HEALTH BRANCH**  
**RS-701 RADIATION MAPPING SYSTEM**

**RADIUM 226**

## **NOTICES**

The mention of trade names or commercial products in this publication is for illustration purposes and does not constitute endorsement or recommendation for use by the State of California.

**TECHNICAL BASIS DOCUMENT FOR THE CA RADIOLOGIC HEALTH  
BRANCH RS-701 RADIATION MAPPING SYSTEM  
RADIUM 226**

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# **TECHNICAL BASIS DOCUMENT FOR THE CA RADIOLOGIC HEALTH BRANCH RS-701 RADIATION MAPPING SYSTEM RADIUM 226**

## **INTRODUCTION**

The Radiation Solutions Inc., RS-701 Radiation Mapping System (RMS) is used to perform *in situ* radiological surface and matrix (volume) contamination scanning surveys for radionuclides that emit photons during their decay process. These surveys are used to identify areas that are likely to represent anomalies from local background for further investigation based on use of other radiological survey instrumentation. This document addresses instrument operation and use, gamma energy calibration, and detector efficiency and minimum detection calculations.

As with any portable field radiological detection instrumentation, the efficiency and detection limits addressed in this document are specific to the referenced assumptions, particularly regarding spatial activity distribution and shielding conditions. Since actual field conditions are not likely to precisely replicate the referenced assumptions, the efficiency and detection limits are only approximations and should be used with caution. Fixed location measurements and/or samples will need to be obtained and analyzed to more precisely quantify site conditions.

## **DESCRIPTION**

The RMS consists of the RS-701 console, two 10 centimeter (cm) by 10 cm by 40 cm sodium iodide (NaI) detectors, a Trimble Ag global positioning system (GPS), a trailer modified to carry the detectors, and a laptop computer (optional). The detectors are oriented parallel to the ground and each other with their long axis pointed in the direction of travel. The bottom of the detector cases stands 27.5 cm above the ground and the gap between the detectors is 29 cm.

The RMS automatically records the operator's location to within 1 meter (requires OmniStar subscription service) and it records the associated one-second spectral data from each detector to a storage device inside the RS-701 console. Figure 1, RMS, shows the system in its entirety. Data is retrieved from the RS-701 console using associated software (RadAssist). Data can be binned according to a region of interest (ROI) for predetermined radionuclides or retrieved for each of the 1024 channels (gamma energy from 0 to 3 MeV). The RadAssist software is capable of removing Compton continuum from the peaks. Data can be exported to an Excel spreadsheet to facilitate mapping using industry standard software (i.e. ArcView or Surfer).

The RS-701 console contains the multichannel analyzers (MCA) for each detector along with basic operation controls. The system uses primordial radiation to perform the initial energy calibration and to maintain the system energy gain, negating the need for external check sources except for quality assurance a covered in the next paragraph.



**Figure 1, Radiation Monitoring System (RMS)**

### **QUALITY ASSURANCE**

Verification of instrument response shall be performed during each run with a Cs-137 check source prior to start and after completion. Any source trends outside  $\pm 2\sigma$  should be investigated and any values outside  $\pm 3\sigma$  shall be investigated.

### **OPERATION**

The operator connects the cables (Detector 1, Detector 2, GPS, and User if computer connected), applies 12 VDC power, turns the console on (press silver button), exposes the detectors to the Cs-137 check source for QA check, and proceeds to collect data.

The typical scan speed is 1 meter per second. Faster scan speeds will require new minimum detectable calculations.

Upon completion of the survey, the system is turned off and a USB memory device is inserted into the RS-701 console. The data may be captured by a laptop computer during operation. The data is retrieved according to predetermined regions of interest (ROI) or a spectral data file; both with associated GPS coordinates.

Data generated from the ROIs normally should be binned according to the following parameters: background +  $2\sigma$ , greater than  $2\sigma$  but less than  $3\sigma$  above background, and equal to and greater than  $3\sigma$  above background. The specified binning may need to be modified based on the variations in naturally occurring background uranium, thorium, and radium; values as high as  $6\sigma$  may need to be used. Data may also be binned according to Z-Scores.

The GPS will not work indoors due to lack of satellite reception.

### **GAMMA ENERGY CORRELATION**

The system energy calibration is an automated function that uses the gamma energies from primordial radionuclides. Each detector gain is adjusted until the gamma energies are in their respective peak channels. A linear equation is used to convert from a channel number to its keV equivalent. This correlation is 3 keV per 1 channel. The system has 1024 channels.

### **Ra-226 SURFACE AREAL EFFICIENCY DETERMINATION**

Measurements were made with a discrete 1.017  $\mu\text{Ci}$  Ra-226 gamma point source that is traceable to the National Institute of Standards and Technology. Data was retrieved using 3 user generated regions of interest (ROI) and is referenced in Table 1, Calibration Data.

The source was placed under the detectors at ground level and moved in increments of 10 centimeters until a field of 1 square meter was measured. The Ra-226 source was placed at each location to allow collection of a minimum of 119 seconds worth of data at each location. The net cps values were used to make efficiency determinations for each ROI, as shown in Table 1, and to determine counts per second (cps) values were modeled to show the detector response patterns, as shown in Figures 3, 4, and 5 while the average net cps values were used for efficiency calculations.

