INNOVATIVE TECHNOLOGY
Summary Report

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Mobile Automated Characterization System

Deactivation and Decommissioning Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

Mobile Automated Characterization System

OST Reference #1798

Deactivation and Decommissioning
Focus Area

Demonstrated at
Argonne National Laboratory-East
Argonne, Illinois

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Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://OST.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Technology Description

The US Department of Energy and the Federal Energy Technology Center (FETC) have developed a Large Scale Demonstration Project (LSDP) at the Chicago Pile-5 Research Reactor (CP-5) at Argonne National Laboratory-East (ANL). The objective of the LSDP is to demonstrate potentially beneficial Decontamination and Decommissioning (D&D) technologies in comparison with current baseline technologies.

The Mobile Automated Characterization System (MACS) has been developed by Oak Ridge National Laboratory (ORNL) and the Savannah River Technology Center (SRTC) for the U.S. Department of Energy's (DOE) Robotics Technology Development Program as an automated floor surface contamination characterization system. MACS was designed for use by Health Physics (HP) personnel in the performance of floor surveys of known or suspected contaminated areas, to be used during any floor characterization task which has significant open areas requiring radiological surveys.

MACS was designed to automate the collection, storage and analysis of large, open floor areas, relieving the HP personnel of this portion of the floor characterization task. MACS does not require a dedicated full time operator and can be set up by the normal HP staff to survey the open areas while other techniques are used on the more constrained areas. The HP personnel performing the other characterization activities can monitor the MACS progress and address any problems encountered by MACS during survey operations. MACS is designed for unattended operation and has safety and operational monitoring functions which will safely shut the system down if any difficulties are encountered. During survey operations, MACS generates a map of surveyed areas with color-coding indicating radiation levels. This map is displayed on the control console monitor during operation and can be printed for survey result documentation. MACS produces data files containing data for all sensors used during a survey, providing a complete record of samples taken and contamination levels found for all areas traversed during a survey. This data can be processed to produce tabular output of the survey results.

The MACS system has three major components, consisting of MACS unit, operator control station, and the battery charging rack. The system demonstrated at CP-5 was equipped with scintillation detectors for measuring alpha and beta emitting contamination, although other types of detector systems could be installed on the MACS unit. The MACS unit consists of a mobile platform with six mounted scintillation detectors. The platform is a commercially available robotic platform with a 250-lb. payload capacity and a zero turning radius that allows the platform to turn without losing position. A preset program specifying the dimensions of the characterization area and the surveying speed is loaded into the MACS prior to use. The MACS unit then characterizes the area according to the program parameters. The actual platform uses dead reckoning and wall locations to identify its location in the characterization area. The dead reckoning monitors the number of rotations of the platform wheels for location determination; however, slippage of the wheels will cause errors in location. To compensate for this and allow for surveying in larger areas, the MACS is equipped with a laser scanner position system. The laser system allows for targets to be placed in the surveying area and the target location input into the computer system operating the MACS. While the characterization is in progress, lasers scan the area for the targets that confirm the location of the system. Figure 1 shows the MACS unit.

Figure 1 Mobile automated characterization system (MACS).

The scintillation detectors mounted to the system are commercially available alpha and beta detectors as seen in Figure 2. The detectors are arranged side by side as shown in Figure 3. The detectors are then covered with a protected cover that acts as a bumper in case of collision as shown in Figure 4.

The MACS computer software is designed to be user-friendly and is easily operated by Health Physics personnel using graphical operator interface programming, without the need for extensive training or formal education in computer codes. Characterization data is saved by the on-board computer system in addition to the real-time concurrent display on the operator interface.

At this time the MACS is not capable of performing surveys along floor/wall boundaries, directly around the base of obstacles, or in areas too small for the system to maneuver. This can be a concern in large areas with numerous support columns or piping in the area; however, MACS can be put to use in large unobstructed areas while personnel with hand-held detection instrumentation focus on the corners, wall/floor boundaries, and other obstacles. Other systems are in development to complement MACS for surveying small floor areas.

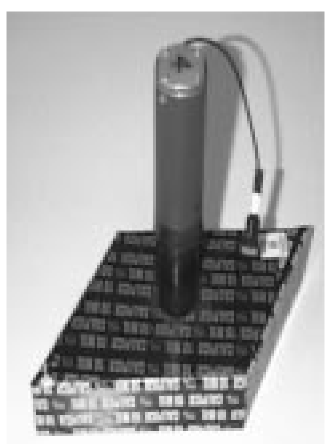

Figure 2 Individual scintillation detector used on MACS.

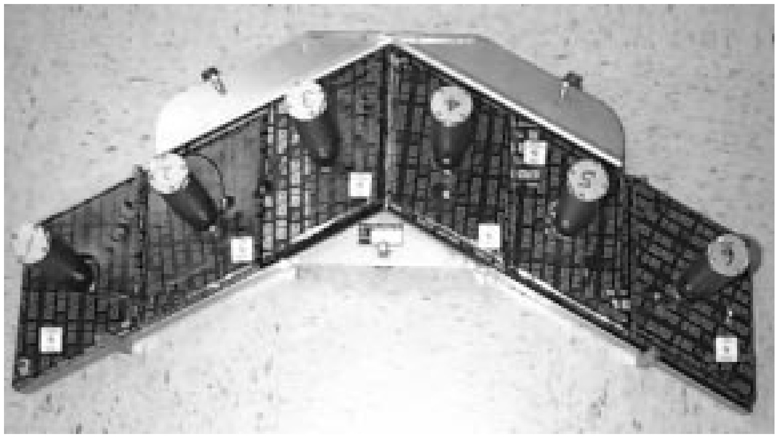

Figure 3 MACS detector array.

Figure 4 Housing covering MACS detectors.

The MACS can be widely used at DOE sites during characterization activities and final release surveys. It allows for conformance with the DOE ALARA policy by limiting the amount of personnel exposure. Currently, the only method of performing surveys is by Health Physics technicians using manually operated surveying equipment and recording survey results by hand. MACS also allows for more accurate surveying speeds and less surveying time since the MACS records both alpha and beta radiation measurements simultaneously.

Cost savings may be attributed to the MACS from a labor savings standpoint for facilities with large areas of open floor space. The time and money necessary to train personnel in radiation worker, OSHA and other job specific training would not be required for the MACS. Time and cost savings may also be seen in the labor and in data manipulation and archiving and transfer to spreadsheet.

Technology Status

The surveying components of MACS are comprised of over-the-shelf items and do not need further technology development. The robotics, positioning system and computer program have undergone laboratory testing and are currently undergoing real-world tests. The CP-5 demonstration was the first time that the MACS was used in an actual D&D environment. The CP-5 research reactor was a heavy-water moderated and cooled, highly enriched uranium-fueled thermal reactor designed to supply neutrons for research. The reactor had a thermal-power rating of 5 megawatts and was continuously operated for 25 years until its final shutdown in 1979. Such operation has produced activation and contamination characteristics representative of other nuclear facilities within the DOE Complex and in other research and commercial reactors and was ideal for demonstrating the MACS. The service floor of the reactor, made of concrete, was the staging location for the demonstration. It was used to support process equipment for reactor operations; however, all the equipment was removed during the initial stages of D&D.

Three ORNL personnel were present during the MACS demonstration. In addition, ANL provided a Test Engineer, a Health Physicist and Health Physics Technicians. Demonstration data for benchmarking was provided by ANL and data for cost analysis was provided by ANL and ORNL. Cost analysis was performed by the U.S. Army Corps of Engineers, and benchmarking activities were performed by ICF Kaiser.

Key Results

The key results of the MACS demonstration are that MACS' greatest application would be in large open areas which would need to be surveyed repeatedly. In addition, the color graphic capability of the MACS to illustrate contamination locations is one of the system's greatest assets. It is easier to visually identify contaminated areas by looking at the color maps than by scanning through pages of coordinate survey data. The color map provides all of the data obtained on one page for easy reference. A technician is less likely to miss something by utilizing the color map. MACS is very suitable for repetitive Surveillance and Maintenance applications. MACS does not require a full time operator. It can be pre-programmed to conduct surveys

Based on the demonstration, MACS will have to improve its reliability to take full advantage of its capabilities. Downtime was experienced during the demonstration due to numerous survey and hardware errors.

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Web Site

The CP-5 LSDP Internet address is http://www.strategic-alliance.org

SECTION 2

TECHNOLOGY DESCRIPTION

System Configuration and Operation

MACS automates the survey of large open areas, relieving the HP personnel of this time consuming and tedious portion of the floor characterization. Although MACS is designed to survey a large percentage of the space requiring characterization, MACS is not designed to cover areas such as floor/wall boundaries, the base of obstacles such as columns or pipes, or areas too small for MACS to maneuver. MACS is intended to be used in conjunction with manual or other remote survey capabilities that address the areas that MACS is unable to survey.

The MACS has three major components, which consists of the MACS unit, operator control station, and the battery charging rack. The commercially available Cybermotion K2A mobile platform measures approximately 45.0"H x 34.5"W x 57.25"L and houses a Z180 microprocessor, a radio link to the control station via a radio frequency local area network (RFLAN), ultrasonic sensors for collision avoidance, and six National Nuclear Corporation scintillating radiation detectors. The vehicle uses dead reckoning and a laser landmark recognition system for navigating. A docking station is used for recharging batteries and position calibration. The interface to the control station is accomplished using a 68030 VME rack running Control Shell and Network Data Delivery System. In addition to these components, a radio modem is located on MACS for communicating with the control station.

