DRAFT FINAL REPORT

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THREE DIMENSIONAL INTEGRATED CHARACTERIZATION AND ARCHIVING SYSTEM (3D-ICAS)

Work Performed Under Contract:
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Submitted By:
CyTerra Corporation
85 First Avenue
Waltham MA 02451

Under Subcontract To:
Coleman Research Corporation
9302 Lee Highway, Suite 800
Fairfax VA

Program Manager:
Dr. George Jarvis
Telephone Number: (781) 622-1363
FAX Number: (781) 622-1370

Principal Investigator/Author:
Dr. George Jarvis
Telephone Number: (781) 622-1363
FAX Number: (781) 622-1370

Submitted To:
U.S. Department of Energy
Federal Energy Technology Center
Morgantown, West Virginia

COR: V. P. Kothari

DISCLAIMER

ABSTRACT

The overall objective of this project is to develop an integrated system that remotely characterizes, maps, and archives measurement data of hazardous decontamination and decommissioning (D&D) areas. The system will generate a detailed 3-dimensional topography of the area as well as real-time quantitative measurements of volatile organics and radionuclides. The system will analyze substrate materials consisting of concrete, asbestos, and transite. The system will permanently archive the data measurements for regulatory and data integrity documentation.

Exposure limits, rest breaks, and donning and removal of protective garments generate waste in the form of contaminated protective garments and equipment. Survey times are increased and handling and transporting potentially hazardous materials incur additional costs. Off-site laboratory analysis is expensive and time-consuming, often necessitating delay of further activities until results are received.

The Three Dimensional Integrated Characterization and Archiving System (3D-ICAS) has been developed to alleviate some of these problems. 3D-ICAS provides a flexible system for physical, chemical and nuclear measurements reduces costs and improves data quality. Operationally, 3D-ICAS performs real-time determinations of hazardous and toxic contamination. A prototype demonstration unit is available for use in early 2000.

The tasks in this Phase included:

- Mobility Platforms: Integrate hardware onto mobility platforms, upgrade surface sensors, develop unit operations and protocol.

- System Developments: Evaluate metals detection capability using x-ray fluorescence technology.

- IWOS Upgrades: Upgrade the IWOS software and hardware for compatibility with mobility platform.

The system was modified, tested and debugged during 1999 and 2000. The 3D-ICAS was shipped on 11 May 2001 to FIU-HCET for demonstration and validation of the design modifications. These modifications included simplifying the design from a two-vehicle system to a single mobile platform, integration of the XRF sensor for enhanced substrate analysis and upgrading of the IWOS operating system.

Several of the system's power supplies were accidentally damaged upon power on because FIU wired 3 phase AC power to the system instead of the requested single phase. Repairs were made in the field to the damaged power supplies but 3 of 5 days time were lost to complete the repairs.

Once the repairs were made CyTerra was able to demonstrate the CLR mapping and the movement of the sensor probe to selected locations on the test wall. The XRF sensor was also demonstrated on a stainless steel substrate. A surrogate solution was determined to be below the detection threshold. The radionuclide and GCMS sensors were not demonstrated due to either failed power supply or lack of time remaining in the schedule. The GCMS

failure was partially the result of the debugging activities that took place during the week for assessing electrical damage. Specifically, GCMS electronic modules, which control the heating of two of gas transfer elements, may have been damaged during field debugging that was required.

Given the financial constraints of the program, CyTerra Corporation decided to return the equipment to Waltham facilities for further assessment. We believe the principles of operation were shown, however a complete demonstration did not occur due to these difficulties. The FIU-HCET TAP report is attached in appendix B.

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Introduction

The objective of this project is to develop a remote system that performs rapid in situ analysis of hazardous organic and radionuclide contamination on structural materials. Characterization sampling and analysis for hazardous organic and radionuclide contamination on concrete, asbestos, and transite for decontamination and decommissioning (D&D) is time-consuming, expensive, and has the potential to of expose humans to radiation and hazardous materials.

The 3D-ICAS-system configuration consists of a mobile sensor and mapper platform that operates through an integrated workstation. During characterization operations, the mapper, using its coherent laser radar (CLR), determines precise locations used to position the multi-sensor probe located on a robotic arm extending from the platform. The CLR generates 3D facility maps to establish a three-dimensional “world view” within which the robotic sensor system can operate. The operator at the integrated workstation, using displayed 3D map information, plans and directs the selection of surface areas to be characterized and the number of samples for a given area. The system then automatically samples these areas, archives the data (3D location, time, and concentrations of each contaminant), and provides map displays at the workstation showing results of the analysis. The data archive allows regulatory review of the characterization process and assures data integrity. The surface sampling allows the establishment of the bounds of regions exceeding regulatory limits.

The Contamination Analysis Unit (CAU) is a subsystem of 3D-ICAS and consists of the organic, radiological and substrate sensors.

In approximately one minute, the high-speed gas chromatograph-mass spectrometer (GC/MS) sensor provides organic analysis, accomplishing detection and fine grain analysis of regulatory concentrations (EPA 1987 spill cleanup policy: 1µg/10cm^2 for high use interior building surfaces). This compares with traditional GC/MS laboratory analysis methods that involve time-consuming sample preparation with associated waste generation. The GC/MS sensor extracts volatile organics directly from contaminated surfaces without contacting the surface. The GC then uses multi-stage focusing to achieve high-resolution insertion into a high-speed gas chromatograph. Detection and additional discrimination are provided by a final stage time-of-flight mass spectrometer (TOF-MS). This high-speed process replaces sample collection and transport as well as hours of solution preparation before injection into an ordinary GC/MS, which typically has a 45-minute run time. Subcontractor Thermedics Detection was responsible for development of the fast GC/MS.

The radionuclide (RN) sensor combines α and ß, counting with energy discrimination on the α channel. This sensor combination identifies and quantifies isotopes of specific DOE interest (uranium, plutonium, thorium, technetium, and americium) to regulatory levels in approximately one minute. Subcontractor Thermedics Detection was responsible for development of the RN sensor.

The X-ray Fluorescence Molecular (XRF) sensor characterizes substrate material such as concrete, transite, wood or asbestos and identifies hazardous elements such as mercury and lead. The surface composition information provided by the XRF can be used to provide estimates of the depth of contamination and to optimize the analysis performance of the other contamination detection sensors. The materials composition information augments the surface geometry maps provided by the coherent laser radar, providing a complete 3D worldview for planning and executing robotic D&D operations.

The Integrated Workstation (IWOS) provides data archiving and display and operator interface. A single mobility platform provides mobility for the robot arm carrying sampling probe, the CAU and the CLR. The units may be placed on separate platforms for extended functionality.

During this phase of work, the major focus was on the simplification of operation. The most noticeable improvement was the integration of all the working hardware onto a single vehicle for more practical applications. In addition, the sensor suite was upgraded to include all possible RCRS and TSCA type analytes with the inclusion of XRF for heavy metals detection. The third major improvement was the upgrade and simplification of the operating system from many small programs to a single unified interface. In its current mode, 3D-ICAS can be operated in a semi automatic mode with minimal human interfacing. The interfacing is for real-time decision-making and the operator is required to operate the system only through a keyboard. These system-wide improvements have greatly reduced the complexity of 3D-ICAS and cleared the path for development of automated operation.

Background

Accurate physical characterization of surfaces and the radioactive and organic contamination is a critical D&D task. Before clean-up operations can begin the site must be characterized with respect to the type and concentration of contaminants and detailed site mapping must classify areas of both high and low risk. 3D-ICAS is being developed as a remote system to perform rapid *in situ* analysis of hazardous organic and radionuclide contamination on structural materials. Surface characterization includes identification of potentially dangerous inorganic materials such as asbestos and transite. Real-time remotely operable characterization instrumentation will significantly advance analysis capabilities beyond those currently employed. Chemical analysis plays a vital role throughout the process of decontamination by providing a means to measure progress and to adjust clean-up strategy. Once the clean-up process has been completed the results of chemical analysis will verify that the site is in compliance with federal and local regulations.

The previous configuration of 3D-ICAS consists of a mobile sensor and mapper platform that operates in contaminated areas and an integrated workstation that remains in a safe location. In this effort, a single platform provides mobility for the robot arm carrying the sensors, for the CLR mapper/tracker and for the IWOS. During characterization operations, the mapper, using its coherent laser radar (CLR), determines precise locations used to position the multi-sensor probe located on a robotic arm extending from the platform. The CLR generates 3D facility maps to establish a three-dimensional “world view” within which the robotic sensor system can operate. The operator at the integrated workstation, using displayed 3D map information, plans and directs the selection of surface areas to be characterized and the number of samples for a given area. The system then automatically samples these areas, archives the data (3D location, time, and concentrations of each contaminant), and provides map displays at the workstation showing results of the analysis. The data archive allows regulatory review of the characterization process and assures data integrity. The surface sampling allows the establishment of the bounds of regions exceeding regulatory limits.

