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# THREE DIMENSIONAL, INTEGRATED CHARACTERIZATION AND ARCHIVAL SYSTEM FOR REMOTE FACILITY CONTAMINANT CHARACTERIZATION*

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## ABSTRACT

The largest problem facing the Department of Energy's Office of Environmental Management (EM) is the cleanup of the Cold War legacy nuclear production plants that were built and operated from the midforties through the late eighties. EM is now responsible for the remediation of no less than 353 projects at 53 sites across the country at, an estimated cost of $147 billion over the next 72 years. One of the keys to accomplishing a thorough cleanup of any site is a rigorous but quick contaminant characterization capability. If the contaminants present in a facility can be mapped accurately, the cleanup can proceed with surgical precision, using appropriate techniques for each contaminant type and location.

The three dimensional, integrated characterization and archival system (3D-ICAS) was developed for the purpose of rapid, field level identification, mapping, and archiving of contaminant data. The system consists of three subsystems, an integrated work and operating station, a 3-D coherent laser radar, and a contaminant analysis unit. Target contaminants that can be identified include chemical (currently organic only), radiological, and base materials (asbestos).

In operation, two steps are required. First, the remotely operable 3-D laser radar maps an area of interest in the spatial domain. Second, the remotely operable contaminant analysis unit maps the area of interest in the chemical, radiological, and base material domains. The resultant information is formatted for display and archived using an integrated workstation. A 3-D model of the merged spatial and contaminant domains can be displayed along with a color-coded contaminant tag at each analysis point. In addition, all of the supporting detailed data are archived for subsequent QC checks.

The 3D-ICAS system is capable of performing all contaminant characterization in a dwell time of 6 seconds. The radiological and chemical sensors operate at U.S. Environmental Protection Agency regulatory levels. Base materials identification is accomplished using a molecular vibrational spectroscopy, which can identify materials such as asbestos, concrete, wood, or transite. The multipurpose sensor head is positioned robotically using a small CRS Robotics A465 arm, which is registered to the environment map by the 3-D laser radar.

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Initial field testing of 3D-ICAS was carried out in October 1997 at Oak Ridge National Laboratory. The results of this demonstration will be discussed and possible application of this system to a number of future projects will be presented. Additionally, a description of each subsystem will be provided.

## Introduction

The three-dimensional integrated characterization and archival system (3D-ICAS) was proposed to the Morgantown Energy Technology Center (now the Federal Energy Technology Center, Morgantown, W.V.) in 1992 as a system to automate the collection of contaminant data and produce a display of the results.[1,2] In October 1997, the system was operated in the Oak Ridge National Laboratory's (ORNL's) Robotics and Process Systems Division (RPSD) high bay area. The culmination of 5 years of design and testing, 3D-ICAS demonstrated several unique capabilities that should serve the Department of Energy (DOE) characterization mission well. One of the most significant developments that 3D-ICAS provides is the ability to perform fast chemical analysis of thermally desorbed samples while simultaneously measuring alpha and beta/gamma activity. Inclusion of molecular vibrational spectroscopy gives the system the ability to identify asbestos-containing materials in less than 10 seconds per measurement. The total sensor "dwell" time on a sample point is under 1 minute. Results from the data collection and analysis can be displayed graphically, in text, or using icon as part of a 3-D model of the volume surveyed. 3D-ICAS is a complex arrangement of three main subsystems, the coherent laser radar (CLR), the contaminant analysis unit (CAU), and the integrated work and operating station (IWOS), each of which is discussed in detail below.

## System Description

A block diagram of the overall 3D-ICAS is shown in Figure 1. Each subsystem identified is discussed below in detail.

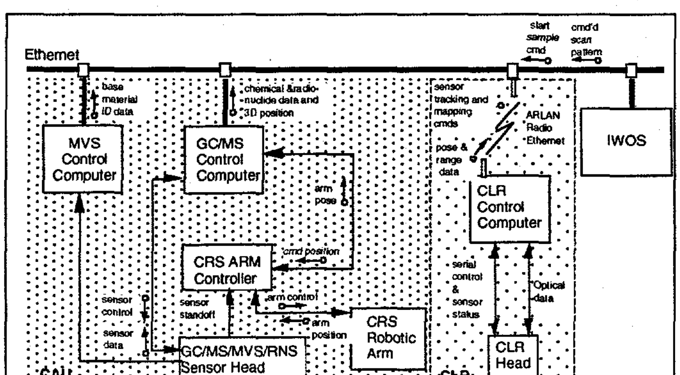

Fig. 1. 3D-ICAS Block diagram.

