

APPLICATION OF AUTOMATED POSITIONING DURING THE SURVEY PROCESS

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Radiological surveys are a time-consuming component of the total decommissioning process. Manual gridding is the common and accepted method currently used by survey teams to give spatial significance to the measured levels of radiation found during on-site surveys. However, the gridding process requires substantial person-hours of labor and is not conducive to real-time data analysis and assessment. In addition, several technical forms pertaining to the results acquired during the survey must be completed manually as a part of the final decommissioning report. The purpose of this research was to develop an automated, computer-based system of performing radiological surveys. A special emphasis was placed on designing the unit for indoor operations. The system was used to determine the spatial data automatically, thus eliminating the need for manual gridding and manual calculations.

Five positioning techniques (ultrasonic positioning, mouse-traverse ranging, laser positioning, inertial navigation ranging, and global positioning) were evaluated prior to the beginning of this project for cost-effectiveness, accuracy, applicability, and overall merit. The two most cost-effective techniques were determined to be ultrasonic positioning and mouse-traverse ranging. These two techniques were coupled, via computer hardware and software, with the necessary detection instrumentation to make of a totally integrated field survey system.

The two positioning techniques were piloted under different circumstances in the field. The most noteworthy application came about during the characterization of a formerly used radiochemical instrumentation laboratory. Both types of positioning provided accurate spatial data for approximately twice as many sampling points in about 40% the time required to perform the survey manually. However, it was determined that the initial costs, lack of ruggedness, and range limitation were the major drawbacks associated with the automated approach.

In summary, a technique for integrating automated positioning into the survey process was elucidated. The system, whether employing either the mouse-traverse or the ultrasonic positioning technique, reduced the time required to perform an accurate survey. In addition, the data handling, control, and management capabilities of the system made it possible to manipulate and report survey results in a more timely fashion. However, it was determined that the field performance of the integrated system was not optimal and could be enhanced through modifications directed at increasing user-friendliness, system ruggedness, and transducer ranging capabilities.

INTRODUCTION

For almost 50 years the U.S. has produced materials for nuclear weapons. With these activities, the generation of radioactive wastes has frequently contaminated sites (DOE, 1991; ORISE, 1993). The U.S. Department of Energy (DOE) has been given the challenge of identifying, managing, and cleaning-up these contaminated locations. This responsibility has resulted in the formation of a 5-year strategic plan: The Environmental Restoration and Waste Management Five-Year Plan. Through this effort, DOE's mission is to eliminate potential radiological hazards to the public and the environment by returning these locations to acceptable use up radioactive waste sites (DOE, 1992). In addition, on recommendations from the State and Tribal Government Working Group, DOE committed to a 30-year goal for the clean-up of all present inventories of inactive sites (EPA, 1993). This long-term strategy is focused on eliminating or reducing potential risks to workers, the public, and the environment. To meet this objective, DOE plans to develop new technologies for containing, isolating, removing, and detoxifying on-site and off-site contamination.

The Formerly Utilized Sites Remedial Action Program (FUSRAP) has been funded by DOE for clean-up of locations that have existing radioactivity as a resultant from operations conducted by the Manhattan Engineer District (MED). The most common radionuclides found on these sites are uranium-238, thorium-232, and their daughters (Hickey et al., 1988). Remedial measures at these sites quite frequently are concentrated indoors in vacated buildings. The four major tasks of FUSRAP are to designate, characterize, remediate, and verify the radioactive nature of a site and, with each of these tasks, there is an associated survey requirement.

In addition to remediating the radiological hazardous confines and sites directly associated with weapons development, DOE has the added responsibility of controlling, and subsequently, eliminating the potential radiation health hazard posed by the uranium mill tailings located at active and inactive uranium mills (Federal Register, 1983). It is estimated that approximately 12,000 surveys will be performed in close proximity to the 24 inactive mill sites (Little et al., 1988). At these mill sites, as well as at the previously discussed indoor facilities and outdoor waste sites, it is essential to perform radiological surveys in order to properly characterize and manage the release of potentially hazardous radiation from the uranium and plutonium decay chains. Other possible sites where radiological characterizations and assessments are required include gaseous diffusion and enrichment facilities, medical laboratories, private enterprises, etc. Thus, a means of optimizing the efficiency and effectiveness of such radiological monitoring and surveying is an imperative.