In approximately one minute, the high-speed gas chromatograph-mass spectrometer (GC/MS) sensor provides organic analysis, accomplishing detection and fine grain analysis of regulatory concentrations (EPA 1987 spill cleanup policy: 1µg/10cm^2 for high use interior building surfaces). This compares with traditional GC/MS laboratory analysis methods that involve time-consuming sample preparation with associated waste generation. The GC/MS sensor extracts volatile organics directly from contaminated surfaces without contacting the surface. The

GC then uses multi-stage focusing to achieve high-resolution insertion into a high-speed gas chromatograph. Detection and additional discrimination are provided by a final stage time-of-flight mass spectrometer (TOF-MS). This high-speed process replaces sample collection and transport as well as hours of solution preparation before injection into an ordinary GC/MS, which typically has a 45-minute run time.

The radionuclide (RN) sensor combines α, ß, and γ counting with energy discrimination on the α channel. This sensor combination identifies and quantifies isotopes of specific DOE interest (uranium, plutonium, thorium, technetium, and americium) to regulatory levels in approximately one minute.

In the previous configuration of 3D-ICAS, the Molecular Vibrational Spectrometry (MVS) sensor was used to characterizes substrate material such as concrete, transite, wood or asbestos. In the current configuration this sensor was enhanced by inclusion of a small X-ray Fluorescence (XRF) sensor. The advantage of this sensor is its compactness, penetration ability through paint and ability to characterize approximately 20 element, including mercury and lead at mid level concentrations. The surface composition information provided by the XRF can be used to provide estimates of the depth of contamination and to optimize the analysis performance of the other contamination detection sensors. The materials composition information augments the surface geometry maps provided by the coherent laser radar, providing a complete 3D worldview for planning and executing robotic D&D operations.

The Integrated Workstation (IWOS) provides system control, ddata display and data archiving through a single operator interface. Immediately after each one to two minute sample period, the 3D-ICAS sensor output and contamination analysis along with CLR position information is available for near real-time monitoring. After a surface mapping operation is completed, 3D-ICAS will provide 3D displays showing contours of detected contaminant concentrations. 3D-ICAS will further provide permanent measurement data and contaminant level archiving, which assures data integrity and allows straightforward regulatory review of the characterization process before and after D&D operations.

Technical Approach

The technical approach during this phase consisted of designing and developing a concept of operations that would allow simplified operations for more useful applications. In the previous configurations the hardware operation was quite complicated and required multiple control platforms. In this phase of work, all the hardware was place onto a single vehicle and operated through a single control computer. During our testing and debugging we have identified no limitations to this approach for 3D-ICAS. Although the vehicle is somewhat large we believe the single vehicle significantly reduces the complexity of the system and will allow for greater applications, for example providing both an indoor and outdoor capability.

Subsystem Descriptions

3D-ICAS has been developed through a three-phase program. Phase I demonstrated the critical technologies including the CLR mapping and high-speed GC sensor concept. Phase II provided integration of the GC and MS subsystems, integration of the multi-sensor probe with the robot arm and the coherent laser radar tracker. The Phase II 3D-ICAS demonstration, involving contamination surface mapping with a CLR guided, robotically maneuvered multi-sensor probe, occurred in November 1995. The Phase III system was integrated and successfully demonstrated on an overhead crane transporter in the fall of 1997 at ORNL.

In the current phase of work, simplification of operation, enhancement to the surface composition sensor and control system upgrade were performed. Due to the progressive generational improvement in computer hardware and operating systems a significant technology improvement is now warranted.

Definitive quantitative measurement of radionuclide, metals, surface composition and organic contamination on building surfaces in less than one minute was the development effort goal. In addition providing a useful data output in terms of maps and views of the work are provide a documented and archival method for data management.

A. High Speed Gas Chromatograph/Mass Spectrometer Subsystem

The high-speed gas chromatograph and mass spectrometer makes up the basis for the organic sensor. It provides quantitative data on the level and identification of contamination on building surfaces in near real time. The details of the subsystem are provided in the following paragraphs.

1. Mass Spectrometer.

Effective High Speed GC/MS performance requires a detector system capable of averaging 100 mass scans over the range of 40-800 amu in 15 milliseconds or less. The time-of-flight (TOF) system is the only full spectrum mass analyzer capable of such a scan rate. The full mass spectrum is necessary for identification of the unknown components of a sample through library searching. Finally, existing TOF technology will allow high repetition scan rates for implementing high duty cycle, high speed operation of the TOF-MS detector when coupled to the High Speed GC. The TOF-MS generates a complete mass spectrum across the mass range 35 to 600 amu every 100 microseconds. An integrated mass spectrum corresponding to 12.8 milliseconds of GC elution time is obtained by averaging 128 mass scans. This integration process yields a signal-to-noise improvement of approximately 11. The ion intensities of the integrated mass spectrum are then summed to generate the total ion chromatogram.

One of the most critical parts of a GC/MS is the interface between the systems. The interface plays the important role both in accommodating the pressure drop from the GC column to the MS ionization source and in enriching the concentration of the analyte in the carrier gas after passing through the interface into the mass spectrometer. In general, removing as much of the carrier gas as possible accommodates the pressure drop. A variety of technologies are available for the removing carrier gas in a GC/MS interface. Briefly, the requirements for a GC/MS interface are high transfer efficiency, no impact on the GC separation, no degradation of compounds, and no preferential removal of compounds or chemical functional groups. In addition to these requirements, the interface in this effort must operate on a fast time scale.

Of all the techniques available, the concept of a molecular beam interface was chosen as optimal. A molecular beam GC to MS interface consists of a heated transfer line to efficiently carry the GC column effluent into a vacuum expansion chamber. The GC column is held in alignment with a skimmer nozzle. The GC column and skimmer are held in close proximity. As the GC column effluent exits the column the lighter carrier gas diffuses away from the sample analyte in the vacuum region. The heavier sample analyte are transferred through the skimmer nozzle in a directed beam with the momentum of the carrier gas. In this approach the carrier gas is removed and the analytes are enriched into a directed beam of molecules. The directed beam of molecules is aligned through the skimmer to intersect the electron gun beam in the ionization source. The introduction of the molecules into the ionization source of the MS in this manner removes the carrier gas, enriches the analyte and generates a directed beam of molecules into the electron gun beam for ionization.

2. GC/MS Processing.

The data from the GC/MS sensor is processed into mass spectra and a total ion chromatogram. The GC/MS data are processed through a National Institutes of Standards and Technology (NIST) Mass Spectral Database, response factor calibration and sample classification algorithms for further data reduction. The electronics technology for the HSGC/MS data acquisition and processing are a high-speed transient digitizer, a high-speed data transfer bus at 20 Mb/sec and a high-speed digital signal processor (DSP). Since the TOF-MS events occur on a nanosecond time scale, the transient digitizer is used to accurately determine the data burst. A mass spectral scale from 35 to 600 amu requires approximately 40 microseconds of data with the individual MS peaks being approximately 15 to 30 nanoseconds wide at the half height point. Thus, to achieve mass spectral resolution of 1 amu at 600 amu, 5 to 10 nanosecond time discrimination is required. The transient digitizer is capable of summing the data burst waveforms in onboard memory to allow signal averaging. At this point in the data flow, the full mass spectrum is represented as time data with a resolution of 5 nanoseconds. The data records are transferred from the transient digitizer to the digital signal processor over a high-speed data transfer bus at 20 Mb/second. This high-speed transfer is used to recycle the transient digitizer for the next set of data. The high-speed digital signal processor performs many crucial functions in the initial stages of the data processing. These function include the conversion of the time-of-flight data into mass spectral scale data, detection of the occurrence of GC peaks and determination whether the detected GC peak is comprised of one or two compounds, e.g., co-eluting compounds. Once the GC and MS information are extracted from the raw data on the high-speed digital signal processor, the data are transferred to the overall system controller.

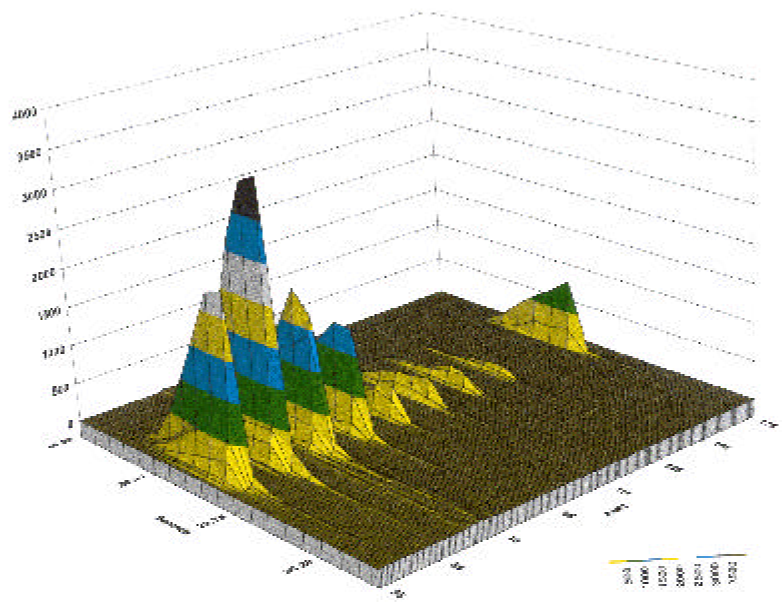

Figure 1. Three dimensional analysis of a hydrocarbon analyte as processed by the organic sensor.