## *Coherent Laser Radar*

The Coleman CLR is a unique, high-precision laser based system, which is used to spatially map an area of interest and to register the CRS Robotics arm to that area. Control of the CLR is accomplished remotely over the ethernet from the IWOS console. The CLR system is mounted on the Mobile Mapping System[3] for mobility purposes, allowing it to be moved around in the area of interest and beyond. Adjacent areas of interest can be referenced to each other so that a large volume map can be generated. Figure 2 shows the CLR system mounted on the Mobile Mapper System.

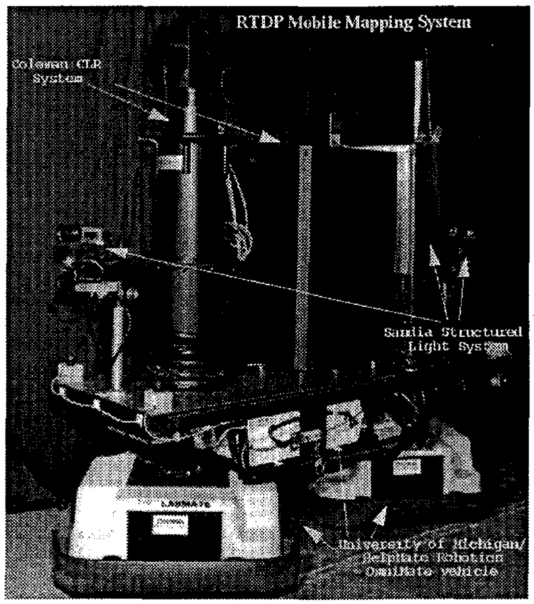


Fig. 2. CLR on the Mobile Mapping System.

## *Contaminant Analysis Unit*

The CAU is the subsystem that performs all the chemical and radiological contaminant analysis and base material identification. It is a complex subsystem consisting of several parts, each of which will be discussed in the following sections. The CAU is shown mounted on the RPSD overhead transporter in Figure 3.

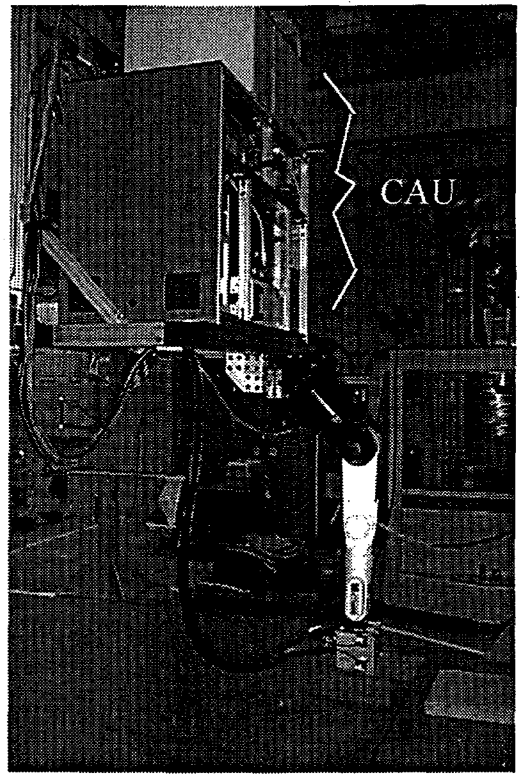


Fig. 3. CAU mounted on the RPSD high bay transporter system.