Current contaminated locations are found either in indoor development/storage facilities or at outdoor geological sites. It is approximated that 80% of past remediation efforts have been aimed at outdoor-contaminated sites while only 20% of the efforts have been directed at indoor contaminated facilities. A current breakdown of the radioactive waste sites designated for clean-up includes 15,000 Department of Defense sites, 9000 DOE sites, 422 Department of Interior sites, 96 Department of Agriculture sites and one location managed by the NOAA (EPA, 1993). For all of these identified locations, an essential component of the decontamination and decommissioning effort, whether inside

a building or outside on a controlled plot of ground, is the radiological survey (DOE, 1992; Berger, 1992; ORNL, 1992).

The objective of the radiological survey is to determine if either a contamination is present, or, if a source is known to be present, to identify and monitor the levels of radiation in the area and compare the results with regulatory criteria (NRC, 1982; NRC, 1974; DOE, 1991; DOE, 1992). However, radiological surveys are a time consuming component of the total decommissioning process. Manual methods of performing surveys involve tedious and somewhat primitive recording methods. They require substantial man-hours tied up in survey technicians and, in addition, are not conducive to real-time data analysis and evaluation.

Various means of portably detecting and measuring levels of gamma, alpha. And beta radiation have been well tested and documented. A means of enhancing the radiological survey by simultaneously and portably collecting, storing, and analyzing both positional and exposure data, while still in the field, would be much more efficient than current survey techniques. Methods of automating the survey process at outdoor sites by using computers and ultrasonics have been proposed and field tested (Berven et al., 1991; ChemRad 1992; Policastro, 1992; Wendling and Wade, 1994). But, as of this date, a total integrated technique with the necessary accuracy indoors has not been tested.

The purpose of this research is to introduce an automated radiological survey methodology developed for performing site remediation and decommissioning. This integrated system makes it possible to efficiently and effectively monitor, collect, and analyze data from indoor-contaminated sites in real-time. Thus, a more intelligent site assessment, and consequential, remediation effort can be made. In addition, the system provides a viable technique for performing the confirmatory surveys after the necessary decontamination has been completed. This method of automating and making portable the radiological survey process could provide DOE with a viable means for mastering the indoor decommissioning component of its 30-year compliance and clean-up goal.

METHODS

System Development

The original conception of the automated survey system came after the survey of the uranium recovery facility in 1991. Based upon the experiences learned from the uranium recovery facility survey. The optimum design included many components that would comprise a totally integrated approach to the survey and decommissioning process.

For the system to be automated, it would be an imperative to have computer control. It would also be necessary to determine the appropriate software, hardware, positioning equipment, and detecting instrumentation. In addition, these components would require proper integration. Hence, in the initial planning phase of this project. It was necessary to establish selection criteria for these components. Based on these criteria, the following components were chosen:

1. Notebook Computer
2. Visual Basic Application Software
3. Stanford Graphics
4. PCMCIA Data Acquisition Card
5. Ratemeter/Datalogger with Gamma and Alpha Detectors
6. Ultrasonic Positioning Transducer

7. Mouse Trackball

The system components and interfaces are shown in Figure 1 while the constructed survey apparatus is illustrated in Figure 2.