MicroShield modeling was performed for a 1  $\mu\text{Ci}$  Ra-226 source distributed on the surface over one square meter (areal source). The detector height above the source is 27.5 cm above the surface. The calculated fluence values (with buildup) for each ROI were then compared to the average net empirical value for each ROI (all 121 discrete measurements). The detector fluence location is at the center-point between the detectors and level with the bottom of the detector case.

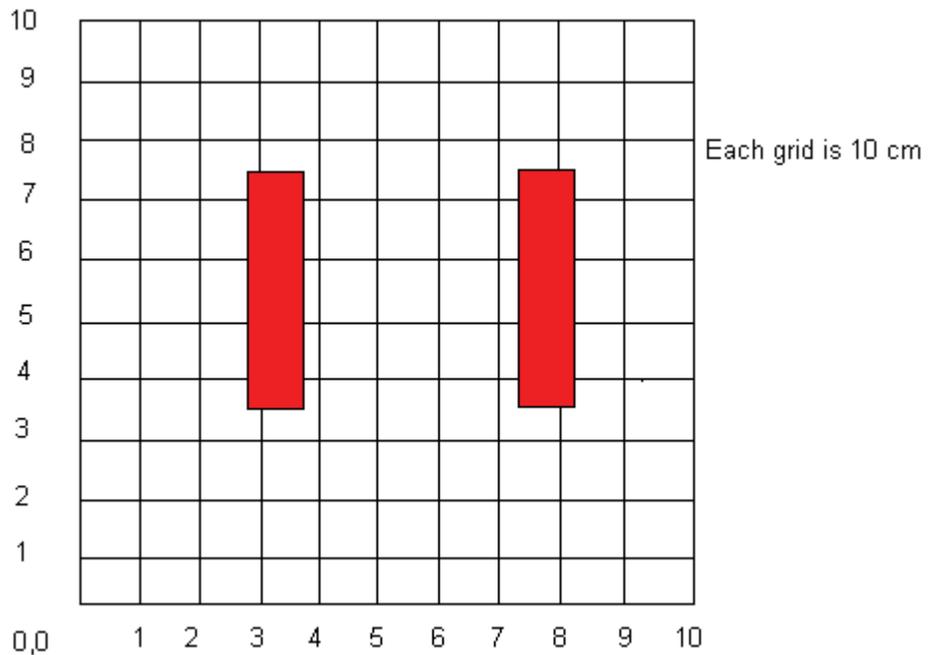
A detector responses for each ROI was calculated by dividing the average net cps values (empirical) by fluence (MicroShield) for each ROI. A net cps per 1 gamma per  $\text{cm}^2$  per second was calculated for each of the ROIs.

**Table 1, Ra-226 Surface Calibration Data (Areal)**

Radionuclide	ROI	Gamma Energy (keV)	Activity ( $\mu\text{Ci}/\text{m}^2$ )	Calculated Fluence (gammas/ $\text{cm}^2/\text{sec}$ )	Detector Response, Net (cps)	Efficiency, (cps per 1 gamma/ $\text{cm}^2/\text{sec}$ )
Ra-226	Gross	45 - 1980	1.02	3.54	2536	716
Ra-226	609 keV	546 - 666	1.02	0.71	242	338
Ra-226	1764 keV	1659 - 1860	1.02	0.28	58.9	210

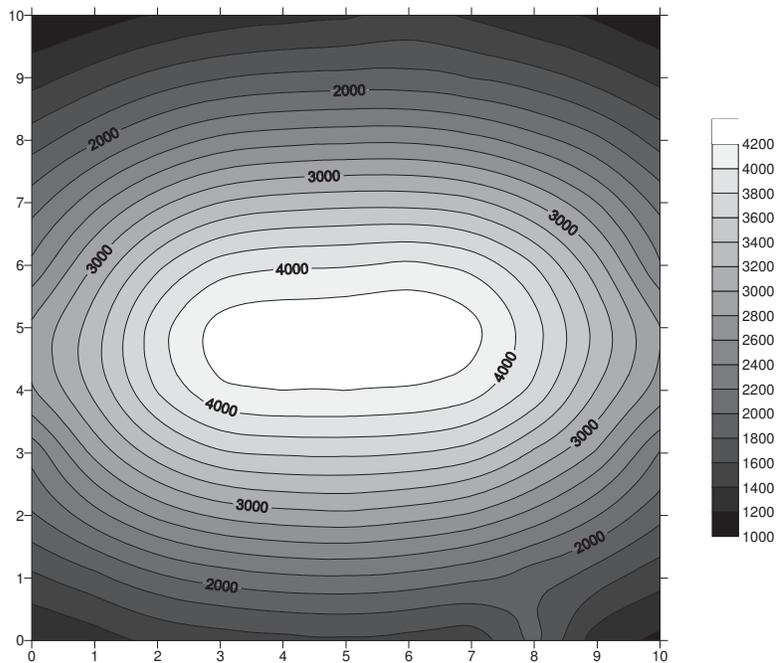
**Ra-226 SURFACE AREAL EFFICIENCY CALIBRATION DATA**

The layout of the detectors in relation to the source measurements is shown in Figure 2, Detector Calibration Layout. Visual representations of the detectors' response to each source location are shown in Figures 3 to 5 while the detector value in cps is referenced in Tables 2 through 4.