## Gas Chromatograph/Mass Spectrometer

The Thermedics Detection Corp. developed a high-speed gas chromatograph/mass spectrometer (GC/MS) unit used in 3D-ICAS that is unique in its speed of operation, while maintaining regulatory levels of contaminant detection into the parts per billion. The uses of an infrared (IR), thermal desorption technique for noncontact surface sampling of organic contaminants allows sampling to a depth of 0.5 to 1 mm in less than 10 seconds. A preconcentration and transport subsystem delivers the sample to the GC/MS systems in less than 20 seconds using a "cold spot" focusing module and a rapidly heated transfer line. The gas chromatograph used in the CAU is also a high-speed unit that uses a radically different chromatographic configuration than normal to obtain temperature-programming rates as high as 1700°C/sec. This represents a 100-fold improvement in separation time, with peaks typically 70 times sharper than those obtained by conventional methods. The mass spectrometer used in the CAU is a high-speed time-of-flight unit that has been selected to match the performance of the GC unit. It uses a thin film resistive detector and orthogonal acceleration microchannel plate detector and time lag focusing to compensate for the energy distribution of ions in the ion source. Sample GC and MS data for diesel fuel are shown in Figures 4 and 5.

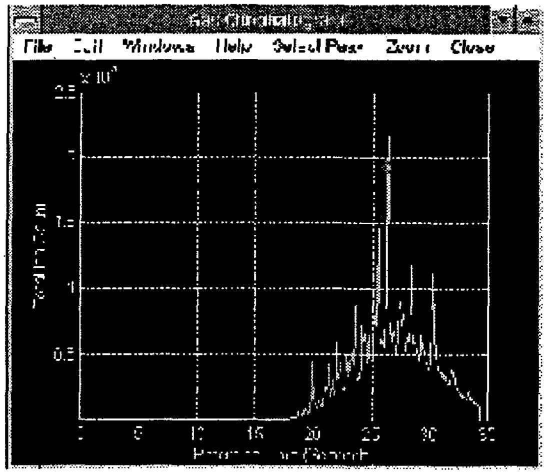

Fig. 4 Mass spectra of Dodecane, 2-methyl at 21.6 sec.

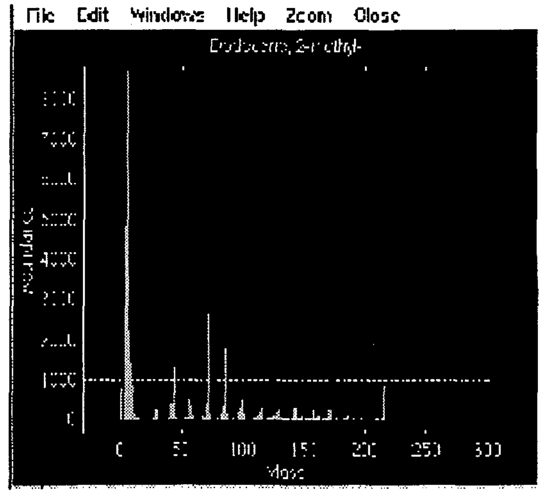


Fig. 5. GC spectra for a sample of diesel fuel.

## Molecular Vibrational Spectrometer

The University of Idaho developed a molecular vibrational spectrometer (MVS) to determine the base material that the integrated sensor head is examining and to set operating parameters for the GC/MS unit. The MVS uses both FT Raman and FT-IR spectrometry to identify base material types. Off-the-shelf laboratory analysis equipment was used for both techniques, but application specific spectrum sorting and recognition algorithms had to be developed for the complex base material mixtures expected at the DOE sites. The MVS uses a Perkin-Elmer System 2000FT spectrometer configured for NIR Raman spectrometry (Nd:YAG laser, InGaAs detector). The MVS can currently identify base materials of wood, concrete, transite, and asbestos and can be programmed to identify other materials also. Figure 6 shows the optical schematic of the MVS probe head.

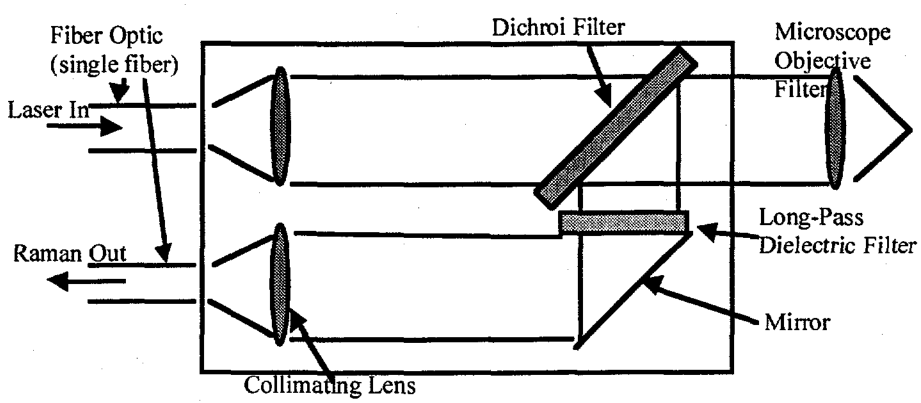


Fig. 6. MVS optical schematic.