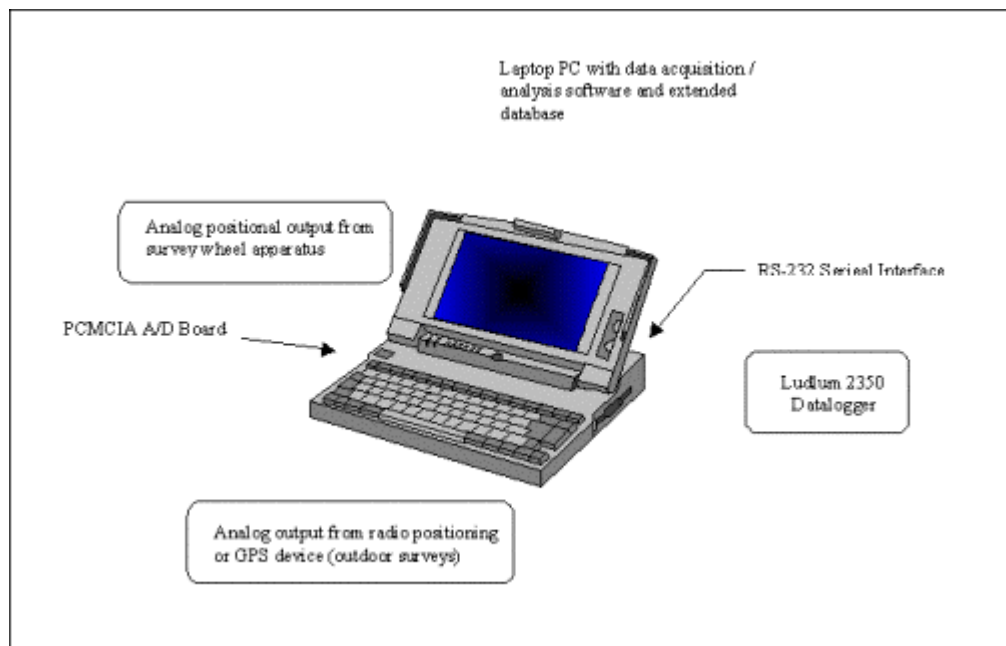


Figure 1. System interfaces.

System Field Implementation

After the system design, development, and procedures was completed, the next logical step was to pilot the technique at an indoor site with a high potential for radioactive contamination. The experimental design would include comparisons between the two automated positioning techniques and the current manual methods employed by survey technicians. It was determined that the ideal location would be one with several rooms of varying sizes. In addition, the site should be one where some initial survey data was available for evaluation for contaminant type and levels.

A site was located that met the above criteria. The location was an instrumentation building located on-site at a facility used for the processing of uranium 238. Arrangements were made to bring the equipment on location and to secure the services of two health physics survey technicians. The technicians were to provide technical expertise and to help with the manual surveys. The rooms in the building varied from very small (e.g., 10 ft. X 10 ft.) to surface areas of 400 meters-squared. Some of the rooms were tiled while others were carpeted.

Since the facility was used for the processing of uranium-238, the expected contaminants were alpha emitters from the U-238 decay chain (i.e., U-238, U-234, Th-230, etc.). Previously, a gamma scan was performed to determine relative levels of contamination. While most of the rooms had some residual contamination, it was



Figure 2. Original survey apparatus design

documented that the levels were low. Due to time constraints (i.e., outsiders were required to be escorted at all times), the preliminary survey planning included the decision to perform only alpha floor surveys and to limit the number of rooms to be surveyed. In addition, it was determined that the type of survey to be performed on-site would be only alpha characterization surveys, utilizing only the manual, ultrasonic (automated), and mouse-traverse (automated) techniques.

Specifically, the main objective of performing the surveys was to test the automated techniques for their viability in the field. In essence, it was necessary to follow the previously outlined procedures and quality assurance techniques to determine if or not the automated system would provide a more effective and time efficient method of performing indoor surveys. Thus, in order to do so, the experimental design needed to include statistical ways of comparing the automated survey system to the traditional, manual methods of performing the indoor survey. The purpose of the rest of this chapter is to elucidate the methods and procedures used during the evaluation, to present the data and results with statistically-sound comparisons, and to provide a discussion of the system performance and viability in the field.

Pre-survey planning included the review of available drawings of the rooms in the facility. It was determined that a good experimental design would be one that included surveys from rooms of varying size. However, since there were no large rooms in the building (i.e., $>100 \text{ m}^2$) the data from the smaller rooms would have to be utilized for data extrapolation and experimental inference. The drawings indicated that most of the rooms at the location were of a rectangular geometry. In addition, sources revealed that the rooms were all primarily free of equipment and obstructions.