**Figure 2, Detector Calibration Layout**

Ra-226 Point Source  
 Average = 2537 net CPS  
 Gross ROI



**Figure 3, Ra-226, Gross ROI CPS Map**

**Table 2, Ra-226, Gross ROI Net CPS Calibration Data**

10	1021	1112	1208	129	13 0	13 2	1	13 1	125	11 1	1039
9	1323	1500	1 1	1 8	18	18	18 9	1 95	1 91	152	13
8	1 03	19 1	22	2	252	25	25	2 2	2281	20	1 18
	210	25 1	2932	20	01			2 1	299	2 02	212
	2 8	011	8	892	9	98	0 1	939	0	0 8	2 13
	28 1	0	91	2	299	18		25	8 0		2808
	2 82	25	81	15	202	20	1	08		18	2 08
	2252	285	29		21		03	00	15	2 9	2181
2	19	232	2 1	2838	2920	2951	2880	2 9	2522	220	185
1	15	1	1951	20	2151	21 1	2129	2030	18	1 89	1 0
0	1201	130	1	150	15	15 9	15	1	18	128	1158
	0	1	2						8	9	10

Average net response is 2537 cps

Ra-226 Poing Source  
 Average = 240 net CPS  
 609 keV ROI

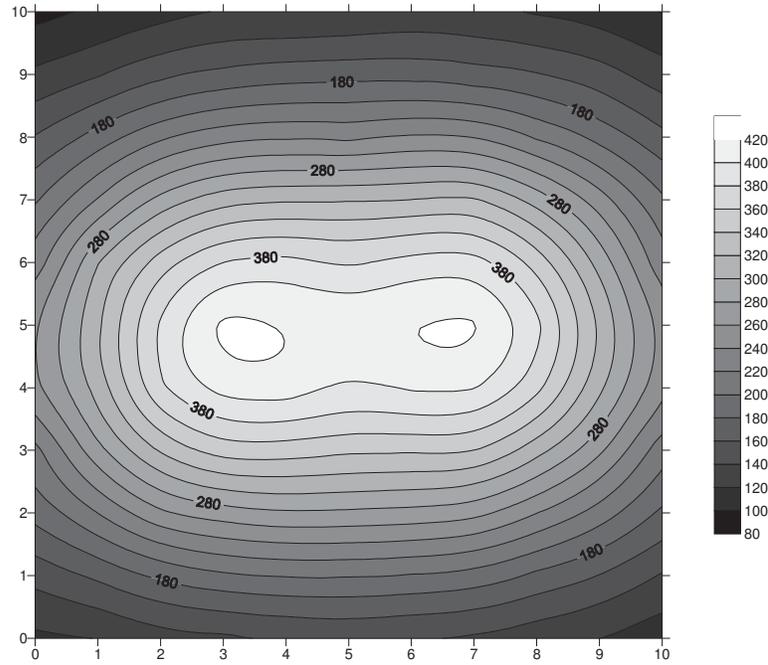


Figure 4, Ra-226, 609 keV ROI CPS Map

Table 3, Ra-226, 609 keV ROI Net CPS Calibration Data

10	9	103 2	113 2	121 2	120 2	122 2	12 2	12 2	118 2	111 2	99 2
9	12	138 2	155 2	1 5 2	1 1 2	1 3 2	1 3 2	1 8 2	1 1 2	1 9 2	129 2
8	1 1 2	188 2	21 2	232 2	23 2	235 2	2 2 2	239 2	21 2	193 2	1 5 2
	19 2	2 1 2	28 2	311 2	31 2	318 2	320 2	322 2	291 2	2 9 2	203 2
	230 2	299 2	3 9 2	380 2	385 2	3 2	38 2	38 2	351 2	292 2	22 2
5	25 2	31 2	382 2	23 2	18 2	12 2	19 2	21 2	38 2	31 2	252 2
	255 2	308 2	3 2	0 2	09 2	39 2	02 2	01 2	3 5 2	30 2	2 2
3	21 2	2 3 2	322 2	3 8 2	3 9 2	3 3 2	3 2 2	3 0 2	30 2	2 2	208 2
2	18	220 2	25 2	2 0 2	2 2	2 2	2 3 2	2 2	2 0 2	211 2	1 2
1	1 2	1 2	18 2	19 2	201 2	201 2	198 2	192 2	1 5 2	159 2	138 2
0	11 2	120 2	132 2	13 2	1 1 2	1 2	1 0 2	13 2	128 2	120 2	108 2
	0	1	2	3		5			8	9	10

