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**A New Forensics Tool: Development of an Advanced Sensor for Detecting Clandestine Graves**

**<u>FINAL REPORT</u>**

**Grant/Award Number: 2007-DN-R-104**

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## ABSTRACT

Locating clandestine graves, identification of victims (development of biological profiles from unidentified persons) and odor recognition (in locating and identifying individuals) are still very difficult, costly and time consuming tasks which impact law enforcement, intelligence and military operations around the world. The Federal Bureau of Investigation recognizes these deficiencies and has funded studies to develop databases comprised of odor signatures of human decomposition, canine scenting and canine tracking abilities. The database comprising the odor liberation from human cadavers was developed at Oak Ridge National Laboratory (ORNL) in conjunction with the University of Tennessee's Decay Research Facility and continues being developed for long-term burials. The purpose of this proposal was to utilize this very specific and unique database of human decompositional odor to develop a sensor package capable of locating clandestine graves. This detector (LABRADOR – light-weight analyser for buried remains and decomposition odor recognition), based on specific chemical compounds found relevant to human decomposition,

is the next step forward in clandestine grave detection and will take the guess-work out of current methods using canines and ground-penetrating radar, which have historically been unreliable. The detector was constructed with off-the-shelf components to minimize costs and has a twelve sensor array platform designed to detect the major classes of chemical compounds found relevant in human decomposition. It is self contained, portable and built for field use. Both visual and auditory cues are provided to the operator.  A data port allows the operator to store data, if desired. Total cost per unit is estimated at $1,000 - $1,500/ unit. Batteries, if fully charged, will last up to six hours of constant use. While not as sensitive as a mass spectrometer, the LABRADOR (in the field in less than 60 seconds) has been shown to provide qualitative data comparable to what is seen with gas chromatography-mass spectrometry headspace analysis with collected field soil samples.

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## EXECUTIVE SUMMARY

Locating clandestine graves, identification of victims (development of biological profiles from unidentified persons) and odor recognition (in locating and identifying individuals) are still very difficult, costly and time consuming tasks which impact law enforcement, intelligence and military operations around the world. The Federal Bureau of Investigation recognizes these deficiencies and has funded studies to develop databases comprised of odor signatures of human decomposition, canine scenting and canine tracking abilities. The database comprising the odor liberation from human cadavers was developed at Oak Ridge National Laboratory (ORNL) in conjunction with the University of Tennessee's Decay Research Facility and continues being developed for long-term burials. The purpose of this proposal was to utilize this very specific and unique database of human decompositional odor to develop a sensor package capable of locating clandestine graves. This detector (LABRADOR – light-weight analyser for buried remains and decomposition odor recognition), based on specific chemical compounds found relevant to human decomposition, is the next step forward in clandestine grave detection and will take the guess-work out of current methods using canines and ground-penetrating radar, which have historically been unreliable. The detector was constructed with off-the-shelf components to minimize costs and has a twelve sensor array platform designed to detect the major classes of chemical compounds found relevant in human decomposition. It is self contained, portable and built for field use. Both visual and auditory cues are provided to the operator. A data port allows the operator to store data, if desired. Total cost per unit is estimated at $1,000 - $1,500/ unit. Batteries, if fully charged, will last up to six hours of constant use. While not as sensitive as a mass spectrometer, the LABRADOR (in the field in less than 60 seconds) has been shown to provide qualitative data comparable to what is seen with gas chromatography- mass spectrometry headspace analysis with collected field soil samples associated with clandestine

graves. Additional sources of sample material to which a preliminary database for the LABRADOR has begun include accelerants, narcotics, explosives and decompositional stages of various tissues.

Since the scientific principles on which these sensors are founded have been well established in the scientific community for many decades, acceptance of this powerful technology should be readily accepted in the eyes of the Courts. Implementation of the procedures and methodologies of this technology will significantly augment the procedures already in use today (canines, probing, GPR) thereby saving time, money and manpower. Success in this project could prove useful in the location of clandestine graves as well as location of ‘surface’ human remains (e.g. World Trade Center) and could become standard practice in many crime scene investigations around the world.

## I. INTRODUCTION

### 1. Statement of the Problem

Locating clandestine graves, especially those many years old, is extremely difficult, costly, time consuming and labor intensive. Methods or instrumentation developed to assist in this task will accelerate the detection and processing of the crime scene, promote recovery of evidence and provide a cost effective resource base which will augment human remains detection canines and ground penetrating technologies already available.

### 2. Literature Review

There are three primary means of locating clandestine graves today: manual probing, ground penetrating radar (GPR) and canines.

Manual probing is very inexpensive and is used to locate disturbed soil regions, but cannot confirm the presence of a corpse and can only be used in small areas. Ground-penetrating radar (GPR) has been used for several years as a non-destructive method of locating subsurface anomalies. GPR is usually expensive and also locates areas of disturbed soil. Under ideal conditions, and if the grave is very fresh, GPR can sometimes indicate the presence of a corpse, but can be easily fooled by objects in the environment (e.g. roots, stumps, rocks, debris, man-made objects, etc.) and requires a significant amount of training to interpret the signals indicative of clandestine graves. No matter how the data is processed and visualized, GPR units can only penetrate to a limited depth. As the electromagnetic pulses dissipate with depth, they eventually fade to nothingness.

According to Benson (1995), the penetration depth of a GPR signal depends on the frequency of the GPR source signal, the GPR antenna radiation efficiency and the electrical properties of the subsurface materials. Energy is lost as the electromagnetic radar signal passes from the transmitting antenna through the subsurface. Eventually, all energy is lost.

After a certain depth, the reflecting signals do not return to the surface. Higher signal frequencies provide high subsurface resolutions, but only penetrate to shallow depths. Low signal frequencies provide low resolution, but can penetrate to depths of 10 meters or more (Beres and Haeni, 1991). Typically, signal losses are high in soils having high water content, posing yet another constraint on this technology.

The working police canine has become an integral part of law enforcement. For centuries, dogs have had a well-established place in law enforcement. They have proven to be invaluable in such vital areas as explosive detection, narcotics detection, and tracking and searching for criminals, lost persons and missing persons. (O'block, Doeren, & True, 1979; Lilly & Puckett, 1997). Man has utilized the scenting power of dogs for thousands of years (Chapman, 1990). The ability of dogs (*Canis familiaris*) to detect human scent is strongly documented throughout the literature. Human scent is composed of skin flakes, perspiration, skin oils and gaseous components (Pearsall & Verbruggen, 1982; Kristofek, 1991). Depending upon the task, police canines utilize different aspects of these components. When tracking the scent of a suspect, the canine follows the skin flakes and disturbances to ground vegetation. If the task is article recovery, skin oils of the suspect have contaminated the object being sought. Canines are capable of locating such objects (i.e. guns) up to 48 hours later (Kristofek, 1991). Airborne scents from fatty acids in the skin oils allow the police canine to even detect a hidden suspects (Kristofek, 1991).

Syrotuck (1977) reported that a comparison of olfactory cell counts between humans and canines indicates that a dog's sense of smell should be at least 44 times better. Other researchers estimate the dog's sense of smell as 100,000 times greater than humans (O'block, Doeren & True, 1979). It has been established that dogs were able to distinguish the odors of different people (Kalmus, 1955) and it is believed that the most probable advantage canines' possess is scent discrimination or the ability to distinguish one scent from others, but the dogs' ability to locate gravesites when no physical evidence is present still remains a mystery.

Canines that detect human remains, commonly referred to as cadaver dogs, have been minimally represented in the law enforcement canine population across the United States. For a variety of reasons this canine detector specialty has not been given the attention that is afforded both explosive and narcotic specialties. At this time, dogs still possess abilities that far exceed that of existing technology. Unfortunately, empirical evidence documenting how the canine utilizes his amazing olfactory skills is far from complete and little scientific testing of law enforcement canines has been conducted (Department of the Treasury, 1993).

In the final analysis, for many agencies, it is not feasible to have a Human Remains Detection (HRD) program. Weighing the cost of training, canine purchase and care, as well as the cost of vehicles and equipment with the actual need, it becomes clear that the addition of another homicide, narcotics or explosive detection team is more practical.