The main components of the survey apparatus included a NEC 486 notebook computer with a configured National Instruments DAQ-700TM PCMCIA data acquisition

card, a Ludlum Model 2350 Ratemeter/DataloggerTM, a Ludlum Model 43-89 Alpha Scintillation DetectorTM, and the two spatial positioning assemblies (i.e., ultrasonic positioning and mouse-traverse).

The necessary computer protocol modifications were made based on the site data and the techniques previously employed and outlined throughout the earlier chapters of this paper. While the normal process of performing indoor site surveys was to take five samples from each 1 m² survey unit, the system protocol was written to include nine sample points per survey unit. This not only would increase data confidence, but would also provide a more energy efficient means of collecting the data. In addition, the nine points could help to serve as justification for not needing to sample in the difficult to get to corner and wall areas (i.e., only six points are taken in the one meter square area defined by one or more walls/surfaces).

The Environmental Survey software, written in Microsoft Visual BasicTM was developed to include a spreadsheet that identified spatial coordinates, cpm/100 m² dpm/100 m² survey unit average, and a 95% confidence comparison value. In addition, the software included algorithms for detector efficiency minimum detectable activity (MDA), the survey unit mean, the survey unit standard deviation, and the 95% confidence value. Code was written that would not allow a value of less than the calculated MDA to be logged. Computer forms (screens) were also created that provided for survey background counts and detector/ratemeter configuration. Since the WindowsTM software environment was used, dynamic links between the various software packages made it easy to move data to and from various software programs (e.g., Visual Basic to Microsoft AccessTM, Access to Stanford GraphicsTM, etc..)

The algorithm entered for determining the MDA was as follows:

$$MDA = \frac{2.71 + [(4.65)(Bt)^{0.5}]}{Et(A/100)}$$

where

- MDA = activity level in disintegrations/minute/100 cm²
- B = background rate in counts per minute
- t = counting time in minutes
- E = detector efficiency in counts per disintegration
- A = active probe area in cm²

Since the counting time is usually set for one minute and the active probe area of the Model 43-89 detector is 100 cm², the MDA is primarily a function of the site background rate.

The equation used to determine the 95% confidence comparison value was as follows:

$$95\%CCV = \bar{X} + 1.86[s/(n)^{0.5}]$$

where,

95%CCV = 95% confidence comparison value (positive side)

$\bar{X}$ = the mean of the data

1.86 = the t-value for sample size equal to 9

S = the standard deviation for the survey unit

n = the number of samples per survey unit

For this survey, the value for n is equal to nine and the calculation for the mean and standard deviation is dependent upon the sample measurements for each survey unit. The standard statistical equations used to determine the sample mean and the sample standard deviation are included in the computer code to determine the appropriate 95% confidence comparison value.

Prior to leaving for the site, a calibration curve was generated by using a check source of thorium-230. In order to determine the ideal high voltage value to use for the survey, an optimum threshold value must be first decided upon. A good “rule-of-thumb” on determining the threshold is to use a value that, with several subsequent measurements, a background rate of not greater than 3 dpm is found. The threshold value that met this criterion for the thorium source was 30 mV. At this threshold, the calibration curve resulted in a plateau midpoint of 850 volts. This value would be used as the survey high voltage and would be entered during the Ludlum 2350 configuration routine.

Upon arrival at the facility, it was resolved that alpha characterization surveys were to be performed on floor areas of 6 m², 12 m², 25 m², and 42 m². Due to the security and time constraints at the facility, the manual method was performed on-site by the health physics technicians and observations were made for comparison. In addition, the mouse-traverse technique and the ultrasonics positioning method were both utilized to survey the 6 m² room. However, compatible “clean” rooms off-site were used to obtain the data for the other three areas.

The operational check-out and calibration procedures were completed prior to beginning the first survey. A 20,000 dpm calibrated check source of thorium-230 was used to determine the efficiency of the detector. The procedure included taking the mean of five subsequent one-minute counts from the detector and dividing it by the calibrated value. Then, by multiplying this resultant by 100, the survey detector efficiency was attained. This value was found to be 19.6%.