The MACS platform is based on the Cybermotion K2A mobile platform and has a payload capacity of 250 lbs, a zero turning radius, and can operate from batteries for up to 9.5 hours at a time. A full recharge time is estimated at 10-12 hours. Open area navigation is possible by using the laser scanner and wall mounted reflective markers placed in known locations. The six scintillation detectors are capable of detecting alpha and beta radiation. MACS does not have gamma detection capability at this time.

The operator control station is a portable UNIX system using a computer mounted in a portable rack with integrated monitor, keyboard, and trackball. The control console houses a VME based Sparc 10 CPU system, RFLAN, and monitor. A graphical user interface is provided at the control console which allows the technician to input commands without requiring familiarity with details of programming the robot. A user is able to graphically designate the area to be surveyed and the robot program is automatically generated and downloaded to the robot. The areas to be surveyed by MACS are specified as large rectangular areas which MACS traverses in a grid pattern. Data is displayed in real-time using the "RADMAP" software package. The control station and MACS are linked via radio frequency (RF) through two small antennas.

MACS is designed to survey the large open portions of areas. MACS can detect and either maneuver around or stop when it encounters obstacles protruding from the floor, such as columns or pipes. MACS detects these obstacles during forward travel. Any obstacles protruding from walls or hanging from the ceiling or that might be contacted during turnaround motions can be identified by a visual inspection of the selected survey area. If such obstacles exist, the survey area must be redefined to avoid these obstacles. This limits the use of MACS in highly cluttered areas where large open rectangular areas are not clear of such obstacles. Definition or redefinition of survey areas for MACS is easily performed using the graphical user interface of the operator console. The user simply defines the largest rectangular area in which no such obstacles exist.

During survey operations, MACS generates a map of surveyed areas with color-coding indicating radiation levels. This map is displayed on the control console monitor during operation and can be printed for survey result documentation. MACS produces data files containing data for all sensors used during a survey, providing a complete record of samples taken and contamination levels found for all areas traversed during a survey. This data can be processed as desired to produce tabular output of the survey results.

Design of the battery charging rack is such that MACS can drive into the charging probe when charging is required. This can be accomplished automatically through programming or manually with a tether. MACS also uses the charging rack to calibrate its position.

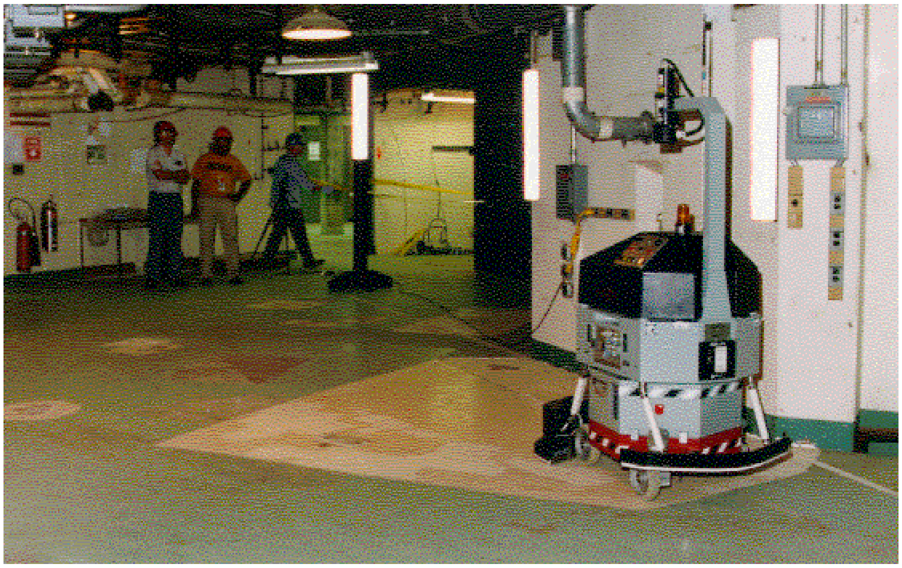

Figure 5. MACS during demonstration at CP-5.

SECTION 3

PERFORMANCE

Demonstration Plan

The MACS demonstration was conducted at the CP-5 Research Reactor at Argonne National Laboratory in Argonne, IL. The major objective of the demonstration was to evaluate the MACS against the baseline technology of manual surveying. Evaluated during the demonstration were the time required to set up the MACS; the overall time required to survey the prescribed floor area; the amount of downtime, if any; the overall battery life of the system with respect to the time the unit could be continually operated before recharging; and the magnitude of the count rates and position of radiation survey data in comparison to manual surveys.

Demonstration Objectives

The MACS system was tested in the basement area of the CP-5 Research Reactor where the floor area of concern had known levels of fixed contamination present. Contamination levels ranged from less than free release levels for alpha and beta to greater than 500,000 disintegrations per minute (dpm) per 100 cm^2 beta. A 15 ft by 40 ft concrete floor area, which represented the single largest rectangular area available in the CP-5 basement, was used for the demonstration. The CP-5 floor service area is representative of the types of floor surface which could be expected to be encountered in a number of facilities. Some floor areas were bare and some painted. The MACS test area also contained an area with steel floor plates inserted within the concrete floor. After some adjustment to the height of the detector array, the MACS unit had no difficulty surveying over the floor irregularity.

The MACS demonstration examined the following objectives:

- The time required to set up the MACS at the facility.
- The overall time required to perform a single survey of the prescribed floor area. It should be noted that two additional surveys of the entire test area were requested in the test plan to allow evaluation of MACS data consistency.
- The magnitude of the count rates and position of radiation survey data for comparison with the manual survey data.
- The amount of downtime which occurs prior to completion of one full survey of the prescribed floor.
- The overall battery life of the system with respect to the time the unit can be operated before recharging. During this test, the MACS unit was operated in a continuous rectangular path with all electrical systems functioning.

MACS Performance

MACS Set up

A breakdown of the set up time is as follows:

Clean area functional check	45 min.
Source check done in clean area	60 min.
Move equipment to survey area	45 min.
Install charging station and laser targets	105 min.
Start up system and operator console	60 min.
Define rectangular survey area on operator console screen using operator interface	5 min.
Visually check area for obstructions in defined survey area and adjust rectangular area if required using operator interface	10 min.
TOTAL TIME	**330 MIN**

The set up time included the partial set up and checkout of systems in a non-radiological controlled area. Equipment then had to be moved to the floor service area, one level below. One of the more time-consuming items was making necessary test area grid adjustments to accommodate MACS without it coming in contact with any obstructions. The test boundary was brought in about 10 inches away from the curved wall to prevent the MACS detector array from making contact with wall obstacles when it pivots its detectors while turning for additional passes. Set up time for MACS was 5 hours and 30 minutes. During repetitive surveys, it is estimated that MACS could be ready to operate in 15-20 minutes after the equipment is stationed and set up. However, consistency and reliability issues will have to be resolved first.

An additional obstruction was a pipe protruding from the reactor shield wall about 23 inches at approximately 5 feet off the floor with a 90 bend toward the ceiling. The MACS unit with its vertical boom containing the guidance would not clear this obstruction. However, the MACS sensors would not have recognized the pipe as an obstruction and would have probably run into it. The test boundary was changed to avoid this pipe.

The CP-5 floor service area is representative of the types of floor surface which could be expected to be encountered in a number of facilities. The MACS test area contained an area with steel floor plate inserted within the concrete floor. After some adjustment to the height of the detector array, the MACS unit had no difficulty surveying over the floor irregularity.

After the last of the MACS laser reflectors were installed without difficulty, MACS completed its system check and was put on the charger to ensure a full charge for the next day's surveys and battery endurance runs. All other systems were powered down and MACS locked out.

MACS Demonstration

Once the set up was completed the MACS survey was started. Since the CP-5 demonstration was the first time MACS had been used in an actual work environment, the test area was surveyed multiple times to observe the consistency of MACS survey results. The test plan therefore called for MACS to survey the test area a minimum of three times. In actual practice only a single survey would be performed. The time required to complete a survey of the test area by MACS was:

First Run	Survey Completed	53 minutes
Second Run	Survey Aborted	Computer lockup
Third Run	Survey Aborted	Computer lockup
Fourth Run	Survey Completed	49 minutes
Fifth Run	Survey Completed	45 minutes
Sixth Run	Survey Aborted	55 minutes for 95% Completion (Computer misinterpretation or Computer lockup)
Battery Endurance Test	3 hours, 50 minutes after the completion of the 6^{th} run	

Prior to the first survey run, the MACS operating control console CPU would not power up. One hour later and after many attempts to correct the problem, the CPU suddenly came up. ANL and ORNL personnel were not adequately able to explain why the malfunction occurred or how it was resolved. Power to the system was confirmed, therefore the problem was definitely within the MACS hardware. The cause of this problem was not determined. To avoid possible delays the following day, the CPU was not powered down at the end of the day.

Once the operating control console CPU was operating, the initial survey of the test area was started and completed without incident. To observe the consistency of MACS data from multiple runs, two additional surveys of the same area were desired. A second survey was started but was aborted automatically after approximately 20 minutes when the radiological sensor computer CPU housed on the MACS vehicle locked up. The cause of this problem was not determined. The data collected during the 20 minutes of surveying was valid data which could have been used but was discarded. If an actual survey was being performed, a new area defining only the area not completed at the time of the abort could have been defined to collect the remaining data. However, the system was reset and the full survey attempted again. After approximately 18 minutes, the radiological sensor computer again locked up automatically aborting the survey. The system was reset and the full survey was again attempted. This attempt and a following attempt were successful providing the three sets of survey data specified in the test plan. Following completion of the required three surveys, a final survey was attempted with the survey area modified. After completing approximately 95% of this survey, the system aborted the run. Survey activity was stopped at this point and a battery endurance run was initiated. It was initially thought that this abort was caused when MACS detected the reactor shield wall and considered it an obstacle that it could not get around. Upon further reflection, it is considered unlikely that MACS would abort this run due to detection of the reactor wall. It is more likely that this abort was again the result of a lock up of the radiological sensor computer CPU. When MACS completes a survey, it appears to do well, however the radiological sensor computer lock up poses a serious reliability issue that must be addressed.