The current concern facing cadaver dog units is that training is inadequate since it is unknown to what odor signals the dogs respond to when alerting and the alerting may not completely be in response to odor. This jeopardizes search and seizure as well as probable cause rules currently established for search warrants and chain of custody.

Investigations to locate clandestine graves are time consuming and difficult. Typical burials are not located in less than 10 years and many of those are either accidental discoveries or are identified by the perpetrator (Figure 1). Many criminal burials occur in remote areas, are typically shallow and are typically wrapped in some type of material (Moenssens, 1988). The slow diffusion of material from the soil and the length of internment make locating clandestine graves via vegetational changes very difficult. Difficulties in obtaining access to cadaver-locating dogs and using them in remote and difficult terrain also present many problems (Personal Communication, Nishan Dulgerian, Criminal Response Team, FBI).

Figure 1. The appearance of a typical ‘clandestine grave’ after discovery and the initiation of recovery efforts.

Many agencies usually employ a combination of all these methods when searching for clandestine graves, mass graves or missing persons, which also results in an increased cost, significant utilization of man-hours, logistic and time concerns.

For the past three years the Federal Bureau of Investigation has funded a study at ORNL seeking to determine the chemical markers associated with odor of human decomposition, primarily aimed at legitimizing the training efforts of cadaver locating dogs. This study has focused on human remains in graves of various depths and of various ages (fresh – 12 years old) under a variety of environmental conditions. The results of this study to date have been the identification of over 400 different chemical compounds liberated from human decomposition in burial situations, of which only about 40 make it to the surface in a reproducible fashion regardless of the depth of burial, and the age of the grave (Vass, 2004; Table 1). This proposal seeks to take advantage of this database by taking the guesswork out of clandestine grave detection by developing a grave specific detector that is field portable, rugged and inexpensive.

| | |
|---|---|
| • Trichloromonofluoromethane<br>• Trichloroethene<br>• Tetrachloroethene<br>• Dichlorodofluoromethane<br>• Dichlorotetrafluoroethane<br>• Trichloroethane<br>• 1-methyl napthalene<br>• Napthalene<br>• Heptane<br>• 2-methyl pentane<br>• Undecane<br>• Methenamine | • Sulfur dioxide<br>• Carbon disulfide<br>• Dimethyl trisulfide<br>• Dimethyl disulfide<br>• Decanal<br>• Benzaldehyde<br>• Nonanal<br>• 2-propanone<br>• 1,4 dimethyl benzene<br>• 1,2 dimethyl benzene<br>• Ethyl benzene<br>• 1-methyl-2-ethyl benzene |

Table 1 – partial list of predominant chemical ‘odor’ compounds liberated during human decomposition.

## 3. RESEARCH – purpose and goals

The purpose of this proposal is to develop an electronic ‘clandestine’ grave detector creating a detector capable of sensing and alarming on the significant odor products of human decomposition.

Goals for this novel detector include:

- field portability
- ruggedness
- inexpensive
- ease of operation
- sensitive
- selective - with a low rate of false positives

This proposal had only **one objective**: to modify off-the-shelf technology creating a detector capable of sensing and alarming on the significant odor products of human decomposition as identified in the ORNL database outlined above. The short time frame and low cost of this proposal is a function of simply modifying existing technology already available for a different purpose. The technology, initially identified as the most likely candidate for modification for this purpose, was a hand-held leak detector called the "Informant 2" dual purpose refrigerant & combustible gas leak detector (Figure 2).

Figure 2. "The Informant 2" as purchased commercially.

This detector was already under evaluation at ORNL as a detector for identifying locations which produce illegal methamphetamines. It is designed to detect all halogens and combustible hydrocarbons using two different interchangeable sensor tips. The combustible sensor is a semiconductor type sensor and has a sensitivity of 50 ppm methane at a minimum. The refrigerant sensor is a heated diode with a sensitivity of 14 g/yr of R-134a. Preliminary testing of these two sensors at the University of Tennessee's Decay Research Facility over graves gave weak responses. The weak responses (for both sensors) are due to the fact that of the 40 specific chemicals under study, several of these are fluorinated halogens and hydrocarbons to which the detector is designed to respond to in a non-specific fashion (e.g. dichlorodifluoromethane; 1,2, dimethyl benzene).

Due to these weak responses, even after modification, it was determined that this instrument would not produce the reliability, sensitivity and accuracy needed for the stated purpose of this proposal. It became quite apparent that additional sensors were required in addition to the ability to visualize and record data real-time. These issues were addressed in the current version of this instrument called LABRADOR (light-weight analyser for buried remains and decomposition odor recognition). This instrument meets all the requirements of this project and was built in-house using twelve commercially available sensors increasing the sensitivity of the unit and the selectivity of the various classes of compounds required for confirmation of clandestine grave detection.

## II. <u>METHODS – Detector Development</u>

The LABRADOR is a hand-held chemical vapor detector based on an array of twelve heated metal oxide sensors (Taguchi sensors). The sensors are low-cost devices that exhibit a change in electrical resistance when exposed to different chemical vapors. Different sensors are designed to have a greater response to particular chemicals or classes of chemical compounds based on the chemical formulation of the metal oxide sensor material and the temperature at which it is operated. Most Taguchi sensors, however, respond to a wide range of chemical vapors which is why an array of sensors was used in the LABRADOR as opposed to one or two sensors. In principle, the greater the number of unique sensors, the greater the specificity will be for a particular vapor when the pattern of the collective sensors is used for identification.

In order to produce a low-cost instrument, a unique approach was taken to electronics employed for driving the sensors and detecting their response. Briefly, each sensor is modulated with a unique audio frequency ranging from 220 Hz to 657 Hz. The audio frequency signals for modulating the sensors are pure sine waves which are offset with a direct current (dc) voltage to provide drive signals that are always positive with respect to signal ground. Each sine wave is buffered with parallel amplifiers to provide two identical signals. One signal is applied to the input of the sensor and the other signal is a reference signal used in the detection scheme.

The output of the sensor is fed into a variable load resistor that is connected to the signal ground path. The voltage developed across the load resistor varies with exposure of the sensor to various chemical vapors.

The detection circuit uses a difference amplifier to amplify the difference in the voltage between the sensor load resistor and the reference signal. The amplitude of the reference signal is continuously adjustable by means of potentiometers mounted on the front panel of the control unit. During normal operation, the sensors are allowed to warm up for several minutes in the presence of the background atmosphere in which measurements will be made. The difference voltage between the sensor load resistor and the reference signal is adjusted to approximately 0 volts by adjusting the amplitude of the reference signal to a level which matches the amplitude of the signal at the sensor load resistor. Because the signals are audio frequency sine waves, the phase between the sensor signal and reference signal must be maintained at 0 degrees in order to properly null the signal.

The detected voltage present at the output of the difference amplifier is buffered and split into two signal paths. One signal path is rectified, integrated, and fed into the input of a bar-graph driver circuit. The bar graphs are 10 segment LEDs that are mounted on the front panel of the LABRADOR control box. Each sensor has its own bar graph and the output is directly proportional to the amplitude of the response of the senor. This provides a simple visual display of the pattern of sensor response for a particular chemical vapor.

The other signal path provided for each sensor is directed of a circuit comprised of two summing amplifiers. The odd number sensors (1,3,5,7,9,11) are fed into one summing amplifier and the even number sensors (2,4,6,8,10,12) are fed into the other summing amplifier. These signals can be output as individual channels of audio signals or they can be combined together through another summing amplifier to produce a single channel of audio data.

An on-board audio amplifier with dual speakers can be used to listen to the sensor response, providing an audible indication of the presence of chemical compounds. The audio amplifier can be used in a stereo mode or a mono mode depending on whether or not the even and odd sensor outputs are treated individually or combined together at described above.

In addition to the audio output, the combined sensor outputs are reduced in amplitude and diode protected so that they can be output into the "Audio Input" port of virtually any computer. The combined audio signal contains the amplitude information for each sensor which can be digitized and stored as a computer *.wav file. The *.wav audio files can be quickly processed using a real-time Fourier Transform routine to extract the response for each individual sensor. Because the sensor signals are pure sine waves, there is minimal cross-talk between sensor channels due to the generation of harmonics and frequency side-bands.

The Fourier Transformed sensor data will ultimately be used to provide real-time sensor data to a computer-based algorithm for improved identification of chemical vapors.