A survey background rate was determined both manually and automatically. Nine points were taken from adjacent, unaffected areas. The mean of these nine samples was then used to set a baseline for determining net sample counts. In addition, the background mean is an important parameter used in the calculation of the detector MDA. The time required to measure the background readings first manually and then automatically was essentially the same.

After the detector efficiency was determined from a calibrated thorium-230 check source, the two survey technicians proceeded with a calibrated field survey meter (with attached alpha detector) to perform a quick alpha scan of the rooms to determine

potentially affected areas. The technicians then began to grid the rooms into survey units of approximately one square meter. The technicians used a calibrated field measuring tape and duct tape to grid the room. Five sample points were taken (i.e., the four corners and the midpoint) to define each survey unit. In addition, one sample location was repeated for every two survey units completed. This is in compliance with the 10% quality assurance criteria recommended for the detector. Since one of the primary contaminants was thorium-230, which has rather stringent release criteria (i.e., 100 dpm/100 cm² average), the count time was one minute for each sample. One technician operated the instrument while the other manually documented the readings. The detector was moved around the sampling area in a “snake-like” fashion for the duration of the one-minute sampling. The manual surveys were observed for time requirements and technique. After a survey was complete, the technicians calculated the required values.

After the background rate and detector efficiency was determined, each of the automated characterization surveys began with an initial tape measurement of room dimensions. Accepted procedures for operational check-out, site calibration, and standard operating procedures were followed. A special effort was made to determine values for repeatability (both spatial and magnitude) and spatial measurement error/accuracy. In order to do so, some of the sampling locations had to be specified as either control or repeat sampling locations. The control data points are defined as those points used as a means of showing spatial repeatability and accuracy. The control points are marked with a pencil or a piece of tape, and the surveyor returns to this location, during the course of the survey traverse, to determine the level of positioning repeatability. In addition, these control points are compared to actual tape measurements for accuracy.

A repeat sample point is one in which the surveyors just repeat the count with the detector/ratemeter. The repeat points are necessary as a quality control measure, required to meet the 10% repeat point criteria recommended by ORISE. The repeat points are usually taken at the midpoint location on the survey lines of adjacent survey units. Specifically, the experimental design followed for the automated techniques involved data gathering methodologies aimed at gaining an insight on the actual process viability. As was hinted to in the previous paragraph, spatial accuracy, temporal efficiency, and measurement repeatability are critical indicators of process field viability. In order to provide some indication of the viability of the automated positioning techniques for field use, the values for spatial accuracy and repeatability for the three meter by four meter room were taken.

A viability and time efficiency comparison, between the traditional manual method and the two automated techniques, was performed. This was accomplished by defining a man-hour comparison coefficient, the dependent variable, and plotting it versus the room floor area, the independent variable. Thus, an equation can be determined from the data taken from the smaller rooms to help describe the time

component for surveys of larger areas. The man-hour comparison coefficient, k , was defined as follows:

$$k = t_a / t_m$$

where,

k = man-hour comparison coefficient
 t_a = total man-hours for automated survey
 t_m = total man-hours for manual survey

Also, a time comparison was made that paired the manual technique against both of the automated techniques. These comparisons were based on the standard statistical t-test, with temporal data obtained from a typical surveyed area and defined survey unit(s). In addition, to show the real-time data analysis capabilities of the system, a real-time profile of spatial and magnitude components for a 2 meter by 3 meter room was generated on-site. The data was taken from the one-minute alpha counts at each floor location and plotted three-dimensionally by linking the database with Stanford Graphics.

Finally, a total area assessment was made by determining the population mean and standard deviation for the 6 m² area. Detector measurement repeatability was determined by repeating the one minute counts at one location in each survey unit. A relative percent difference calculation was made on this data and compared to the <20 criteria for acceptance.

