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Characterization of Contamination Through the Use of Position Sensitive Detectors and Digital Image Processing

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Abstract

This report describes development of a significant new method for monitoring radioactive surface contamination. A floor monitor prototype has been designed which uses position sensitive proportional counter based radiation detectors. The system includes a novel operator interface consisting of an enhanced reality display providing the operator with 3 dimensional contours of contamination and background subtracted stereo "clicks". The process software saves electronic files of survey data at very high rates along with time stamped video recording and provides completely documented surveys in a visualization oriented data management system. The data management system allows simple reassembly of strips of data that are taken with a linear PSPC and allows visualization and treatment of the data using algorithms developed for processing images from earth resource satellites. This report includes a brief history of the development path for the floor monitor, a discussion of position sensitive proportional counter technology, and details concerning the process software, post processor and hardware. The last chapter discusses the field tests that were conducted at five sites and an application of the data management system for data not associated with detector systems.

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Executive Summary

This Phase II SBIR has been successful in the development of a significant new method for monitoring radioactive surface contamination. The effort has also fostered the parallel development of a visualization oriented data management system for survey data of any kind. The systems, more fully described in this report, provide the ability to examine and study surface contamination to an extent never realized before and to provide radiation surveys which are so completely documented that the entire radiation survey can be reexamined by anyone at a later date. This allows the person reviewing the survey to see what the surveyor saw, including the display indications and the actual surface that was surveyed. Additionally, the survey data can be studied using image processing algorithms that were developed, for the most part, by the National Aeronautics and Space Administration (NASA) to study the large quantities of data developed by earth resource imaging satellites. These algorithms find use in other data intensive analysis tasks such as nuclear medicine and digital radiography, which also require visual examination of data (Page, 1995).

Most surface contamination measurements today, including those conducted for site closure surveys, involve use of a simple radiation detector such as a pancake Geiger Mueller tube or 100 square centimeter thin window proportional counter. A two step process is used for performing and documenting a radiation survey. In an initial step, the detector is scanned over a surface while a meter indication is looked at to see both gross readings and any evidence of trends. Data is manually recorded for any area exhibiting elevated readings. During the second step of the survey process, selected points are carefully measured and manually recorded. When areas that exceed a desired value or that show unusual trends are identified from the meter indication, a notation of the meter indication is made and later transcribed to a simple drawing of the area. Additionally, several other fixed locations are recorded, either because of historical interest in the spot (i.e. contamination is frequently found near floor drains), or because of some formal documentation requirements such as site closure surveys in which the area is gridded into one meter square plots with five specified measurements taken in each square meter (ORAU, 1992). The data can also be embedded in a spreadsheet for both documentation and simple statistical analysis. If sufficient data is taken, or if the surveyor has a good memory, a rough contour plot of contamination can be reconstructed. At the leading edge of conventional technology, there has also been development of radio systems that can telemeter meter readings and location back to a computer allowing location and reading values to be automatically logged as the surveyor walks around. (The system requires establishment of a series of reference radio towers for localization.) Data from a survey conducted in this fashion has recently been entered into a computer aided design package to allow manual drawings of contamination contour levels overlaid on a site drawing.

Extensive quality control measures are needed to ensure accurate surveys with conventional technology as error can easily result from missed meter readings or incorrectly transcribed data. Also, an incomplete number of data points can result in lower survey confidence levels. Conducting a survey at current day release limits using these conventional technologies is limited to scanning rates for area coverage of as low as 25 square centimeters per second and rarely exceeds a few hundred square centimeters per second. Fixed point measurements and closure survey documentation requirements have resulted in costs of about one man-hour per square meter for sites that have been remediated and are clean and unobstructed.

This research has successfully demonstrated a floor monitoring system that uses a wide area, computer controlled position sensitive proportional counter that is mounted in a motorized cart. (See Figure 1.) The floor monitor records all of the count rate data from all of the surfaces scanned as a function of position in an electronic file. The electronic file is processed later in a visualization oriented data management system called the post processor. The position sensitive proportional counter, developed under a previous successful SBIR, allows one detector to act as the equivalent of hundreds of individual detectors aligned in a row (SRA, 1992). This permits simultaneous collection of hundreds of times more data than a conventional system with a single detector at the same scanning speed. Because the data is recorded during the scan, there is no need for conventional technology's second step of careful measurement and recording the data at selected points. Because all of the data is recorded, there is hundreds of times more measurement data available to permit highly detailed statistical analyses of the survey, which allows survey results to be asserted at a significantly higher confidence level. This would ultimately permit radiation surveys to be conducted at scanning speeds that are an order of magnitude higher than those used with conventional technology (2.54 or 5.08 centimeters per second) with resulting cost savings. The system includes a video camera and recorder that records a visual record of the survey that is time stamped to allow correlation of the visual image with the survey data.

The new floor monitor detector collects information at a much higher rate than conventional systems. This data could not be provided to the operator with conventional meters or bar graphs without "information overload" occurring. A novel operator interface had to be developed to assist the operator in conducting and managing data collection. Two new technologies were applied to solve this problem. First, the operator was provided with an "enhanced reality" display (see Figure 2). This display is not a full immersion virtual reality display helmet, which isolates the user from the surroundings. In contrast, the display projects a virtual computer monitor into the eye of the user, while only obstructing part of the field of view of one eye. Thus, the normal field of vision is enhanced with computer generated data. The use of a computer monitor display allows presentation of the greater density of information available to the operator in a manner that permits effective monitoring to occur. In the basic display developed for the floor monitor, an operator is provided with basic operational information and a three dimensional wire frame plot of the surface contamination that was most recently scanned (see Figure 3).

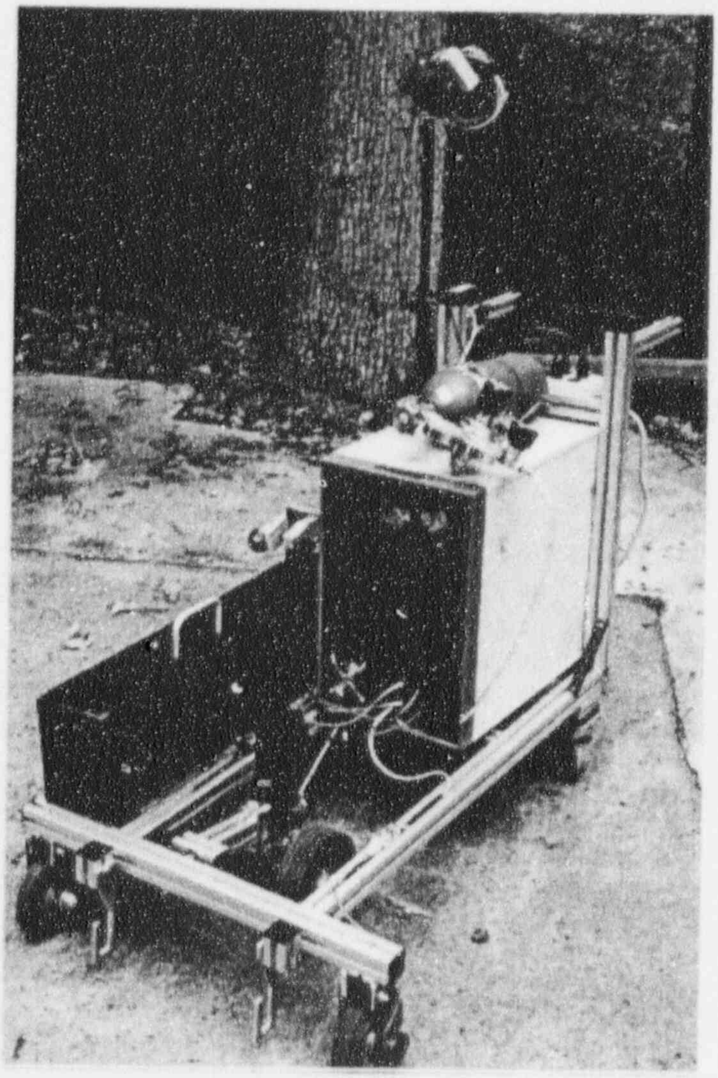

Figure 1 SRA Floor Monitor

Also, the use of a computer permits the necessary calculations to be performed to look for contamination in excess of regulatory requirements and provides the operator with an alarm that permits investigation of the results in the field.

The second new technology that was developed was stereo, background subtracted clicks. In conventional monitoring, an important tool for effective detection of anomalous areas is the audible signal or "click" that signals a count in conventional detection systems. The human ear is capable of detecting the change in time between counts when the count rate is around 1 Hz (Sommers, 1975). At higher count rates, the human ear becomes less able to detect differences.

Some manufacturers of conventional radiation detectors provide the user with the ability to divide the count rate by a factor to lower it to a range where the human perceptive abilities are maximized. This practice, however, also reduces the count rate from any radioactive contamination by the same factor, effectively reducing the sensitivity of the instrument by the same factor. This SBIR has successfully developed a new method which subtracts a user defined rate from the background in a statistically random fashion. When a value similar to the 2500 counts per minute background encountered in PSPCs is subtracted, the background subtracted event rate falls to a value of zero that is perturbed by the statistical fluctuations in background. These clicks are indistinguishable from normal background levels of 50 counts per minute encountered using pancake Geiger Mueller tubes and lie close to the optimum of a human operator's ability to detect changes. However, unlike conventional systems that divide background by a factor, this new method does not reduce the intrinsic efficiency of the detector, permitting audible detection of contamination at lowered levels. Additionally, the "clicks" can be provided to a headset and heard in stereo, with the stereo signal providing an indication of the position in the counter where the event occurs.

Figure 2 Enhanced Reality Display

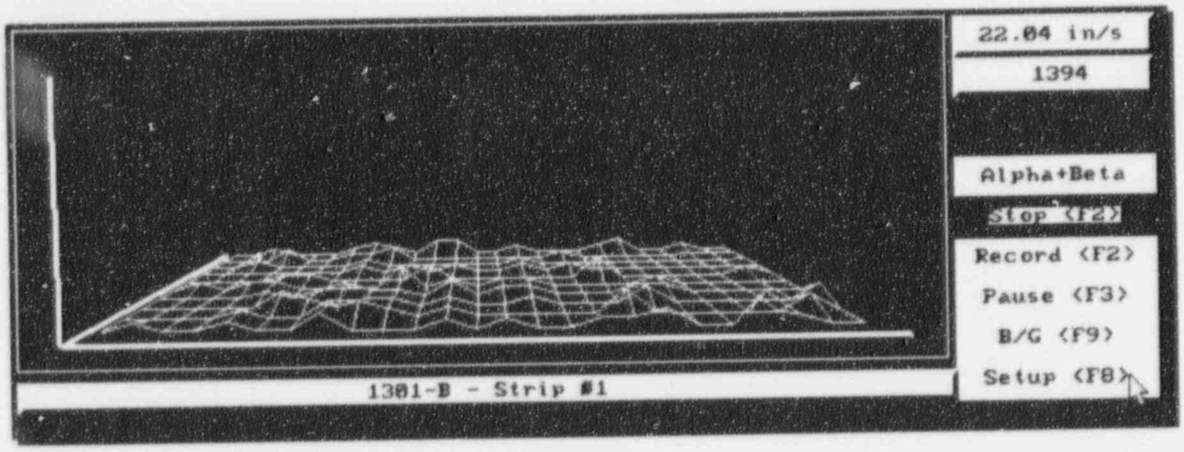

Figure 3 Display of Operator's Screen

The combination of an enhanced reality display, providing three dimensional contours of contamination for the operator, along with the stereo encoded, background subtracted clicks provides a system that emphasizes the operator interface. This approach maximizes the "co-activation" of the senses (providing the operator with data using more than one sensory input) which psychologists believe is necessary to minimize the response time to recognize an event (Miller, 1982). It permits a technician to continue to survey with this revolutionary system while using the senses most used today.

