RADIATIONS SOLUTIONS, INC.
RS 700 SYSTEM OVERVIEW

SET-UP, PARAMETERS, DATA PATH, ANALYSIS

V. BRANDT

May 3, 2011

This page intentionally left blank.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS, DEFINITIONS AND EQUATIONS

AC	Asphalt concrete, commonly called asphalt, is concrete consisting of aggregate rock and a bitumous binder
CoV	Coefficient of Variation = $\frac{Standard\ Deviation\ of\ measurements}{Average\ of\ measurements}$ Predicted CoV = $\frac{\sqrt{Average\ of\ measurements}}{Average\ of\ measurements}$
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
σ	Sigma is the standard deviation, Std. Dev. of the measurements of interest.
Std. Dev.	Standard Deviation, $\sigma = \sqrt{\frac{(x_i - \bar{x})}{N - 1}}$ 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 σ 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 console multi-channel analyzer (MCA) and a laptop computer for real-time gamma ray and GPS position monitoring and data collection.

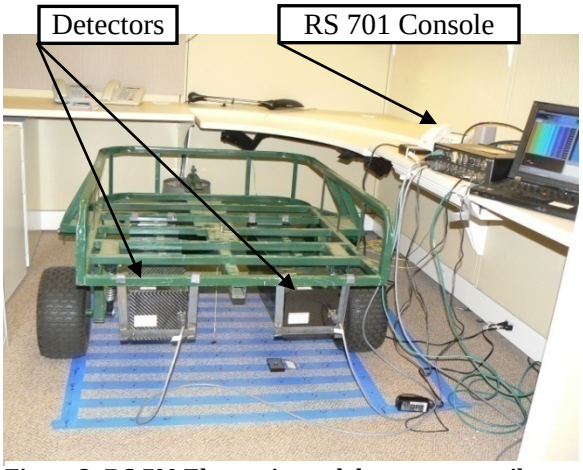


Figure 2: RS 700 Electronics and detectors on trailer

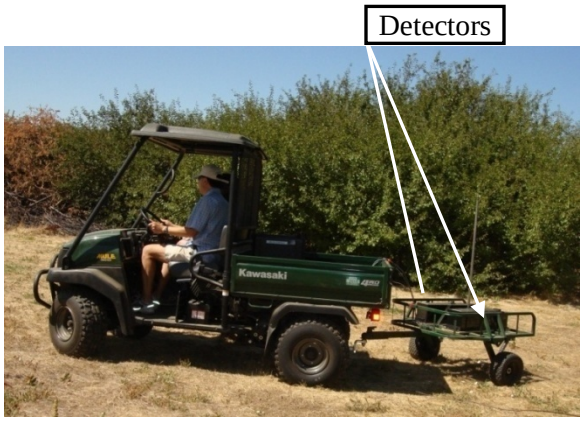


Figure 1: RS 700 Mapping system (towed array)

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 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	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

Manufacturer	Model	Serial Number	Function
Radiations Solutions, Inc.	RS 701	7017	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 laptop computer, RS232 cable for connecting the GPS antenna to the RS 701 console, laptop computer with power cord, and mouse (optional).

- **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:

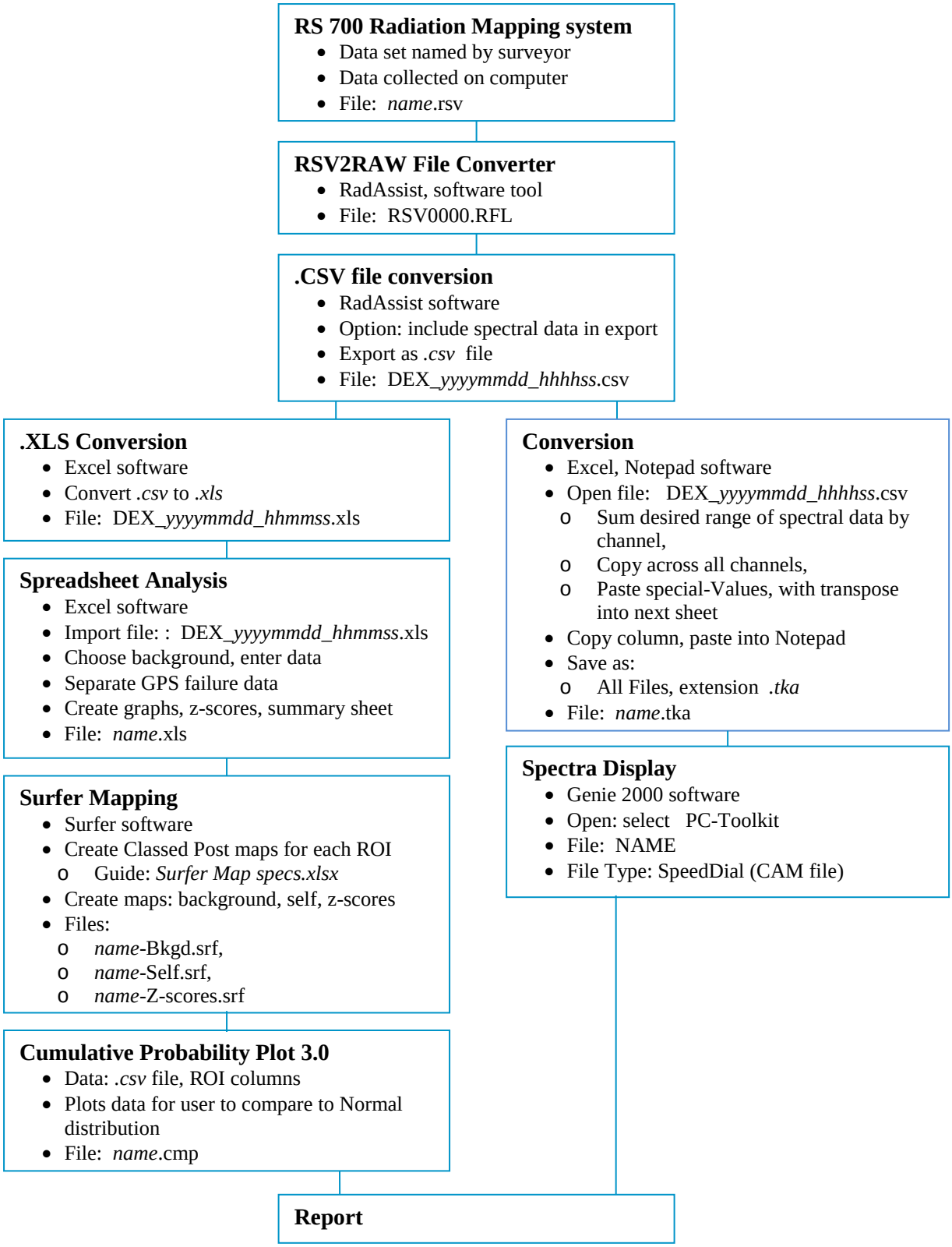
1. *RSV to RAW File Conversion*-proprietary software tool, part of the RadAssist software package, which formats the data for RadAssist to open and to export. Creates *.RFL* file or files depending on the number of 1-second data sets. These files are placed in the same folder as the original *.rsv* file.
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.*

   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 and should be investigated further.

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. Radiations Systems 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; *Surfer* (map plotting software) and *Cumulative Probability Plot 3.0* (software to compare data values to normal distribution as a function of slope in a two-axis graph). Spectral data was also examined using the *Genie 2000* and *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 an 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.

- **CUMULATIVE PROBABILITY PLOTS**

The cumulative probability plots are graphical representation for assessing whether data is approximately normally distributed. Elevated measurements are represented by circles at the right side of the graph, which are much farther from the slope line than the other graph points, for example four to six circle diameters, or greater, above the line.

APPENDIX A: TECHNICAL BASIS DOCUMENT FOR THE CA RADIOLOGICAL HEALTH BRANCH RS-701 RADIATION MAPPING SYSTEM; RADIUM 226