## III. RESULTS

1. Statement of results

The detector was constructed with off-the-shelf components to minimize costs and has a twelve sensor array platform designed to detect the major classes of chemical compounds found relevant in human decomposition. It is self contained, portable and built for field use. Both visual and auditory cues are provided to the operator. A data port allows the operator to store data, if desired. Total cost per unit is estimated at $1,000 - $1,500/ unit. Batteries, if fully charged, will last up to six hours of constant use. While not as sensitive as a mass spectrometer, the LABRADOR (in the field in less than 60 seconds) has been shown to provide qualitative data comparable to what is seen with gas chromatography- mass spectrometry headspace analysis with collected field soil samples associated with clandestine graves. Additional sources of sample material to which a preliminary database for the LABRADOR has begun include accelerants, narcotics, explosives and decompositional stages of various tissues.

**Field portability** – the LABRADOR is self contained with battery life lasting up to six hours when fully charged. The battery pack and the instrument can easily be carried by one person doing field searches. Future solid state circuitry will reduce the total weight of the instrument even further.

**Ruggedness –** The instrument has been field tested and will withstand moderate vibrational shocks. It is not weatherproof and therefore should not be submerged in water or used during heavy downpours. Weatherproofing can be achieved, but will require additional funding.

**Inexpensive –** current estimates range from $1,000 - $1,500 per unit which is well within the original specifications of the project.

**Ease of operation –** the LABRADOR can be held by one person and was ergonomically designed to be carried by one arm. One button turns the unit on, signal stabilization occurs in less than one minute. Ambient air backgrounds can be zeroed in less than one minute, can be performed visually, auditorially or with computer assistance and requires only the adjustment of one channel per sensor.

**Sensitive –** estimates on the sensitivity of the LABRADOR are in the parts per million range. An increase in sensitivity can be achieved with more sophisticated sensors, but this will significantly raise the unit cost of the instrument.

**Selective** – Preliminary experiments show that the LABRADOR can easily distinguish chemical constituents of explosives, narcotics, accelerants and the various stages of human decomposition (can even differentiate animal [pig] from human). The LABRADOR has a much more difficult time being able to correctly identify mixtures of chemical classes, but was not designed to work in very dirty environments. It was designed to primarily operate in outdoor, non-urban settings where the background chemicals are in low concentrations.

<u>2. Response Database</u>

The following data in Figure format represents the LABRADOR sensor output (what the operator will see on the visual display portion of the instrument) in response to the chemicals liberated from decomposing human remains. This data was collected at the University of Tennessee’s Anthropology Research Facility (over a six month period) and has been (initially) validated from recovered remains of forensic cases and known burials (cemeteries) up to 100 years old. The data is organized in increasing Accumulated Degree Days (ADD - the accumulation of the average daily temperature, in Celsius, over time) and indicates which sensors respond, as well as the magnitude of the response, to the age of the decompositional event (which of course changes over time). This is not a complete assemblage, but is included only to show expected changes in sensor response as decomposition progresses from early to late decomposition. Table 2 below indicates which sensors in the LABRADOR respond to which general classes of chemicals. In actual field exercises and searches, the LABRADOR should first be zeroed to eliminate any environmental chemicals that may be present. Depending on the amount and type of ground cover (and for best results – refer to Appendix) the surface of the ground can be broken up using a shovel or trowel before taking any readings.

| Sensor | Figaro TGS | Chemicals Detected |
|---|---|---|
| 1 | 813 | CG: LP-Gas, Propane, General Combustible Gases |
| 2 | 822 | Organic Solvents, Alcohol, Toluene, Xylene, Other volatile organic vapors |
| 3 | 842 | CG: Natural gas, Methane |
| 4 | 830 | CFCs (HCFCs & HFCs): R-22, R-113 |
| 5 | 831 | CFCs (HCFCs & HFCs): R-22, R-21 |
| 6 | 832 | CFCs (HCFCs & HFCs): R-22, R-134a |
| 7 | 883T-84Z | Water Vapors |
| 8 | 825 | Toxic Gas: Hydrogen Sulfide |
| 9 | 813 | CG: LP-Gas, Propane, General Combustible Gases |
| 10 | 826 | Toxic Gas: Ammonia Gas |
| 11 | 800 | Indoor Pollutants, Air Contaminants |
| 12 | 821 | Hydrogen Gas |

**Table 2**. List of Figaro TGS Gas Sensors used in the LABRADOR with corresponding detectable chemicals. CG - Combustible Gas. CFCs - Chlorofluorocarbons. HCFCs – Hydrochlorofluorocarbons. HFCs – Hydrofluorocarbons.

Figure 3. LABRADOR odor profile representative of early human decomposition (113 ADD).

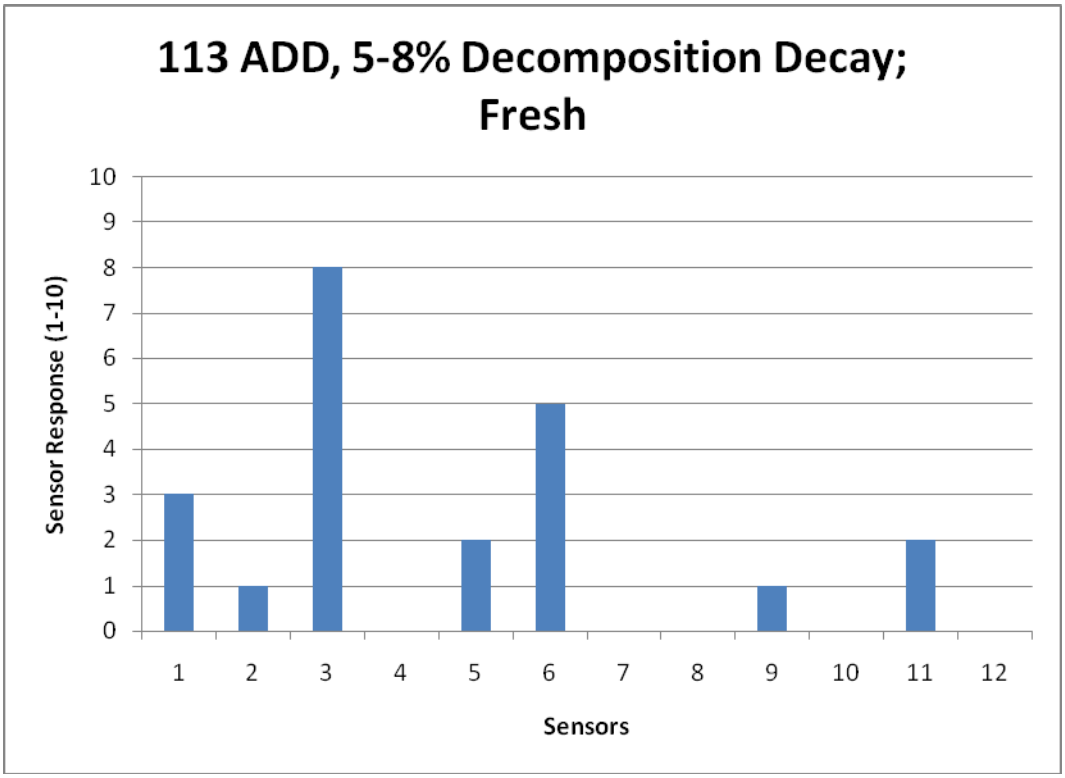



Figure 4. LABRADOR odor profile representative of early-mid human decomposition (216 ADD).