## Radionuclide Sensor

The radionuclide sensor (RNS) is designed to provide detection and identification of medium-to-high levels of radiation from uranium, plutonium, thorium, technetium, and americium and their isotopes. The sensor used is an Eberline Instruments model 6A analyzer with a remote probe located in the integrated sensor head. The sensor incorporates a diffused junction, solid state detector and a 256-channel pulse height analyzer. When the remote probe is held within 2–3 mm of a surface, the energy resolution is 0.04 MeV, which is sufficient to identify the major alpha emissions of U235 (4.40 MeV), U-238 j(4.18 MeV), Pu-239 (5.15 MeV), Pu-242 (4.88 MeV), Th-230 (4.68 MeV), and numerous other isotopes. The RNS is intended only as a "field level" survey instrument, providing a good indication of radioactive levels that will warrant significant cleanup efforts. Figure 7 shows the RNS location within the integrated remote probe head.

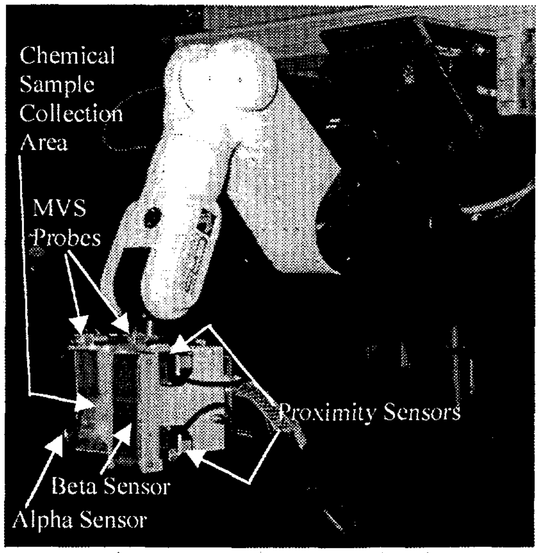

Fig. 7. Integrated sensor head.

## Integrated Sensor Head

The integrated sensor head (ISH) is simply a housing for the various sensor probes to be mounted on. It is an aluminum box, as shown in Figure 7, which separates the various sensor probes so that their individual operation does not interfere with each other. The ISH includes four standoff laser proximity sensors, which allow the arm control software to measure the distance and angle between the sensor head face and the surface of interest. The ISH provides the "cold spot" chemical collection surface for the gas collected after IR excitation of surface contaminants. This surface is rotated 180° then heated to release the contaminant into the GC transfer tube. The ISH also contains a moving film, beta particle discriminator for the beta/gamma detector. This moving film is progressively thicker so that over the 60-second beta particle count period, identification of a wide range of particle energies can be accomplished.

## CRS Robotics 6DOF Arm

3D-ICAS uses a CRS Robotics A465, 6 degrees-of-freedom arm to hold and position the ISH close to the surface of interest. The CRS arm has a 10 Kg payload and ~ 750-mm reach in most directions. The

IWOS software maintains control of the CRS arm over a network connection through the GC/MS control computer. The IWOS operator indicates desired contaminant sampling points and the IWOS software calculates arm positions needed to reach those points and sends the movement commands to the arm controller.

### *Integrated Work and Operating Station (IWOS)*

The IWOS is an OS/2 based Pentium workstation with an ethernet connection to the other 3D-ICAS computers. The IWOS is the master-operating console for 3D-ICAS and contains software to control the CLR as well as the CAU. Once an area of interest has been mapped with the CLR, the 3-D data set can be viewed on the IWOS, and the operator can select contaminant sample points. The IWOS software determines the reachability of the operator-selected sample points for the current CAU position and indicates reachable points with a green icon and unreachable ones with a red icon.