There were slight differences in the areas surveyed using MACS and by the manual survey. ORNL considered that MACS would be too close in proximity to the walls in the corners at position (0,0) and (40,0) therefore, MACS was programmed to survey approximately 1.2 feet inside that boundary. In addition, to avoid the protrusion from the cut face on the inner wall, MACS was programmed to survey approximately 1.3 feet inside that boundary. On the 6th run, MACS survey area was changed to survey inside the boundary areas by approximately 0.5 feet.

MACS could not supply survey sheets during the test due to a printer or CPU interface malfunction. Therefore, there is no time recorded for the production of survey data sheets. ORNL had to work with the MACS computer to get the proper shading of color to show where contamination existed. It should be noted that the Operating Control Console shows real time color representation of survey data while MACS is operating. This would be an advantage to Health Physics personnel using MACS.

Manual Survey Set up

In comparison, the total time to manually complete the survey test area was 4 hours and 30 minutes. This time includes time to set up equipment, calibrating instruments, making appropriate maps and paperwork to document characterization and actual time to complete the physical survey. The breakdown of time is as follows:

Instrumentation operational check:	35 min.
Survey area for exposure rate with Bicron:	10 min.
Survey floor with FM-4G	20 min.
Survey floor with PRM-5 W/PG-2	40 min.
Survey floor with Electra NE	45 min.
Take 100cm sq smears of area	10 min.
Count smears	50 min.
Large area smear samples (1 m^2 smears)	10 min.

Modify/Update survey maps	20 min.
Record data	30 min.
Total	270 min.

The time required to record data on working maps is included in survey time for the manual data. An instrumentation operations check is included in the manual-surveying total. Additionally, the manual survey performed was closer to a final release survey in detail and amount of sample points obtained than a characterization survey. In general, characterization surveys have fewer data points than free release surveys, as their intent is not regulatory release but information gathering. If the MACS is to be used during characterizations and not final release surveys this factor should be considered in comparison of the survey durations. The baseline survey includes both direct measurements for total (fixed-plus-removable) contamination, smear samples for removable contamination, and exposure measurements with an industry standard tissue equivalent meter (Bicron). These are required for almost all surveys. Although MACS is capable of determining total contamination measurements, MACS is not capable of performing smears of surface areas to detect removable contamination or measuring exposure rates. This must also be factored when comparing the two methods for survey durations and costs.

Manual data position reference was obtained using a tape measure. A rectangular area approximately 40 ft by 15 ft was marked on the floor using tape. The locations of the values recorded were referenced from this rectangle. The sensor readings and position measurements were manually recorded on a grid.

The MACS position reference system is significantly more complex. MACS uses a combination of dead reckoning and a laser navigation system for continuous position corrections. The laser navigation system requires the placement of a number of fiducial markers near the area to be surveyed. The location of these fiducial markers must be input into the computer while planning the path. It is important to locate these fiducial markers within an inch or two. This, coupled with the lack of easy references in the circular CP-5 building, partially explains the significantly longer than normal set up time. Another factor is that in making measurements using the rectangular area marked for the manual survey, it was discovered that a rectangle was not sufficiently accurate for MACS to be used as a reference for locating the MACS fiducial markers. MACS fiducial markers had to be placed using the manual tape measure as well.

MACS was programmed to survey to approximately 1.2 feet from the walls, and 1.3 feet from the cut face on the inner wall. In comparison, it must be noted that obstacles or walls did not limit the manual surveys and can be performed in any size or shape environment.

Data Comparison

The data obtained using MACS and the manual survey were very similar. Both methods located the same "hot" spots with minor variations in the readings. The major advantage in the data comparison is the presentation of the data. Manual survey requires a grid system to be developed, and the survey data taken with respect to the grid. Generally the results of the manual survey are presented as a series of numbers for each grid. The MACS data output is color coded to give a visual representation of the contamination. Figure 6 shows a greyscale representation of a color printout from MACS for Run number 6 based on the grid system used for the manual survey. The original figure, in color, is accompanied by a color key sheet showing the corresponding activity levels per color. Although these do not reproduce well when converted into Grayscale, the color key is extremely beneficial for interpreting the data and determining contamination trends. Using the color representation, ORNL had to work with the MACS computer to get the proper shading of color to show where contamination existed. It should be noted that the Operating Control Console shows real time color representation of survey data while MACS is operating. After ORNL refined the color range charts the MACS identified additional spots that were not indicated on the first color survey. Due to the differences in the boundaries of the two surveys, MACS did not survey over areas along the edges where the manual survey indicated there was contamination.

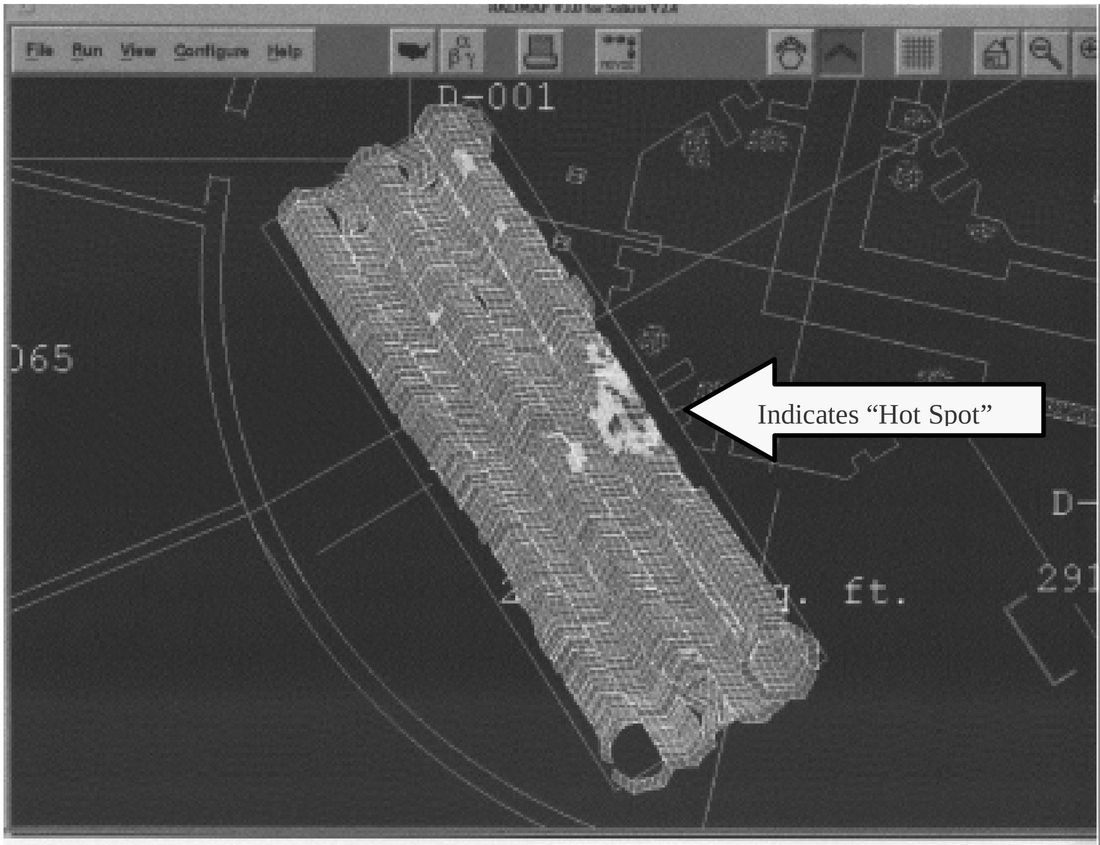

Figure 6. MACS graphical output of run #6.

Although the color scheme gives a quick and clear view of the location and the relative levels of contamination, the current implementation of the graphical data display limits the number of ranges to 6. An increase in the number of ranges would be of significant benefit.

The life of the battery was tested by monitoring the battery life during the survey runs and during an endurance run. At initial start, the battery had a full charge of 25.8 volts. The operating time of the unit was recorded with the corresponding battery reading to determine the battery life. The demonstration determined that 24.0 volts would equate to 9.5 hours of survey time.