The floor monitor concepts were largely described and prototyped during the earlier Phase I effort on this research. One of the major comments that was received from reviews of the earlier Phase I prototype, was the absolute need to somehow solve the documentation issue. One manager's reaction to the prototype was "You've developed a system capable of taking thousands of time more data than we currently do, and I can't get all of the data from a conventional system recorded!" (SRA, 1993). The comment provided a real focus for the Phase II development effort. Recording the data was an easily implemented function, since the floor monitor was already computerized. The positional data was collected by placing a wheel encoder on one of the wheels. This device provided computer signals of wheel position, allowing measurement of distance traveled. In fact, any method of position measurement can be used, including the radio based systems designed for deployment with conventional survey instruments. The data was binned into 25 square centimeter areas (5 cm by 5 cm) roughly corresponding to the area of the classic pancake Geiger Mueller tube when held 1.27 centimeters above the surface being monitored. These areas are called pixels, which expresses their ultimate use in an image processing system described later. Four of these areas can then be summed into the 100 square centimeter and square meter areas that are expressed in regulatory requirements (NRC, 1974). Because the 25 square centimeter area is smaller than the area specified in the regulatory limit, it can also be summed into an alternate set of 100 square centimeter area by displacing the summation one pixel up and one pixel over. This method assures that the 100 square centimeter area with the maximum activity is correctly summed and does not have its peak activity split into four adjoining areas. Position sensitive detectors can also be summed into "virtual" detectors of arbitrary area. This permits the single detector to act as an array of small detectors as well as an array of large detectors (U. S. Patent 5,440,135 and patent pending 08/471,000).

A survey is planned by drawing a simple outline of the area to be surveyed and establishing the path the floor monitor will travel. The survey is conducted by executing a series of straight passes, called strips, that cover the area. The width of a strip is the width of the PSPC. The length of a strip is measured by the position encoding wheel. This permits taking survey data in a manner that closely mimics the methods used for conventional surveys and avoids the need for complex radio telemetry systems. The data is logged to a file that contains the most recent background taken, calibration and operational parameters, and the survey data in vectors that contain the time and counts obtained from each 25 square centimeter pixel across the detector. After a "Start" indicator is actuated using a hand pointing device that emulates a computer mouse, new data is logged as the floor monitor is rolled across the floor each time the monitor advances 5 centimeters. When a given strip is completed, the user actuates a "Stop" indicator and the strip file is closed. The next time "Start" is pressed, a new strip file is opened for the next strip. Backgrounds and calibrations can be interspersed with strips, allowing a user to obtain high quality data. Calibrations can be performed by simply rolling over a calibration source that has the desired radionuclide, with the data recorded automatically. In fact, since all of the data is recorded, it is possible to replay a survey at a later time and observe the exact display that was seen. This offers the potential to provide realistic training with this floor monitor, by replaying actual survey data.

The quantity of data generated by the floor monitor is hundreds of times that typically generated by conventional surveys. An area 25 meters on a side has 250,000 pixels (25 centimeter square). This area can be surveyed in 1.5 hours with a 2 meter wide PSPC, using a survey speed of 5 centimeters per second, and less time at higher survey speeds. In this survey, 100% of all measurements are recorded. There is no easy way to deal with this quantity of data and study it as numbers. A data management system that is oriented towards visualization was developed to meet this need (VisuSpect, 1995). The application was developed as a Windows based system, permitting easy movement of images and data between the data management application and other standard software such as spreadsheet and word-processing applications. It facilitates write-up of a survey report, with much of the data automatically generated into a Microsoft Word (TM) document format.

Figure 4 is derived from the data management system of a survey conducted at an EPA building in Montgomery Alabama, which had both Strontium-90 and Radium-226 contamination. It corresponds to an image of about 10,000 pixels, where each pixel is presented as a color corresponding to the counts acquired when the detector passed over that area of the room. The image is a compilation of a series of strips taken on a beta plateau, and shows several artifacts. The data has been treated as an image. In the upper left hand corner, there is a general trend in increasing counts to a square artifact. This artifact was a source storage safe which likely impaired the ability of the conventional survey instruments used during the redemption of the contamination in the building, resulting in insufficient decontamination in that area.

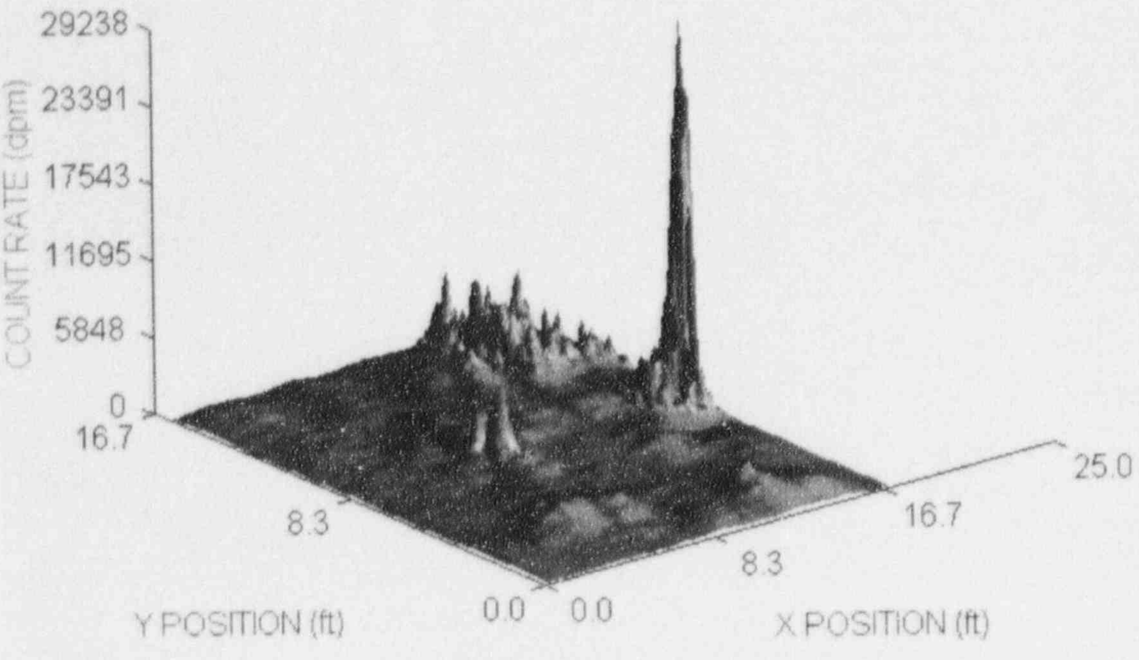

Figure 4 3-D plot of Wiener filtered surface activity data in an EPA building

There are two prominent artifacts, one in the center of the image and one along the right hand side. Figure 5 is a composite image which shows two images captured from the video that was taken during the survey, and shows that the center peak is associated with a floor drain, while the peak on the right side of the room is associated with a crack in the slab floor. Close examination of Figure 4 also shows a lowered region of contamination along the right hand side of the image, corresponding to an area of the room that had been subjected to scabbling (a concrete removal process used for decontamination). The survey was repeated on the alpha plateau and showed none of the structure of Figure 4, which means the contamination was primarily Strontium-90, and not radium. All of the data is available electronically. An interested person could actually replay the survey in the floor monitor and observe the same images the surveyor saw.

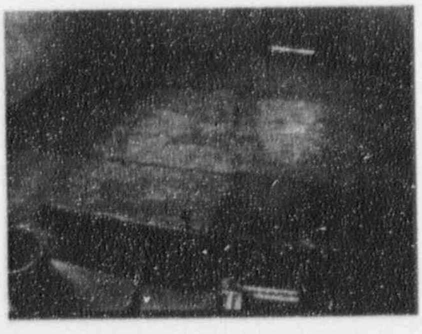

Figure 5.a Floor Drain

Figure 5.b Floor Crack

One of the most interesting data sets collected in this research is shown in Figure 6. This figure was derived from a PSPC based laundry monitor operated by Eastern Technologies, Inc. (ETI) in Ashford, Alabama, which was configured to run the floor monitor software, and is an image of PSPC data for a set of anti-contamination coveralls. There were 2 two meter PSPCs (one above and one below a conveyor system) that were jumpered together to act as a single four meter long detector. As clothing passed through the PSPCs, the beta flux from the clothing was recorded for both the front and back sides at the same time. The region between the two objects is the jumper in between the two PSPCs. The remaining 2 meters of PSPC detectors would lie above and below the image in Figure 6, but were removed for clarity. One can see a prominent peak in an area corresponding to the shoulder of the anti-contamination clothing. The entire garment was uniformly contaminated providing an image that outlines the shape of the clothing.

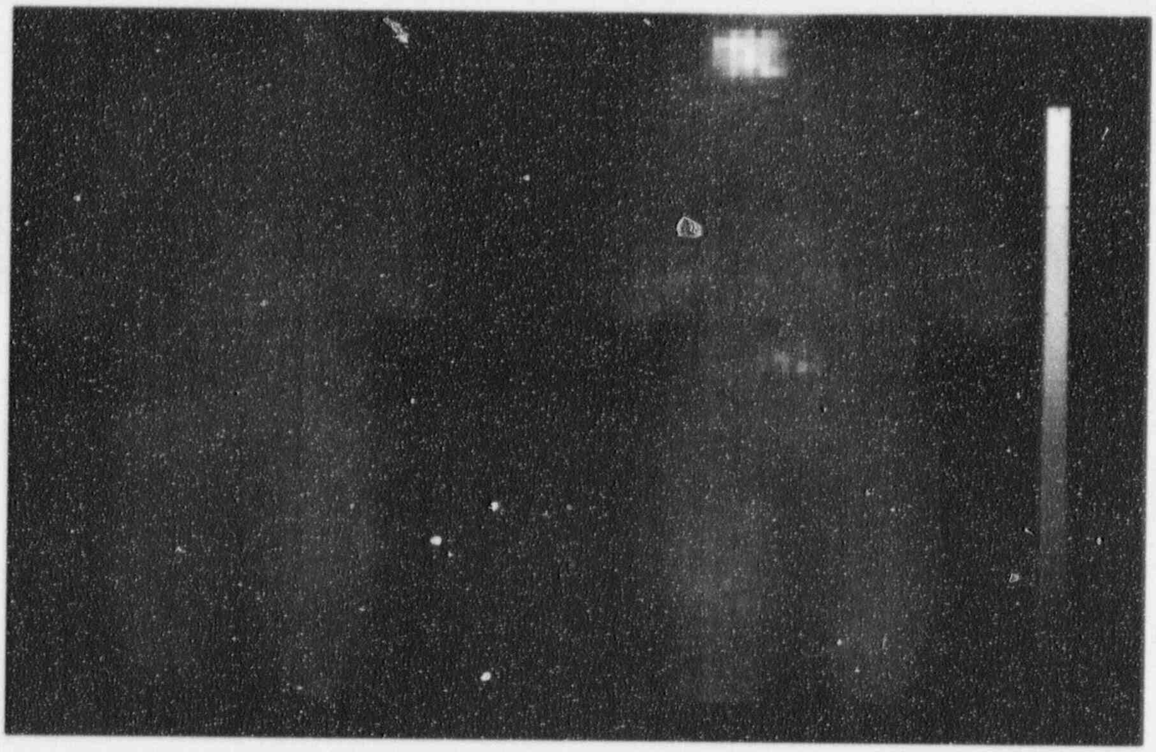

Figure 6 Display of Monitored Clothing

The graph on the right in Figure 7 shows the probability distribution function (pdf) for the square meter of clothing at the center of the garment, and the graph on the left shows the pdf for a square meter of surface at the shoulder area. The pdf plots the cumulative probability against the contamination level seen in dpm per pixel. The pdf for the center of the garment shows a nearly normal distribution of contamination, which is expected from physical processes that are additive. The shoulder region shows a strongly non-normal distribution, indicating that processes were engaged that differed from those that caused the overall garment contamination. During the 1980's, commercial nuclear power plants in the US were faced with the complex dosimetry associated with hot particles. It was suggested that thermoluminescent dosimeters could be fabricated into a lab coat which would provide both dosimetry and anti-contamination clothing at the same time. The data from the PSPC based ALM could accomplish the same function. Evaluating the beta energy on the clothing using Feather analysis or a beta spectrometer would permit the PSPC based ALM to perform the same function once thought of as the impossible ideal for dosimetry.

The use of the probability distribution functions generated by the data management system and shown in Figure 7 also represents a new method for characterizing contamination. This distribution is made from the 400 (25 square centimeter) measurements that are made in each square meter of surface. The lower end of the distribution, along with a knowledge of the system efficiency, provides a direct measure of the lower limit of detection that was achieved during the radiation survey. If the survey was conducted in an area that is clean, this also was the detection limit of which the system was capable. Application of a contamination to risk factor would permit a direct measure of the risk associated with a particular pdf, and could result in better decision making for radiological contamination. As an example, assuming both distributions shown in Figure 7 were below release limits, decontamination processes that resulted in the normal distribution would provide a lesser degree of risk. Studies could be made of the best decontamination processes, and the best conditions (i.e., decon solution concentration, temperature, pH, etc.) for removing contamination.