B. Radionuclide Sensors

Because the majority of the isotopes that are anticipated to be encountered during D&D operations are alpha emitters (Am, Th, Pu, U) and one is a beta emitter (Tc), a set of two detectors was determined to best meet the functional needs for the radioisotopes of interest. The radionuclide sensor system includes both a diffused junction silicon detector for alpha emitting isotopes and a sealed gas proportional detector for beta/gamma emitting isotopes. A multichannel analyzer is integrated with the diffused junction detector for discrimination of the alpha isotopes.

This design ensures that all the isotopes of interest will be identified. The specific alpha emitting isotopes U^{238}, U^{235}, Pu^{239}, Pu^{242}, Am^{241} and Th^{230} are identified and quantified. The total beta/gamma activity will be reported as Tc^{99}. Isotopic discrimination of beta emitters is not integrated in the current design because the current state of the art instrumentation for beta discrimination would make the MSP weight and size unmanageable. Gamma activity can be discriminated from the beta activity simply by mechanical shuttling of metal plate discriminators.

1. Alpha Detection

The starting point for the alpha detection was Eberline's existing commercial product, the Alpha-6. This device is typically used in air monitoring application for discrimination of low levels of airborne alpha isotopes. The alpha isotopes are discriminated on the basis of pulse height determined from the penetration depth of the particle through the silicon substrate. The data are recorded as a function of energy in the multichannel analyzer. The discrimination is based upon "regions of interest" which are collection of channels summed together to give a response for a particular isotope. A one-inch detector was integrated into the MSP. The associated electronics were integrated into the control software for the sensors.

2. Beta/Gamma Detection

The starting point for the beta/gamma technology was Eberline's Gas Proportional detector and modular detector board used in various commercial products. The gas (argon-carbon dioxide mixture) undergoes ionization by incident radiation. Charge is collected on the anode that is capacitive coupled to a comparator. Thresholds in the comparator discriminate noise and high-energy alpha emission from the beta/gamma response. A two-inch diameter gas proportional tube was integrated into the MSP. A film winder with various thickness of shielding discriminates the gamma radiation from the beta. The associated electronics were integrated into the control software for the sensors.

D. X-Ray Fluorescence (XRF)

In an attempt to provide the most useful information, we are currently evaluating the NITON model 701A X-Ray Fluorescence Spectrometer for addition to the system. The device is capable of determining substrate composition even if the surface is painted. It is also capable of adding information on toxic metal and substrate identification. It will be tested in the robotic system in the fall 1999.

The starting point for the XRF was NITON corporations model 701A handheld XRF unit with surface identification routines installed. The unit was modified to allow the safety shutter to be opened remotely via a cable release system, and to allow remote operation via computer control of the acquisition software. The built-in battery was replaced with a power supply. Safety from the Cd^{109} source is integrated into the unit.

E. Coherent Laser Radar (CLR)

The coherent laser radar is a high precision laser based ranging system, which is used to physically map an area and to determine the coordinate for positioning the sampling head on the robotic arm to a remote location. Control of the CLR is accomplished remotely over ethernet link from the IWOS console. In operation reference points are used to locate and transform the room and sampling head positions. The CLR system is mounted on the vehicle for mobility purposes, allowing it to have a large view of the working are. Figure 2 shows the CLR system mounted on the 3D-ICAS vehicle.

F. System Integration

3D-ICAS system uses its coherent laser radar (CLR) to obtain 3D facility maps, then uses the CLR generated 3D data to guide a robot arm borne multi-sensor probe along surfaces for contamination detection, 3D mapping and archiving.

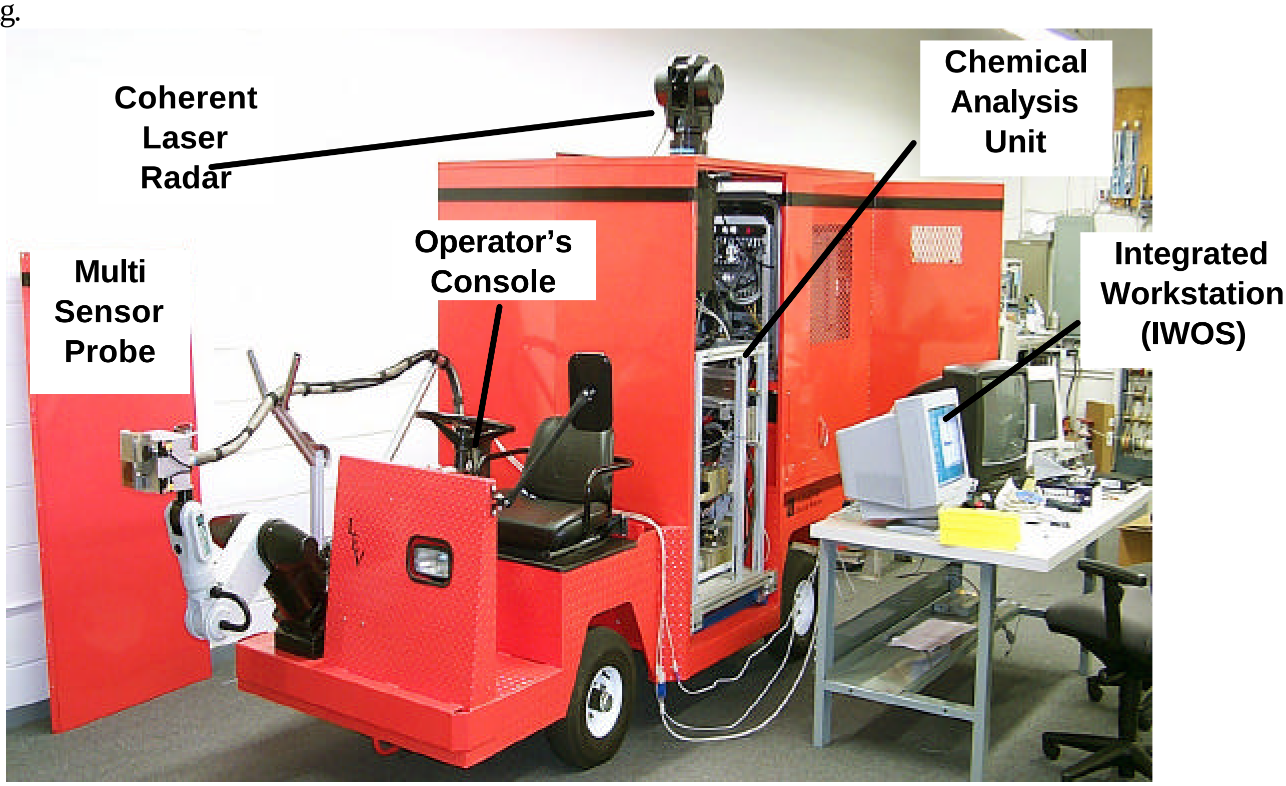

Figure 2. Prototype Demonstration Unit Under Development

1. Robot Arm

A model 465A robot arm from CRS Robotics (CRS) was selected, programmed and used to manipulate the sensor probe in a limited area. The CRS 465A robot arm has about the same reach as a human's arm. The CRS C500 controller is programmed in the Robot Applied Programming Language (RAPL II), a language developed by CRS, which is a derivative of BASIC and C. In this phase of work, the robot arm is being mounted on the front end of the mobile platform (Figure 2) allowing for full working space access.

2. Multi-Sensor Probe

The multi-sensor probe (Figure 3) comprises the GC sensor head, XRF probe, two radionuclide sensors, one for alpha particles and one for beta/gamma emissions, and four proximity sensors. The probe is a cube 6 inches on a side and weighs 6 lbs. The system uses commercial proximity sensors mounted at the four corners of the face of the probe. These proximity sensors provide a capability to move the probe up to a flat surface and maintain a standoff distance of 1 mm.

3. Robot Arm Platform

The electric vehicle provides mobility for the Robot Arm. The control of the arm is through commands issued from

IWOS over serial communications link. The management of the Multi-Sensor Probe umbilical and Robot Arm is through mechanical conveying system as shown in Figure 2. Although the Robot Arm only has a reach of 2 ft The multi-Sensor Probe could be placed as much as 20 ft from the unit. Limitations in resources drove the selection of this particular version of the Robot Arm in Phase II.

Figure 3. Photograph of Multi-Sensor probe Head

4. Control Strategy

The multi-sensor probe moves to each point specified in the survey list in the order in which they appear in the list generated by the integrated workstation. Movement between points is along a standard sequence of steps. First, the multi-sensor probe moves from the rest position along a straight line to a position near the next survey point, rotating along the way so that the face of the probe is nearly parallel to the surface at the end of the segment. Second, the probe moves toward the surface until the proximity sensors detect the surface. The final approach is accomplished in small steps under control of the proximity sensors. The sensor system is commanded to acquire the contaminant sample and initiate processing. Then the probe moves along a straight line to the arm's rest position. The scan data are processed to provide an accurate estimate of the probe's location and orientation.