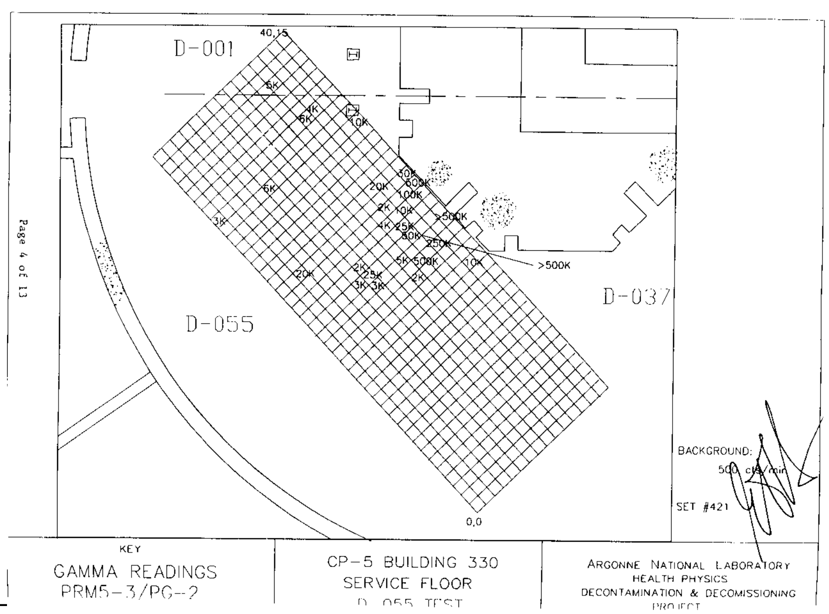

Figure 7 - Manual survey map.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology Applicability

MACS is a complete system for surveying floors or surfaces for alpha and beta contamination. MACS has maximum utility in facilities that have large areas to survey; however, even in small facilities with relatively irregularly shaped rooms, the use of MACS in conjunction with manual surveys can reduce the time and cost for surveys.

Some of the key advantages of MACS are:

- The analytical capabilities of MACS. After the survey patterns are programmed into the computer, data output allows for easily determining trends in contamination location and quantities.
- The interface with MACS is easy to learn and manipulate.
- Collection of the data by the computer increases the reliability of the measured data and relieves the operator of much of the routine data recording and transcribing, thus reducing operator fatigue and improves performance.
- The color graphic capability of MACS to show the locations and quantities of contamination is a significant asset. It is much easier to analyze data from a color map than from pages of coordinate survey data, with much less likelihood of missing data from the color map.
- MACS has sufficient battery longevity to allow one full shift of survey capability.

The major limitation of MACS is in surveying rooms with large number of obstacles, corner-wall boundaries, or areas where complex maps are required. Combining manual surveys with MACS will reduce this problem. Additionally, the computer lockouts must be addressed before MACS is ready for industrial distribution.

Competing Technologies

The baseline methodology to the MACS is manual surveys by trained Health Physics technicians. Manual surveys are time consuming and tedious. This can lead to high labor costs, unreliable data and potentially unnecessary exposure. See Appendix C, Baseline Technology - Manual Characterization, for details related to procedures and equipment used in manual baseline survey.

A competing technology also demonstrated as part of the CP-5 LSDP is the Shonka Research Associates, Inc.'s (SRA) Surface Contamination Monitor and Survey Information Management System (SCM/SIMS) for surveying surfaces for alpha and beta contamination and documenting the measured data. The SRA surface contamination monitor and survey information management system SRA-SCM/SIMS is designed to perform alpha and beta radiation surveys of horizontal and vertical surfaces.

Another competing technology for surface characterization is the Three-Dimensional, Integrated Characterization and Archiving System (3D-ICAS), funded through the DOE's Federal Energy Technology Center. Coleman Research Corporation is the prime contractor.

Patents/Commercialization/Sponsor

No patents have been obtained for the MACS.

SECTION 5

COST

Introduction

This cost analysis compares the relative costs of the innovative and baseline technology and presents information which will assist D&D planners in decisions about use of the innovative technology in future D&D work. This analysis strives to develop realistic estimates that represent actual D&D work within the DOE complex. However, this is a limited representation of actual cost, because the analysis uses only data observed during the demonstration. Some of the observed costs will include refinements to make the estimates more realistic. These are allowed only when they will not distort the fundamental elements of the observed data and eliminate only those activities which are atypical of normal D&D work.

Methodology

This cost analysis compares an innovative technology for a remotely operated Mobile Automated Characterization System (MACS) against a baseline technology of manually surveying for radiological conditions. The MACS technology was demonstrated at ANL under controlled conditions which facilitated observation of the work procedures and typical duration of those procedures. The cost analysis is based on those scans using the MACS which appear to be representative of typical work.

The manual survey was demonstrated just prior to the innovative technology demonstration on a 600 square foot (ft^2) area. The baseline is developed using the labor, equipment, production rates, and productivity loss factors (PLF) from a time log of the demonstration by ANL. Additional efforts were applied in addition to the manual demonstration performed on a 600 square foot (ft^2) area for setting up the baseline cost analysis to assure unbiased and appropriate production rates and crew costs. Specifically, a team consisting of members from the Strategic Alliance and the U.S. Army Corps of Engineers (USACE) review the estimate assumptions to ensure a fair comparison between the MACS demonstration and the manual survey demonstrated on the 600 square foot (ft^2) area.

The selected basic activities being analyzed are mobilization, characterization, and demobilization. Waste disposal is not an activity necessary in this study. The activities come from the Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary (HTRW RA WBS), USACE, 1996. The HTRW RA WBS, developed by an interagency group, is used in this analysis to provide consistency with the established national standards. Further, the specific criteria analyzed are the costs for obtaining the equipment, training on-site personnel in equipment use, conducting the surveys, and recording and reducing the results. This applies to both the baseline, since sites generally have and use their own manual instruments, and the innovative technology.

Some costs are omitted from this analysis so that it is easier to understand and to facilitate comparison with costs for the individual site. The ANL indirect expense rates for common support and materials are omitted from this analysis. Overhead and General and Administrative (G&A) rates for each DOE site vary in magnitude and in the way they are applied. Decision-makers seeking site-specific costs can apply their site's rates to this analysis without having to first back out the rates used at ANL. The impact resulting from this omission is judged to be minor because overhead is applied to both the innovative and baseline technology costs. Engineering, quality assurance, administrative costs and taxes on services and materials are also omitted from this analysis for the same reasons indicated for the overhead rates.

The standard labor rates established by ANL for estimating D&D work are used for the work performed by local crafts. Costs for site owned equipment, such as trucks for transport or Health Physics Technician (HPT) radiological survey equipment, are based upon an hourly rate for Government ownership that is computed using OMB Circular No. A-94. Estimated equipment prices from vendors are used to establish a most probable cost for a site to acquire the equipment. The estimate allows for the vendor's G&A, overhead and fee mark up costs. Additionally, the analysis uses an eight-hour workday, a five day work week, and no overtime. The production rates and observed duration used do not include "non-productive" aspects such as work breaks, donning and doffing clothing, loss of dexterity, and heat stress. These "non-productive" elements are accounted for by including a Productivity Loss Factor (PLF) if and when applicable. The PLF is a historically based estimate of the fraction of the workday that the worker spends in non-productive activities.

Cost Data

Table 1. Innovative Technology Acquisition Costs

ACQUISITION OPTION	ITEM	COST
Equipment capital cost by supplier	MACS Components: includes Robot platform, On-board computer, Detector systems, Stationary workstation, and software,	$199,200
Supplier investment	Assembly of components	$48,000
Government Provided Service	Software program modifications	$18,000
Site Engineering Design for procurement	Plans, specification preparation, bidding process, evaluation, and award by non-procurement departments	$37,000
TOTAL OF ABOVE	Assembled MACS ready to mobilize	$302,200.00
NOT AVAILABLE COMMERCIALLY		

Acquisition of the technology as a complete commercial instrument is not anticipated. This analysis assumes the MACS technology acquisition consists of the DOE Site developing a plan and specification package for a contract to assemble the instrument components. It is assumed that as demand for MACS increases, ORNL will make units commercially available. The purchase cost of a complete MACS unit is estimated to be $302,200.

Summary of Cost Variable Conditions

The DOE complex presents a wide range of D&D work conditions because of the variety of functions and facilities. The working conditions for an individual job directly affect the manner in which D&D, including characterization, work is performed. As a result, the costs for an individual job are unique. The innovative and baseline technology estimates presented in this analysis are based upon a specific set of conditions or work practices found at CP-5, and are presented in Table 2. This table is intended to help the technology user identify work differences that can result in cost differences.

Table 2. Summary of cost variable conditions

Cost Variable	MACS	Manual Survey
Scope of Work		
Quantity and Type	One full pass to cover 600 square feet (ft^2) using multiple detectors measuring only total alpha and beta contamination. MACS does not have capability for removable contamination or exposure rate surveys.	Four Manual surveys of same 600 ft^2 using 4 detectors: an Electra NE; FM-4G; and a PRM-5 w/PG-2; and a BICRON. Detected Alpha, Beta, and Gamma , including total and removable contamination quantities.
Location	D-055, service floor of building 330: below the reactor floor; a relatively large clear 600 ft^2 area.	D-055, service floor of building 330: below the reactor floor; a relatively large clear 600 ft^2 area.
Nature of Work	Survey provides detailed remote computer controlled data collection.	People enter area to gather the readings and record on paper.
Work Environment		
Worker Protection	Anti-contamination disposable suits and boots were not required for entry into the demo area. Gloves were worn as a precaution when personnel were required to touch bldg surface.	Same normal requirements as during surveying. These requirements were lessened as further information concerning the radiological conditions was gathered.
Level of Contamination	Classified as an area with "fixed" contamination on the floor but no "loose" contamination	Classified as an area with "fixed" contamination on the floor but no "loose" contamination
Work Performance		
Acquisition Means	Assembled by ANL with support from ORNL.	Site owned equipment used by site personnel, no new incremental training necessary
Production Rates	Rates for 3 surveys varied from 11.4 ft^2/min to 14.1 ft^2/min and 3 surveys were aborted & inconclusive.	Gamma Scan 15 ft^2 /min Alpha - Beta Scan 30 ft^2/min Alpha-Beta Direct 13.3 ft^2/min Smear Samples (See Table 3)
Equipment & Crew	Demo: 3 ORNL persons demonstrated. Future scenario & basis of cost study: Two HPTs for set up and operation.	One HPT using each detectors during 4 passes through area
Work Process Steps	1. Obtain equipment from warehouse 2. Transport from receiving to work location 3. Instruction for operators 4. Set up work area to accommodate equipment 5. Set up equipment/check out & calibrate 6. Detailed surveys for alpha & beta 7. Detailed surveys for gamma 8. Data evaluation, map print out by system 9. Decontaminate and release 10. Transport to warehouse	1. Prepare plans 2. Transport equipment 3. Instrument check outs 4. Set up and enter area 5. Perform 4 surveys for separate readings 6. Take Samples of area 7. Perform sample "counts" 8. Modify/Update survey maps 9. Manually record data for report 10. Review data, evaluate, & make report 11. Decontaminate and release 12. Return transport
End Product	Characterization for planning work	Characterization for planning work

Observed unit costs and production rates for principal steps of the demonstrations for both the innovative and baseline technologies are presented in Table 3. The innovative technology rates are developed from the 600 ft^2 demonstration area, and the baseline technology rates on a similar 600 ft^2.