Average net response is 240 cps

Ra-226 Point Source  
 Average = 58.9 net CPS  
 1764 keV ROI

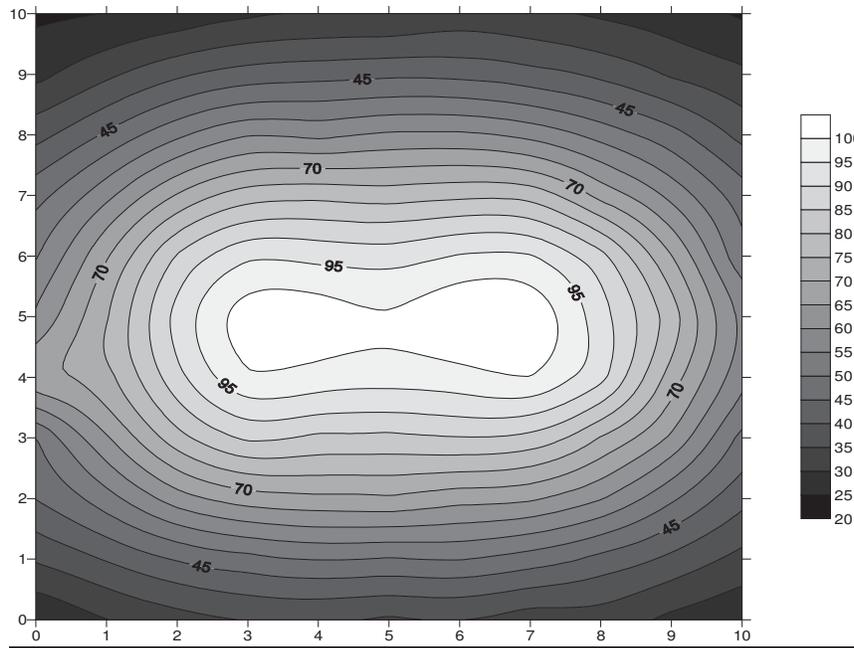


Figure 5, Ra-226, 1764 keV ROI CPS Map

Table 4, Ra-226, 1764 keV ROI Net CPS Calibration Data

10	2 1	25 1	2 8	29 2	30 2	30 2	32 3	31	29 3	2	2
9	28 5	33 9	39	2 2	3 2		3	1	38 8	3 3	31 1
8	38 2	5 8	53 9	59	58	0 8	0 9	58 5	53 1		38
	8 1	58 5	0 5		8		8 8	8 3	8 2	58 5	
	5 5	9	85 5	9 1	93 2	92	95	95 5	8	0 2	51 2
5	0	5	91	102	102 3	100 3	103 5	103	91 9	5	58
	9	3 3	88 3	99 3	9	9	9 8	100	91	2	5 5
3	9 8	3	8	85 9	83	83	8	83 5	5	1	8 5
2	5 2	52 9	2	5	8 8	9 3	8	5 8	0	50 9	1 5
1	35	0	5	8 3	50 2	9 5	50 3		3	38	33
0	25	29 9	33	35 2	35	3 2	35 1	32 3	32 8	28 8	2
	0	1	2	3		5			8	9	10

Average net response is 58.9 cps

**CALIBRATION CALCULATION FOR Ra-226 SOIL MATRIX**

Data referenced in this section is only for calculating priori detection limits and should not be used as a conversion tool for converting detector cps to a pCi/g or cps to  $\mu$ Ci value for Ra-226. Contamination may be in the form of a homogenized mixture or in the form of discrete particles. Because the distribution of the contamination is not known prior to performing the survey or even immediately after the survey, data generated by the instrument should be used as indication only.

Discrete or point source efficiencies were obtained by dividing the activity of the Ra-226 (1  $\mu$ Ci) point source by the average net cps for each ROI.

Soil matrix contamination detection limits were calculated by modeling soil contamination using MicroShield. Input assumptions to calculate a fluence value include: 1 pCi/g Ra-226 (decayed 1 year to ensure gamma-emitting progeny are in secular equilibrium, soil density 1.5 grams/cc, detectors are 27.5 cm above the surface, and area of 1 meter by 1 meter with a soil depth of 15 cm. A scan speed of 1 meter per second is assumed. MicroShield calculations are provided in Attachment B. The calculated fluence values are based an average discrete 1 cm<sup>2</sup> area at the center of the detectors and at the corner of one of the detectors. See Table 5, Calibration Data (Soil Matrix) for additional information.

Typical background data referenced in this document were obtained from 300 one-second data collections. These values may or may not represent actual site conditions. Actual background data from the survey site should be used to calculate average and standard deviation values using the methodology noted below.

**Table 5, Calibration Correlation (Soil Matrix)**

<b>Radionuclide</b>	<b>ROI</b>	<b>Gamma Energy (keV)</b>	<b>Activity (pCi/g)</b>	<b>Calculated Fluence gammas/cm<sup>2</sup>/sec (middle/detector corner)</b>	<b>Efficiency – (net cps per 1 gamma/cm<sup>2</sup>/sec) (Table 1)</b>	<b>Calculated net cps Response (1pCi/g)</b>
Ra-226	Gross	45 - 1980	1	0.51 (0.64/0.37)	716	361.6
Ra-226	609 keV	546 - 666	1	0.10 (0.13/0.1)	338	34.9
Ra-226	1764 keV	1659 - 1860	1	0.04 (0.05/0.03)	210	8.4

## DETECTION CALCULATIONS FOR RA-226 POINT SOURCES AND SOIL MATRIX

### 609 keV Bi-214 ROI – Soil Matrix

For the purposes of calculating a typical detection limit, an average background value for 609 keV ROI from the Bi-214 (Ra-226 progeny) peak was 161.1 cps with a standard deviation of 12 cps. Background ambient radiation levels were 6  $\mu$ R/hr. This equates to the following detection limits:

Background + 2 $\sigma$ (24 net cps)	=	0.70 pCi/g
Background + 3 $\sigma$ (36 net cps)	=	1.03 pCi/g
Background + 6 $\sigma$ (72 net cps)	=	2.10 pCi/g