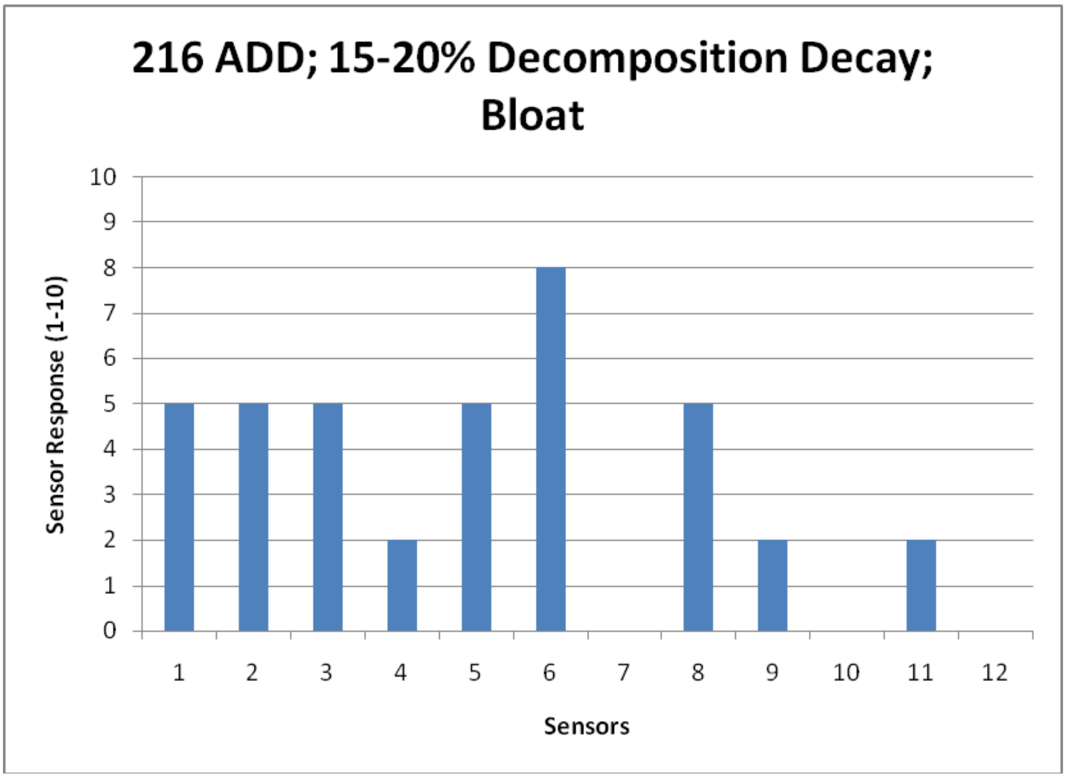


Figure 5. LABRADOR odor profile representative of mid human decomposition (362 ADD).

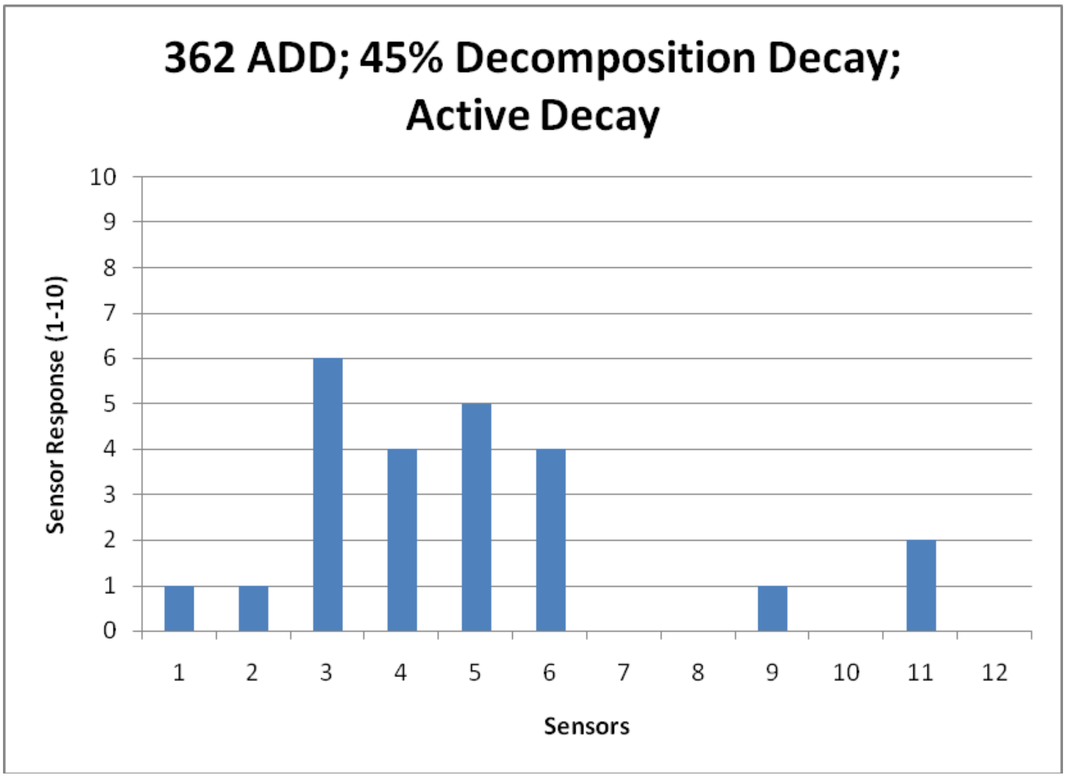



Figure 6. LABRADOR odor profile representative of mid-late human decomposition (412 ADD).

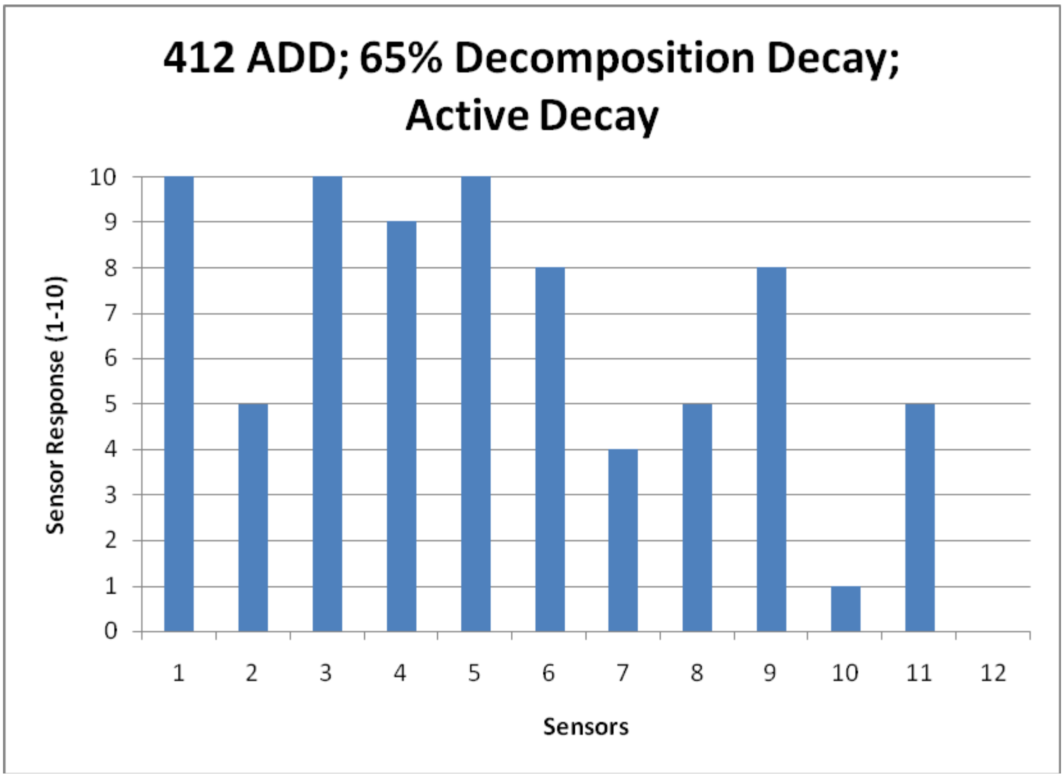
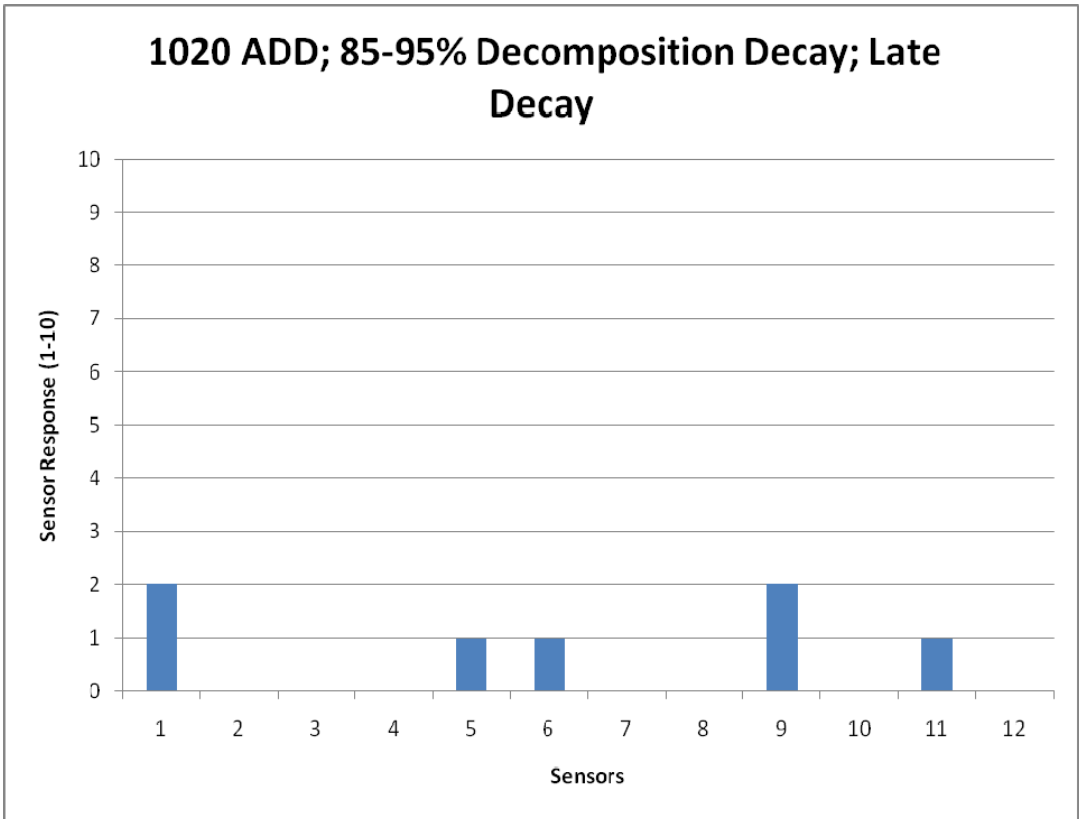