5. Database Function

The database capability developed for the 3D-ICAS system serves as a repository for all of the data collected by the system. As the data are gathered, the system automatically archives it for easy retrieval and display by the Integrated Workstation (IWOS). Data are recorded for each survey point. The location of the sensor head is recorded precisely in facility coordinates along with the entire data structure from all of the sensors. The data structure includes raw data from the radionuclide (RN) and High-Speed Gas Chromatograph/Mass Spectrograph (HSGC/MS) sensors, and the Molecular Vibrational Spectrometer (MVS). The data structure also includes processed assignments for four organic compounds provided by the HSGC/MS. Finally, the database holds any specific images generated from the raw 3D mapper data.

6. Data Display: Facility Scene

A facility scene image is generated from the 3D facility frame mapper data by selecting the area to display and an optical viewpoint and converting range from the viewpoint into a rendered image. The facility scene is rendered in black and white so that subsequent contamination overlays in color will be highlighted.

7. Data Display: Contaminants

When a facility scene is displayed on the IWOS, the database can be queried for related survey information. The data can be overlaid on the facility scene as color-coded points or displayed in one of several different graphical or list windows. Each contaminant is displayed in its own window. The window contains the grayscale facility scene overlaid with contamination levels in color. A box with color codes is placed at each location where a measurement was made. The color of the different sections of the box depends on the concentration of the contaminant. Green, yellow, and red indicate below level of concern, above concern but below need for remediation, and needing remediation for contamination respectively. Default thresholds for defining the three contamination levels are provided; the user may change the thresholds. More detailed displays of contamination data are keyed from the facility scenes with contamination overlays on them. For any contamination display, the operator can select a location to get detailed information about with the mouse. Radionuclide activity levels are displayed in tabular form. Gas chromatograms are displayed in graphical form. Masses of the five organic compound classes are displayed as a bar graph. Secondary displays consisting of mass spectrograms are obtained by clicking on desired peaks in the gas chromatogram; mass spectrograms are displayed as graphs and also in tabular form.

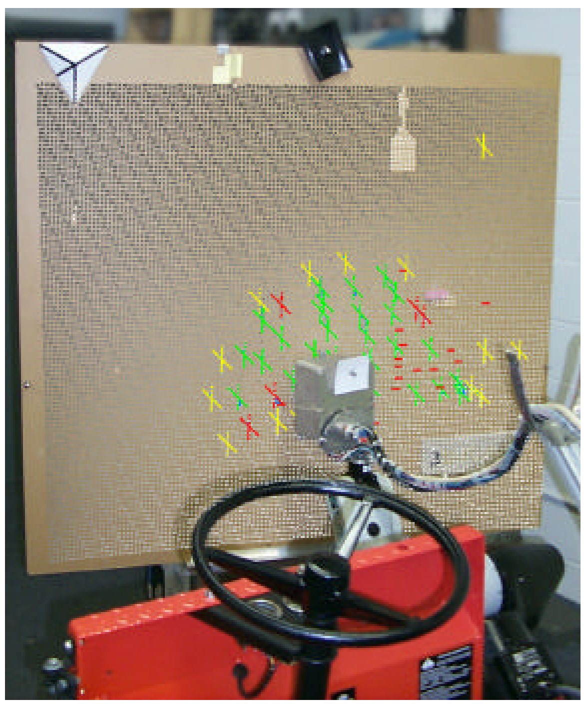

Figure 4. Overlay of Surveyable Points Map and Site Photograph

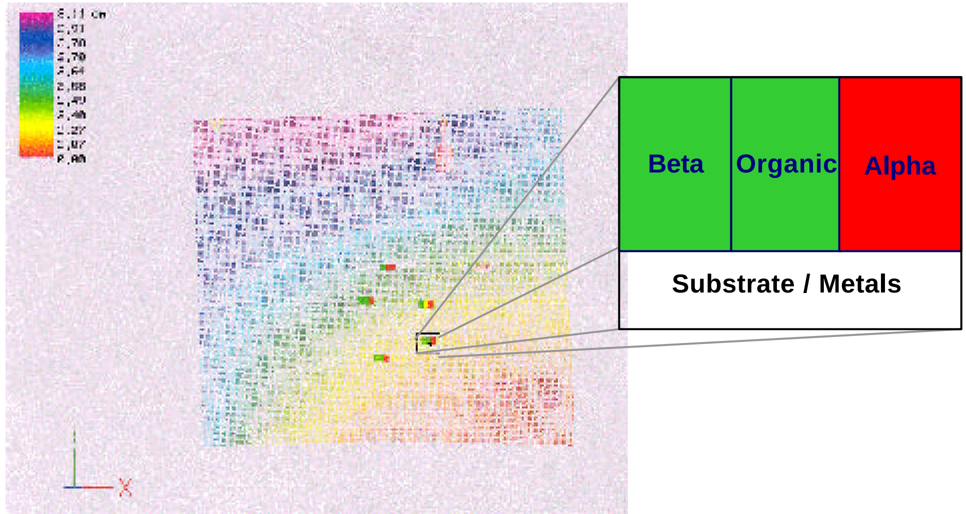

Figure 5. Top Level Contamination Map and legend.

The detailed data package contains the following information:

High Speed GC/MS	Chromatogram to identify organic chemicals Mass Spectra, NIST/EPA/NIH Identification Library Organic Chemicals classification
Radionuclides	Detects and Quantifies Pu, Am, U, Th, Sr, Tc
X-Ray Fluorescence	Detects Hg, Pb, Cr, U Asbestos, Concrete, Metal
Survey Information	Agency, Building, Room, Point of Contact, etc. Special Notes

Single Vehicle System

A major consideration was the need for a relatively large vehicle. Due to limitations of the current CLR system, the manipulator arm for sampling is required to be at least 2 meters distance from the CLR sensor head. In addition, the current CAU system requires approximately 1.1 m^3 in volume, other necessary components include the operating console with its associated Monitor, computer and printer for hardcopy occupies approximately 0.2 m3 and the CLR console occupies 0.6 m^3. We mounted the hardware onto an electric vehicle as a simple cost effective testbed for the single vehicle concept.

Control and Operations

During this effort, the operational control was made simpler and more robust with a conversion from the OS/2 operating system to Windows NT. This entailed a significant rewrite of C and C++ code used to issue commands and coordination of the subsystems operations. The conversion was successful and appears to be operable by a single knowledgeable individual.

Test Results

3D-ICAS provides a flexible system for physical, chemical and nuclear measurements reduces costs and improves data quality. Operationally, 3D-ICAS performs real-time determinations of hazardous and toxic contamination. The overall objective of this project is to develop a semi-autonomous integrated system that performs rapid in-situ analysis of hazardous organic, metals and radionuclide contamination on structural materials. The contamination measurement data are presented in an overlay of a 3-D model (map) and contamination found in an area.

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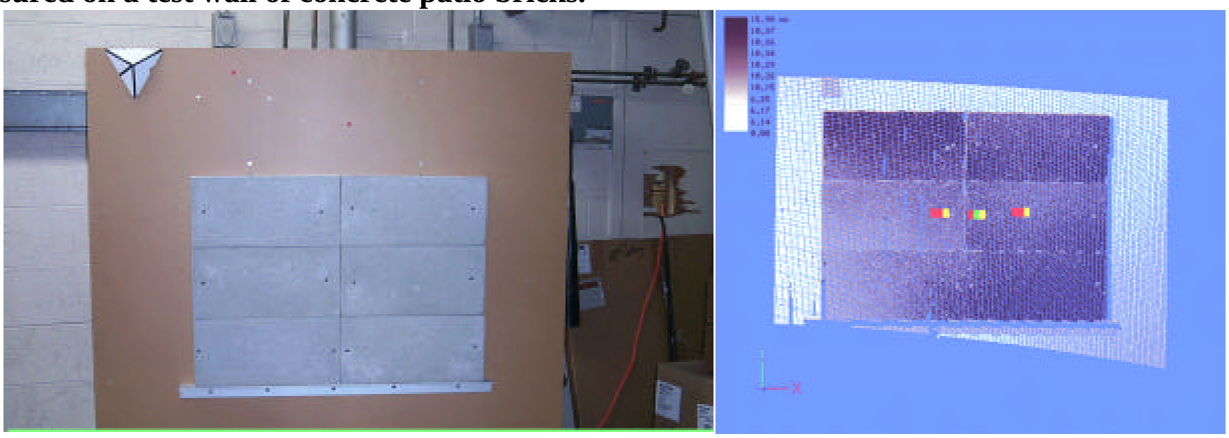
Example of generating such a map is shown in Figure 6. A test wall was fabricated using a sheet of plywood with 6 concrete patio bricks attached. The darker area is made from the concrete bricks. The markings indicate where measurements were made. In this case a mock up of beta and organic contamination with lesser amounts of alpha. The markings are coded to indicate the type and approximate levels of contamination.

Figure 6. Example of 3D-ICAS generated map showing organic and radioactive contamination as measured on a test wall of concrete patio bricks.