### 609 keV Bi-214 ROI – Point Source on Surface

For the purposes of calculating a typical detection limit, an average background value for 609 keV ROI from the Bi-214 (Ra-226 progeny) peak was 161.1 cps with a standard deviation of 12 cps. Background ambient radiation levels were 6  $\mu$ R/hr. This equates to the following detection limits:

Background + 2 $\sigma$ (24 net cps)	=	0.10 $\mu$ Ci
Background + 3 $\sigma$ (36 net cps)	=	0.15 $\mu$ Ci
Background + 6 $\sigma$ (72 net cps)	=	0.30 $\mu$ Ci

### 1764 keV Bi-214 ROI– Soil Matrix

For the purposes of calculating a typical detection limit, an average background value for 1764 keV ROI from the Bi-214 (Ra-226 progeny) peak was 23.4 cps with a standard deviation of 5 cps. Background ambient radiation levels were 6  $\mu$ R/hr. This equates to the following detection limits:

Background + 2 $\sigma$ (10 net cps)	=	1.19 pCi/g
Background + 3 $\sigma$ (15 net cps)	=	1.80 pCi/g
Background + 6 $\sigma$ (30 net cps)	=	3.57 pCi/g

### 1764 keV Bi-214 ROI– Point Source on Surface

For the purposes of calculating a typical detection limit, an average background value for 1764 keV ROI from the Bi-214 (Ra-226 progeny) peak was 23.4 cps with a standard deviation of 5 cps. Background ambient radiation levels were 6  $\mu$ R/hr. This equates to the following detection limits:

Background + 2 $\sigma$ (10 net cps)	=	0.17 $\mu$ Ci
Background + 3 $\sigma$ (15 net cps)	=	0.25 $\mu$ Ci
Background + 6 $\sigma$ (30 net cps)	=	0.51 $\mu$ Ci

### Gross ROI– Soil Matrix

For the purposes of calculating a typical detection limit, an average background value for Gross ROI was 3349 cps with a standard deviation of 57.9 cps. Background ambient radiation levels were 6  $\mu\text{R/hr}$ . Care should be taken due to the easily-attenuated low energy photons used to calculate the fluence conversion factors. This equates to the following detection limits:

Background + $2\sigma$ (116 net cps)	=	0.32 pCi/g
Background + $3\sigma$ (174 net cps)	=	0.48 pCi/g
Background + $6\sigma$ (347 net cps)	=	0.96 pCi/g

### Gross ROI– Point Source on Surface

For the purposes of calculating a typical detection limit, an average background value for Gross ROI was 3349 cps with a standard deviation of 57.9 cps. Background ambient radiation levels were 6  $\mu\text{R/hr}$ . Care should be taken due to the easily-attenuated low energy photons used to calculate the fluence conversion factors.. This equates to the following detection limits:

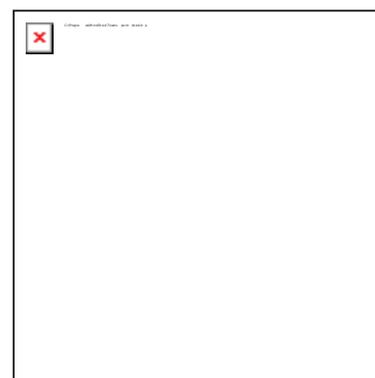
Background + $2\sigma$ (116 net cps)	=	0.05 $\mu\text{Ci}$
Background + $3\sigma$ (174 net cps)	=	0.07 $\mu\text{Ci}$
Background + $6\sigma$ (347 net cps)	=	0.14 $\mu\text{Ci}$

**Appendix A**  
**Radium 226 MicroShield Modeling**

**MicroShield 7.00**  
**Dept. of Health Services (06-msd-7.00-1126)**

<b>Date</b>	<b>By</b>	<b>Checked</b>	
<b>Filename</b>	<b>Run Date</b>	<b>Run Time</b>	<b>Duration</b>
radium point mshield.ms6	November 29, 2009	8:40:47 AM	00:00:00
<b>Project Info</b>			
Case Title	Ra-226 1 $\mu$ Ci Pt		
Description	1 $\mu$ Ci Ra-226 point source over 1m by 1m		
Geometry	13 - Rectangular Volume		

<b>Source Dimensions</b>			
Length	1.0 cm (0.4 in)		
Width	100.0 cm (3 ft 3.4 in)		
Height	100.0 cm (3 ft 3.4 in)		
<b>Dose Points</b>			
<b>A</b>	<b>X</b>	<b>Y</b>	<b>Z</b>
#1	28.5 cm (11.2 in)	50.0 cm (1 ft 7.7 in)	50.0 cm (1 ft 7.7 in)
<b>Shields</b>			
<b>Shield N</b>	<b>Dimension</b>	<b>Material</b>	<b>Density</b>
Source	1.00e+04 cm <sup>3</sup>	Air	0.00122
Air Gap		Air	0.00122



**Source Input: Grouping Method - Linear Energy**  
**Number of Groups: 25**  
**Lower Energy Cutoff: 0.015**  
**Photons < 0.015: Included**  
**Library: Grove**