## Demonstration Results and Future Applications

The 3D-ICAS was setup and operated in the ORNL's RPSD high bay area in October 1997 (Figure 8). The system was used to create a spatial map of a test stand (Figure 9), on which were placed several radioactive test targets along with a sample of diesel fuel. The system was then used to collect data at several sample points on the test stand. The resulting computer model with color-coded contaminant tags is shown in Figure 10. Table 1 shows base material identification accuracy obtained from the MVS during testing at the University of Idaho with several base materials.

Future applications of the 3D-ICAS are currently being examined, with some support for a role in the large-scale demonstration at Idaho National Engineering and Environmental Laboratory. While the 3D-ICAS that was demonstrated at ORNL is a very unique instrument with many cost saving features (compared to current manual survey techniques), it is still considered a "laboratory prototype" and needs further testing and development prior to deployment in a "hot" environment.

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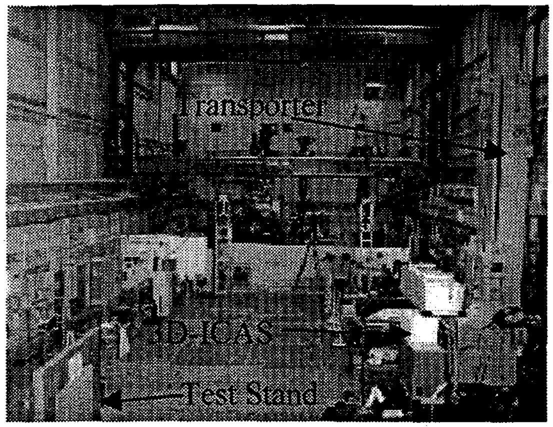


Fig. 8. 3D-ICAS installed on overhead transporter in ORNL high bay.

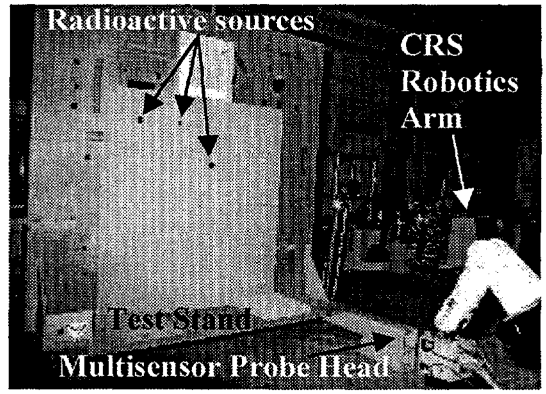


Fig. 9. Photo of 3D-ICAS sensor head approaching test stand.

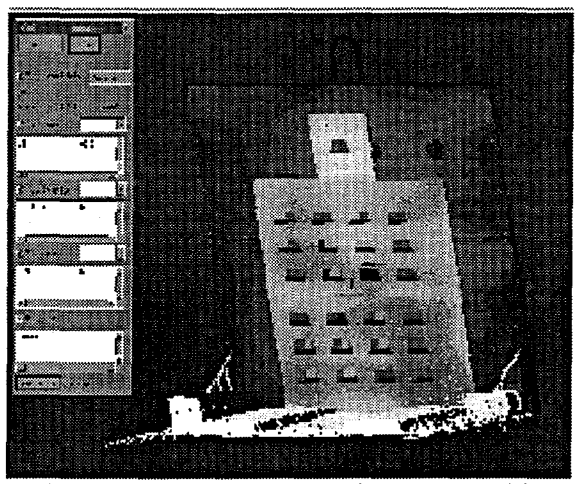

Fig. 10. Computer model of test stand with contaminant sample data shown.

Table 1 – MVS material identification accuracies

| Sample Type | Mean Classification Rate | Mean Probability |
|---|---|---|
| ACM | 94.9 | 91.0 |
| Brick | 97.8 | 97.9 |
| Cement | 97.1 | 94.8 |
| Wood | 99.8 | 96.3 |
| Other | 85.7 | 84.8 |
| Organic | 68.3 | 63.5 |
| Inorganic | 94.1 | 69.5 |