Table 3. Summary of unit costs & production rates observed during the demonstration

INNOVATIVE TECHNOLOGY			BASELINE TECHNOLOGY		
Cost Element	**Unit Cost**	**Production Rate**	**Cost Element**	**Unit Cost**	**Production Rate**
Set up of : Grid layout; and Navigational aids (for determination of total dpm/unit area)	$0.093 / ft^2 $2.80 / ft of perimeter	20 ft^2 / minute 218 ft^2 / hour OR 40 perimeter ft/hr	Set up Grid layout and survey for exposure rate with BICRON (Tissue equivalent exposure rate measuring instrumentation)	$0.02 / ft^2	60 ft^2 / minute
Smear/Sampling: Option Not Available	Not Applicable	Not Applicable	Smear Sampling: 100 cm^2 , Count smears, Large area smears (All required for surveys – total time for all steps in one Production rate)		8.56 ft^2 / minute
Smear/Sampling: Option Not Available	Not Applicable	Not Applicable	Smear Sampling <u>steps</u>: 100 cm^2 Count smears Large area smears	 $0.02 / ft^2 $0.08 / ft^2 $0.02 / ft^2	 60 ft^2/ minute 12 ft^2 / minute 60 ft^2/ minute
Detailed Survey for alpha and beta total contamination measurements only	$0.29 / ft^2	12.5 ft^2 / minute or 12.8 linear feet(LF)/ min traversed	3 ea. Detailed Surveys (alpha, beta and gamma): FM-4G PRM-5 w/PG-2 Electra NE	 $0.03 / ft^2 Not used $0.07 / ft^2	 30 ft^2 / minute 15 ft^2 / minute 13.3 ft^2 / minute

The unit costs and production rates shown in Table 3 exclude mobilization, technology set up time, or other losses associated with non-productive time, except where the individual activity requires preplanning or setup time. The overall costs of the innovative technology, including mobilization and demobilization costs, was $6.41/ft^2. The overall costs of the baseline technology, including mobilization and demobilization costs, was $1.14/ft^2. The mobilization and demobilization costs are included in Figure 7.

Potential Savings and Cost Conclusions

The manual survey baseline, for the conditions stated in Table 3 and assumptions established in Appendix C, is approximately one-sixth the cost of the MACS innovative technology, based on the demonstration. A significant portion of higher costs in the innovative case is related to equipment set up, movement to the survey area, system start up and check out, grid layout, and reflector installation. The next largest difference is in the mobilization costs, of approximately $1,000. This is based on the transportation of a 650 pound item requiring more personnel and equipment than four hand held or vacuum-cleaner-sized detectors. The additional electronics gear requires more attention to calibration and programming the path to follow than telling a person to walk the area. A comparison of the costs for mobilization, characterization, and demobilization for both technologies can be seen in Figure 7.

As Figure 7 shows, the MACS has higher costs in all three cost categories. Since the mobilization and demobilization costs remain relatively constant, the MACS technology will be more attractive, from a cost standpoint, for larger area job scopes.

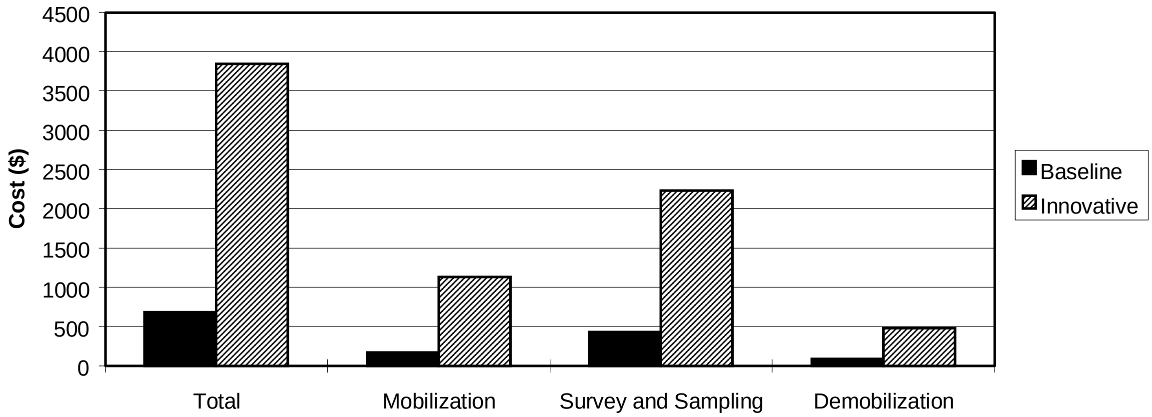

Figure 7. Cost comparison between MACS and manual technology.

Potential for savings are in the sectors of a) working a larger area per one mob and demob, b) reducing personnel exposure by laying out a larger area, using computer generated maps, data, and finished reports, and d) using MACS in repetitive Surveillance & Maintenance (S&M) operations requiring only one installation of reflectors for many uses.

Reflectors are placed around the perimeter of the survey area and requires personnel to be exposed while installing them. As the survey area becomes larger, the perimeter increases at a much slower rate. The relative amount of personnel exposure decreases as the work scope increases. This cost analysis did not determine a rate of cost per personnel exposure saved, but this should be considered if innovation technology installation time is greater than the duration of manually surveys for small areas.

The cost of the equipment includes all the capability to sense and store data to produce a report automatically. Using the output obviously reduces the cost of people to manually record data and prepare reports. Once the computer is programmed, continued and repetitive use of MACS will save money and possibly errors to data.

A combination of the previous savings are magnified when this equipment is utilized in S&M situations. An area is laid out once, equipment is mobilized once, and the machine monitors daily, monthly, annually, or at other repetitive sequences. It eliminates repeated exposure to personnel using the baseline technology. MACS can run for 8 to 9.5 hours continuously without being attended. Scenarios like these have not been developed or priced for this analysis. The sensitivity to site specific conditions such as mobilization details, the number of set ups, the size of area(s), and training require a decision maker to tailor this analysis for his or her site by substituting the expected quantities into Table C-1, Appendix C.

At a production rate of 750 ft^2 per hour and a maximum battery capacity of 9.5 working hours as observed during the demonstration, the maximum daily rate of area coverage would be 7,125 ft^2. However, due to lost productivity, and an assumed 8 hour work day, MACS runs approximately 6.3 hours and recharges overnight. The resulting reduced daily production area would be 4,725 ft^2, with a cost of $1,005, excluding the personnel operating it. The purchase price of the MACS system has been estimated to be $302,200. To completely amortize the purchase cost of MACS would require 307 days of productive use or 1,450,600 ft^2 of area to be characterized. After that, the unit cost would start decreasing and reduce the overall characterization costs.

A current disadvantage to the MACS equipment is that it is not available commercially, except in all its individual components. The unit cost and the resultant hourly rate developed herein is almost prohibitive unless a site has a very large area upon which to operate it.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

The regulatory/permitting issues related to the use of the MACS technology at the ANL CP-5 Test Reactor are governed by the following safety and health regulations:

- Occupational Safety and Health Administration (OSHA) 29 CFR 1926

—1926.300 to 1926.307	Tools-Hand and Power
—1926.400 to 1926.449	Electrical - Definitions
—1926.28	Personal Protective Equipment
—1926.102	Respiratory Protection
—1926.102	Eye and Face Protection

- OSHA 29 CFR 1910

—1910.211 to 1910.219	Machinery and Machine Guarding
—1910.241 to 1910.244	Hand and Portable Powered Tools and Other Hand-Held Equipment
—1910.301 to 1910.399	Electrical - Definitions
—1910.132	General Requirements (Personal Protective Equipment)
—1910.133	Eye and Face Protection
—1910.134	Respiratory Protection
—1910.147	The Control of Hazardous Energy (Lockout/Tagout)

- 10 CFR 835 — Occupational Radiation Protection

Disposal requirements/criteria include the following Department of Transportation (DOT) and DOE requirements:

- 49CFR Subchapter C Hazardous Materials Regulation

—171	General Information, Regulations, and Definitions
—172	Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, and Training Requirements
—173	Shippers - General Requirements for Shipments and Packagings
—174	Carriage by Rail
—177	Carriage by Public Highway
—178	Specifications for Packaging

- 10CFR 71 Packaging and Transportation of Radioactive Material

Safety, Risks, Benefits, and Community Reaction

With respect to safety issues, the technology is considered quite safe. Standard safety precautions used when in a radioactive environment must be taken. Additionally, the use of lasers requires the use of standard eye protection. There are no identified risks to the community or environment.