<b>Nuclide</b>	<b>Curies</b>	<b>Becquerels</b>	<b><math>\mu</math>Ci/cm<sup>3</sup></b>	<b>Bq/cm<sup>3</sup></b>
Bi-210	2.9582e-008	1.0945e+003	2.9582e-006	1.0945e-001
Bi-214	9.9937e-007	3.6977e+004	9.9937e-005	3.6977e+000
Pb-210	3.0180e-008	1.1167e+003	3.0180e-006	1.1167e-001
Pb-214	9.9937e-007	3.6977e+004	9.9937e-005	3.6977e+000
Po-210	1.5755e-008	5.8295e+002	1.5755e-006	5.8295e-002
Po-214	9.9916e-007	3.6969e+004	9.9916e-005	3.6969e+000
Po-218	9.9957e-007	3.6984e+004	9.9957e-005	3.6984e+000
Ra-226	9.9957e-007	3.6984e+004	9.9957e-005	3.6984e+000
Rn-222	9.9957e-007	3.6984e+004	9.9957e-005	3.6984e+000

<b>Buildup: The material reference is Source Integration Parameters</b>					
X Direction					10
Y Direction					20
Z Direction					20
<b>Results</b>					
<b>Energy (MeV)</b>	<b>Activity (Photons/sec)</b>	<b>Fluence Rate MeV/cm<sup>2</sup>/sec No Buildup</b>	<b>Fluence Rate MeV/cm<sup>2</sup>/sec With Buildup</b>	<b>Exposure Rate mR/hr No Buildup</b>	<b>Exposure Rate mR/hr With Buildup</b>
0.0516	1.478e+04	3.037e-02	3.095e-02	7.614e-05	7.757e-05
0.1862	1.213e+03	9.018e-03	9.098e-03	1.566e-05	1.580e-05
0.2798	1.040e+04	1.162e-01	1.170e-01	2.184e-04	2.198e-04
0.3527	1.405e+04	1.981e-01	1.992e-01	3.823e-04	3.845e-04
0.4644	6.642e+02	1.234e-02	1.239e-02	2.419e-05	2.430e-05
0.5579	2.336e+02	5.214e-03	5.235e-03	1.021e-05	1.025e-05
0.6112	1.769e+04	4.327e-01	4.343e-01	8.437e-04	8.469e-04
0.7646	2.760e+03	8.450e-02	8.477e-02	1.616e-04	1.621e-04
0.817	7.337e+02	2.400e-02	2.407e-02	4.554e-05	4.567e-05
0.9363	1.367e+03	5.127e-02	5.141e-02	9.551e-05	9.576e-05
1.0605	2.229e+02	9.471e-03	9.495e-03	1.727e-05	1.732e-05
1.1298	7.620e+03	3.449e-01	3.457e-01	6.212e-04	6.227e-04
1.2359	2.367e+03	1.172e-01	1.175e-01	2.071e-04	2.075e-04
1.2827	5.922e+02	3.044e-02	3.050e-02	5.330e-05	5.341e-05
1.3908	3.240e+03	1.806e-01	1.809e-01	3.099e-04	3.106e-04
1.5173	1.106e+03	6.723e-02	6.736e-02	1.128e-04	1.130e-04
1.623	9.158e+02	5.958e-02	5.969e-02	9.807e-05	9.825e-05
1.7581	7.042e+03	4.963e-01	4.971e-01	7.982e-04	7.996e-04
1.846	9.159e+02	6.778e-02	6.789e-02	1.074e-04	1.076e-04
1.8833	1.496e+02	1.130e-02	1.131e-02	1.779e-05	1.782e-05
2.1186	4.342e+02	3.689e-02	3.694e-02	5.601e-05	5.609e-05
2.2042	1.843e+03	1.629e-01	1.631e-01	2.442e-04	2.445e-04
2.2934	1.204e+02	1.107e-02	1.109e-02	1.639e-05	1.641e-05
2.4479	5.765e+02	5.659e-02	5.667e-02	8.201e-05	8.212e-05
<b>Totals</b>	<b>9.104e+04</b>	<b>2.616e+00</b>	<b>2.624e+00</b>	<b>4.615e-03</b>	<b>4.629e-03</b>