Figure 7. LABRADOR odor profile representative of late human decomposition (1020 ADD).




## IV. <u>CONCLUSIONS</u>

1. <u>Success of Instrument development</u>

Preliminary research has shown that the goals of this project have been met. This project has led to the development of a low cost, portable instrument capable of detecting and differentiating human decompositional odor in an environmental setting. The LABRADOR is also able to distinguish between animal carcasses and human corpses (in limited studies using pig carcasses) and also shows promise in detecting narcotics, accelerants used in arsons, and explosives, thereby extending its range of use beyond the goals of this study. Even so, some might argue that the best aspects of the LABRADOR would be that this new technology will help search efforts by lowering costs and manpower requirements without tiring or becoming distracted.

This exciting new technology does come with its own limitations. The sensitivity of the instrument does not yet compare with that of a canine's nose. Although the LABRADOR will 'alert' in the same places as a cadaver dog, the canine may be more sensitive to a moving chemical plume or to low odor concentrations. Currently, the LABRADOR is limited to detecting shallow burials in mild environments although it does have the advantage that it can identify locations with higher concentrations of odor which allows for detailed mapping of the chemical plume which will significantly assist in the location of the source since chemical plumes typically migrate from the source (decompositional events) due to many factors such as groundwater movement, land slope or soil type/porosity. Performing GC/MS headspace analysis on collected soil indicated that the LABRADOR correctly identified areas with higher odor signatures.

The impact of extreme environments on the LABRADOR's detecting capabilities is not quite clear. The instrument performs best under environmental conditions that are favorable for the emission of soil gas vapors from the ground such as early or mid-morning when the ground begins heating up from sun exposure or during times of low barometric pressure (similar to what is observed with canine searches). Future modifications will **correct/adjust** for more extreme environmental conditions such as high winds, very hot or cold ambient temperatures, fluctuating humidity levels, and highly odorous plant vegetation.

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2. Implications for policy and practice

Successful completion of this instrument: 1) indicating that the hand-held grave detector functions and alerts properly, and 2) confirmation/validation of increased sensitivity and specificity, shows that the LABRADOR holds great promise as a critical new tool for forensic investigators that will continue the trend of revolutionizing crime scene investigations.

Since the scientific principles on which these sensors are founded have been well established in the scientific community for many decades, acceptance of this powerful technology should be readily accepted in the eyes of the Courts. Implementation of the procedures and methodologies of this technology will significantly augment the procedures already in use today (canines, probing, GPR) thereby saving time, money and manpower. Success in this project could prove useful in the location of clandestine graves as well as location of 'surface' human remains (e.g. World Trade Center) and could become standard practice in many crime scene investigations around the world.

3. Implications for future research

Obviously this is the first step for instrument development with this level of sophistication and several refinements must be undertaken before it can be released to the public for use in the field. The current version uses point-to-point wiring which is not the preferred electronic package for field use. This adds additional weight to the unit and conversion to solid state electronics will both reduce the weight of the instrument and increase its reliability for field use. Field testing using a greater variety of soil types and varying grave ages must also be conducted and sufficient data collected for a valid statistical comparison of the outputs. Additional data that needs to be collected includes a detailed study of the responses and chemical signatures evaluating the long-term stability of the LABRADOR that will identify time-dependant changes (if any). Finally, all environmental conditions which might affect LABRADOR results have not yet been evaluated and include colder weather, humidity extremes, soil moisture content and the effects of barometric pressure.

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## VI. DISSEMINATION OF RESEARCH FINDINGS

Project findings will be presented at either the annual AAFS or IAI conference, as well as the NIJ program review. The results of this proposal are being summarized in a final report to NIJ for publication on their Web site. Results of this research will be published in peer-reviewed journals (such as the Journal of Forensic Sciences). Furthermore, the results of this project will be included in seminars and lectures provided to crime scene investigators and police officers at the National Forensic Academy (NFA) located in Knoxville, TN. Additional seminars and lectures will be provided both nationally and internationally as the opportunity arises to law enforcement agencies, attorneys and science conferences. Upon request, researchers will help facilitate training sessions to aid in dissemination of the developed technology.

Most importantly, the development of CRADAs with instrument manufacturers and distributors will be undertaken allowing researchers and law enforcement personnel access to these technologies. In addition, our close collaboration with the University of Tennessee Forensic Anthropology Center, the Knoxville Police Department Crime Laboratory and various Medical Examiner Office's will allow us to the opportunity to have this technology evaluated by criminalists in the field as this technology continues to develop and mature.

# APPENDIX A: USER MANUAL

***DRAFT***

***Not Approved for Public Release***

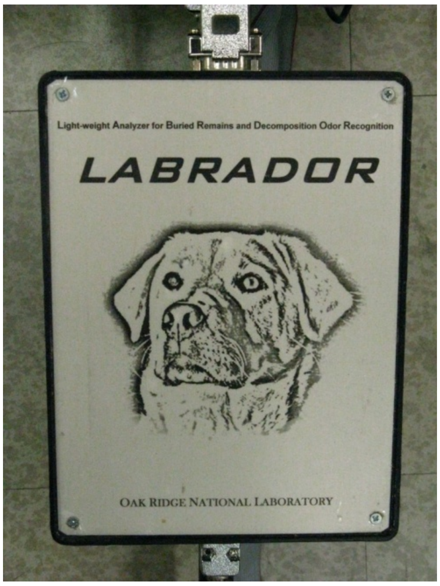
# LABRADOR

Light-weight Analyzer for Buried Remains and Decomposition Odor Recognition


# User Manual

***DRAFT***

***Not Approved for Public Release***





***The human body liberates over 400 chemicals as we revert back to the dust from whence we came***. These volatile organic compounds, amino acids, inorganic constituents, and noxious gases are released from a decaying body at specific time points and in specific ratios. This ‘chemical signature’ can uniquely characterize the state of decomposition.

Built as an electronic sniffing tool, the “Light-weight Analyzer for Buried Remains and Decomposition Odor Recognition” (LABRADOR) locates and identifies buried human remains based on their chemical signature. The LABRADOR ‘sniffs’ the volatile compounds generated from these buried remains, and rather than barking, the instrument responds with visual and auditory cues to help pinpoint the hidden grave.

