

**Final Report**  
**Field Validation of Real Time Airborne Lead Analyzer**

**Naval Facilities Engineering Service Center**  
**Environmental and Life Support Technology**

**November 2001**



## Table of Contents

1. Introduction.....	1
1.1 Background Information.....	1
1.2 Official DoD Requirement Statement.....	1
1.3 Objectives.....	1
1.4 Regulatory Issues.....	1
1.5 Previous Testing.....	2
2. Technology Description.....	2
2.1 Description.....	2
2.2 Strengths, Advantages, and Weaknesses.....	3
2.3 Cost and Performance Factors.....	3
3. Site/Facility Description.....	3
3.1 Background.....	3
3.2 Site/Facility Characteristics.....	4
3.2.1 Local Shooting Range.....	4
3.2.2 NAB Little Creek Facility.....	4
3.2.3 Twentynine Palms Facility.....	4
3.2.3 Oak Ridge Facility.....	5
4. Demonstration Approach.....	6
4.1 Performance Objective.....	6
4.2 Physical Setup and Operation.....	7
4.2.1 General.....	7
4.2.1.1 Extraction Efficiency Test.....	8
4.2.1.2 Capture Efficiency Tests.....	8
4.2.1.3 Comparison Tests.....	8
4.2.1.4 Interference Test.....	8
4.2.1.5 NAB Little Creek Field Test.....	8
4.2.1.6 Twentynine Palms Field Test.....	9
4.2.1.7 Oak Ridge Field Test.....	9
4.3 Sampling Procedures.....	10
4.3.1 Extraction Efficiency Tests.....	10
4.3.2 Capture Efficiency Tests.....	10
4.3.2 NAB Little Creek Field Test.....	10
4.3.3 Twentynine Palms Field Test.....	11
4.3.4 Oak Ridge Field Test.....	11
4.4 Analytical Procedures.....	11
5. Performance Assessments.....	12
5.1 Performance Data.....	12
5.1.1 Interference Testing.....	12
5.1.2 Extraction Efficiency Testing.....	12
5.1.3 Capture Efficiency Testing.....	14
5.1.4 Comparison Tests.....	14
5.1.5 NAB Little Creek Field Test.....	15
5.1.6 Twentynine Palms Field Test.....	15
5.1.7 Oak Ridge Field Test.....	15

5.2 Data Assessment.....	18
5.3 Technology Comparison.....	23
6. Cost Assessment .....	24
6.1 Cost Performance .....	24
6.2 Cost Comparisons to Conventional and Other Technologies.....	25
7. Regulatory Issues.....	26
7.1 Approach to Regulatory Compliance and Acceptance.....	26
8. Technology Implementation .....	26
8.1 DOD Need.....	26
8.2 Transition.....	26
9. Lessons Learned.....	27
10. References.....	27

## APPENDICES

A – Points of Contact.....	A-1
B – Oak Ridge Field Test – Day 1 AeroLead™ Graphical Data.....	B-1
C - Oak Ridge Field Test - Day 2 AeroLead™ Graphical Data .....	C-1
D - Oak Ridge Field Test - Day 3 AeroLead™ Graphical Data.....	D-1
E - Oak Ridge Field Test - Test Plan and Tabular Data .....	E-1
F – AeroLead™ Calibration Procedure.....	F-1
G – Comparative Methods.....	G-1
H – ASTM-E1775 Specification.....	H-1
I – Comparison Test Data .....	I-1

## LIST OF FIGURES

Figure 3-1	Rodriguez shooting range .....	4
Figure 3-2	Twentynine Palms bullet trap DCU.....	5
Figure 3-3	Oak Ridge test setup .....	6
Figure 4-1	Dem/Val test timeline .....	8
Figure 4-2	Capture efficiency test setup.....	11
Figure 5-1	Capture efficiency Test 1 .....	15
Figure 5-2	Capture efficiency Test 2 .....	15
Figure 5-3	Comparison test results.....	16
Figure 5-4	ORNL NIOSH results.....	18
Figure 5-5	ORNL AeroLead™ results combined.....	23