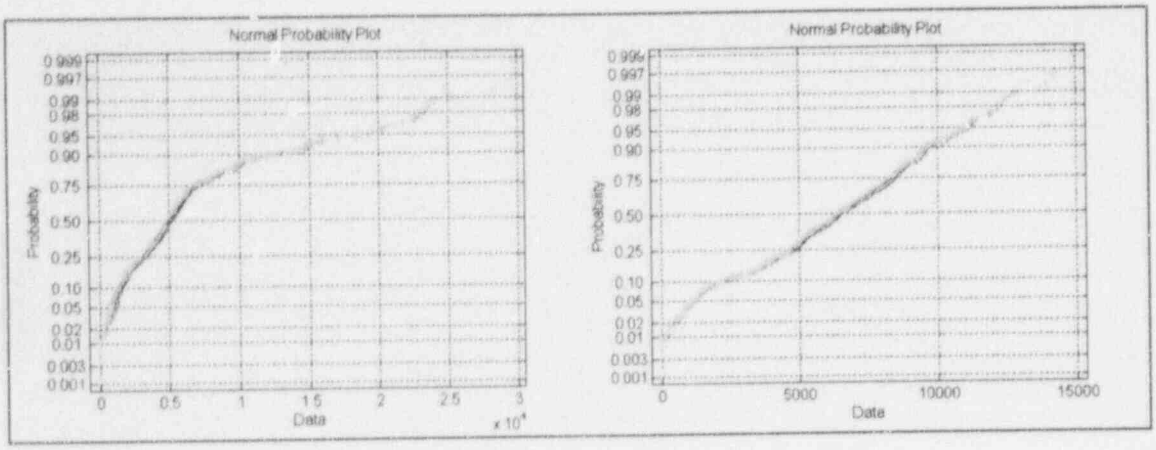

Figure 7 Probability Distribution Function (pdf) for the Square Meter of Clothing and for the Shoulder Area

In summary, this research has resulted in the development of a new technology for assessing surface contamination. Use of this technology should dramatically lower the cost and improve the quality of contamination monitoring in the U. S. nuclear industry.

FOREWORD

NUREG/CR-6450 is not a substitute for NRC position papers or regulations, and compliance is not required. The results, approaches, and methods described in this NUREG are provided for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein.

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A special acknowledgment is extended to the health physics staffs of K-25 & Y12, directed by Jim Bogard with special assistance from Scott Wical (K-25) and Tony England (Y12). The trials provided crucial practical testing of the final design. The generous use of facilities and personnel coupled with access to previous survey data provided invaluable tools for evaluation of the system under field conditions.

The authors further acknowledge Jim Kitchens of the Environmental Protection Agency (EPA) for his assistance in the characterization survey of an EPA building in Montgomery, Alabama.

The cooperation of Eastern Technologies, Incorporated (ETI), a nuclear laundry services company, is also gratefully acknowledged. Mark Fellows and Larue McWaters facilitated the contamination characterization studies, conducted on clothing at their Dothan, Alabama, plant. The data acquired from this study was useful in the development of the imaging and statistical functions embedded in the data management system.

A final acknowledgment is directed to the US Nuclear Regulatory Commission Office of Nuclear Regulatory Research for their support and guidance, throughout the term of this research. Dr. Stephen A. McGuire served as the Phase I and Phase II project manager for this SBIR project.

1. INTRODUCTION

Most contamination monitoring in the nuclear industry is done by using either wide area proportional counters or plastic scintillators, the former being the most commonly used method. Proportional counters have excellent sensitivity to high energy beta radiation, are low cost, and are relatively insensitive to gamma radiation. Insensitivity to gamma radiation results in minimum need for shielding the probe for ambient radiation levels.

Proportional counters can be operated with portable rate meter electronics but have an active area of only a few hundred square centimeters. The rate meters usually have an electronic time constant on the order of a few seconds. Thus, their capability to survey large areas is much less than one square foot per second at unrestricted release levels and is often as low as .05 square feet per second.

Plastic scintillators have adequate gamma sensitivity (if sufficiently thick), but also require a mylar window for a light shield. Scintillators have lower efficiencies for low energy alpha and beta radiations, and background rates further degrade their minimum detection ability. Massive lead shields are used to reduce background rates in scintillators, limiting their portability to heavy rolling carts for the shields and supporting electronics. These lead shields also prevent convenient use of scintillator probes in areas with difficult access.

Traditional contamination monitoring systems face a trade off with fixed area detectors. Large detectors provide a good measurement of average areal contamination but cannot measure localized contamination well. The converse is true for small detectors.

Emphasis on decommissioning of nuclear sites, along with NRC regulatory guidance for unrestricted release, has caused sites to enforce release surveys more stringently. As an example, the Fernald Environmental Monitoring Project (FEMP, formerly FMPC) recently spent more than \$500,000 for a comprehensive top-to-bottom survey of the site at unrestricted release limits. As another example, decommissioning of the Radiation Sterilization Plant in Georgia, following a leak in a cesium source capsule, required man-years of technician time to document that the site was below unrestricted release limits for the closure survey. Thus, there is need for a sensitive system for large scale radiological monitoring at nuclear sites.

Position sensitive proportional counters (PSPCs) have advantages over simple proportional counters for this task. The detector may be electronically divided into hundreds of sections, reducing the effective background by the same proportion. The number of sections is limited by the system resolution. Systems have been demonstrated that resolve 1000 elements on any one axis. A detector built with PSPC technology, divided into 1000 sections, each with a background of 1/1000 that of the total detector, would realize a reduction in its minimum detectable limit by a factor of more than 30. A PSPC with an area of 1.5 square feet (1400 cm^2) would have the detection limit of a 44 cm^2 proportional counter and greater coverage than any other commonly used detector. Such a system could easily quantify contamination per 100 cm^2 area and average contamination over larger areas. This would allow exact implementation of release limits, avoiding the need for the conservative assumptions commonly used with conventional contamination monitors. It would be capable of surveys 30 to 100 times faster than conventional detection systems. Position sensitive detectors can be summed into "virtual" detectors of arbitrary area. This permits the single detector to act as an array of small detectors as well as an array of large detectors (U. S. Patent, 5,440,135 and patent pending 08/471,000).

Despite the added complexity of supporting electronics, the components in a PSPC can be small (e.g., integrated circuits, ICs), allowing such a detector to be completely portable. If 3D contamination levels were displayed in real time, a floor monitor could rapidly survey large areas as compared to conventional technology.

The capability of computer systems to interpret real-time data from detector systems has been limited by the algorithms used. These algorithms have been made both simple and complex, but they are all less sensitive to live-time changes than the human eye. A system that takes advantage of user interaction via 3D visualization of peaks would have the advantage of lower detection limits than any other detectors available in the nuclear industry.

Computer requirements to analyze 3D data and search for peaks are non-trivial, particularly when done on a real time basis. Mini-computers are used for medical imaging systems. They analyze data off line over several minutes. To acquire and analyze data from a floor monitor, a computer has to analyze and update information on a second by second basis. In contrast to computers, trained human observers are extremely capable of looking for patterns. As such, a technician provided with a radiation meter that displays 3D contamination levels in real time may greatly exceed a computer's ability to recognize contamination at or near release levels. The technician could also adjust his survey speed and re-do areas that may not be statistically significant to software, but show an unusual pattern of activity. The human observer, coupled to a system that provides readout of contamination in 3D, produces a more capable system.

The SRA Floor Monitor developed as a result of this research is a PSPC based radiation detector, using visual and audible identification. Data is logged to disk to provide for importing into the data management system. The data management system provides cataloging and documentation of survey data, while offering an extensive array of image processing and statistical analysis functions.

This research project has developed a floor monitor for radioactive contamination capable of surveying 30 to 100 times faster than conventional technology at current release limit levels. Such monitoring technology can serve a major need for federal and commercial nuclear facilities. The PSPC based floor monitor developed in this project could result in the savings of millions of dollars annually in the world wide nuclear industry. Most of these savings would be as a direct result of reduced labor time to complete a survey.

2. HISTORY OF SRA PSPC RESEARCH

2.1 Phase I Overview

During Phase I research, a field prototype PSPC based floor monitor using visualization techniques was designed and fabricated. The prototype included a miniature virtual video screen. The video screen is mounted on a headband and partially covers one eye. The optics in the system can be focused to provide a virtual image located at 3 feet from the user and superimposed over his forward field of view. A user can simultaneously view the virtual image and the normal surroundings in his field of view. In contrast to the virtual monitor, the display in a VCR camera is not a virtual display and forces a user to focus at close distances to see the image being recorded. A long period of time is required to focus the "free" eye on the scene being taped; therefore, a user must choose between viewing the general scene or the material being taped, since eyes cannot superimpose the two images. The virtual display provides an enhanced view of reality that permits the user to superimpose a view of the measured contamination on top of the floor being monitored.

The hardware for Phase I research consisted of one PSPC configured with associated detector electronics and gas supply. Peripheral equipment included a microprocessor-based computer, acquisition and analysis system, and a video display system. A 3D mapping of the surface contamination levels was provided via the virtual video screen.

The final configuration chosen consisted of a PSPC mounted in a sheet metal enclosure with a screened window that faced the floor. Lawn mower style wheels were attached to the housing, including the hardware used for adjusting height. The two large diameter rear wheels were fixed, with a single swivel wheel on the front. The tricycle gear style wheel configuration worked well. No effort was made to reduce the size, weight or power consumption of the computer and electronics, as this was a prototype. A standard personal computer was rolled alongside the cart to provide the operating system.

The system was demonstrated to about 20 people, including managers and technicians of the Environmental Survey and Site Assessment Program (ESSAP) at the Oak Ridge Associated Universities (ORAU) at the end of March, 1993. The ESSAP at ORAU is funded by NRC to develop and validate survey methods (ORAU, 1992). Response was very favorable. In general, reactions were divided into three classes: reaction to the physical configuration, reaction to the new technology, and consideration of the regulatory impact of the new technology.

Reaction to the physical configuration was positive, but frequent "exceptions" were given. The bulk of the comments indicated the need for a line of detectors with differing lengths (for smaller and larger areas) and widths(for slower, higher resolution scans and faster, lower resolution). Also, detectors with more rugged screens and even larger wheels are needed for outdoor application.

The reaction to the new technology was overwhelming. It took more than an hour to move people from reacting to the virtual reality display and PSPCs to reacting to the system as an integrated contamination monitoring tool. A number of sources were placed on the floor, and participants used the floor monitor to locate the sources. Comments for improving the user interface were all directed towards giving the user the ability to modify scale and perspective.

Extensive discussion was held on the regulatory impact of the technology. The major comment was the need to save data for later plotting and report generation. The users did concede that conventional technology did not record data, but felt that this new technology must.

During Phase I research, the feasibility of the monitor was proven. The software and hardware components were developed, and a laboratory prototype fabricated. Tests were conducted to identify adequacy and accuracy of user visualization of peak identification.

Traditionally, source identification by the user has been limited to one dimensional information, such as a meter indicating count rate. During Phase I, software was written by SRA that displays 3D surface maps of contamination levels. New data is added to the plot as it is acquired and processed. At the same time, the oldest data on the plot is removed. This process of acquiring data and updating the display proceeds in a real-time fashion. A demonstration program utilizing these instrument routines was coded to provide a test bed for video and computer system evaluation. 3D visualization makes live-time interpretation possible. The user can see not only current data, but also data from previous acquisition. This enables easy identification of trends in data.

The software for the floor monitor, PSYCOSIS© (an acronym for Position Sensitive Contaminated Surface Identification System), samples data from the detector system and provides three-dimensional visualization of surface contamination. As contamination above background is detected, a peak corresponding to its position along the detector and its activity level enters on the back row of the graph. As the monitor is moved forward, the peak moves towards the viewer. However, the software developed during Phase I did not include the ability to record data, an important feature for users.

2.2 Other Relevant Projects

Position sensitive proportional monitoring technology was deployed in an automatic radiation laundry monitor and a portal monitor. Studies were conducted to understand specific hardware requirements for different process monitoring systems as well as general hardware requirements. For a more detailed discussion of these projects see NUREG/CR-5868, Development of Position Sensitive Proportional Counters for Hot Particle Detection in Laundry and Portal Monitors (SRA, 1992).