MicroShieW 00 06-ms -W00-1126) W

Dept of Health Services W

Results With BuiWup W

FILE: C:\ra mapping\ra mapping rs 01\Ra-226 Eric \ra ium point mshieW ms6W

Case Title: Ra-226 1  $\mu$ Ci Pt W

This case was run on Sunday, November 29, 2009 at 8:40:4 WAMW

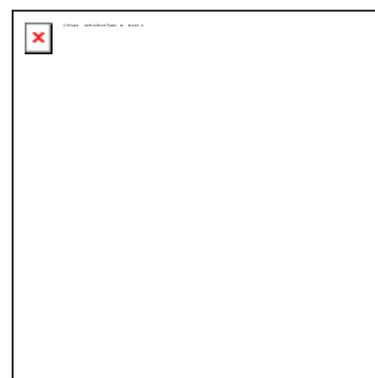
Dose Point # 1 - 28 5,50,50) cmW

Group #W	Energy W MeV W	Activity W photons/secW	Fluence RateW photons/cm <sup>2</sup> / W secW	Energy FluenceW MeV/cm <sup>2</sup> /secW	Exposure RateW mR/hrW
1	0.0516	1.47 004	5. -001	3.0 5 -00	7.757 -005
	0.1 6	1. 13 003	4. 6 -00	.0 -003	1.5 0 -005
3	0. 7	1.040 004	4.1 -001	1.170 -001	.1 -004
4	0.35 7	1.405 004	5.64 -001	1. -001	3. 45 -004
5	0.4644	6.64 00	.66 -00	1. 3 -00	.430 -005
6	0.557	.336 00	.3 3 -003	5. 35 -003	1.0 5 -005
7	0.611	1.76 004	7.107 -001	4.343 -001	.46 -004
	0.7646	.760 003	1.10 -001	.477 -00	1.6 1 -004
	0. 17	7.337 00	. 46 -00	.407 -00	4.567 -005
10	0. 363	1.367 003	5.4 0 -00	5.141 -00	.576 -005
11	1.0605	. 00	. 53 -003	.4 5 -003	1.73 -005
1	1.1	7.6 0 003	3.060 -001	3.457 -001	6. 7 -004
13	1. 35	.367 003	.506 -00	1.175 -001	.075 -004
14	1. 7	5. 00	.37 -00	3.050 -00	5.341 -005
15	1.3 0	3. 40 003	1.301 -001	1. 0 -001	3.106 -004
16	1.5173	1.106 003	4.43 -00	6.736 -00	1.130 -004
17	1.6 3	.15 00	3.677 -00	5. 6 -00	. 5 -005
1	1.75 1	7.04 003	. -001	4. 71 -001	7. 6 -004
1	1. 46	.15 00	3.67 -00	6.7 -00	1.076 -004
0	1. 33	1.4 6 00	6.007 -003	1.131 -00	1.7 -005
	.11 6	4.34 00	1.744 -00	3.6 4 -00	5.60 -005
3	. 04	1. 43 003	7.3 -00	1.631 -001	.445 -004
4	. 34	1. 04 00	4. 35 -003	1.10 -00	1.641 -005
5	.447	5.765 00	.315 -00	5.667 -00	. 1 -005
<b>TOTALS: W</b>		<b>9 104e+004 W</b>	<b>3 663e+000W</b>	<b>2 624e+000W</b>	<b>4 629e-003 W</b>

**MicroShield 7.00**  
**Dept. of Health Services (06-msd-7.00-1126)**

<b>Date</b>	<b>By</b>	<b>Checked</b>	
<b>Filename</b>	<b>Run Date</b>	<b>Run Time</b>	<b>Duration</b>
radium soil mshield.ms6	November 29, 2009	8:26:43 AM	00:00:02
<b>Project Info</b>			
Case Title	Ra-226 Soil		
Description	Ra-226 1 pCi/g - 1 g/cc 1m by 1m by 15 cm		
Geometry	13 - Rectangular Volume		

<b>Source Dimensions</b>			
Length	15.0 cm (5.9 in)		
Width	100.0 cm (3 ft 3.4 in)		
Height	100.0 cm (3 ft 3.4 in)		
<b>Dose Points</b>			
<b>A</b>	<b>X</b>	<b>Y</b>	<b>Z</b>
#1	42.5 cm (1 ft 4.7 in)	50.0 cm (1 ft 7.7 in)	50.0 cm (1 ft 7.7 in)
<b>Shields</b>			
<b>Shield N</b>	<b>Dimension</b>	<b>Material</b>	<b>Density</b>
Source	1.50e+05 cm <sup>3</sup>	Igneous	1.5
Air Gap		Air	0.00122



**Source Input: Grouping Method - Linear Energy**  
**Number of Groups: 25**  
**Lower Energy Cutoff: 0.015**  
**Photons < 0.015: Included**  
**Library: Grove**

<b>Nuclide</b>	<b>Curies</b>	<b>Becquerels</b>	<b>μCi/cm<sup>3</sup></b>	<b>Bq/cm<sup>3</sup></b>
Bi-210	6.6560e-009	2.4627e+002	4.4373e-008	1.6418e-003
Bi-214	2.2486e-007	8.3198e+003	1.4991e-006	5.5465e-002
Pb-210	6.7905e-009	2.5125e+002	4.5270e-008	1.6750e-003
Pb-214	2.2486e-007	8.3198e+003	1.4991e-006	5.5465e-002
Po-210	3.5449e-009	1.3116e+002	2.3633e-008	8.7442e-004
Po-214	2.2481e-007	8.3180e+003	1.4987e-006	5.5454e-002
Po-218	2.2490e-007	8.3214e+003	1.4994e-006	5.5476e-002
Ra-226	2.2490e-007	8.3214e+003	1.4994e-006	5.5476e-002
Rn-222	2.2490e-007	8.3214e+003	1.4994e-006	5.5476e-002