DATA AND RESULTS

Spatial Accuracy and Spatial Repeatability:

The main purpose of this research was to show that automated positioning could provide an effective and efficient means of replacing the time consuming efforts involved in the manual gridding of indoor survey sites. Calculations for spatial accuracy and spatial repeatability provide two objective measures for the evaluation. Thus, spatial accuracy and repeatability data were obtained from the 12 m² survey area using both positioning techniques.

The mean accuracy for the ultrasonic positioning technique was 99.6% in the x-direction and 98.5% in the y-direction. The standard deviation was calculated to be 1.7% in the x-direction and 1.5% in the y-direction. Thus, at the 95% confidence level, the accuracy for the ultrasonic positioning technique can be stated as 99.6% +/- 0.76% in the x-direction and 98.5% +/- 0.64% in the y-direction. The 95 % confidence levels for these and the following spatial parameters were calculated by using the following equation:

$$P_{95} = \bar{X} \pm 1.96[s/(n)^{0.5}]$$

where,

P_{95} =the 95% confidence parameter desired
 $\bar{X}$ =the mean of the data
 S = standard deviation
 n = the number of samples

The mean calculated for the relative percent difference (RPD) between the control points was 0.3% in the x-direction and 0.1 % in the y-direction. The standard deviation was found to be 0.5% in the x-direction and 0.5% in the y-direction. Thus, at the 95% confidence level, the RPD for the ultrasonic positioning technique can be given as 0.3% +/- 0.2% in the x-direction and 0.1% +/- 0.2% in the y-direction.

For the mouse-traverse technique, the mean accuracy calculated for the x-direction at the 95% confidence level was 100.1% +/- 1.4% while the 95% confidence level mean in the y-direction was found to be 100.7% +/- 2.0%. The 95% confidence level RPD for the mouse-traverse technique in the x-direction was calculated to be 1.7% +/- 0.7%. The corresponding 95% level for the RPD in the y-direction was determined to be 2.7% +/- 1.2%. Table I summarizes the positioning parameters.

Table I
Ultrasonic and Mouse-Traverse Positioning Statistics

TECHNIQUE	Accuracy % X-Direction (95% CL)	Accuracy % Y-Direction (95% CL)	RPD (%) X-Direction (95% CL)	RPD (%) Y-Direction (95% CL)
Ultrasonic Positioning	99.6% +/- 0.76%	98.5% +/- 0.64%	0.3% +/- 0.2%	0.1 +/- 0.2%
Mouse- Traverse	100.1% +/- 1.4%	100.7% +/- 2.0%	1.7% +/- 0.7	2.7% +/- 1.2%

Survey Time Comparison

In order to provide some indication of the time efficiency of the automated techniques, a test was needed that would allow for the comparison of the temporal components of both of the automated survey techniques against the traditional, manual survey. In order to do so, it was necessary to define a man-hour comparison coefficient. In essence, this is just the man-hours required to perform an automated survey of a particular divided by the time required to complete the survey with the manual technique. It was determined that the optimum man-hours coefficient is approximately 0.40 for the largest of survey areas. Thus, the system can facilitate the survey of large rooms at about two and one-half times the rate of that of the manual survey. In addition, the automated survey procedure includes nearly twice as many data points for statistical analyses and site assessments.

A three-dimensional profile, generated from the spatial and magnitude data sampled during the survey is given in Figure 3. Figure 3 shows the three-dimensional plot of the data from the mouse-traverse survey of one of the survey areas. It is possible to generate these type of drawings anytime during the survey process, thus allowing for real-time, analytical assessments.