This hand-held instrument should not be used as a stand-alone method but rather as an augmentation to other cadaver-locating tools such as cadaver dogs, geophysical measurements (magnetometers, soil resistivity, ground penetrating radar, metal detectors), and other such tools.

This sniffer is designed to be used in locating human remains from acts of terrorism, genocide, accidents and natural disasters, but the LABRADOR’s capabilities are not limited to clandestine grave detection.  The instrument also shows promise in detecting narcotics, accelerants used in arsons, and explosives.

I. LABRADOR Layout

The following figures depict the different components of the LABRADOR. Before initial setup, you should familiarize yourself with the layout of the instrument.


**Figure 1.  Main Output Head.  (A) Power switch.  (B) Fan Speed Knob.  (C) Individual Sensor Selection Switch.  (D) Sensor Null Adjustment Knobs.  (E) Sensor Response Display.  (F) Computer Interface Summing Amplifier Selector Switch.**

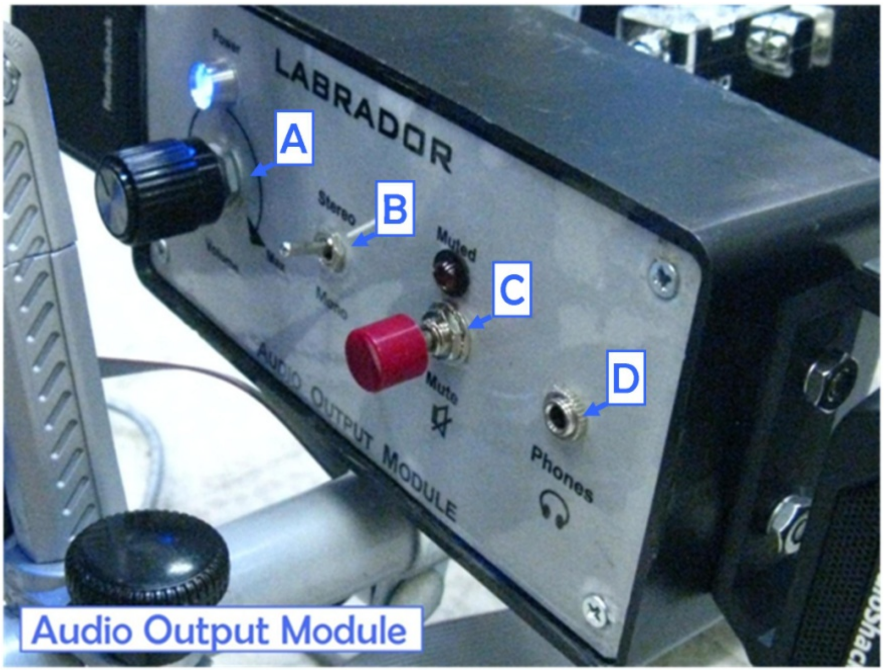



**Figure 2. Audio Output Module. (A) Volume Knob. (B) Stereo/Mono Switch. (C) Mute Button. (D) Audio Output Jack for Headphones.**

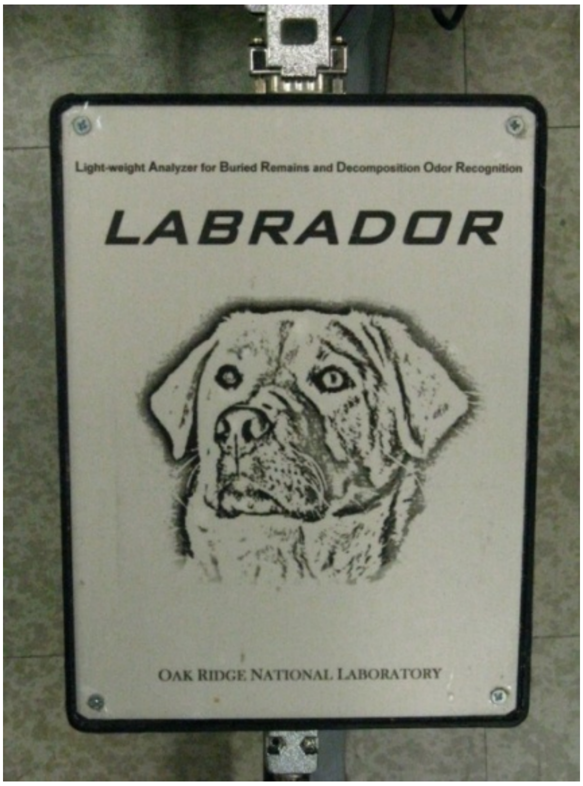
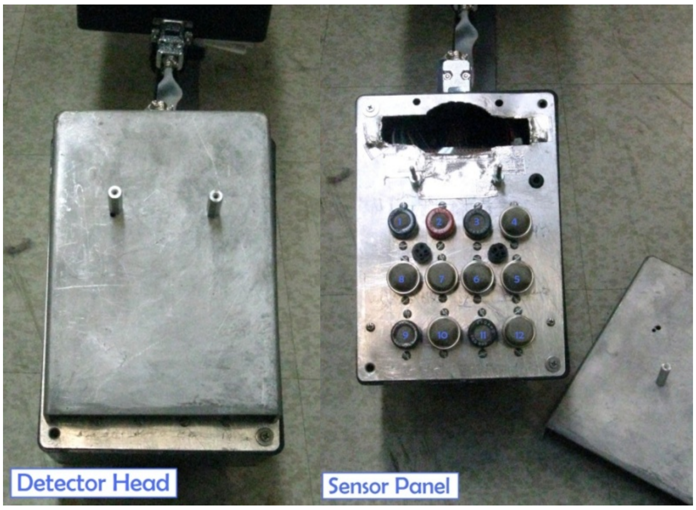



**Figure 3. Oscillator Module**




**Figures 4 & 5. Detector Head and Sensor Array (located on the Detector Head).**


**Figure 6. Battery Supply**

Assembly Instructions

After removing the instrument from its case, attach the four modules to the metal handle (Main Output Head, Audio Output Module & two speakers, the Oscillator Module, and the Detector Head) with the appropriate brackets and bolts.
Attach the four ribbon cables (4) to the appropriate mating connectors according to Diagram 1. Connect the power cable to the battery pack from outlet F. If desired, connect auxiliary computer interface cable from port B to the "Audio Input" port of an external laptop or desktop computer.
Ensure that the speakers are connected to the jacks located on left and right sides of the rear panel of the Audio Output Module. Check all connections and tighten all screws before turning the LABRADOR on.