Research included construction of a laundry monitor using position sensitive proportional counter technology and its placement at Farley Nuclear Power Plant, Figure 2.1, where it was initially used on an experimental basis. It eventually replaced the conventional laundry monitor at Farley during the 1991 outage.

Following completion of the field studies with the laundry monitor, a portal monitor was developed to further explore the application of position sensitive proportional counter technology, Figure 2.2.

Figure 2.1 SRA Laundry Monitor as deployed at Farley Nuclear Power Plant

Figure 2.2 SRA Portal Monitor Prototype

3 IMPLEMENTATION

3.1 Design Approach

3.1.1 PSPCs

The following discussion is taken from NUREG/CR-5868 and is included as a discussion of the advantages and disadvantages of position sensitive proportional counters (PSPCs) (SRA, 1992).

Position sensitive counters were developed in the 1960's and have been used for experimental purposes. Radiation events in a position sensitive counter create pulses that travel to each end of the counter. Propagation of the pulses is described by the same equations that model the performance of transmission lines. Positional information can be derived by examining the percent of total charge delivered to each end (SRA,1990). Current technology allows positional information to be established to better than one part in a thousand. That is, a one meter long anode wire can be electronically divided into 1000 or more segments, each 0.1 cm long.

Wide area counters have background of approximately 0.25 counts per second (cps) per square inch of detector. Thus, a 17" by 7" detector has background count rates on the order of 30 cps. The theoretical lower limit of detection for such a counter is 11 cps with a six second count. (NCRP, 1978). A position sensitive detector of the same area would have a detection limit of 0.5 cps for the same count period. This lower limit results from the fact that each segment of the counter behaves as a separate detector. This advantage holds regardless of count time. By triggering the acquisition of data through an incremental encoder, two-dimensional position information is available which can be used to locate the contamination (SRA,1990). Despite the added complexity of position sensitive counters, the overall system cost can be lower than a system of conventional counters. This is because of the reduction in the electronics required.

There are several ways to encode the position of a radioactive particle or contamination. Table 3.1 provides a summary of the classes of position sensitive proportion counters. Table 3.2 summarizes the relative advantages and disadvantages of the various approaches.

The simplest method to obtain greater positional information is with the use of discrete systems. As seen from Table 3.1, one can use separate radiation detectors for each position where data is desired. The advantages of this multi-detector system are its simplicity and its relatively low cost for a single detector. In addition, these systems are easy to build and design.

Table 3.1 Methods of determining position with proportional counters

TYPE	PHYSICAL PRINCIPAL	ENCODING DEVICE	READOUT & CIRCUITRY
Discrete	Multi-detector Systems Multiwire Counters	Detector Cathode or Anode Wire	Discriminator/Scalar Discriminator/Scalar
*Continuous	*Pulse Propagation by Diffusion	*Resistive Capacitive (RC)	*Spectrometer with Charge Division Spectrometer with Pulse Shape/Time Discrimination
		Inductive Capacitive (LC)	Spectrometer with Delay Line
	Pulse Propagation by Electromagnetic Wave	Same as Diffusion	Same as Diffusion

*Position Sensitive Proportional Counters used in this research

However, the relative disadvantages of this approach have prevented manufacturers from continuing to increase the number of detectors beyond 25 typically used today. More detectors provide improved resolution and detection limit, but they increase cost and overall complexity. This requires additional manpower to maintain the system. Additional disadvantages for discrete detector systems occur because of the dead zones between each counter.

To overcome some of these deficiencies, multiwire counters have been developed. These discrete systems incorporate numerous anode or cathode wires to localize the contamination. Multiwire systems can provide resolution of half of the wire spacing used and solve the problem of dead zones between adjacent detectors (Eichholz and Poston, 1985). The alternate way to establish position sensitive proportional counters is to use a principle for continuously determining the position of events inside a single counter. This was the approach selected for this research. One major class of position sensitive proportional counters utilizes the distributed resistance and capacitance (RC) of the anode wire to encode the position of the ionizing event (see Table 3.1). An ionizing event in a proportional counter deposits an electrical charge on the anode wire. The distributed resistance and capacitance causes the charge to diffuse along the wire as a function of wire position (Ford, 1979). The pulse that is formed on an anode wire will travel down the wire becoming broadened with distance. The distributed resistance and capacitance of the anode wire serves to integrate the voltage pulse.

There are two alternate electronic methods available for exploiting this phenomenon to locate the position of the event. In pulse shape or time discrimination method (i.e., time division)(Kopp et al., 1975) both ends of the anode wire are provided with preamplifiers and amplifiers. Voltage sensitive preamplifiers are used which preserve the shape of the pulse from the anode wire. Filter amplifiers then provide additional pulse shaping and differentiate the signal to create a bipolar pulse. The bipolar pulse's value crosses zero at a time corresponding to the peak of the voltage pulse from the proportional counter. A logic signal from a zero crossing discriminator is used to start a time to amplitude converter (TAC). The other end of the anode wire is used to generate a stop signal after a suitable delay. The TAC converts the relative time difference between the start signal and stop signal into a pulse whose height is proportional to position.

Figure 3.1 shows a circuit for RC encoded position sensitive proportional counters (i.e., charge division). The distributed resistance of the anode wire causes the total charge deposited on the anode wire to divide. In the case of the circuit shown in Figure 3.1, charge sensitive preamplifiers effectively ground the anode at each end. The charge delivered to each of the charge sensitive preamplifiers is proportional to the position of the event in the counter. Preamplifier A has a charge delivered to its input of $(X/L) * Q_0$ where X is the location of the event relative to the end A. Filter amplifiers are again used to differentiate and amplify the pulse. Pulses are summed to provide the energy signal, and the charge from one side is divided into the total charge to provide positional information. The summation and division can be performed either with analog electronics or with a computer.

Continuous position sensitive proportional counters have also been fabricated by others which use delay line readouts or which utilize the electromagnetic wave to encode the positional signal (Lampton et al.,1987). These systems, while capable of a higher count rate than the diffusion based system, have a complex electrode structure to shape and delay the electromagnetic wave delivered to each end of the counter. Because of the complexity for fabrication of this system, detector size is frequently limited.

This research used the charge division circuitry. As shown in Table 3.2, there are many advantages of the diffusion method for an RC encoded position sensitive proportional counter. A single anode wire can be divided into as many as several thousand detector elements. There are no dead zones between detectors. Internal sources can be collimated to irradiate one segment of the anode wire. The use of these internal sources permits the system to self align and calibrate. While the circuitry is more complex than a single counter, as the total number of counters exceeds ten, a single continuous position sensitive proportional counter will cost less than a multi-detector conventional system. The inherent simplicity of an RC encoded system with one high voltage and two preamp/amps per thousand detectors reduces the overall cost and complexity as well as the maintenance requirements. When deployed in a system, such as a floor monitor, multiple detectors can be combined to act as a single counter. The co-axial cable used to jumper the detectors acts as a region of the combined detector that is insensitive to radiation. Thus, a floor monitor can be built in virtually any configuration using only one set of electronics.

Table 3.2 Advantages and disadvantages of proportional counter systems

TYPE/PRINCIPAL	ADVANTAGES	DISADVANTAGES
Discrete Multi-Detector or Multi-wire systems	Simple Low Cost for One Detector Easy to Design and Build	More Detectors Required for Improved Resolution and Lower Limit of Detection More Detectors Increase Cost, Maintenance, and Complexity Manual Calibration Required Not Self Source Checking Dead Zones between Counters Cannot Distinguish Hot Particle from General Contamination Must Use Assumptions to Convert Count Rate to Activity Per Unit Area
*Continuous using Pulse Propagation by Diffusion	Single System Able to Resolve More than 1000 elements No Dead Zones Between Elements Able to Self Calibrate Able to Self Source Check Reduced Maintenance, Cost and Complexity Improved Lower Detection Limit Can be Operated in High Background Areas Able to Identify Hot Particles Can Measure Average Contamination per Unit Area	Cost Approaches that of 10 single counters
Continuous using Pulse Propagation by Electromagnatic Wave	Capable of High Count Rate	Complex Electrode to Fabricate Detector Size Limited

* Position Sensitive Proportional Counters used in this research

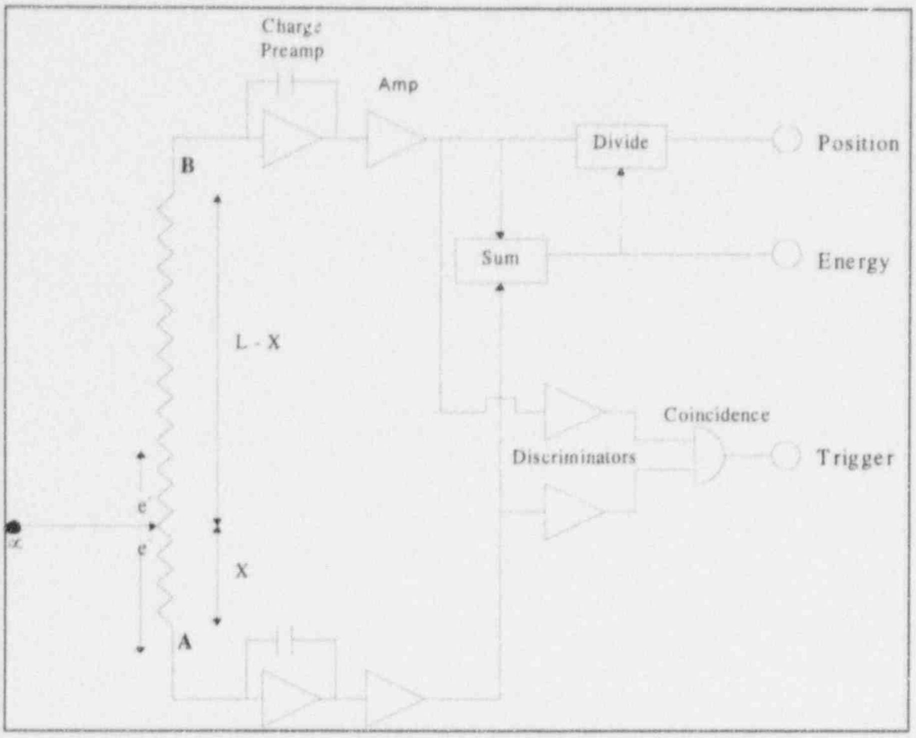

Figure 3.1 Charge Division Position Sensitive Counter

3.1.2 Overview of Process Software

Phase I provided sufficient process software to accomplish "proof of principle". During Phase II, the data acquisition software (i.e, PSYCOSIS©) was evolved into a hardened control and interface application.

A major effort was put towards the development of the user interface. The user relies on a mouse cursor and on screen buttons to provide interaction with the program. A standard keyboard is also available to the user as an input device. Figure 3 in the Executive Summary shows the display as seen by the operator through a head mounted display. The system uses controls analogous to a video cassette recorder. Data is continually acquired and binned by the floor monitor. When the "Record" button is depressed, count rate data is logged to the disk each time the encoder wheel increments by 2 inches. The user may "Stop" or "Pause" the logging of data by pressing the appropriate buttons.

The user may configure and maintain the system using the interface. The High Voltage can be varied between the alpha or alpha-beta plateau by simply clicking on "Alpha+Beta". The name on the button will change to reflect the current setting. A background reading is attached to the end of every strip. This file is used by the data management system to aid in image enhancement. Clicking on "B/G" causes the monitor to update the current background file by acquiring, binning, and averaging the counts over a preset time limit. This time limit and other configuration settings (i.e. electronic configuration, survey information, calibration, etc.) can be accessed by clicking on "Setup"

Every effort has been made to achieve a real time performance. Data acquisition is triggered as a result of input from the position encoder or as a result of an internal clock, but count rates are logged to disk only as a result of detector movement. The process software also provides control of high voltage, gains, and discriminators .

To calibrate for a particular isotope the monitor is rolled over a calibrated source. The source strength is entered via keyboard so that efficiencies can be calculated. These efficiencies are applied to the alarm logic routines so the system may provide zone alarm enunciators to further assist the operator in recognition of contaminated areas.