The steps of operation include detailed mapping using the CLR, characterization survey using the CAU and data review. Immediately after each survey session, the 3D-ICAS sensor output and contamination analysis along with CLR position information is displayed on a topographical map (see Figure 6). After a surface mapping operation is completed, 3D-ICAS will provide 3D displays showing contours of detected contaminant concentrations. 3D-ICAS will further provide permanent measurement data and contaminant level archiving, which assures data integrity and allows straightforward regulatory review of the characterization process before and after D&D operations.

As such it provides a unique capability to establish and display detailed three-dimensional (3D) maps (digitized models) of structures with the precise location of hazardous contamination (accurately identified and quantified to regulatory levels) reflected on those maps.

Detailed displays of the measurement data include alpha spectrum, 5 beta measurements with coarse energy discrimination, x-ray fluorescence for substrate and toxic elements identification and fast GC/MS for PCBs, fuels, explosives, and CWA identification. We have demonstrated sampling on concrete, wood and metal walls.

3D-ICAS performs these challenging functions in an integrated fashion, faster than any other technology and does so with minimal exposure of humans to the contaminated areas and without generating additional waste streams. Unique features are:

- Real-time identification and quantification of volatile organics, hazardous metals, and radionuclides to regulatory levels, identification of substrate materials on walls, ceilings and floors.
- Eye-safe, non-contact 3D mapping of structures or objects under any lighting conditions.

- Complete record of all data measurements with versatile integrated 3D display of measured work scenes and hazardous contaminants by type and concentration and a permanent archival database for off-line quality analysis and regulatory review.

3D-ICAS offers significant opportunities to perform environmental management activities faster, cheaper, better and safer. 3D-ICAS has the attributes of a superior technology in that it is an advanced crosscutting technology applicable to multiple DOE Environmental Management focus areas (Decontamination and Decommissioning, Radioactive Tank Waste Remediation, or Mixed Waste Characterization, Treatment, and Disposal). Wherever a need exists to characterize the surfaces of structures or specific objects (buildings, waste storage tanks, fixtures, drums, pipes, etc.); or detect, identify, and quantify virtually all hazardous materials; and or perform these complex functions in an integrated manner 3D-ICAS is the technology of choice.

Demonstration

A demonstration was planned to test and perform survey type operations. The demonstration site chosen was Florida International University's Hemispheric Center for Technology(FIU, HCET), With the assistance of the FIU personnel a demonstration was performed during the week of May 14, 2001.

The following is a brief description of our technology demonstration trip at FIU.

The 3 Dimensional Integrated Characterization and Archival System (3D-ICAS) was shipped on 11 May 2001 to FIU-HCET for demonstration and validation of the design modifications. These modifications included simplifying the design from a two-vehicle system to a single mobile platform, integration of the XRF sensor for enhanced substrate analysis and upgrading of the IWOS operating system.

Several of the system's power supplies were accidentally damaged upon power on because, at the test site, the requested single-phase receptacle was mistakenly wired with 3-phase AC power. Repairs were made in the field to the damaged power supplies but 3 of 5 days time were lost to complete the repairs.

Once the repairs were made CyTerra was able to demonstrate the CLR mapping and the movement of the sensor probe to selected locations on the test wall. The RN and XRF sensors were also demonstrated but the GCMS sensor had failed. The cause of the GCMS failure is believed to be known at this time. Specifically, GCMS electronic modules, which control the heating of two of gas transfer elements, may have been damaged during field debugging that was required.

Given the financial constraints of the program, CyTerra Corporation decided to return the equipment to Waltham facilities for further assessment. We believe the principles of operation were shown, however a complete demonstration did not occur due to these difficulties.

Significant events from this demonstration are listed below.

- The five-day demonstration of the 3D-ICAS was witnessed by four IUOE engineers (for vehicle operation details: Bruce Lippy, Patrick Bell, Aaron Ondo and Chip) and three FIU personnel (Marshall Allen, Cindy Zhang and Poornima Lakshman). Evaluations from IUOE personnel were positive and no significant improvements were suggested immediately.
- The power supplies on several component systems (specifically the robot power system, IWOS computer and

MS heaters), unfortunately, were adversely affected by incorrect input power. The tools and resources for field debugging were inadequate as several subcomponents required detailed, on-site repairs and may have caused additional damage. This significantly hampered the schedule for demonstration of the complete integrated system.

- The major accomplishments and notes from each major functional component are listed below.
  - **<u>CLR Mapping</u>**

i. Demonstrated 3D-mapping of the wall and calibration of the location system using three fiducial steel balls and a trihedral.

ii. Made two quick maps of ~ 1m×2m area. The wall maps showed fine details such as interpanel cracks/joints, etc., in addition to, tape, bolts and holes. Each map took approximately 2-3 hours to complete. The second map was used for later robotic arm function.

iii. The 3D-ICAS vehicle was moved to the sampling position from the mapping position and illustrated the *transformation* of the mapping information to the new vehicle location (translated coordinate system).

iv. The micrometer-range accuracy of the laser-based system is demonstrated.

v. In the first attempt, when the CLR equipment was outside the vehicle for repairs calibration was found to be difficult. This was due to poor signal quality and standard deviation in the laser measurements. During these repairs to robot controller, attempts to gain back some time resulted in low quality maps. This low quality map resulted from the instrument rack being outside of its intended design location. Once the instrument rack was pushed back inside (its design location) and stabilized, the operation was smooth.

  - **<u>Robot Function</u>**

i. Demonstrated the motion response of the robotic arm to both manual (in terms of angles and joint number) and laser-assisted (by pointing the laser) commands.

ii. Survey of multiple-point set was conducted by choosing a number of points on the map using the interactive software-IWOS.

iii. Sensor-head (probe) was shown to move to the intended location for sampling.

  - **<u>Integrated Sampling System</u>**

i. Demonstrated the entire sampling schedule that orchestrates the sampling (organics, heavy metals and RN) sequence. It takes approximately 2 minutes for the entire sampling and analysis cycle at each location.

ii. Also demonstrated the working of the sampling methodology and logic.

iii. Print-outputs from the analyzers were generated to illustrate the reporting system.

iv. Acoustic noise measurements made by IUOE personnel suggested that the system makes no significant noises. During sampling, the measured maximum acoustic noise level was 76.6 dB @ 2000 Hz, which is well within the OSHA limits (90 dB).

  - **Contamination Analysis Unit**
    - **Flash GC/Mass Spectrometer**

i. Operation of the GC/MS was demonstrated through running the schedule several times.

ii. Injection of semi-volatile pesticide sample using *top injection* located on the GC, showed an overloaded peak, due to no split on the injector.

iii. It was later learned that the power supply that feeds the sample transfer umbilicus heaters was not functional and the sample is lost somewhere in the umbilicus before reaching the GC/MS.

- **XRF Heavy Metal Analyzer**

iv. Using a stainless steel ruler, the functionality of the device was demonstrated. The XRF picked up all the trace metals such as Cr, Mo, etc., in the ruler. The concentration range was in 1-150 $\mu m/cm^2$ range.

v. The XRF is a bulk composition sensor with limited capability for detecting trace level surface contaminants. The XRF did not pick up the sample surface contamination, introduced by injecting microliter quantities of mixed-salt solution on to a ceramic tile. A combination of the liquid salt solution soaking into the substrate and the contaminant concentration not being high enough, e.g. $\mu g/cm^2$, are determined to be the contributors to this result.

- **RadioNuclide (**a **and** b -) **Detectors**

i. There was not enough time left for the team to demonstrate the detailed operation of these detectors.

Two significant pieces of information werew obrttainined during the demonstration. The CLR map of the test wall prepared by FIU and the analysis of a piece of stainless steel using the XRF.

The CLR map of the test FIU wall is presented in Figure 7. It can be seen that the section of wall contrains four pieces of plywood and 4 holes with bolts are in the corners.