A major benefit is that the improved accuracy and reliability of the system can provide the public with increased confidence that the various radiation surveys are being conducted in a professional manner. In addition, the rich display capabilities of MACS allows various visual orientated presentations of the survey results, which can increase the public acceptance of the data. Reduction in exposure should also be realized by reducing the amount of time personnel are required to be in a radiological area collecting data.

SECTION 7

LESSONS LEARNED

Implementation Considerations

MACS has the potential to have widespread use in characterization surveys. Due to the nature of final release surveys, MACS may be used to supplement manual surveys, but will not be able to replace the need for final verification of release status by manual survey.

MACS is ideal for large open areas without obstacles or irregular geometries. MACS can be programmed and allowed to run with minimal operator input, reducing dose to the HP technicians while producing easy-to-read color maps of characterization data.

Technology Limitations and Needs for Future Development

The MACS technology would benefit from the following design improvements:

- Develop gamma detection capabilities.
- Improve system reliability.
- MACS can improve on obstruction detection capabilities, especially objects protruding from walls above ground.
- Although the color scheme gives a quick and clear view of the location and the relative levels of contamination, the current implementation of the graphical data display limits the number of ranges to 6. An increase in the number of ranges would be of significant benefit. It is recommended that MACS increase its color selection capability for appropriate contrast.

Technology Selection Considerations

Any large nuclear site can make use of this technology. The technology is applicable for documenting the conditions of large surface areas, primarily for alpha or beta surface contamination. The MACS technology can be applied to routine operational surveys, characterization surveys and free release and site closure surveys. The system is not recommended for areas of less than a few square meters or surveys with less than a hundred measurement points, since the visualization of the data becomes less useful for small data sets.

APPENDIX A

REFERENCES

Strategic Alliance for Environmental Restoration, CP-5 Large-Scale Demonstration Project, *Technology Summary Sheet for the Demonstration of the Mobile Automated Characterization System,* Argonne National Laboratory, January 1998.

Strategic Alliance for Environmental Restoration, CP-5 Large-Scale Demonstration Project, *Data Report for the Demonstration the Mobile Automated Characterization System,* Argonne National Laboratory, January 1998.

Strategic Alliance for Environmental Restoration, (November 1996) *CP-5 Large Scale Demonstration Project, Test Plan for the Demonstration of the Mobile Automated Characterization System at CP-5*, Argonne National Laboratory

Strategic Alliance for Environmental Restoration, *CP-5 Large Scale Demonstration Project, Test Plan for the Demonstration of the Pipe Crawler System at CP-5*, November 1996.

Occupational Safety and Health Administration, (OSHA) 29 CFR 1910, *Occupational Safety and Health Standars*, 1974.

Occupational Safety and Health Administration, (OSHA) 29 CFR 1926, *Occupational Safety Regulation for Construction*, 1979.

APPENDIX B

ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
CC	cut concrete (an activity)
CF	cubic feet (foot)
CFM	cubic feet per minute
CY	cubic yards
D&D	Decontamination and Decommissioning
Decon	decontamination
Demob	demobilization
DOE	Department Of Energy
Equip (Eq)	equipment
FCCM	Facilities Capital Cost Of Money
FETC	Federal Energy Technology Center
H&S	Health and Safety
HR	hour
HTRW	Hazardous, Toxic, Radioactive Waste
LF	lineal feet (Foot)
LLW	Low Level Waste
LS	lump sum
MACS	Mobile Automated Characterization System
Min	minute
Mob	mobilization
NESP	National Environmental Studies Project
NRC	Nuclear Regulatory Commission
PCs	protective clothe(s) (clothing)
PLF	productivity loss factor
PPE	personnel protective equipment
Qty (Qnty)	quantity
RA	Remedial Action
SAFSTOR	Safe Storage
SF	square feet (foot)
UCF	unit cost factor
UOM	unit of measure
USACE	U.S. Army Corps Of Engineers
WBS	Work Breakdown Structure
WPI	Waste Policy Institute

APPENDIX C

TECHNOLOGY COST COMPARISONS

This appendix contains definitions of cost elements, descriptions of assumptions, and computations of unit costs that are used in the cost analysis.

Innovative Technology -- MACS

MOBILIZATION (WBS 331.01)

Load at warehouse
Definition: Position at dock and load MACS onto a pickup truck to transport MACS equipment from the warehouse to the CP-5 Reactor Building, Argonne National Laboratory. This cost element includes the cost of a rigger, a forklift and operator as required, plus the truck and driver.

Assumptions: MACS is not currently available commercially, but under development at Oak Ridge National Laboratories. It was assumed the equipment would be site owned and stored at the warehouse. Mobilization is from the warehouse to the D&D area. Hourly truck and forklift rates, taken from the Means Mechanical Cost Data pricing manual, are $12.68 and $12.73 per hour after adding the Procurement indirect expense factor. The 1 hour duration was not observed but extrapolated from the time to “off-load equipment from the truck”, which was observed to be 40 minutes.

Transport to & Unload at warehouse
Definition: Transport MACS equipment from warehouse to CP-5 area and unload from truck. This cost element does not include cost of MACS equipment during transport, but includes the means by which it is transported.

Assumptions: Includes one truck and driver, one forklift and operator, and 1 rigger for 1.92 observed hours. Rate for transportation equipment and crew are the same as in the previous account. Standby for MACS equipment is excluded based on the calculation of amortization covering only production usage.

Return vehicles
Definition: Time required to return the truck and forklift after the previous use.

Assumptions: Time is estimated at 15 minutes based on a similar traveled distance that was observed during the demonstration. Includes truck, forklift and the material handling crew defined above.

Unpack, Survey & Prepare
Definition: Equipment is unpacked, surveyed for radiological contamination, and prepared for use.

Assumptions: The observed duration is 45 minutes. Crew make up based on judgment of the test engineer after observing 3 ORNL personnel and 1 HPT from site accomplishing this task. Since our basis of estimate is that site personnel will perform this function in our assumed scenario, only 2 HPTs are involved. HPT rate is $56.00/hour. An amortized cost for the MACS equipment is charged during the survey.

Source and functional tests, and calibration

Definition: A source check is performed in a "clean" area before commencing the survey of the contaminated area. It consists of ensuring no damage occurred during transport and that all the connections are proper. An amortized cost for the MACS equipment is charged during the testing period.

Assumptions: Again, even though 3 ORNL personnel actually did this function, our scenario, selected by the ANL test engineer, utilizes only 2 HPTs at $56/hr.

Instruction for Site/Contractor Crew

Definition: Instruction to ensure proper use of equipment and interpretation of characterization results. This is an estimated activity and was not observed during the demonstration.

Assumptions: Assumed that the vendor provides one operator to perform on-the-job training during the first day of operation of the equipment. Assumed that the service is included in the purchase price of the assembled product. Assumed that the instruction is conducted prior to performing the work. There are 2 site HPTs trained.

CHARACTERIZATION (WBS 331.17)

Note: This characterization is a sub category of the category D&D as opposed to the generalized overall category for characterization.

Set Up and move to work area, do start up and check out the system

Definition: Time required for setting up, allowing equipment to warm up, double check the programmed path versus the actual grid, adjust as necessary to match, and moving from one survey location to another. An amortized cost for the MACS equipment is charged during the survey.

Assumptions: The duration for moving into the area is 45 minutes, complicated by partial disassembly to fit into an elevator. The duration for setting up all equipment, including re-assembly after the elevator incident, is 2 hr 45 min. The duration for starting up the systems and checking out proper operation, responses, measurements and computer communications is 1 hr 45 min. Crew consisted of all 3 ORNL demonstration participants. But for this scenario, ANL personnel said 2 local HPTs can handle the work required in those time frames.

Preparations: Layout floor grid and Install Laser reflectors

Definition: A grid is marked out on the floor, and reflectors are mounted on the wall or placed free standing around the perimeter to provide necessary stationary navigational reference points for the MACS dead-reckoning method of traversing the area.

Assumptions: Time and personnel utilized were not observed during the demonstration. ANL personnel provided information of 2 HPTs working 30 minutes could lay out the grid. Installation of the reflectors takes 2 hours 45 minutes using 2 HPTs. Two methods of defining the scope are possible, in square feet of area or perimeter linear feet defining that same area. With known dimensions, a reliable and useful relationship exists between the length, width, area, and the rate at which the robot travels to cover the area.

Detailed Survey

Definition: After the systems are all checked out, the robot platform, with onboard computer and sensors, starts traveling along the grid controlled by computer pre-programming. An amortized cost for the MACS equipment is charged during the survey

Assumptions: Crew is assumed to consist of 2 HPTs. Only one pass over the area is required because of using multiple sensors to detect the alpha and beta counts. Detection of Gamma Rays is not a capability of this technology. The demonstration ran 3 passes over the same area only to check for consistency of time required and readings at all grid point locations, which was very successful. The traversing time is 48 minutes for 600 square feet, the average of 53 min., 49 min., and 43 min. That is a production rate of 12.5 SF/min.

Note: A different type of detector may be added to MACS to incorporate the "Gamma" capability.

Evaluate Data & Produce Final Report
Definition: This activity covers printing out later the data sensed during the survey and stored in the database and reviewing it for reasonableness and summarizing it into a final report.