3.1.3 Overview of Post Processor

A major technical comment from the staff at ORAU during field studies was the need for documentation of surveys. Documentation of surveys requires that the monitor be capable of downloading its data and that software be written to document survey results. SRA anticipated that data corresponding to the count rate encountered in each 25 cm^2 area would be saved by the floor monitor (U.S. Patent 5,440.135 and patent pending 08/471,000). This would permit summing data into overlapping 100 cm^2 and 1 m^2 areas. This data will support licensees in directly implementing federal guidance such as Regulatory Guide 1.86 (NRC, 1974) as well as more recent guidance (ORAU, 1992). For a more complete discussion of the post processor than that included below, see Appendix A.

Data is imported into the data management system through a program called STITCHER©. The Floor Monitor records data in a series of strips. These strips of arbitrary length and direction can be reassembled by a technician, using STITCHER© into an accurate depiction of the surveyed region.

A second application, called VisuSpect©, for processing, reporting and archiving data from the new floor monitor, was also developed. VisuSpect© takes the electronic data and provides integration with digital imaging software and image filtering algorithms. Imaging software is used in many applications to look for data buried in noise. More than 30 algorithms have been developed by NASA for studying the data from earth resource satellite mapping. This data is studied and viewed as images rather than numbers because the quantity of data is large. Another application for imaging software is nuclear medicine, where physicians can examine a gamma camera image of nuclides deposited in an organ. Imaging software permits each point in a data field to be displayed as a pixel whose intensity or color is proportional to the counts for that area. Software in gamma cameras permit easy modification of the data field with digital subtraction and other mathematical transformations. In nuclear medicine, this software permits rapid examination by the physician for irregularities in the image. The effectiveness of this technique for examining contamination survey data was studied. Its potential use includes supervisory review of data and examination for trends in data that may not be observable from simple plots. As an example, very low level contamination present in a crack in the floor (lower than detection limits for pancake GM probe or other conventional detectors) may not have been seen in real time in a single pass with the floor monitor as it existed at the end of the Phase I research. However, overlaying adjacent surveys permitted examination of the entire data field. Use of digital image processing permits observation of the slight artifact that will be present in the data field.

The image functions available in the data management system aid in the recognition and characterization of surface contamination. The following are examples of many of the imaging techniques. Color examples of actual floor monitor output are included in Appendix B.

Colormaps

Colormaps can be used to help isolate regions in an image. Figure B.1 is an image plot of the surface activity of a survey region, using the standard SRA colormap. This colormap illuminates the entire intensity range of the image. The upper intensities in an image can be highlighted by using a colormap that maps the lower intensity values to darker colors. Figure B.2 uses the Hot colormap to demonstrate this point.

Thresholding

Another method of isolating regions of interest involves manipulation of the colormap. A technique known as thresholding allows the user to set upper and lower limits for a colormap. All data values above the upper limit are mapped to the highest value in the colormap, while data values below the lower limit are mapped to the lowest value in the colormap. Values between the limits are mapped in a linear fashion.

Cropping

Color is related to the value of a data point through the colormap of the image. The colormap is a list of 256 colors. The lowest value in the image is normally mapped to the lowest color in the colormap, while the highest value in the image is mapped to the highest color in the colormap. All of the data between these values is assigned to a color in a linear fashion. As a result of this linear mapping, extreme values of large magnitude in an image can overwhelm lesser valued data points that may be of interest. One method to compensate for this suppression is to crop the image so that the areas containing extreme values are removed. The colormap of the image will be adjusted between the values of the remaining data points.

Wiener Filter

A Wiener Filter scales itself based on the local variance in the image. This filter acts to suppress the background, while preserving the more intense regions of the image. This helps to isolate regions of interest. Care must be taken, however, when filtering the data. In the presence of extreme values, some regions of interest may be suppressed. The Wiener Filter is effective in cases where the values in the image do not vary drastically. See Figure 4 in the Executive Summary for an example of the Wiener Filter.

Plot Types

A variety of plot types are available to the user, including both 2-D and 3-D renderings. Figure B.3 is a contour plot which helps to isolate the regions of interest. Figure B.4 contains an image plot of the same surveyed region. The contour can be overlaid onto a pseudocolor plot, Figure B.5, to provide excellent recognition of the regions of interest. Figure B.6 contains a cropped image which is the plot of a grid location.

Statistical Functions

The SRA data management system is capable of statistical analysis as well as visual analysis. Regions that exceed release limits can be readily identified by analyzing the data in one square meter areas. A user friendly interface has been designed to facilitate quick analysis of the data. The user is presented with a grid that contains all of the statistical information for each one square meter area. The background color of a cell is changed based on the value of the maximum dpm/100 cm^2 averaged over one square meter (red) and the maximum dpm/100 cm^2 (yellow) release limits. When these release limits are changed, the grid is automatically updated to reflect cells exceeding those limits. By clicking on a particular grid, a cumulative probability distribution graph is obtained. See Figure 7 in the Executive Summary.

3.1.4 Overview of Hardware

The Shonka Research Associates, Inc. (SRA) Floor Monitor Model FM-1 is shown in the Executive Summary, Figure 1. The system consists of a computer controlled, position sensitive proportional counter (PSPC), along with supporting equipment. (U.S. Patent 5,440,135 and patent pending 08/471,000) The PSPC is mounted in front of the floor monitor cart in a separate enclosure with wheels. The cart provides a frame for mounting support equipment. The system has major components that permit sophisticated monitoring of surface contamination with all of the information logged to a data file for later processing by a data management system. Major subsystems on the floor monitor include:

1) PSPC detector with enclosure; enclosure can be set at a controlled height above the surface and supports LED's that provide indication of area contamination above setpoints

2) Wheeled Monitor Cart with rack mount enclosure
3) Industrial (IBM-PC compatible) rack mount computer system
4) SRA developed, rack-mounted electronics for system interface
5) 1/4 Horsepower DC gear motor, controller and drive wheel for 0 to 50 cm/sec controlled speed
6) Wheel encoder for position measurement
7) VCR camera for logging visual image of survey
8) Head mounted virtual computer display
9) Headphones for stereo position encoded and background subtracted clicks for audible monitoring
10) Compact P-10 gas supply system for PSPC

PSPC Detector

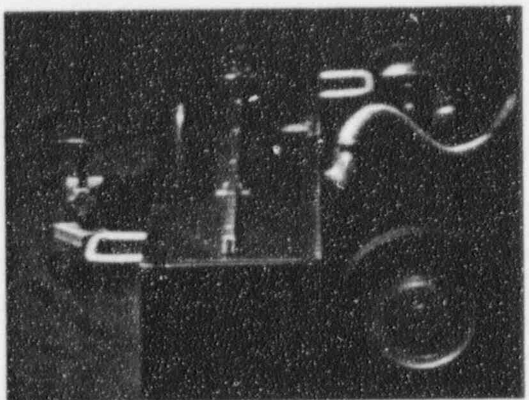
Figure 3.2 PSPC Detector Enclosure

Figure 3.2 shows the detector enclosure with LED bar. The detector enclosure is a box that contains a 137 cm wide detector, with a 132 cm long by 13 cm wide aluminized mylar window. The window is held above the floor by three wheels whose height can be adjusted such that the entrance window of the PSPC is maintained from 0.3 cm to 3.0 cm above the surface being monitored. The height is set depending on the roughness of the surface being monitored. The window is protected by an inexpensive fiberglass screen of low areal density. The detector is instrumented with preamplifier-amplifier modules which amplify the electronic signal from each end of the anode wire. Position information is obtained by using the inherent resistance of the anode wire as a voltage divider, with the pulse height from each end used to calculate the position. For a given event, the difference between the pulse heights from each end of the PSPC divided by the sum of the pulse heights is the relative position. The sum of the two pulse heights is the energy of the event, which is the information obtained from traditional, non-position sensitive proportional counters (SRA, 1992). A sample and hold circuit retains the pulse height information until it is read by a Keithley-Metrabyte DAS-1400 card. This system is described in the electronics section below. In essence, the primary functional difference between the PSPC and other, commercially available wide area proportional counters is that both ends of the anode wire are used for signal processing in a PSPC.

The detector and its associated electronics are capable of position resolutions of better than 0.1% of the effective length (which is a small fraction of a centimeter). It can be equipped with collimated alpha sources on each end which provide a stable artifact in the position and energy spectra of the pulses. These are used to stabilize the gain and discriminators to provide a self-calibrating system. (U. S. Patent 5,440,135 and patent pending 08/471,000).

Normally, the output from the detector is summed into 5 centimeter lengths across the detector. These are called bins. As the detector is rolled across the ground, positional information is used to establish the count and time for each 5 cm bin in 5 cm increments. Thus, the raw count rate data is established for each 5 cm by 5 cm area of floor surface. This area is nearly equal to the field of view observed by an industry standard pancake GM counter held at 1.27 cm (1/2 inch) from the surface. The system can be configured to establish any size detector element or pixel. Sizes below about 2 cm provide no benefit for beta monitoring because of air scattering of the betas. Sizes of less than 1 cm can be used if a collimator is used for betas, or for alpha monitoring since the range of the alpha in air is quite small. Great care is required to locate the start location of the survey when the system is used at resolutions below 5 cm if exact registration of the image is required.

When the system is in record mode, the data is logged to an electronic binary file, along with information to correct for dead time. When the system is in record mode the VCR camera is time stamped and started and stopped to coincide with the recording of detector count rate data. The 25 cm^2 area is also called a pixel, since it is the minimum element size used to form pictures of the contamination in the post-processor. Counts are summed into square areas 10 cm on a side. This provides the contamination per 100 cm^2 as is commonly specified in regulatory requirements. This data is examined for exceeding an alarm setpoint based on the background counts, efficiency, and desired confidence level of the setpoint. When a setpoint is exceeded, the nearest LED is lighted and the alarm is noted in the operator display.

Butane or propane gas is used in the PSPC, at nominal flow rates of 20 cc/min after the detector is purged. Purging can be accommodated at flow rates up to liters per minute.

Wheeled Monitor Cart with Rack Mount Enclosure

A wheeled cart, fabricated of light weight extruded aluminum channel is used to mount all accessories. Although the prototype system uses heavy, rack mounted computers and electronics, overall system weight remains less than 160 pounds. This is easy to lift for the recommended two person operating crew. The overall workload of the system is such that a two person crew who rotate job responsibilities is optimum. The rack mounted enclosure is isolated from the cart with rubber mounts, providing added isolation from vibration for the computer and electronics.

Industrial (IBM-PC compatible) Rack Mount Computer System

The host computer for the application is an IBM-PC compatible personal computer. The computer is an INTEL 80486/DX2 microprocessor based system with a 66 MHz clock speed. The computer is rated for an extended temperature operating range and features hardware for limiting the likelihood of vibration induced failure. It was available from another project for use with the prototype floor monitor. Subsequent models will likely use portable industrial computers. The computer has multi-function data acquisition cards for acquiring digital and analog data from the system and for providing analog and digital data to the system. Inputs include the sample and hold circuit output for the two ends of the detector, along with a read back signal for the high voltage. Also digital inputs from the coincidence circuit (used to correct for system dead time), the wheel encoder for position measurements, and the trigger signal indicating that a valid event is available for digitization. Outputs include analog voltages used for setting high voltage, discriminator level, background subtract rate for the stereo click circuit, and digital signals such as the high current drivers used to power the LED's that indicate an alarm.

SRA Developed, Rack-mounted Electronics for System Interface

The analog and digital electronics that are used to interface the system are custom electronics developed by SRA. The electronics are modularized in a rack mounted card cage that is derived from the S-100 Bus. Cards are separated by functionality to provide for easy debugging and maintenance, and include the following: High voltage card, two preamplifier-amplifier cards with discriminators and sample and hold circuits, logic card for processing digital signals and providing coincidence analysis, and a sound card for generating background subtracted stereo clicks. The card cage also includes a large linear power supply and the back plane needed to transfer power and signals between the various components.

1/4 Horsepower DC Gear Motor, Controller and Drive Wheel

Maintaining a constant survey speed manually can be difficult for the operator under field conditions. Therefore, a constant speed drive mechanism was added to the frame. A DC gear motor with controller and drive wheel are capable of driving the floor monitor at speeds of 0 to 50 cm/sec. The gear motor controller has a switch for power and a knob for varying the speed. It can control speeds below 1 cm/sec. The drive wheel is engaged by a lever arm that lifts and raises the wheel off of the floor. Although speeds in excess of 50 cm/sec are possible, the computer was not able to process all data at speeds greater than 45 cm/sec. There was no effort to reduce the power requirements of the system. It would be relatively easy to reduce the power requirements for the computer and electronics to provide a DC powered floor monitor, but the drive motor would remain a high power accessory that would dictate AC power for the system. Although a constant speed is desirable, it is not necessary because the system uses the wheel encoder and internal timer in the computer to derive position and count time as a function of distance. The gear motor is a highlv useful convenience accessory that reduces the workload for the surveyor and provides more consistent results.