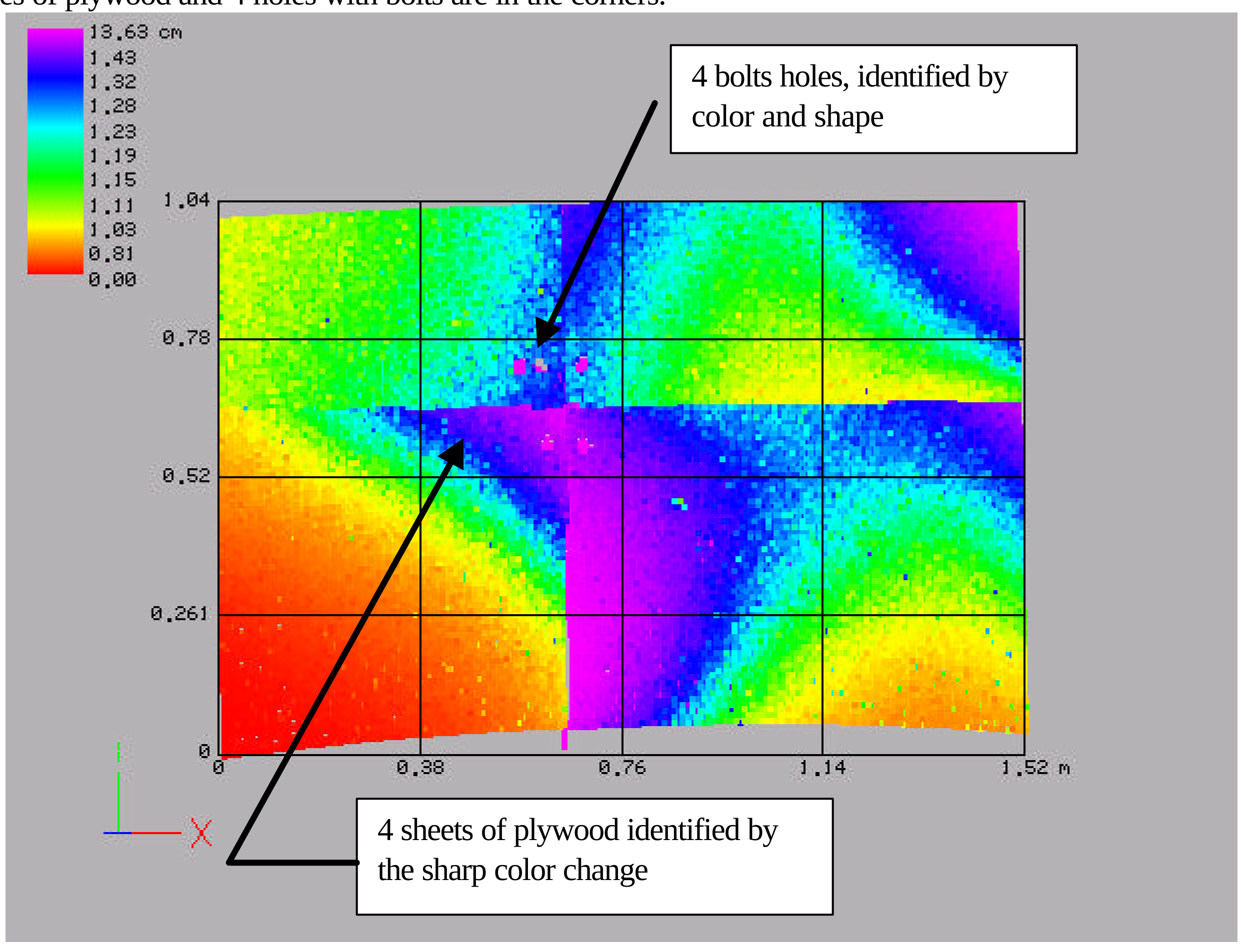


Figure 7. A section of the test wall as measured by CLR during demonstration at FIU.

A piece of stainless steel was analyzed for composition and the results found were the following:

Mo	Ni	Co	Fe	Mn	Cr
3.7	8.3	5.1	136.6	7.7	41.0

The composition of the stainless steel is similar to type 301. This is a common type of stainless steel.

Conclusions

The completed 3D-ICAS will be directly applicable to DOE facility characterization and decontamination and decommissioning. The sensor subsystems of 3D-ICAS represent advances in portable real-time chemical analysis for chemical constituents and dangerous materials of interest to DOE. The CLR 3D mapping subsystem can perform as a critical subsystem over a wide range of DOE robotic applications and industrial metrology applications. The availability of this technology will positively impact DOE clean-up operations in the following ways:

- Improved Performance
- Reduced Cost
- Reduced Health Risk
- Reduction of Environmental Risk

Recommendations

Based on the technological developments and performance at several demonstrations we recommend continued development of the 3 Dimensional Integrated Characterizations and Archiving System in the following areas:

- Automated operation,
- Landmark recognition,
- High precision, 6 DOF, long reach manipulator arms for sampling,

These are fundamental technology areas for development of the 3D-ICAS concept. It is clear that specialization of the technology to meet DOE and DOD needs will require continued development.

If the appropriate development took place in these areas it is conceivable that the small, e.g., 2000 in^3 , 100W sensor package, could be adapted to existing mobile robotic systems with an remote communications. This system could be used for environmental characterization, security monitoring and treaty verification applications.

Nomenclature

3D-ICAS	Three Dimensional Characterization and Archiving System
amu	atomic mass units
CCD	Charge coupled detector
CLR	coherent laser radar
CRS	CRS Robotics
D&D	Decontamination and Decommissioning
DOE	Department of Energy
DR	diffuse reflectance
ENIR	extended NIR
FT	Fourier Transform
GC	Gas Chromatograph

GC/MS	gas chromatographs-mass spectrometer
HSGC/MS	High Speed Gas Chromatograph/Mass Spectrometer
IR	Infrared
IWOS	Integrated Workstation
Mb/second	megabits per second
METC	Morgantown Energy Technology Center
MS	Mass spectrometer
MSP	Multi-sensor Probe
MVS	Molecular Vibrational Sensor
NIR	near IR
NIST	National Institutes of Standards and Technology
ORNL	Oak Ridge National Laboratory
PCA	principal components analysis
PCB	polychlorinated biphenyl
RAPL	Robot Applied Programming Language
RN	Radionuclide
SNR	Signal to Noise Ratio
SOM	self-organized mapping
TDI	Thermedics Detection, Inc.
TOF-MS	time-of-flight mass spectrometer
UI	University of Idaho

Acknowledgments

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Appendix A: Field Test Plan

(DRAFT)
FIELD DEMONSTRATION PLAN

THREE DIMENSIONAL INTEGRATED CHARACTERIZATION AND

ARCHIVING SYSTEM
(3D- ICAS)

(Phase III)

Work Performed Under Contract:
DE-AC21-93MC30176

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Submitted by:

Coleman Research Corporation
Thermo Electron R&D Center
25-C Olympia Avenue
Woburn, MA 01801

Program Manager: Dr. George B. Jarvis
Phone Number. (781) 933-4060
FAX Number. (781) 933-4683

Principal Investigator: Dr. George B. Jarvis
Phone Number. (781) 933-4060
FAX Number. (781) 933-4683

***Submitted* to:**

U.S. Department of Energy
National Energy Technology Laboratory
Morgantown, West Virginia 26507-0880
COR: V. P. Kothari

TABLE OF CON'I'ENTS

Introduction

This Field Demonstration Plan applies to the third phase of a three-phase development by Coleman Research Corporation, with subcontractors Thermedics Detection and the University of Idaho, which culminates in a state-of-the-art, integrated semi-autonomous topographic mapping and contaminant survey system. The Three Dimensional Integrated Characterization and Archiving System (3D- ICAS) will have application to multiple Environmental Management focus areas such as Decontamination and Decommissioning, Radioactive Tank Remediation, and Mixed Waste Characterization, Treatment and Disposal, wherever there is a need to survey structural surface contamination rapidly.

The 3D-ICAS system comprises six main subsystems: The Multisensor Probe head (MSP); the contaminant analysis unit (CAU) the three dimensional (3D) coherent laser radar (CLR); the integrated workstation (IWOS), the CRS sensing robot arm subsystem (SRAS), and the survey archive database (SADB). The MSP is attached to the end of the robot arm and houses radionuclide sensors (RN) for detecting and quantifying alpha and beta emissions, the sampling head for desorbing and collecting organic materials for quantitative analysis via high speed gas chromatography with mass spectrometer (HSGC/MS), the x-ray fluorescence (XRF) instrument for elemental metal and substrate identification, the molecular vibrational spectrometry (MVS) fiber optics for detecting and identifying inorganic materials, and proximity sensors for guiding the probe to as little as 1 mm standoff distance from the surface. 3D-ICAS is a versatile system that addresses specified real-time characterization needs:

- Physical mapping of indoor facilities.
- Analysis on substrate materials such as cement, concrete, asbestos containing materials (ACM), and asbestos.
- Detection, classification, and quantification of alpha and beta radioactive emitters.
- Detection, identification and quantification of elemental metals.
  Detection, classification, and quantification of volatile organic compound surface contamination.
- Overlay of contamination of physical map.

The robot arm conveys the MSP to the desired position for making contaminant measurements. The CLR subsystem maps the survey area to provide a spatial map of the facility and guidance to the robot arm, both with millimeter accuracy. The survey archive database contains a complete record of spatial and contaminant data and provides capability to display contaminant data overlaid on a physical map of the surveyed facility with hyperlinks to detailed sensor measurement data.

Operational procedures consist of placing the equipment in the area to be surveyed, activating the mapper to obtain a topological map of the facility, selecting locations to be surveyed, and initiating the contaminant survey. The operator merely specifies the area to be mapped. Otherwise, the system operates autonomously and unattended, although the operator may monitor the progress of the survey and intervene if necessary.

Phase I of the development demonstrated individual components of the system. Phase II continued sensor development and integration and demonstrated an integrated characterization and archiving system in the laboratory with the robot arm and the CLR stationary. The MVS sensor was demonstrated separately and was not integrated with the rest of the system. The area that can be surveyed without repositioning the base of the robot arm is limited because the CRS robot arm has about the same reach as a human arm. Phase III continued the development to a field-operable prototype. Specifically the MVS was integrated into the system and the equipment packaged for field operations and the contaminant analysis equipment was placed in a single rack mount device. During an October 1997 field demonstration, all of the success criteria were met.