<b>Buildup: The material reference is Source Integration Parameters</b>					
X Direction					10
Y Direction					20
Z Direction					20
<b>Results</b>					
<b>Energy (MeV)</b>	<b>Activity (Photons/sec)</b>	<b>Fluence Rate MeV/cm<sup>2</sup>/sec No Buildup</b>	<b>Fluence Rate MeV/cm<sup>2</sup>/sec With Buildup</b>	<b>Exposure Rate mR/hr No Buildup</b>	<b>Exposure Rate mR/hr With Buildup</b>
0.0516	3.326e+03	5.446e-04	5.525e-03	1.365e-06	1.385e-05
0.1862	2.729e+02	4.517e-04	1.635e-03	7.844e-07	2.838e-06
0.2798	2.340e+03	6.641e-03	2.105e-02	1.248e-05	3.955e-05
0.3527	3.161e+03	1.217e-02	3.585e-02	2.349e-05	6.921e-05
0.4644	1.494e+02	8.262e-04	2.232e-03	1.620e-06	4.377e-06
0.5579	5.256e+01	3.699e-04	9.431e-04	7.244e-07	1.847e-06
0.6112	3.981e+03	3.158e-02	7.825e-02	6.157e-05	1.526e-04
0.7646	6.211e+02	6.610e-03	1.527e-02	1.264e-05	2.920e-05
0.817	1.651e+02	1.916e-03	4.338e-03	3.635e-06	8.230e-06
0.9363	3.076e+02	4.267e-03	9.264e-03	7.950e-06	1.726e-05
1.0605	5.016e+01	8.187e-04	1.711e-03	1.493e-06	3.121e-06
1.1298	1.714e+03	3.038e-02	6.229e-02	5.473e-05	1.122e-04
1.2359	5.327e+02	1.061e-02	2.117e-02	1.873e-05	3.740e-05
1.2827	1.332e+02	2.784e-03	5.497e-03	4.875e-06	9.626e-06
1.3908	7.290e+02	1.691e-02	3.261e-02	2.902e-05	5.597e-05
1.5173	2.488e+02	6.450e-03	1.214e-02	1.082e-05	2.036e-05
1.623	2.061e+02	5.822e-03	1.076e-02	9.584e-06	1.771e-05
1.7581	1.585e+03	4.954e-02	8.959e-02	7.969e-05	1.441e-04
1.846	2.061e+02	6.852e-03	1.223e-02	1.086e-05	1.939e-05
1.8833	3.366e+01	1.148e-03	2.039e-03	1.808e-06	3.212e-06
2.1186	9.770e+01	3.860e-03	6.657e-03	5.861e-06	1.011e-05
2.2042	4.146e+02	1.721e-02	2.939e-02	2.580e-05	4.407e-05
2.2934	2.709e+01	1.181e-03	1.998e-03	1.748e-06	2.958e-06
2.4479	1.297e+02	6.127e-03	1.021e-02	8.879e-06	1.480e-05
<b>Totals</b>	<b>2.048e+04</b>	<b>2.251e-01</b>	<b>4.727e-01</b>	<b>3.901e-04</b>	<b>8.339e-04</b>

**MicroShieW 00 06-ms -W00-1126) W**  
**Dept of Health Services W**  
**Results With BuiWup W**  
**FILE: C:\ra mapping\ra mapping rsi rs 01\Ra-226 Eric \ra ium soiWnshieW ms6W**  
**Case Title: Ra-226 SoiW**  
**This case was run on Sunday, November 29, 2009 at 8:26:43 AMW**  
**Dose Point # 1 - 42 5,50,50) cmW**

Group #W	Energy W MeV W	Activity W photons/secW	Fluence RateW photons/cm <sup>2</sup> / W secW	Energy FluenceW MeV/cm <sup>2</sup> /secW	Exposure RateW mR/hrW
1	0.0516	3.3 6 003	1.070 -001	5.5 5 -003	1.3 5 -005
	0.1 6	.7 00	.77 -003	1.635 -003	. 3 -006
3	0. 7	.340 003	7.5 4 -00	.105 -00	3. 55 -005
4	0.35 7	3.161 003	1.017 -001	3.5 5 -00	6. 1 -005
5	0.4644	1.4 4 00	4. 06 -003	. 3 -003	4.377 -006
6	0.557	5. 56 001	1.6 0 -003	.431 -004	1. 47 -006
7	0.611	3. 1 003	1. 0 -001	7. 5 -00	1.5 6 -004
	0.7646	6. 11 00	1. -00	1.5 7 -00	. 0 -005
	0. 17	1.651 00	5.30 -003	4.33 -003	. 30 -006
10	0. 363	3.076 00	. 4 -003	. 64 -003	1.7 6 -005
11	1.0605	5.016 001	1.613 -003	1.711 -003	3.1 1 -006
1	1.1	1.714 003	5.514 -00	6. -00	1.1 -004
13	1. 35	5.3 7 00	1.713 -00	.117 -00	3.740 -005
14	1. 7	1.33 00	4. 5 -003	5.4 7 -003	.6 6 -006
15	1.3 0	7. 0 00	.345 -00	3. 61 -00	5.5 7 -005
16	1.5173	.4 00	.000 -003	1. 14 -00	.036 -005
17	1.6 3	.061 00	6.6 7 -003	1.076 -00	1.771 -005
1	1.75 1	1.5 5 003	5.0 6 -00	. 5 -00	1.441 -004
1	1. 46	.061 00	6.6 7 -003	1. 3 -00	1. 3 -005
0	1. 33	3.366 001	1.0 3 -003	.03 -003	3. 1 -006
	.11 6	.770 001	3.14 -003	6.657 -003	1.011 -005
3	. 04	4.146 00	1.333 -00	. 3 -00	4.407 -005
4	. 34	.70 001	.713 -004	1. -003	. 5 -006
5	.447	1. 7 00	4.17 -003	1.0 1 -00	1.4 0 -005
<b>TOTALS: W</b>		<b>2 048e+004 W</b>	<b>6 588e-001 W</b>	<b>4 W2W6-001 W</b>	<b>8 339e-004 W</b>