Wheel Encoder for Positional Measurement

Positional data is obtained through the use of a high resolution encoding wheel mounted on one of the non-driven cart wheels. This provides for a simple way to document the survey using techniques that follow traditional methods. A survey is conducted by drawing the area to be surveyed and choosing the lines of travel for the floor monitor. Each line or strip of data is taken successively with the data recorded in sequential files. These files encode the position of the monitor along a strip, a time stamp for each acquisition and the count rate recorded for each bin. This technique follows the traditional practice in conducting surveys and avoids the need for the complex electronics such as the Ultrasonic and Ranging Data Systems (USRAD). This low cost method also has a precision of a few inches, greatly exceeding the capability of satellite based global positioning systems (GPS).

VCR Camera for Logging Visual Image of Survey

A tripod mounted video cassette recorder documents the survey area. The VCR is operated by the computer to coincide with the recording of data. The tape can be viewed by data management computer which has a video input board that permits the user to capture images from the videotape. The videotape is an important source of documentation. Often, the data in the digital image of the contamination field will have an artifact such as a line. The time during the survey that the artifact was recorded can be obtained by clicking the mouse on the region of interest. The videotape can then be advanced to the same time period and reviewed. Viewing the videotape allows the surveyor to see if there is a physical structure (e.g. crack in the floor; oil spot or other stain; equipment mounting hard point; etc.) that can be associated with the artifact. If so, the survey report can also incorporate a captured image of the object. This can greatly simplify subsequent decontamination efforts. It also provides for an unprecedented degree of documentation for survey data. However, security requirements may preclude use of the video recording devices..

Head Mounted Virtual Computer Display

A heads up display mounted on a hard hat or a lightweight headband, Figure 2 in the Executive Summary, provides the operator with a virtual terminal interface to the floor monitor. The terminal superimposes the image onto a user's surroundings in a viewing mode that is called Enhanced Reality by researchers. The display only obstructs a small section of the field of view of one eye. The brain is able to synthesize a view that overlays the display on the normal field of vision. Thus, the operator can view the display for the presence of elevated count rates indicative of contamination, without his surroundings being obscured. The display provides controls for the floor monitor that include start, stop and pause functions using the icons common to consumer electronics (VCRs, stereos, etc.). The display also includes three dimensional wire frame plots of the count rate on the monitor, binned into the 25 cm^2 counters across the PSPC. The monitor also shows the user when he is in record mode, the number of the survey strip being recorded, and the distance traveled. The user is also prompted with a speed indicator on the display to aid in maintaining constant speed. This allows the setpoints to be met with the desired false alarm rate and confidence level.

Headphones

Psychologists have noted that the ability to make a decision is enhanced when the human's decision making process is presented with multiple and reinforcing stimuli. Subjects make the appropriate response more quickly when offered redundant cues than they do when only a single cue is present. J. Miller carried out analyses of experiments of this kind and concluded that the brain uses both cues jointly and simultaneously to retrieve the appropriate response. He termed this process *co-activation* (Miller, 1982). The process of co-activation with the floor monitor also reduces the errors that might occur because of the drudgery associated with continuously monitoring a display.

Use of sight in humans engages only one of their senses. Audible enunciation should be added to the system to compliment the 3-D display . Two tasks were researched to accomplish this. Because of the large area of the PSPCs, the background count rate will be a few thousand counts per minute. At this rate, human observers cannot distinguish individual counts and rely on the "tone" variations to identify elevated count rate from contamination. For most people, the ability to detect contamination above this background is limited to hundreds of counts per minute above background.

At lower count rates characteristic of GM detectors (approximately 50 cpm), the human ear can distinguish individual counts and "hear" an increase of a few counts per minute. A novel method for mathematically "transforming" the high PSPC background would be to subtract it from the "click" rate.

If one calculates the average count rate in the last two seconds, an average of 84 counts will be seen for a 2500 count per minute background. If one subtracts 84 counts from the observed count rate, one will not observe zero, but will observe the statistical fluctuations about zero. This will appear as a variable count rate which corresponds to the standard deviation of the counts subtracted (approximately 9 counts per 2 seconds) or 360 counts per minute. It would be extremely rare to observe no counts in any one second. If any source is measured, the audible count rate would reflect the net count rate plus a background that is significantly lower then 2500 counts per minute. Thus, the subtraction of a fixed background can be done to transform high count rates, where human observations are limited, to lower count rates, where the observer can more easily identify count rate increases.

The human ear perceives the direction of sound using a combination of amplitude and arrival time differences (Grossberg, 1995). Research was performed on the shape of a digitally synthesized pulse that would sound like a "click" from a conventional analogue Geiger tube circuit, on position encoding by both pulse height and time variation, and on a variety of methods for subtracting background.

To further enhance the usefulness of the audible indictors, they were stereo encoded. The location of an event in a PSPC was used to modulate stereo earphones to provide a direct audible clue of where the event occurred. The pulse height from each end was used to set amplifier gains for stereo earphones. The method also used different tones for alpha and beta radiation. While this technique offers only two dimensional data (as compared to the 3-D data available visually, showing past events), the information represents a significant improvement over conventional technology, where audible clicks provide no positional information and cannot be background subtracted.

The floor monitor also has headphones which are used for stereo position encoded and background subtracted clicks for audible monitoring. The clicks are often the most sensitive indicator of contamination during a conventional survey. The stereo-encoded, background-subtracted clicks allow the operator to focus on conducting the survey in a manner similar to traditional survey methods. The floor monitor includes a circuit that removes an operator selected rate from the events processed by the stereo circuit. The wide area PSPC has backgrounds similar to proportional counters (150 cpm per 100 cm^2 ; about 2500 cpm total). This background would be too high to allow effective audible monitoring of changes in rate. By subtracting about 2500 cpm from the system, the audible rate drops to a stochastic quantity centered about zero with a standard deviation of about 50 cpm. This sounds similar to background event rates from a traditional pancake GM probe and is in a count rate magnitude where human operators are very sensitive to rate changes. Any increase in click rate due to contamination is quickly discerned.

Compact P-10 Gas Supply System for PSPC

A 20 cubic foot gas cylinder was incorporated into the system. The cylinder is capable of two weeks of operation at normal flow (20 cc/min), and weighs substantially less than the somewhat larger cylinders typically used with proportional counter systems.

4. FIELD TESTS

4.1 ORAU - Initial Test of Prototype

The prototype system was delivered to the Oak Ridge Institute of Science & Education (ORISE), operated by ORAU for evaluation during year one of the 2 year project. The evaluation team was lead by Wade Adams (Health Physicist/Project Leader) and included several survey technicians on the ORISE staff. A one day training session was held to introduce the users to the equipment and to demonstrate its functionality. The reaction to the technology was extremely favorable. The equipment remained on site for twenty days. During this time, several technicians used the equipment to conduct surveys at the ORISE site. The system, as delivered to ORAU, consisted of both the floor monitor and the post processing systems.

The majority of the comments from the evaluation team were extremely favorable. They were excited by the technology provided by the system and impressed with the ease of use of the system. The evaluation also generated many useful comments and criticisms.

They were thrilled at the idea of automatic report generation. A rudimentary report generator was included in the post processor prior to deployment to demonstrate the ability of the system. ORISE provided a copy of a closure survey, so that specific formats required for their documentation could be addressed.

Many of the technicians stressed the ease of use provided by the floor monitor and post processing system. There was concern that the amount of information presented in the post processor would be overwhelming, but when asked about the post processor, one technician replied,

> "I really like the way you have this software setup. It's as straight forward as any piece of software I've ever used. Any one who's semi-computer literate can flow through this with no problem..."

They were also impressed with the quick setup time of the floor monitor. ORISE was conducting an evaluation of another system that uses radio telemetry (the USRADs system) to provide location tracking. The SRA unit was so easy to deploy that the technicians were halfway through with the survey in the amount of time it took to set up the other system.

The team surveyed the surface of a lab room that contained both active and dummy sources. They first surveyed the area using their present techniques, and then using the floor monitor. Survey time was dramatically decreased using the floor monitor, although a low level alpha point source (39.5dps ^{241}Am) and a soft beta distributed source (86dps ^{99}Tc) were not recorded. During the debriefing session it was learned that the floor monitor was being operated on the alpha + beta plateau for this particular test. The undetected ^{241}Am source would have been found with the monitor operating on the alpha plateau.

While the evaluation team had many wonderful thing to say about the floor monitor, there were also some constructive criticisms. The main problems that were denoted by the evaluation team were the weight and bulk of the system. Also the equipment should be designed to better handle rugged terrain. Concerns of the survey team were:

- The drive motor drags
- The device is too heavy
- The electrical cord gets in the way
- The drill motor position interferes with the operators walking behind the unit.
- The heads up display is uncomfortable
- The unit pulls slightly to the right.

The amount of information received from the ORISE staff was highly valuable to the development team and resulted in the development of the totally new hardware for the floor monitor. The new hardware addressed all of the issues identified with the first floor monitor.

4.2 ETI

A study was conducted at Eastern Technologies, Inc. (ETI), a commercial laundry facility, in Dothan Alabama on Wednesday May 17, 1995. The purpose of this study was to gather data by scanning pre and post washed laundry, using the SRA floor monitor equipped with two six foot detectors wired in series. The data was brought into the post processor and imaged.

Five pre-wash garments were scanned four times each, two times at 2"x2" and two times at 1"x1" resolutions. Low level contamination over the entire garment surface produced a well defined image above background. The entire garment was distinguishable in the image, and any hot spots were easily identified. See Figure 6, Executive Summary.

The garments were scanned again after being washed, four times each. The detectors alarmed on garments #1 and #5. This field study showed that the detector is capable of imaging clothing after a beta overexposure and calculating the minimum, maximum, and average areal contamination and standard deviation per cm^2, 100 cm^2 and per m^2. The maximum dose rate from the garments at ETI was calculated to be 2 mrem per hour to the skin. The garments had been washed several times prior to the measurement.

The ETI study demonstrates the ability of this system to visualize point and distributed sources. Entire rooms may be surveyed, recorded, and rendered in much the same way as the clothing processed at ETI.

4.3 K-25 Survey

Shonka Research Associates (SRA) conducted surveys of two areas of K-25 at Oak Ridge, Tennessee, as part of an operations assessment of the Floor Monitor on August 30, 1995. The survey was performed with staff from the Oak Ridge Institute for Science and Education (ORISE). The Energy / Environment Systems Division at ORISE was tasked with evaluating both the Floor Monitor and the data management system. The survey technician noted areas of increased activity as a result of both the visual and audio detector information provided by the instrument (SRA, 1995a).

4.4 Y-12 Survey

Shonka Research Associates (SRA) conducted a survey of areas of the Y-12 Plant in Oak Ridge, Tennessee, as part of an operations assessment of the Floor Monitor on September 6, 1995. The Survey Report generated includes a comparison of survey results with site-specific guidelines for releases (SRA, 1995b). The survey was performed with staff from the Oak Ridge Institute for Science and Education (ORISE). AC power was not available for this area, requiring the floor monitor to be successfully operated from a portable generator.

4.5 EPA Survey

Shonka Research Associates (SRA) conducted a survey of the Dosing Building at the EPA Montgomery, Alabama, Site, as part of an operations assessment of the Floor Monitor on September 19, 1995. The survey consisted of 2 separate survey sections. The first was a survey conducted at the detector's alpha + beta plateau; the second was at the beta plateau. The sections were surveyed in eight strips, each four feet wide. The speed of the floor monitor was set to 2 in/sec for all surveys with the survey rate approaching 4 m^2/min. The recorded alpha plus beta survey data was imported to the SRA data management system for processing and storage. The data set was subjected to a Wiener Filter which scales itself based on the local variance in the image. This helped to isolate regions of interest. The survey was performed with EPA staff (SRA, 1995c).