Continuation of the Phase III included adding a x-ray fluorescence detector to the sensor suite to expand the detection capability into elemental metals, continued development of the Integrated Work and Operating System (IWOS) and integrating the subsystems onto a single mobility platform. Now RCRA and TSCA contaminants as well as radioactive isotopes can be detected and quantified. 3D-ICAS is re-designed to be deployed on a single mobility platform to provide virtually unlimited survey capability for contamination and mapping. In the field-deployed system, the mobility platform will convey the analysis equipment and the robot arm to a convenient location and the robot arm will move the MSP around locally for the contaminant survey.

Safety And Health

The only hazardous equipment in the Phase III 3D-ICAS are the 785 nm 250 mW Raman laser used by the MVS and the Cd radioactive source in the XRF. Since both MVS laser beams are focused at a point a few millimeters from the MSP there is no significant danger. In addition, shutters are installed in the system so that the laser beam and the Cd source will be blocked from exiting the sensor head except when a measurement is being made, at which time the probe head is within a few millimeters of the surface being surveyed. No direct path from the laser or the Cd source to an observer is possible and the probe head blocks virtually all of the reflected light from the laser system.

Non-hazardous substrate material will be used during the test and debug task at the Thermo Electron R&D Center laboratory in Woburn MA. These are wood, concrete, brick, etc. It is hoped that a relatively benign asbestos containing material (ACM), e .g. Transite, can also be used. Asbestos may be used at the DOE site demonstration at the discretion of DOE.

Non-hazardous contaminants will be used during the demonstration in the Thermo Electron R&D Center laboratory. As in the Phase II demonstration, contaminants will be limited to a low level alpha source (Th^{230}) and diesel fuel. Other contaminants may be used at the field site if approved by the site coordinator.

Success Criteria

The success criteria for the current task include performing a semi-autonomous mapping, contamination survey cycle including repositioning of the vehicle. The success criteria for Phase III focused upon demonstrating a fieldable, Maturity Level V, fast, semi-automated contaminant characterization system. We plan to demonstrate a fully integrated system's ability to perform the following:

- Map a work area, e.g., 1 square meter per hour,
- Perform contamination survey,
- Re-position the mobile vehicle to re-measure a contaminated location, and
- Identify contamination.

Field Demonstration Procedures

Introduction

Our goal is to demonstrate the integrated measurement capability of 3D-ICAS, document the time required for surveying larger areas and provide a data report that is useful for conducting clean-up or post clean-up characterization by other methods.

The methods for demonstrating the survey capabilities of 3D-ICAS include using a wall section consisting of wood, concrete and piping and also having contamination sources. Sources of contamination would be placed on both the wood and concrete sections. Once the wall is prepared, a 3D map is measured and finally the contamination survey conducted using the sensor system. These source could include metal contamination for the X-Ray fluorescence sensor (XRF), diesel or PCBs at trace levels, e.g., 10 to 1000 ug / cm^2 for organic contamination and low-level radiation sources for the alpha and beta sensors, e.g., thorium check standards. The surveys are conducted in both a random pattern as well as selected point measurement.

Field Demonstration

The purpose of the field demonstration is to show the operation of the 3D-ICAS system mounted on the mobility platform. In this demonstration, one mobility platform with integrated subsystems will be used. The platform conveys the CLR mapper so that the CLR has unobstructed views of the room reference tooling balls and the SRAS simultaneously. The platform also conveys the SRAS and the CAU so as to extend the area that can be reached by the MSP.

Field Demonstration Protocol

The area to be surveyed will be designated before the demonstration to facilitate mapping the area prior to the demonstration. The analysis equipment vehicle will be driven to within six inches of the desired initial position. The survey points will be selected so that the SRAS be moved to multiple positions at one location of the platform. The contamination toxic heavy metals such as mercury or lead, diesel oil and alpha and/or beta emitter will be applied to a concrete wall to demonstrate the ability of positioning the vehicle.

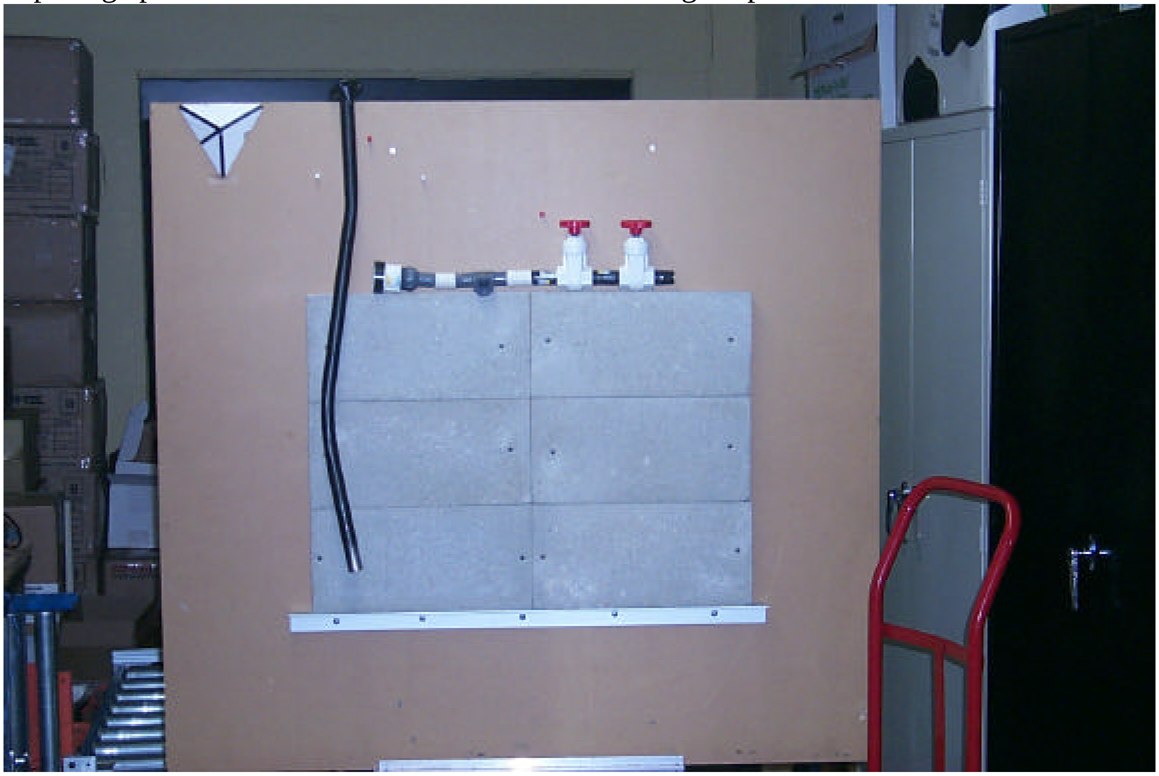
It is anticipated that the following steps will be demonstrated. These are the high-level steps necessary to generate a data package from 3D-ICAS operations of a facility characterization operation. This is a generic set of step that would be used in the field for any facility characterization

1. Move vehicle into room
2. Set-up rooms coordinate targets for mapping
3. Map the section of the room of interest, e.g., the demonstration wall
4. Set-up the characterization sensors survey, that is choose point to survey
5. Conduct the survey
6. Generate the data package

Wall Description

A 4 x 4 foot plywood panel will have several concrete blocks mounted. A one to three inch diameter pipe would also be mounted on this wall. Simulated liquid contamination could be applied to the concrete blocks and or pocket sources of the FIU design. Additional sources are applied to the front surface of the wall to simulate the low-level radiation surfaces.

A photograph of the wall is shown below. The FIU designed pockets are not cut into the wall at this time.



Recommended Sources:

- Organic sensor - diesel oil
- Metals/substrate sensor – lead or mercury, concrete and wood
- Radiation sensor – thorium check standard
- Laser mapping – metal & plastic pipe, wood and concrete surfaces of varying elevation

Analysis Of Demonstration Results

To be supplied after the demonstration.

The goal of the demonstration is the single vehicle operation of 3D-ICAS meeting the success criteria. The results of the demonstration will be assessed in terms of accuracy of identifying contamination and the ability to locate specific points after the vehicle has been repositioned. Thus both pre- and post clean-up performance can be assessed.