Assumptions: The duration is assumed to be 30 minutes. This part of the demonstration actually failed due to equipment malfunction, but should normally not take longer than 30 minutes for the scope involved. Manpower required is the operator of MACS and an engineer for review.

PPE

Definition: This cost element provides for the personal protective equipment and clothing used during the work activity.

Equipment	**Quantity in Box**	**Cost Per Box**	**Cost Each**	**No. of Reuses**	**Cost Each Time Used**	**No. Used Per Day**	**Cost Per Day**
Booties	200	50.00	0.25	1	0.25	4	1.00
Tyvek	25	85.00	3.4	1	3.4	4	13.60
Gloves (inner)	12	2.00	0.17	1	0.17	8	1.36
Gloves (outer pair)			7.45	10	0.75	1	0.75
Glove (cotton Liner)	100	14.15	0.14	1	0.14	8	1.12
Total							$ 17.83

The PPE costs are predominantly from the ANL activity cost estimates for 1996.

Assumption: The demonstration conditions were such that PPEs were not required. However, a more realistic situation with unknown conditions at sites is to assume that PPEs are required during the grid layout and the reflector installation activities. In either case, a respirator is not required. Therefore, the value used in the estimate is $17.83 per person per day.

Daily Meeting
Definition: This cost element provides for safety and project planning meetings during the workday for the crew.

Assumptions: The estimate assumes one 15 minute safety meeting per day involving all the personnel to participate in the activities for the day. That's based on typical practice at ANL, not observed times from demonstration.

Productivity Loss Factor
Definition: Losses from productive work occurring during the course of the work due to PPE changes, ALARA, height of reach inefficiencies, etc.

Assumption: The duration used for the preliminary survey and the detailed survey do not account for work breaks or PPE changes, and were not observed and recorded during the demonstration. Consequently, these types of costs are estimated and added to the innovative cost in this cost element. The duration of work performed in the controlled area is adjusted by a factor of 1.27 to account for these losses based on the factors shown below (AIF, 1986):

Base 1.00

+Height	0
+Rad/ALARA	0
+Protective Clothing	0.15
= Subtotal	1.15
X Resp Prot	1.00
= Subtotal	1.15
X Breaks	1.10
=Total	1.27

DEMOBILIZATION (WBS 331.21)

Survey Equipment and Decontaminate for free release
Definition: MACS equipment is surveyed for contamination and decontamination is performed as needed for free release.

Assumption: The assumed duration of 0.5 hours was used for a crew of one HPT, with the other HPT in standby for the same duration. An amortized cost for the MACS equipment is charged during the survey

Load and Transport Equipment and Off-load at warehouse
Definition: Similar to Mobilization in reverse. Load onto pickup truck, transport to warehouse, and off-load at warehouse using a forklift and 2 riggers and a truck driver. Equipment hourly rates from the Means and Dataquest pricing books for construction equipment,

Assumption: An amortized cost for the MACS equipment is not charged during transport.

Innovative Technology – MACS Characterization

COST ANALYSIS

The costs for performing the work with the MACS innovative technology consists of 1) Mobilization of the equipment from a warehouse to CP-5, 2) Off-loading it at the work site, 3) Unpack it and make necessary checks, 4) Take it into the work area ,set it up, and start up the equipment for testing. 5) Layout a grid system and the laser reflectors, 6) perform the survey, 7) Make the reports using the computer data, and 8) Demobilize. This scenario is intended to represent the cost for normal D&D work using the MACS. The sequence of events of the demonstration had some additional steps such as multiple runs over same area and an unattended endurance run for knowledge of the maximum operating period. Other adjustments of the observed data from the demonstration are shown below:

- Based the estimate on assuming the work will be performed using site-owned equipment operated by 2 HPT site workers. The demonstration used 3 personnel from ORNL who had developed this equipment.
- Mobilization is from a site warehouse because it is assumed owned.
- There is a relatively large capital expense involved because the equipment is not available commercially. A separate estimate was necessary to establish a cost greater than just the bare component comprising the MACS.
- A site would need a large number of opportunities to use the equipment before it became cost-effective.
- MACS equipment hourly rates were based on the test engineers phone conversations with the several vendors involved.

- Estimate includes a daily meeting, whereas the demonstration may not have held one. It is normally ANL procedures to do so, so it is included.

Several factors could improve the cost effectiveness of MACS. If a site had a very large single area or an aggregate of several areas to be characterized, the investment could be spread, or amortized, over a large scope of work. Or, if multiple, repetitive uses are frequent over the same or different areas, then a similar improvement could be achieved.

At a production rate of 750 SF per hour and a maximum battery capacity of 9.5 working hours as observed during the demonstration, the maximum daily rate of area coverage would be 7,125 SF. However, due to lost productivity, and an assumed 8 hour work day, lets run it only 6.3 hours and recharge overnight. The resulting daily production area would be 4,725 SF, with a cost of $1005, excluding the personnel operating it. To completely amortize the MACS would require 307 days of productive use or 1,450,600 SF of area to be characterized.

Since the MACS only works well in unrestricted, open areas, some amount of manual, hand-held, supplemental surveying will be necessary. Neither the demonstration nor this estimate accounts for that situation. A potential user should factor into this innovative technology analysis a certain amount of the “sampling” activities using normal equipment.

The activities, quantities, production rates and costs observed during the demonstration are shown in Table C-1 Innovative Technology Cost Summary Table.

TABLE C--1 INNOVATIVE TECHNOLOGY COST SUMMARY

Work Breakdown Structure (WBS) & Sub-activities	Unit Cost (UC) Labor Hour (hr)	Labor Rate	Equipment Hour	Equipment Rate	Other Rate	Total UC	TQ Qnty	Unit of Measure	Total Cost (TC) note	Note: TC=UC x TQ Note: Qnty = Quantity; TQ = Total Comments
MOBILIZATION (mob)- WBS 331.01								**Subtotal:**	**$ 1,134**	
Load at Warehouse	1	$ 121	1	$ 25.41		$146	1	Lump Sum (LS)	$ 146	Time is estimated, not observed. 2 Riggers @ $40.20,plus pickup, teamster, & forklift at @$12.68, $40.40 & $12.73 per hr, respectively
Transport to and Unload at bldg.	1.92	$ 121	1.92	$ 25.41		$281	1	Trip	$ 281	
Return vehicles	0.5	$ 121	0.5	$ 25.41		$73	1	Trip	$ 73	
Unpack, survey and prepare	0.75	$ 112	0.75	$ 159.49		$204	1	Task	$ 204	2 HPTs handling equip. and third HPT surveying @ $56/hr = $168/hr
Source & functional checks, calib.	1	$ 112	1	$ 159.49		$271	1	Task	$ 271	2 HPTs @ $56/hr = $112/hr
Instruction for site/contr. crew	1.42	$ 112				$159	1	Set	$ 159	set = 2 classes. Non-recurring
CHARACTERIZATION (char) - WBS 331.17								**Subtotal:**	**$ 2,235**	
Set up, move to work area, and start up and system checkout	5.25	$ 112	5.25	$ 159.49		$ 1,425	1	L.S	$ 1,425	crew= 2 HPTs; observed time for 3 sub-functions. 3 setups per 8000 SF
Preliminary survey, layout grid	0.0008	$ 112	0.001		$ -	$ 0.09	**600**	SF	$ 56	1 HP & 1 HPT, both at $56/Hr for 30 minutes, area of 600 SF yields 1200 SF/hr for 2 craft
Install reflectors for navigation	0.025	$ 112				$ 2.80	**110**	Feet (FT)	$ 308	Perimeter feet
Detailed survey	0.0013	$ 56	0.001	$ 159.49		$ 0.29	600	SF	$ 172	48 minutes to do 600 SF
Evaluate data and final report	0.5	$ 147	0.500	$ 159.49		$153.25	1	Report(s)	$ 153	1 HPTs plus supervising Engineer
Daily safety, task meetings	0.25	$ 233			$ -	$ 58.20	1.00	Meetings (mtg)	$ 58	15 minutes each for riggers, driver, HP,HPT, supv engineer personnel. One mtg per 3000 SF in a day
Personnel Protective Eq. (PPEs)					$ 36	$ 36	1.0	day	$ 36	Not required per demonstration
PRODUCTIVITY LOSS (factor)	0.88	$ 112				$ 98	0.27	percent	$ 27	27% applied to grid & reflector
DEMOBILZATION (demob) - WBS 331.21								**Subtotal:**	**$ 478**	
Survey equip. and decon.	0.5	$ 112	0.5	$ 159.49		$135.75	1	LS	$ 136	Decon and survey equipment & supplies in HP rate. Applied once at completion of scope.
Load and transport equipment	1.25	$ 121	1.25	$ 25.41	$13.20	$ 196	1	Trip	$ 196	Applied once at completion of SF.
Unload at warehouse	1	$ 121	1	$ 25.41	$ -	$ 146	1.0	LS	$ 146	Applied once at completion of SF.
Area dimensions	40	length	15	width				**Total**	**$ 3,847**	
								Unit cost	$ 6.41	per square foot surveyed

Baseline Technology - Manual Characterization Survey

MOBILIZATION (WBS 331.01)

Preliminary Survey Plans
Definition: This cost element is for planning the initial manual survey and developing the necessary documentation that is needed to allow that work to begin.

Assumption: The effort is assumed to be ½ hour for 2 HPTs @ $56.00/hour.

Transport & Equipment from warehouse to work area
Definition: The on-site transport to the CP-5 is provided in this cost element.

Assumption: The effort is assumed to be ½ hour for a crew of 1 truck driver @ $40.40/.