4.6 Niagara Mohawk

The data management system is not limited to data from SRA detector systems. It may be used with any arrayed data. For example, the data management system was used as part of a calculation for Niagara Mohawk Power Corporation's Nine Mile Point 2 Plant in Lycoming, New York. The system was used to plot the contours of constant dose rate around the turbine building and to generate three dimensional dose rate intensity plots. These plots helped to identify impacted site buildings (SRA, 1995d).

5. SUMMARY

Shonka Research Associates, Inc. (SRA) has developed an automated contamination monitor to meet the growing need for accurate characterization and documentation of radioactive surface contamination. The computer performs the necessary calculations in real time to provide the operator with multiple sensory input including a three dimensional map of the radioactive flux from all scanned surfaces, stereo-encoded, background-subtracted clicks corresponding to events in the detector, and alarms to indicate contamination in excess of regulatory requirements. All acquired data is logged to disk for automatic transfer into a digital image processing data management system called the post processor (VisuSpect, 1995). A video camera, mounted to view the scanned surface, is synchronized to the acquisition cycle and provides an actual image of the scanned surface to facilitate identification of artifacts in the data. (U.S. Patent 5,440,135 and patent pending 08/471,000).

The SRA Position Sensitive Proportional Counter (PSPC) allows one detector to act as the equivalent of hundreds of individual detectors aligned in a row. As the line detector rolls forward, a wheel encoder or elapsed time (at a constant speed) permits simultaneous collection of hundreds of times more data than a conventional system to permit highly detailed statistical analyses of the survey. This allows survey results to be asserted at a significantly higher confidence level. With conventional detectors, a designer is faced with a trade-off. Larger detectors are more efficient for displaced radioactive contamination but are subject to greater background count rates. This limits their ability to see small localized sources. Smaller detectors have low backgrounds and are better able to see localized sources but have poor efficiency for large area dispersed radioactive material. A scanning line detector, such as SRA's PSPC technology, can pixellate the data field to a size much smaller than the smallest available conventional detector. The data field can then be summed to create a virtual detector of any size or multiple arrays of virtual detectors of differing size. The use of virtual detectors permits the surveyor to simultaneously look for small localized contamination and diffuse sources.

The post processor provides the ability to examine and study surface contamination to an extent never realized before and provides radiation surveys which are so completely documented that all elements of the survey can be re-examined by anyone at a later date (VisuSpect, 1995). In addition to creating a permanent record of all of the data, the person reviewing the survey may see calibration information, electronics configuration, display indications, and a video image of the scanned surface. Additionally, the survey data can be studied using image processing and statistical algorithms. These algorithms find use in other data-intensive analysis tasks such as nuclear medicine and digital radiography, which also require visual examination of data.

The SRA Floor Monitor provides for the measurement and documentation of surface contamination to an unprecedented extent. Conventional methods for contamination characterization provide only minimal data from an exhaustive error prone process. The SRA Monitor advances current survey speeds by orders of magnitude, provides more accurate data, generates complete automated documentation, and enables in depth study of contamination through digital imaging and statistical analysis.

With the increasing number of site decommissionings and heightened public concern for safety, the demand for accurate characterization of radioactive contamination is increasing. Some controversial facilities (typically located in populated areas) have required more than five man-years of effort to survey and document the final facility status for industrial facilities of less than 30,000 square feet of area. This does not include the numerous surveys performed during cleanup and remediation (or decontamination and decommissioning). It also does not include confirmatory surveys made by the state regulatory agencies. These surveys are currently conducted at great expense to both the licensing agency and the tax payer. The SRA Floor Monitor with its orders of magnitude increase in speed, improved accuracy, and automated documentation system, will provide significant decreases in the cost of characterization surveys.

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(U.S. Patent 5,440,135)	U.S. Patent 5,440,135. Self-Calibrating Radiation Detectors for Measuring the Areal Extent of Contamination. Issued to Shonka Research Associates, Inc. 1995.
(U. S. patent pending)	Patent pending, 08/471,000.
(VisuSpect, 1995)	VisuSpect©. Software developed by Shonka Research Associates, Inc. 1995.

APPENDIX A

Overview of Post Processor

The SRA Data Management System provides a method of maintaining multiple surveys and includes a high-performance numeric computation and visualization package. SRA detector systems provide log files of real time survey data. These log files can be assembled and visually inspected using the SRA Data Management utilities. Image enhancement techniques allow the user to locate artifacts that could be overlooked by the unaided eye. The surveys may be stored on magnetic media or output to paper.

SRA's Data Management System contains imaging features presently used on many high end operating systems. A concerted effort has been made to port many of these features to a standard operating system. Microsoft Windows provides a method for linking the numerous imaging utilities onto a commonly supported desk top operating system with which most computer users are familiar. The data management system includes utilities to aid in the inspection of survey data. These applications include:

- Microsoft Vidcap
- STITCHER©
- VisuSpect©
- Microsoft Word

Microsoft VidCap

VidCap is a data-capture application that lets you capture video sequences onto your computer system. With VidCap, you can capture individual frames from the video tape recorder that is mounted on the detector. The video image may be compared directly on the computer monitor with the imaged data from an SRA detector. Viewing the videotape allows the surveyor to see if there is a physical structure (e.g. crack in the floor; oil spot or other stain; equipment mounting hard point; etc.) that can be associated with an artifact in the data. The video may be captured and included in survey reports to aid with decontamination and to provide an increased level of documentation of the site.

STITCHER©

STITCHER© provides a mouse driven GUI for assembling individually acquired strips of data into a complete visual representation of any activity that may be present on a surface. For survey applications the strips of data, provided by an SRA detector system, can be assembled graphically into the survey pattern followed by the technician.

When STITCHER© is opened, tiles of survey data strips are selected and the approximate survey area is noted. The user is provided with a proportionally sized window with a tool bar on the bottom. Pressing the "strip" tool calls up one survey strip at a time. The strip can be dragged into position using a mouse. Double clicking the direction indication calls up a tool for changing direction. Strips can be overlayed, as shown in Figure A.1. When all strips are properly oriented and placed, clicking the file assembles an array of count values with associated backgrounds and calibrations. The largest value for a pixel is used when strips overlap. The strip width is proportional to detector width. The length is read from the strip file as reported by the incoder wheel on the floor monitor.

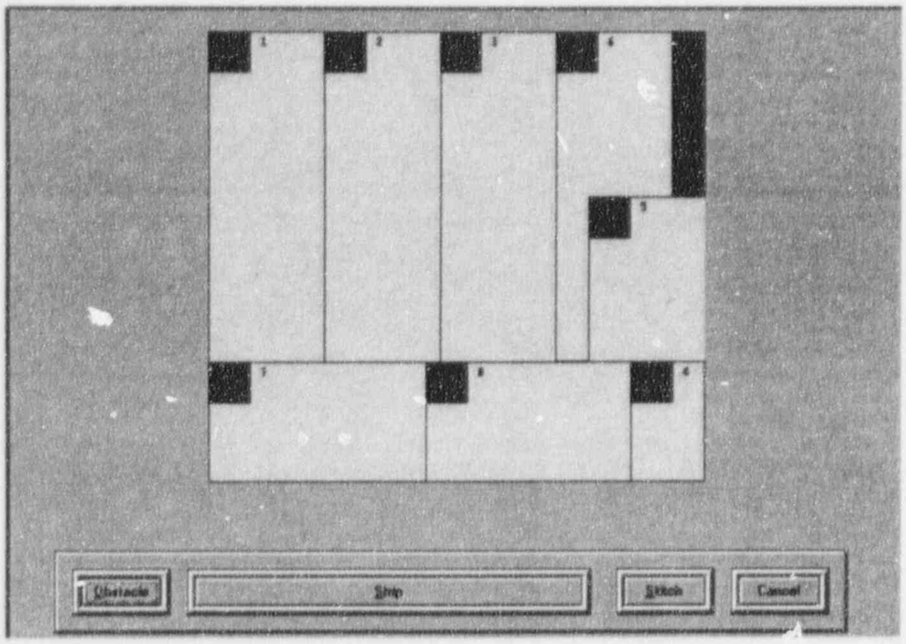

Figure A.1 STITCHER© Survey Pattern

VisuSpect©

VisuSpect© simplifies the study and reporting of radiological survey information. It is integrated with SRA's PSPC based monitor technology. (U. S. Patent 5,440,135) The name VisuSpect© stands for *visual inspection*. VisuSpect© integrates numerical analysis, matrix computation, signal processing, and imaging into an easy-to-use Graphical User Interface (GUI). VisuSpect© relies on the application MATLAB®[1] for computationally intensive tasks. VisuSpect© couples MATLAB®'s computational power with a user friendly, mouse driven environment, dedicated to visual interpretation of survey data. Many of the image enhancement techniques, statistical functions, and retrievable survey information are detailed as follows:

1) Colormaps
Colormaps provide a means to map a data value to a particular display color. Many different effects can be achieved through variations in the color map Color plays an important role in determining how an image is interpreted; therefore, colormaps provide a powerful tool to aid in the visual inspection of data.

2) Plot Types
VisuSpect© provides a variety of functions to display survey data. Some plot lines in three dimensions, while others draw surfaces and wire frames. The following list summarizes these functions. Examples of each type of plot are included in Appendix A.

> **Contour** - A map showing surface contamination by means of contour lines. This type of plot provides a quick representation of contamination levels.
>
> **Image** - An image that displays the activity in each pixel mapped to the current color map. This is the quickest of all the plot types. It is a direct mapping, so shading (see next section) has no effect. Image plots allow the user to see the raw data in its pixelated form.

---

[1]© The Math Works Inc. 24 Prime Park, Natick, Mass 01760

Pseudocolor - A rectangular array of cells whose colors are determined by the count rate in each pixel. The speed of this plot varies greatly with the shading technique, unlike the Image plot. This plot type is better suited for visualizing surfaces. With interpretive shading it produces a photograph quality non-pixelated image.

Pseudocolor/Contour - This plot type overlays a contour map onto the pseudocolor plot to aid in identification of contamination regions in the image.

Mesh - This plot creates wire frame 3-C perspective plots of the data displayed as heights above an underlying plan. This is the fastest type 3-D plot. It is an excellent method for quickly visualizing the surface contamination.

Surface - This type creates solid 3-D perspective plots of data points, displayed as heights above an underlying plane. Surface plots provide the best method for visualizing surface contamination, but this plot type is the slowest, due to the calculation required to generate the image.

Surface W/Light - An off image light source is used to illuminate a Surface plot.

3) Shading Methods
Shading controls the method in which the edges of the data points are rendered. Note that shading will not effect image or contour plots. The following shading methods are available in VisuSpect©.

Faceted - Faceted shading is flat shading with superimposed black mesh lines. This method balances rendering time with readability. It presents the user with clearly separated patches, so the discrete values of the data points are clearly visible.

Flat - Flat shading is piece wise constant; each patch has a constant color, determined by the color values of the data points. This method is the quickest but least informative of the shading methods.

Interp - Interpolated shading (Gouraud shading) is piece wise bilinear; the color in each patch varies linearly and interpolates the end or corner values. Data values are discrete (2"x2") representations of the surface. This method interpolates the data to attempt to define the points between the data values. This method provides photo quality images.

4) Zoom and Crop
The user may enlarge areas of interest in the image, by selecting the region with the mouse pointer. The entire data set is maintained in memory, but only the selected region is displayed in the survey window. The crop function works the same as the zoom function, but the size of the data matrix is reduced when crop is utilized. The processing times for filters and statistical functions can be greatly reduced by cropping out the areas of interest.

5) Automated Report Generation
VisuSpect© has the capability to automatically generate standard reports. Once Print Report is selected the user is prompted with a list of sections. The user selects which sections are desired for the report. VisuSpect© then exports the required text, figures, and tables to a Microsoft Word document. The document may then be revised or appended. VisuSpect© is capable of sending the report directly to the printer. The survey report also outputs data entered in the floor monitor such as technician's initials, date, and location of the survey.

6) Background Subtract
During a survey technician may take a background reading before any survey strip. These background readings are assembled in the same format as the survey data measurements. When background subtract is selected, the background matrix is subtracted from the data matrix. This helps to eliminate any artifacts in the image that are direct contributions of inherent backgrounds present in the system.

7) Thresholding
You can use Thresholding to stretch or crop a colormap. Values below the lower set point map to the lowest value of the colormap and values above the upper set point map to the highest value in the color map. This helps to visualize area in an image that would be suppressed in the presence of an intense artifact by making the display more sensitive in the region of interest.