Acronyms and Abbreviations

ACM	Asbestos containing material, e.g. transite
3D	Three Dimensional
3D-ICAS	Three Dimensional Integrated Characterization and Archiving System
6-DOF	Six Degrees of Freedom, i.e. coordinates and three orientations
ALARA	As low as reasonably achievable
AM	Amplitude modulation
AMU	Atomic Mass Unit
BMP	Bit-Mapped Picture
CAU	Contaminant Analysis Unit
CCD	Charge coupled device
CLR	Coherent Laser Radar
CLR	Coherent Laser Radar
CMU	Carnegie-Mellon University
COR	Contracting Office Representative
CRC	Coleman Research Corporation
CRS	CRS Robotics, Corp.
D&D	Decontamination and Decommissioning
DB2	A commercial database management system
DBMS	Database Management System
DOD	Department of Defense
DOE	Department of Energy
DR	Diffuse reflection
DRO	Diesel Range Organics
DSP	Digital Signal Processor
ENIR	Extended near-infrared
EPA	Environmental Protection Agency
FM	Frequency modulated continuous wave
FT	Fourier transform
FWHM	Full-width at half maximum
GC	Gas Chromatograph
GC/MS	Gas Chromatograph combined with Mass Spectrometer
HMF	Heavy metal fluoride
HSGC/MS	High-speed GC/MS
IBM	International Business Machines
IWOS	Integrated Workstation
MATLAB	A commercial high level programming language published by The MathWorks.
MDA	Minimum detectable activity
MS	Mass Spectrometer

MSP	Multisensor Probe
MVS	Molecular vibrational Spectrometer
NASA	National Aeronautics and Space Administration
NIR	Near infrared
NIST	National Institute of Standards
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
OS/2	A multi-tasking 32 bit operating system for Personal Computers
PC	IBM compatible personal computer
PCA	Principal components analysis
PCB	Polychlorinated biphenyl
RN	Radionuclide
SADB	Survey archive database
SNR	Signal-to-noise ratio
SOM	Self-organizing map artificial neural network
SQL	Structured Query Language.
SRAS	Sensing robot arm subsystem
TDI	Thermedics Detection, Inc.
TEDE	Total Effective Dose Equivalent
TOF-MS	Time-of-flight mass spectrometer
UI	University of Idaho
UNIX	A computer operating system
VPT	Volume phase technology

Appendix B: Draft 3D-ICAS TAP Summary Sheet

TECHNOLOGY ASSESSMENT PROGRAM (TAP)
Characterization Technology Assessment Summary

Three Dimensional Characterization and Archiving System (3D-ICAS)

DEMONSTRATION OBJECTIVE

The Three Dimensional Characterization and Archiving System (3D-ICAS) was demonstrated at FIU-HCET on May 14-19, 2001 by CyTerra Corporation. The purpose of the demonstration was to evaluate performance of the integrated 3D-ICAS with respect to its ability to characterize surface contamination associated with radioactive, heavy metal and organic contaminants.

TECHNOLOGY DESCRIPTION

Figure 1. Operator driving 3D-ICAS to show its maneuverability

Figure 2. 3D-ICAS measuring contamination level on the wall

The Three Dimensional Characterization and Archiving System (3D-ICAS) is a remote system that performs real time in-situ analysis of hazardous organics and radionuclide contamination on structural materials. The 3D-ICAS system comprises six main subsystems:

1. Multisensor Probe (MSP): attached to the end of the robot arm, houses radionuclide sensors (RN), which detects and quantifies radiation levels; the sampling head for desorbing and collecting organic materials for quantitative analysis via high speed gas chromatography with mass spectrometer (HSGC/MS); the X-ray fluorescence (XRF) instrument for toxic metal and substrate identification; the molecular vibrational spectrometry (MVS) fiber optics for detecting and identifying inorganic materials, and proximity sensors for guiding the probe to a 1 mm standoff distance from the surface.
2. Integrated WorkStation (IWOS): operated outside the contaminated area that the 3D-ICAS is examining and remotely controls the 3D-ICAS.
3. Contamination Analyzing Unit (CAU): extracts and analyzes the contaminated samples taken from the inspected area.

4. 3D Coherent Laser Radar (CLR): surveys the area to provide a spatial map of the facility and guides the robot arm with millimeter accuracy.
5. CRS Sensing Robot Arm Subsystem (SRAS): conveys the MSP to the desired position for making contaminant measurements.
6. Survey Archive Database (SADB): contains a complete record of spatial and contaminant data and provides capability to display contaminant data overlaid on a physical map of the surveyed facility with hyperlinks to detailed sensor measurement data.

All subsystems are integrated onto a single vehicle, which is operated on electrical batteries. Operational procedures consist of placing the equipment in the area to be surveyed, activating the mapper to obtain topological map of the facility, selecting locations to be surveyed and initiating the survey. The operator, who may be located remotely in a safe environment, merely specifies the area to be mapped. Otherwise, the system operates autonomously and unattended, although the operator may monitor the progress of the survey and intervene if necessary. Mapping, survey and analytical results are automatically saved in the computer and may be retrieved after the job is completed.

RESULTS

Several of the system's power supplies were damaged on the first day of the demonstration because the requested single-phase receptacle had been mistakenly wired with 3-phase AC power. (FIU-HCET has since implemented measures that will prevent similar situations from reoccurring). Repairs were made in the field to the damaged power supplies. Because tools and resources for field repair and debugging were insufficient, on-site repairs may have caused additional damage to the system. The repair lasted approximately 2 and half days, resulting in a significant deviation from the demonstration plan.

Once the repairs were complete, CyTerra was able to demonstrate the following capabilities of the system:

1. CLR mapping and calibration of the location system using a trihedral and three steel spheres attached to a frame with x, y and z arms.

   Two 3D maps of a plywood wall were made. The mapped area was 26 ft^2 and 16 ft^2 respectively. The maps showed fine details such as joints between plywood panels, and tapes and bolts on the wall. The second map was later used to direct the robotic arm to the survey points.

2. The motion response of the robotic arm to the laser-assisted (by pinpointing laser) commands.

   The sensor probe was moved to multiple locations on the wall for measurements. These points were selected by choosing a number of points on the map using interactive software-IWOS.

3. The entire sampling schedule that coordinates the sampling sequence: organics, heavy metals and radionuclides.

   Multiple measurements were taken without using contaminated sources to demonstrate the sampling schedule. It took approximately 2 minutes for the entire sampling and analysis cycle at each sampling point. A hard copy report was printed out upon completion of the measurements.

4. Functionality of the sensor

(a) XRF sensor. The XRF is a bulk composition sensor with limited capability for detecting trace-level surface contamination. Using a stainless steel ruler, the functionality of the device was demonstrated. The XRF picked up all the trace metals such as Cr, Mo, etc. in the ruler. The concentration of each element was in the 1-150 $\mu g/cm^2$ range. The XRF, however, was not able to identify the heavy metal content on a test surrogate provided by FIU-HCET. The test surrogate was prepared by injecting 200 microliters of mixed solution on to a ceramic tile over an area of 4 cm by 4 cm. The heavy metal content on the surrogate contains 0.1-5 mg of Br, Cr, Pb, Ag, and Hg. The reason may be that the contaminant concentrations were below XRF's detection limit.

(b) GC/MS sensor. The GC/MS sensor was not able to function during the demonstration. The cause was unknown at the time. After the equipment was shipped back to CyTerra Corporation, it was determined that the GC/MS electronic modules that control the heating of two of the gas transfer elements may have been damaged during field repair.

(c) Radiological sensors. Functionality of the alpha and beta radiological sensors was not demonstrated due to time constraints.

5. Other information collected

Table 1 lists other information collected during the demonstration that may be useful for potential technology users.

Table 1. Significant data collected during 3D-ICAS demonstration

Aspect	Results	Comment
Time for unloading equipment from transport trailer	30 minutes	The demonstration site does not have a loading dock. If a loading dock were available, it is expected that less time would be needed to unload equipment.
Time for setting up mapping operation	2 hours and 23 minutes	Time required for field repairs due to power problem is excluded.
Mapping rate	17.3 ft2/hr	
Time for setting up robotic arm	3 hours and 15 minutes	Time taken to set up the robotic arm so that it could properly follow the laser-assisted commands. Time required for field repairs due to power problem is excluded.
Time for a measurement cycle	2 minutes per sample	Each cycle contains measurements of organics, heavy metals and radionuclides.
Time for measurement including selecting points to be measured though the computer	4-5 minutes per sample	This number was calculated based on the few measurements (<10) taken during demonstration.
Time for setting up XRF	1 hour and 13 minutes	Time for field repairs due to power problem is excluded.
Training requirement	Complex system. Needs intensive equipment specific training	
Area the equipment can reach for a measurement without moving the vehicle	≤ 6 ft^2	The area is no more than 2 ft by 3 ft
Area the equipment can reach for a measurement by moving the vehicle	Between 2 to 5 feet above the ground	
Time for packing equipment	50 minutes	This time applies to packing activities after completion of the demonstration and prior to shipment

HEALTH AND SAFETY FACTORS

The noise level generated during the 3D-ICAS operation was below the OSHA action limit of 85 dBA. Potential health and safety issues identified during the demonstration include (1) a lack of warning device or guarding of the three-foot-radius spherical area in which the robotic arm is capable of reaching; and (2) the absence of proper lockout/tagout procedures for conducting maintenance and repair on the equipment.

SUMMARY AND RECOMMENDATIONS

The demonstration was not able to achieve its objective due to the problems stated above. Nevertheless the concept and principles of 3D-ICAS operation were demonstrated. The 3D-ICAS was developed to conduct rapid RCRA, TSCA and NRC contamination measurements in large facilities. The demonstrated equipment was still an R&D prototype. Much development is still required before it is ready for field deployment.

For additional information about this characterization technology assessment, contact Cindy Zhang, Project Manager, Technology Assessment Program, FIU-HCET, (305) 348-6340, email: zhangc@hcet.fiu.edu.