Source Check the Instruments
Definition: Use a "source" to check and calibrate the detectors for proper operation.

Assumptions: The observed time, during the baseline demonstration, is 35 minutes for 1 HPT and a supervising engineer.

CHARACTERIZATION (WBS 331.17)

Set up and move to work area
Definition: This account covers basically the time for the HPT to report to the area with his detectors.

Assumption: Observed time is 10 minutes.

Detailed survey -- Gamma Scan
Definition: Cost activity includes surveying for background ambient low energy gamma and x-ray levels using the Eberline PRM 5-3 hand held pulse rate meter with the Eberline PG-2 large area scintillator detector. The activity is measured as a "per square foot of area surveyed" cost.

Assumptions: ****This activity has been omitted due to comparison with the innovative technology which is incapable of reading gamma.****

Detailed survey -- Alpha and Beta Scan
Definition: Cost activity is for establishing general areas of alpha and beta particle contamination and includes using the Eberline FM-4G floor monitor equipped with the Eberline PAC-4G-3 portable alpha meter. The activity is measured as a "per square foot of area surveyed" cost.

Assumptions: The observed time is 20 minutes, a production rate of 30 SF / min.

Detailed survey -- Alpha and Beta direct Scan
Definition: Cost activity includes using the Bicron Electra Rate-meter for taking detailed counts for alpha and beta particle emissions from areas of contamination identified with the alpha beta scan. The activity is measured as a "per square foot of area surveyed" cost.

Assumptions: The observed time is 10 minutes, a production rate of 60 SF / min.

Sampling
Definition: Covers taking the 100 cm square smear samples of the "hotter" spots identified, counting of smears, and taking the large area smear samples as a final check.

Assumptions: The baseline requires this sampling function, whereas the innovative case does not.

Record and analyze data
Definition: Cost activity includes collection, recording, analysis, and interpretation of data from surveys conducted. The activity is measured as a "per square foot of area surveyed" cost. One HPT.

Document Results in a Report
Definition: Cost activity includes documenting the levels of contamination measured onto CADD drawings of the floor area surveyed. The activity is measured as a "ft^2 area surveyed" cost. One HPT.

Daily Meeting
Definition: This cost element provides for safety and project planning meetings at the start of the workday for all personnel involved.

Assumptions: The estimate assumes one 15 minute safety meeting per day involving all the personnel to participate in the activities for the day. That's based on typical practice at ANL, not observed times.

PPEs
Definition: This cost element provides for the PPEs and clothing used during the work activity.

Assumptions: The chart on Appendix page C-4 applies in the baseline case also. PPEs are required during all manual survey/scanning activities.

Productivity Loss Factor
Definition: Losses from productive work occurring during the course of the work due to PPE changes, ALARA, height of reach inefficiencies, etc.

Assumption: The duration used for all surveys and sampling activities do not account for work breaks or PPE changes. The "non-productive" times were not observed and recorded during the demonstration. Consequently, these types of costs are estimated and added to the baseline cost in this cost element. The duration of work performed inside the controlled area only is adjusted by a factor of 1.27 to account for these losses based on the factors shown below (AIF, 1986):

Base	1.00
+Height	0
+Rad/ALARA	0
+Protective Clothing	0.15
= Subtotal	1.15
X Resp Prot	1.00
=Subtotal	1.15
X Breaks	1.10
=Total	1.27

Data Evaluation and Report
Definition: This cost element provides for review of the survey results and development of survey reports.

Assumptions: The effort for this is assumed to require 1 hours.

DEMOBILIZATION (WBS 331.21)

Decontaminate and Survey Out
Definition: Equipment and personnel are surveyed for contamination and decontamination is performed as needed for free release.

Assumption: The duration of 1 hour is assumed for 1 HPT.

Transport for Return
Definition: Same as Mobilization - Unload and Transport, but in reverse.

COST ANALYSIS

Baseline Technology – Manual Characterization Survey

The baseline technology is assumed to be characterization using conventional equipment and methodologies, otherwise known as a “manual” survey. The baseline technology cost estimate takes data from a manual survey conducted on the D-055 “test” floor area of the Building 330, at ANL. To generate a comparable estimate between the baseline and the innovative technology, only those baseline activities considered equivalent to the capabilities of the innovative technology are included in the estimate. Tests such as conducting sampling of loose material using smears are included. Additionally, since manual survey was conducted only on the “test” area of Bldg. 330 those production rates experienced are used in this baseline estimate. The area is the same in both demonstration.

Manual test considered equivalent to the demonstrated capabilities of the MACS device include measurements to assess the general level and location of alpha and beta contamination and measurements to asses the precise level of alpha and beta contamination.

Cost data on the instrumentation used for equivalent tests was gathered in order to establish equipment hourly rates. These include current purchase price, re-calibration expenses, and consumable supplies. They were then amortized over an anticipated life span of 15 years based on current experience and use of existing equipment at ANL.

Production rates are measured in square feet (SF) per minute. The unit rates shown in the estimate below are the reciprocal of that and expressed in hours per SF. Assumptions for formulating the baseline cost estimate are summarized as follows:

- All survey equipment is owned by ANL.
- Surveying work is performed by one HPT.
- Productivity loss factors are considered.
- Radiological characterization is for alpha and beta contamination only. The manual system is capable of measuring gamma, but was eliminated to make it comparable to the MACS.
- A PIE is added to the purchase price at 9.3%.
- Demobilization consists of surveying-out equipment only once at the completion of all surveying work.
- CADD or hand drawings of the area survey are available to record the results of the survey.

The activities, quantities, production rates and costs utilized in the baseline are shown in Table C-2.

TABLE C--2 BASELINE COST SUMMARY

Work Breakdown Structure (WBS) and sub-activities	Unit Cost (UC) Labor Hour(Hr)	Labor Rate	Equipment Hr	Equipment Rate	Other Rate	Total UC	TQ Qnty	Unit of Measure	Total Cost (TC) note	Note: TC=UC x TQ Note: Qnty = Quantity; TQ=total quantity Comments
MOBILIZATION (mob)- WBS 331.01								**Subtotal:**	**$ 169**	
Preliminary survey plans	0.50	$ 112				$56.00	1	Lot	$ 56	1/2 hr for HPT and HP supervisor @$56/hr
Transport to work area from warehouse	0.5	$ 40	0.5	$ 12.68		$26.54	1	Trip	$ 27	Pickup truck (Means) @$12.68 & Teamster @$40.40 for 1/2 hr. (Hand held equip.)
Instrument(s) opeartion checks	0.58	$ 147	0.58	$ 2.05		$ 86.45	1	Lump Sum (LS)	$ 86	35 min, 1 HPTs @ $56/hr,1 Engr, $91/hr
Detailed survey plan & grid	0.00	$ 56	0			$0	600	SF	$ -	Grid not required for this baseline
CHARACTERIZATION (char) - WBS 331.17								**Subtotal:**	**$ 431**	**a DECONTAMINATION sub-account**
Setup and move to work area	0.17	$ 56				$ 9.52	1	LS	$ 10	A minimal effort
Detailed manual survey (4 individual passes made)							**600**	Square feet (SF)	$ -	Used 600 SF per demo, which is basis for the production rates for surveys.
Alpha and Beta--using FM-4G	0.0006	$ 56	0.0006	$ 0.82		$ 0.03	600	SF	$ 19	
Gamma --using PRM-5 w/PG2	0	$ 56	0	$ 0.52		$ -	600	SF	$ -	MACS doesn't have this capability. This B/L activity excluded for comparison.
Alpha & Beta --using Electra NE	0.0013	$ 56	0.0013	$ 0.71		$ 0.07	600	SF	$ 43	Below: cost of the 3 surveys summed:
A & B direct survey w/BICRON	0.0003	$ 56	0.0003	$ 0.71	$ -	$ 0.02	600	SF	$ 10	$ 71
Sampling										$ 68
Take 100 cm square smears	0.0003	$ 56	0.0003	$ 0.15		$ 0.02	600	SF	$ 10	Above: sum of the 3 sample steps cost:
Count Smears	0.0014	$ 56	0.0014	$ 3.00		$ 0.08	600	SF	$ 49	Equip. rate is guesstimate.
Large area smear samples	0.0003	$ 56	0.0003	$ 0.15		$ 0.02	600	SF	$ 10	
Daily Safety meeting	0.25	$ 243				$ 60.85	1	mtg	$ 61	2HPTs,1 driver, 1 Engr,
Personnel Protective Equipment					$ 18	$ 17.83	1	Days	$ 18	Applys to all survey & sampling time, 1 HPT
Productivity loss factor	0.653	$ 56				$ 36.59	0.27	Percent	$ 10	Applys to all survey & sampling time, 1 HPT
Obtain maps and modify	0.330	$ 56				$18.48	1	Tasks	$ 18	20 min./ task
Record all survey data manually	0.500	$ 56				$28.00	1	Tasks	$ 28	30 min./ task
Data review, evaluation, and manually prepared report	1.000	$ 147			$ -	$147.00	1	Report(s)	$ 147	Assumed 1 report for 600 SF. 1 Health Physicist ($56) & 1 Engineer ($91/hr)
DEMOBILZATION (demob) - WBS 331.21								**Subtotal:**	**$ 85**	
Decon & Survey Out	1	$ 56	1	$ 2.05		$ 58.05	1	LS	$ 58	
Transport for return	0.50	$ 40	0.50	$ 12.68		$ 26.54	1	Trip	$ 27	
Area Dimensions =	40	length	15	width				**Total**	**$ 684**	
								Unit cost	$ 1.14	