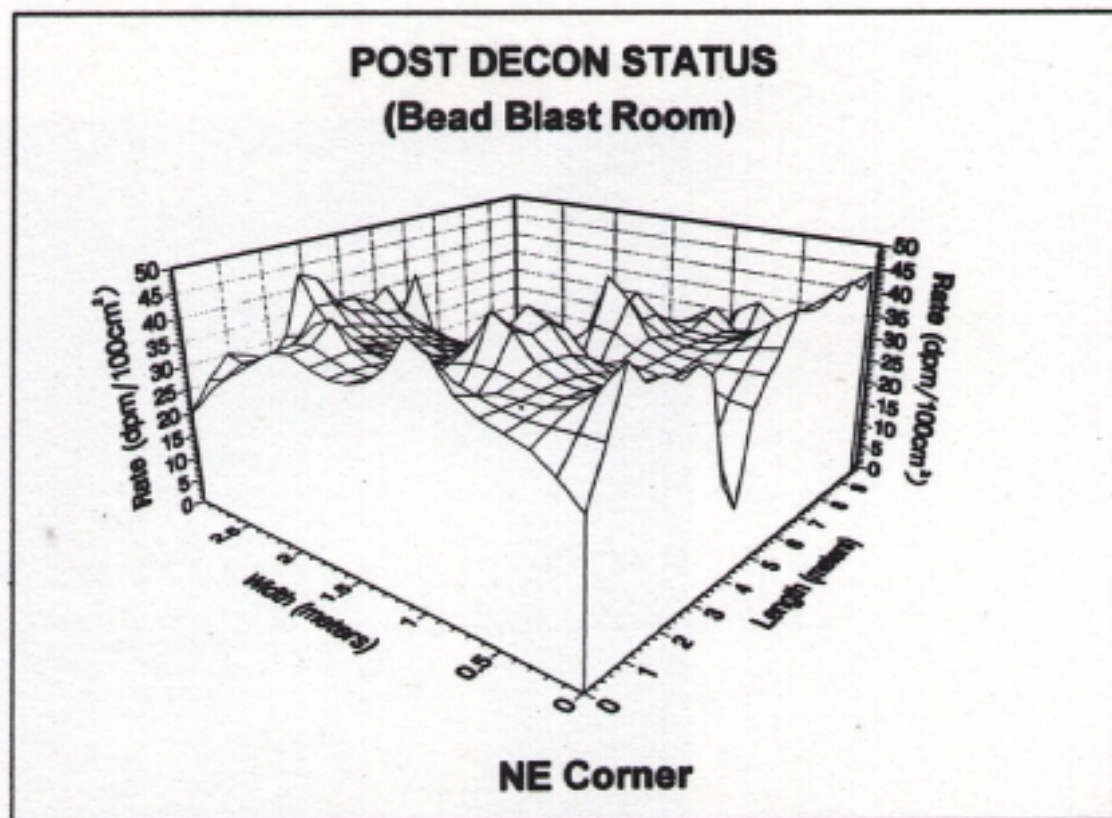


Figure 3. Contour profile from mouse-traverse survey.

Detector Repeatability

For quality control purposes, ten percent of the points sampled will be counted twice (Berger, 1992). In order for the data to be considered acceptable, the relative percent difference (RPD) between the two samples must be less than 20 (ORISE, 1993). Three out of the fifteen repeat points resulted in RPD values exceeding the 20% criteria. Thus, those three points would need to be repeated for a final status survey. The mean RPD for the data was calculated to be 12% with a standard deviation of 8%. The average RPD for the mouse-traverse 6 m² survey was calculated to be 11% with a standard deviation of 8%.

CONCLUSIONS

A list of conclusions from the field surveys is as follows:

1. Both automated techniques provide an effective and efficient means for facilitating the indoor radiological survey process.
2. Even for smaller areas, the automated techniques are viable.
3. For larger area rooms, both automated techniques provide the capability of sampling nearly twice as many points as that of the manual technique in 40% of the time.
4. The temporal characteristics of both of the automated techniques are essentially the same.
5. An equation can be developed that describes the temporal characteristics of the automated methods for larger area rooms.
6. The spatial accuracy characteristics of both automated techniques are comparable.
7. The spatial repeatability of the ultrasonic technique exceeds that of the mouse-traverse technique.
8. Data profiles can be generated in real-time for field analytical assessments.
9. The characterization survey for thorium-230 resulted in criteria compliance for the area.
10. The RPD analysis uncovered three out of fifteen points beyond the 20% criteria.
11. Future research should be directed at extending the range and flexibility of automated positioning survey system.

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