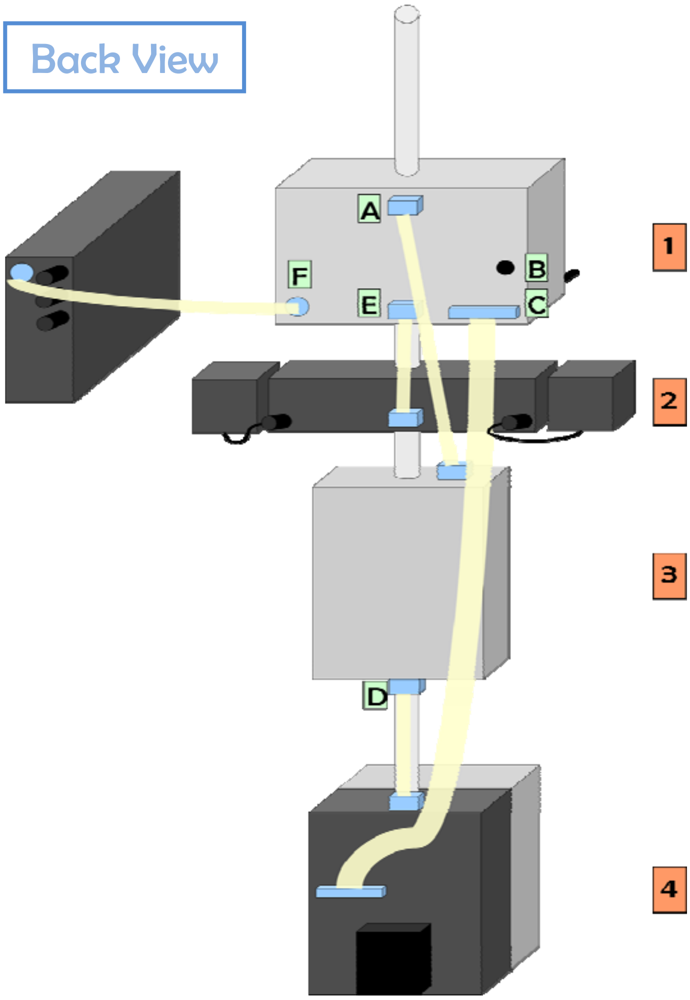


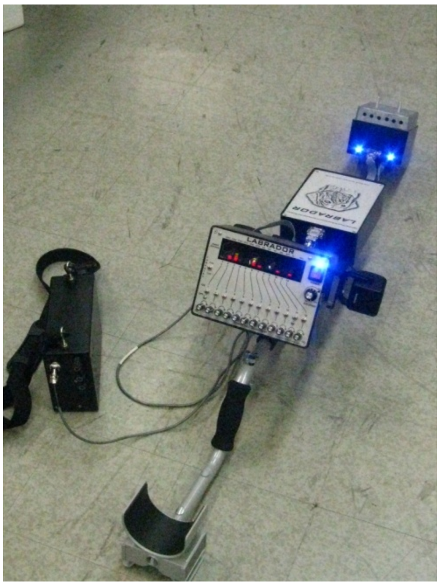

**Diagram 1.** Four main heads. (1) Main Output Head. (2) Audio Output Module. (3) Oscillator Module. (4) Detector Head.

Connect cables as indicated by labels. (A) Main Output Head to Oscillator Module. (B) Auxiliary audio output jack. (C) Main Output Head to Detector Head. (D) Oscillator Module to Detector Head. (E) Main Output Head to Audio Output Module. (F) Main Output Head to Battery Supply.

Turning LABRADOR On

Turn on the red power switch located on the upper right side of the Main Output Head. Four blue LEDs should be lit. These LEDs are located (1) above the power switch on the Main Output Head, (2) above the volume knob on the Audio Output Module, and (3 & 4) on top of the Detector Head. If any of the LEDs are not lit, turn off the power and check the connectors of the cables. If any of the LEDs continue to not be lit, a possible electrical fault is indicated. Turn off the system and disconnect the Battery Pack. Do not attempt to use the instrument
Turn all twelve sensor selection switches to the "On" position. These switches are located beneath the sensor response screen on the Main Output Head. An audible

signal should be present and the sensor bar graphs should indicate some level of response. (Note: The sensor bar graph outputs have not been "nulled" at this point in time and will likely drift for several minutes during the initial warm-up period.)




Adjust the fan speed knob clock-wise to turn on the instrument's fan. The fan speed knob is located beneath the power switch on the Main Output Head.

Ensure that the audio volume is adjusted to a comfortable audible level. Red "MUTE" button located on the Audio Output Module can be used to decrease the volume without changing the audio level setting. While muted, a red LED will flash continuously. Muting can be turned on or off simply by pressing and releasing the "MUTE" button.

Depending on user preference, either a MONO or STEREO audio signal can be selected by a front panel switch located on the Audio Output Module. In the "Stereo" mode, the audio output from sensors 1, 3, 5, 7, 9 and 11 is output to the left speaker while the audio output from sensors 2, 4, 6, 8, 10 and 12 is output to the right speaker. In the "Mono" mode, the audio signals from all sensors are output from both speakers at the same time. The "Stereo" mode can be used to provide a greater range of audible patterns for the instrument operator to employ in determining the nature of a chemical signature. The "Stereo" feature works best if headphones are used instead of the attached speakers.

A similar treatment of the audio signals is used for the computer interface. A switch located on the front panel of the Main Output head allows the external computer to monitor either two channels of information (odd and even sensors) or one channel of combined information. The "2-channel" (2-Ch) mode provides greater dynamic range and is less prone to signal distortion and the generation of spurious frequency signals. However, under normal conditions, the selector switch can be set for 1 channel (1-Ch) of information.

## II. Zeroing (Sensor Nulling)

After turning on the LABRADOR, the instrument should be zeroed or nulled in the ambient environment in which it will be used. Zeroing should be conducted in a location away from sources of man-made or natural chemical vapors. This includes any highly odorous sources such as aromatic vegetation, decomposing waste, solvents, gasoline, petroleum products, fresh paint, etc. If re-zeroing is required during use, it should be conducted in the same location if possible.

Begin the zeroing process only after the LABRADOR has had at least 5 minutes of warm-up time. Starting with Sensor 1, slowly rotate the sensor "Null" potentiometer in the direction necessary to decrease the level of the signal indicated on the corresponding bar graph. Continue to rotate the "Null" potentiometer until the corresponding sensor bar graph no longer indicates a response (no segments lit). Repeat this process for each sensor until the sensor display screens shows no response on any sensor.

Next, turn all sensor selection switches to the “OFF” position except for Sensor 1. If the operator can hear sound, adjust the sensor null adjustment knob until very little or no sound can be heard. Repeat this step consecutively with all twelve sensors. Ensure that only one sensor at a time is turned ON during this process.

*Alternate method*: If the LABRADOR is connected to a laptop computer preloaded with a Fast Fourier Transform program (such as SpectraPLUS), operate the software in a Real Time Mode and visually adjust each sensor null adjustment knob until the corresponding sensor peak is minimized or completely disappears. All of the sensor select switches should be in the “ON” position if using this alternate method.

III. Sample Flow Settings

The LABRADOR offers multiple sample flow rate adjustments for maximum odor detection at varying heights and under different operating conditions. Users can adjust the fan speed on the LABRADOR’s Main Output Head from 0 to 10 depending on the environmental conditions. Each fan speed corresponds to a flow rate, ranging from 33 L/min to 83 L/min. This adjustment allows users to select the amount of air sample that flows across the gas sensors. The following chart presents the fan speeds and corresponding flow rates.

| Fan Speed | Flow Rate (L/min) |
|---|---|
| OFF | 0 |
| 1 | 33 |
| 2 | 39 |
| 3 | 44 |
| 4 | 50 |
| 5 | 55 |
| 6 | 61 |
| 7 | 64 |
| 8 | 77 |
| 9 | 80 |
| 10 | 83 |

**Table 1. Fan speeds and corresponding flow rates in liters per minute.**

Additionally, the optimal settings for varying heights above the ground are presented in Table 2. In general, the LABRADOR functions well at a medium flow rate (55-61 L/min or Fan Speed 5-6) with the opening of the Detector Head located close to the surface (0-2” above ground). The optimal settings were determined in the laboratory by placing the LABRADOR’s Detector Head at varying heights above a point source of 10% ethanol.

| Height Above Surface (in) | Fan Speed | Flow Rate (L/min) |
|---|---|---|
| 0” | 5-6 | 55-61 |
| 2” | 5-6 | 55-61 |
| 4” | 8 | 77 |

**Table 2. Optimal fan speed settings at varying heights above the surface (in inches).**

The optimal fan speed settings can be greatly impacted by the ambient wind speed at the immediate location of the Detector Head. If the LABRADOR is exposed to high wind movement in the field, it may be necessary to increase the fan speed to compensate. In addition, it might be necessary to attach a Wind Screen to the Detector Head. This attachment will help to compensate for a variety of field sampling conditions so as to help eliminate any potential interference in the signal response.

## IV. Optimal Environmental Conditions

The LABRADOR is a chemical vapor/soil gas detector and as a result, will perform best in the field under environmental conditions that are favorable for the emission of soil gas vapors from the ground. Early morning and mid-morning hours are likely a good choice as the ground begins heating up from exposure the sun and warmer air.

In general, users should avoid extreme environmental conditions such as high winds, very cold or hot temperatures, and wet soils. Avoid using directly after moderate or heavy rains because the saturation may suppress chemical signatures coming from the ground and excess moisture in the air directly above the soil might produce false readings for the sensors.

Future evaluation will determine the magnitude of the impact from high winds, very cold environmental temperatures, and highly odorous plant vegetation on the LABRADOR’s capabilities.