Figure A.2 shows the impact of thresholding on an 8 bit gray scale image with a data field that lies between one and 16. Standard mapping evenly divides the range of values into the 8 available shades of gray. Thresholding the data allows the viewer to see an image that suppresses the lowest count rate areas (backgrounds) and compresses the highest count rate areas.

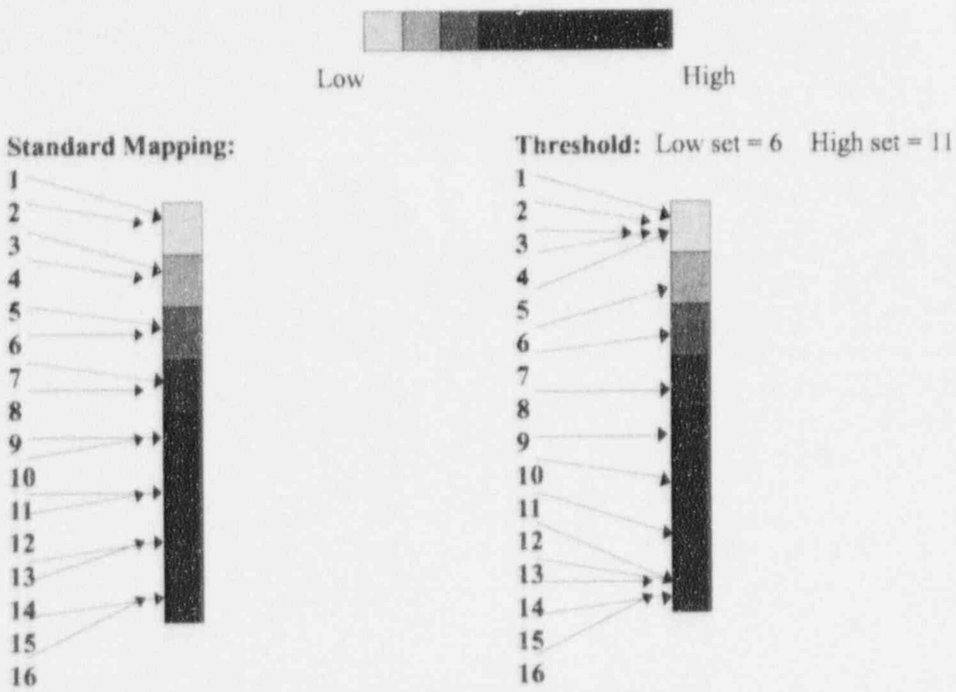

Figure A.2 Threshold Use in Gray Scale

8) Filters
VisuSpect© provides a variety of linear and nonlinear filters. One of the most useful of these is the Wiener filter. The adaptive Wiener filter is more selective, preserving edges and other high frequency parts of an image. The Wiener filter tailors itself to the local image variance. Where the variance is large, the Wiener filter performs little smoothing. Where the variance is small, the Wiener filter performs more smoothing. This filter is the best for filtering out background noise; however, it does require more computation time. As is the case with all smoothing filters, care must be taken not to smooth away pertinent data.

9) Edge detection

Edges are those places in an image where the intensity changes rapidly. VisuSpect© makes this determination by comparing the first derivative of the intensity to some threshold, or by checking the second derivative for a zero crossing. The available methods are:

Marr-Hildreth - method returns edges at the zero crossings of the Laplacian of Gaussian filtered version of the image.

Prewitt - finds edges, using the Prewitt approximation to the derivative. It returns edges at those points where the gradient of the image is maximum. This algorithm is sensitive to horizontal and vertical edges.

Roberts - finds edges, using the Roberts approximation to the derivative. It returns edges at those points where the gradient of the image is maximum. This algorithm is sensitive to diagonal edges.

Sobel - finds edges, using the Sobel approximation to the derivative. It returns edges at those points where the gradient of the image is maximum. This algorithm is sensitive to horizontal and vertical edges.

10) 100 cm^2 statistics

VisuSpect© contains many tools for conducting statistical analysis of the data and checking release limits. The survey window can be changed at any time to display the 100 cm^2 or square meter data. SRA detector systems provided data in 25cm^2 pixels. Current standards express release limits in terms of 100 cm^2. Offsets must be applied when summing the 25 cm^2 data to 100 cm^2. If the offsets are not applied, a 100 cm^2 region that contains contamination in excess of the release limits could be averaged into adjacent 100 cm^2 regions. VisuSpect© provides a plot that overlays the 100 cm^2 zones and their offsets onto one image so that all possible 100 cm^2 configurations are rendered.

VisuSpect© also provides numeric analysis. The survey may be divided into one square meter sections. Figure A.3 shows this data for a 5 m by 6 m room. The mouse was used to select the 4th meter across and 5th meter up from the lower left corner (0,0) and shows the mean, maximum, minimum and standards deviation of the dpm / 100 cm^2. For each section the mean, maximum, minimum and standard deviation for each region are placed into a grid. As the dpm/100 cm^2 and the dpm/100 cm^2 averaged over one square meter release limits are adjusted, the background color for each grid that exceeds that limit changes color. This helps the user to immediately discern the regions of the survey that violate the release limits. When the user selects a grid with the mouse a cumulative probability distribution graph is generated.

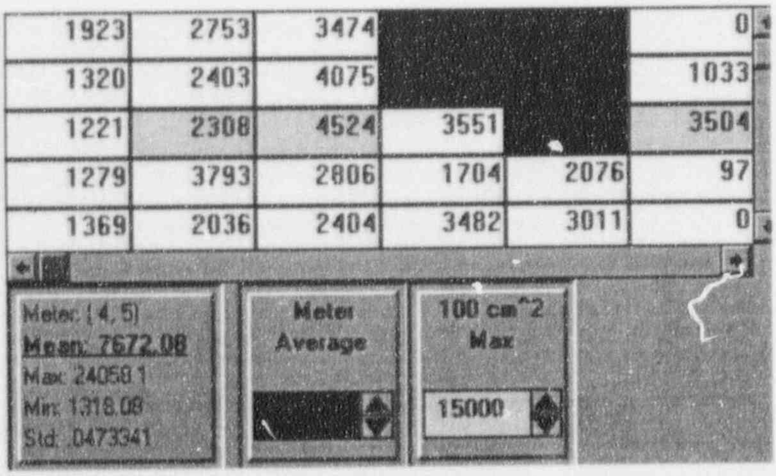

Figure A.3 VisuSpect© Analysis Display

If the graph is linear, the grid contains general contamination that is normally distributed. If the graph is non linear, extreme values exist in the data.

11) Survey Information
VisuSpect© provides an information menu that gives the user access to many useful items. The pattern that was used to survey the room or the background spectrum for a particular survey strip can be plotted. Also a time index can be provided by selecting a particular pixel with the mouse. This time index can be used to advance the video tape to the time that that particular pixel was acquired. The survey memo, a text file updated by the technician when surveying to document survey conditions or problems, may be viewed. A viewer is loaded when a file is opened that details the technician's name, area surveyed, date, time, equipment serial number, calibration date, and the electronic settings for the instrument during the survey.

Context sensitive help is also available within VisuSpect©. Figure A.4 shows the data available.

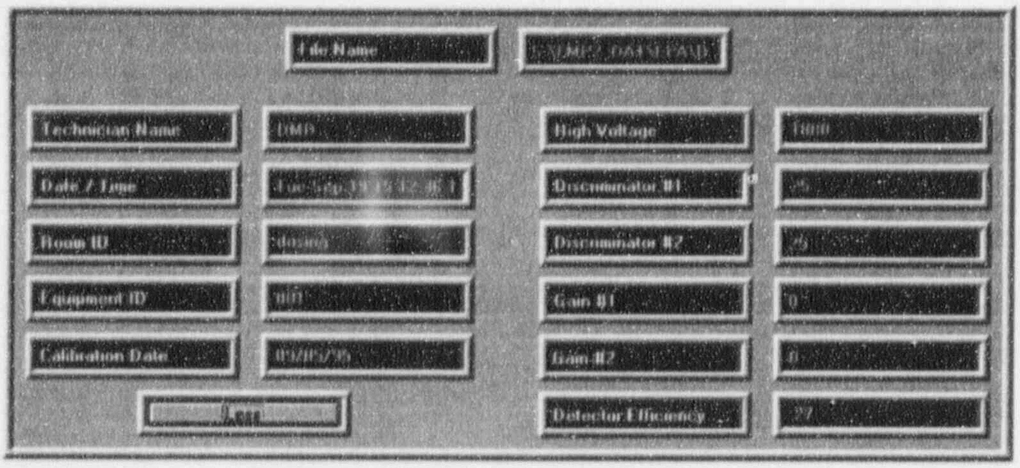

Figure A.4 VisuSpect© Information Menu

Microsoft Word

Microsoft Word is a word processing program from Microsoft. When requested via a pull down menu, a report is automatically generated in Word. The report shows any figure that was generated or screen captured and writes a summary based on the electronic survey information shown in Figure A.4. The user can then go in and edit the report, adding notes and comments as desired.

APPENDIX B

Figure B.1 Image plot with SRA colormap

Figure B.2 Surface plot with hot colormap

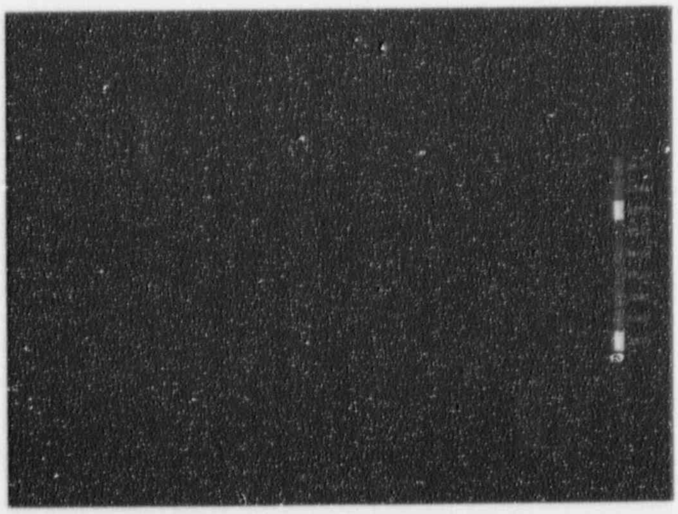

Figure B.3 Contour Plot

Figure B.4 Image Plot

Figure B.5 Pseudocolor/Contour Plot

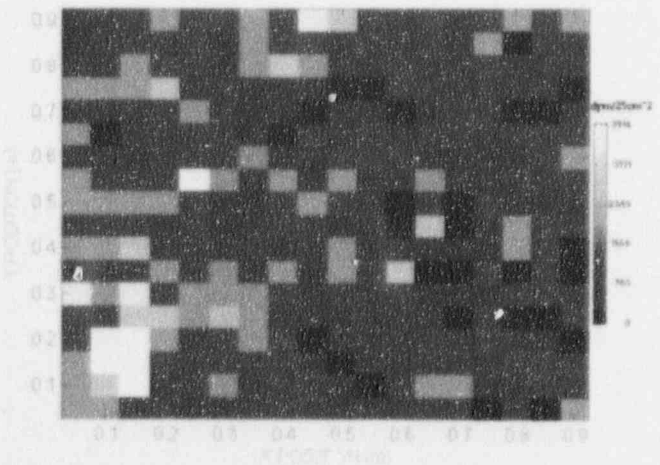

Figure B.6 Image Plot of Grid Location (4,2)

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10. SUPPLEMENTARY NOTES

S. McGuire, NRC Project Manager

11. ABSTRACT (200 words or less)

This report describes development of a significant new method for monitoring radioactive surface contamination. A floor monitor prototype has been designed which uses position sensitive proportional counter based radiation detectors. The system includes a novel operator interface consisting of an enhanced reality display providing the operator with 3 dimensional contours of contamination and background subtracted stereo "clicks". The process software saves electronic files of survey data at very high rates along with time stamped video recording and provides completely documented surveys in a visualization oriented data management system. The data management system allows simple re-assembly of strips of data that are taken with a linear PSPC and allows visualization and treatment of the data using algorithms developed for processing images from earth resource satellites. This report includes a brief history of the development path for the floor monitor, a discussion of position sensitive proportional counter technology, and details concerning the process software, post processor and hardware. The last chapter discusses the field tests that were conducted at five sites and an application of the data management system for data not associated with detector systems.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

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