## V. Detecting Chemical Vapors (Odor Signatures) in the Field

Once the LABRADOR has been zeroed and properly adjusted, it will be ready for detecting chemical vapors. Proceed by walking at a slow pace carrying the instrument over the target search area with the Detector Head located 1 or 2 inches above the ground (if possible). As you are walking, slowly move the instrument back and forth in a sweeping motion while maintaining the distance from the surface of the ground as close as possible. Refer to the chart above to adjust fan speed according to height off ground. If the LABRADOR encounters chemical vapors, it should respond within a few seconds. Remain at the same location for at least 10-30 seconds to register a stable chemical signature.

If the LABRADOR reacts to a particular point of origin, the user should consider digging a small hole and placing the Detector Head inside the hole. This will allow the instrument to record a better signature of the chemicals in the soil and may help narrow down the location of the clandestine grave.

After the instrument responds to a particular source, it should be removed from the chemical vapors, and sufficient time should be provided for the sensors to return to zero before moving to a new area. If an excessive amount of time is required for the sensors to return to zero, the operator may need to re-zero the instrument in a clean location.

In most cases, correctly zeroing the instrument in the ambient environment should reduce the frequency of false positives due to environmental influences such as vegetation, animal bones, and waste; however, the user should periodically check to make sure the instrument is zeroed. Additionally, the instrument operator should constantly be alert to potential sources of chemical vapors (containers, strong odors, dead animals, etc.) that could lead to a false indication.

## VI. Understanding Signal Output


The LABRADOR is intended to detect the volatile chemicals associated with clandestine graves and provide visual and audible signals when a grave is encountered. When the instrument 'sniffs' a particular odor, it will display a unique pattern on the signal response screen of the Main Output Head as well as produce a unique sound through the speakers. The visual patterns of many standard chemicals, accelerants, explosives, and controlled substances have been documented for reference purposes (see Appendix A). Although the exact signature may vary slightly depending on environmental conditions, the general pattern should remain constant. Please remember that each chemical's decay rate varies; thus, a signature may last for only a few seconds or up to several minutes. Additionally, the LABRADOR may require 10-30 seconds to recognize a particular chemical signature.

Generally, most users will find the visual patterns to be easier to recognize; however, if desired, users can plug headphones into the audio output jack on the Audio Output Module and listen to the audio signal. Each chemical (and combination of chemicals) will produce a unique sound, allowing the user to identify graves by the audio pattern alone.

VII. Recording Audio Output

The LABRADOR's recording feature allows the user to save the signal output for further processing in the laboratory. The audio signal can be recorded easily using a handheld digital recorder or an external laptop computer with an audio input port and sound recording software. Simply connect the recording device to the auxiliary audio output jack on the back of the Main Output Head with an auxiliary cord. These recordings can be analyzed or processed on a computer with an audio analyzer program (Recommended: SpectraPLUS Professional).

If using an external laptop to record the audio signal, any recording software such as Window's Sound Recorder can be used; however, the files will need to be converted to a *wav* file to be used in the SpectraPLUS software.

VIII. Data Analysis of Recorded Audio Signal (using SpectraPLUS software)

Because each sensor is modulated with a unique audio frequency sine wave, the response of each sensor can be easily recovered using a Fourier Transform routine. SpectraPLUS Professional is Fast Fourier Transform software, which allows the user to calibrate the LABRADOR more accurately, subtract background noise from the audio output, and analyze each audio signal's unique properties.

Before using the SpectraPLUS software with recorded data, the files must first be converted to a *wav* file and the following settings should be configured before performing any activities within the program.

Open SpectraPLUS. Click "View" on the upper toolbar, and ensure that a check-mark is beside "Spectrum". Use this particular window to zero the LABRADOR by turning the sensor null adjustment knobs until each peak disappears.

Click "Options" on the upper toolbar and then click "Scaling". Select "Linear" in the Amplitude Axis and the Frequency Axis boxes. Click OK.

Next, click "Spectrum" under the "Options" drop-down menu (same as before). Select "Line graph" and set Plot Top to "5" in the Plot Options box. The Plot Top can be adjusted later if needed. Enter 100Hz and 800Hz for the Start and Stop frequencies in the Frequency Span box. Click OK.

The program should now be ready for zeroing the instrument, recording audio signals, or analyzing recordings.

*Zeroing (Sensor Nulling)*: The LABRADOR must be connected to the computer running this software via the auxiliary audio output jack on the back of the Main Output Head.

Click “Mode” on the upper toolbar, and select “Real Time”. Click the RUN button located in the upper left corner. Adjust each sensor null adjustment knob on the LABRADOR until each corresponding sensor peak in SpectraPLUS disappears. Click STOP when finished.

*Recording*: The LABRADOR must still be connected to record audio signals with this software. Switch to the “Recorder” mode (located on the “Mode” drop-down menu). Click the RECORD button located in the upper left corner. If recording a specific location, first record approximately 15 seconds of background noise. Click STOP when finished. Save the audio file by clicking CTRL+S or “Save” under the “File” drop-down menu.

*Analysis*: To review previously recorded files, open the file from the “File” drop-down menu (or click CTRL+O). Click the PLAY button located in the upper left corner. Clicking the RECORD button will record any sound to the end of the opened file.

## IX. Turning LABRADOR Off

When finished using the LABRADOR, simply turn off the main red power switch on the Main Output Head and disconnect the battery. Consider turning off the instrument during extended periods of inactivity in order to conserve the battery.

## X. Storage/Handling

After powering off the LABRADOR, wipe down the instrument with a clean cloth. Remove the metal covering on the Detector Head and gently wipe off the sensor heads. Ensure that the instrument is clean of debris or dirt. Disconnect cables, remove the four main modules from the metal handle, and carefully place all parts back into the case. Avoid storing the instrument in extreme environments.

Battery Pack Charging: The battery pack is recharged using three NiMH chargers. Remove four screws from the battery pack cover and remove the cover. Disconnect each battery from their mating connector. Do not remove the batteries from the box. Attach the chargers to batteries 1, 3 and 5. Charge the batteries for a maximum of 7 hours (if fully discharged). After charging batteries 1, 3 and 5, disconnect the chargers and attach them to batteries 2, 4 and 6. Charge the batteries for 7 hours (if fully discharged). After all batteries have been fully charged, disconnect the chargers and re-attach the batteries to their corresponding connectors (Batteries 1 and 2 connect to red wires, Batteries 3 and 4 connect to purple wires, Batteries 5 and 6 connect to orange wires)

Warning: Exercise caution when charging batteries. Never short the battery terminals. Never allow the batteries to heat excessively. Never connect the batteries in reverse. Do not overcharge the batteries.

## XI. Specifications

Battery Pack Construction: 6 NiMH cells (7.2 volts nominal) 3,200 mAH

Battery Pack Outputs:
+12 Volts (regulated)
-12 Volts (regulated)
+7.2 – 8.4 Volts (unregulated)

Battery Run Time: 4 – 6 hours if fully charged

Sensor Array:

| Sensor | Figaro TGS | Chemicals Detected |
|---|---|---|
| 1 | 813 | CG: LP-Gas, Propane, General Combustible Gases |
| 2 | 822 | Organic Solvents, Alcohol, Toluene, Xylene, Other volatile organic vapors |
| 3 | 842 | CG: Natural gas, Methane |
| 4 | 830 | CFCs (HCFCs & HFCs): R-22, R-113 |
| 5 | 831 | CFCs (HCFCs & HFCs): R-22, R-21 |
| 6 | 832 | CFCs (HCFCs & HFCs): R-22, R-134a |
| 7 | 883T-84Z | Water Vapors from Food |
| 8 | 825 | Toxic Gas: Hydrogen Sulfide |
| 9 | 813 | CG: LP-Gas, Propane, General Combustible Gases |
| 10 | 826 | Toxic Gas: Ammonia Gas |
| 11 | 800 | Indoor Pollutants, Air Contaminants |
| 12 | 821 | Hydrogen Gas |

**Table 3**. List of Figaro TGS Gas Sensors used in the LABRADOR with corresponding detectable chemicals. CG - Combustible Gas. CFCs - Chlorofluorocarbons. HCFCs – Hydrochlorofluorocarbons. HFCs – Hydrofluorocarbons.