## LIST OF TABLES

Table 4-1	ASTM-E1775 Specification Summary.....	7
Table 5-1	Extraction Efficiency Data.....	13
Table 5-2	Non-extracted Membrane Data.....	14
Table 5-3	Adjusted Extraction Efficiency Data .....	14
Table 5-4	ASTM-E1775 Precision Requirements.....	15

Table 5-5	Oak Ridge Field Test Data.....	17
Table 5-6	Analytical Laboratory Results of Non-Extracted Filters Using NIOSH Method 7082 .....	18
Table 5-7.	Data Assessment Summary .....	19
Table 5-8.	Calibration Solution NIOSH Analysis .....	20
Table 5-9.	Averaged Results for Individual AeroLead™ Instruments .....	22
Table 5-10.	Averaged Combined Results for AeroLead™ Instruments .....	22
Table 5-11.	Precision of Each AeroLead™ Instrument Based on Mean Result Compared to NIOSH Method 7082 Mean Result.....	22
Table 5-12.	Accuracy (Bias) for Each AeroLead™ Instrument Compared to NIOSH Method 7082 .....	23
Table 5-13.	Precision and Accuracy (Bias) for All AeroLead™ Instruments Combined Compared to NIOSH Method 7082 .....	24
Table 5-14.	Technical Performance Comparison .....	24
Table 6-1.	AeroLead™ User Cost Estimate.....	25
Table 6-2.	AeroLead™ Consumables Cost Estimate.....	25
Table 6-3.	Comparative Methods Cost Estimate .....	26

## Acronyms

AAM	Ambient air monitor
ASTM	American Society of Testing and Materials
ASV	Anodic Stripping Voltammetry
BDL	Below the minimum detection limit
COTS	Commercial-off-the-shelf
DCU	Dust collection unit
DOD	Department of Defense
ELS	Environmental and Life Support
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FAAS	Flame Atomic Absorption Spectrometry
GFAAS	Gas Furnace Atomic Absorption Spectrometry
HEPA	High Efficiency Particulate Air
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry
LBP	Lead-based paint
LIPS	Laser Induced Plasma Spectrometer
MCAGCC	Marine Corps Air Ground Combat Center
NAB	Naval Amphibious Base
NFESC	Naval Facilities Engineering Service Center
NIOSH	National Institute of Occupational Safety and Health
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
Pb	Lead
PBZ	Personal breathing zone
PC	Personal computer
PEL	Permissible exposure limit
PPE	Personal Protection Equipment
R&D	Research and Development
RSD	Relative standard deviation
SBIR	Small Business Innovative Research
TWA	Time-weighted average



**Final Report**  
**Field Validation of Real Time Airborne Lead Analyzer**

**Naval Facilities Engineering Service Center**  
**Environmental and Life Support Technology**

**November 2001**

# 1. Introduction

## 1.1 Background Information

OSHA estimates 936,000 sites in the U.S. are potentially hazardous due to the risk of airborne lead inhalation. DOD real estate records indicate there are more than 2,600 munitions related sites containing lead, and there are over 101 million square feet of Army buildings that were built before the 1978 ban on lead-based paint (LBP). DOD is responsible for maintaining 166,000 family housing units, 65% of which are estimated to contain LBP and require abatement. Environmental responses at these sites require EPA-mandated monitoring (40 CFR 50) as well as verification of worker safety according to OSHA regulations. These regulations do not provide a real-time method to verify compliance. Rapid, on-site airborne lead measurements are therefore needed to provide a basis for immediate response to airborne lead levels that are near or exceeding EPA limits and OSHA Permissible Exposure Limits (PELs) to minimize any significant exposure to field personnel. In 1995, OSHA issued over 3,000 citations for violations of the General Industry Standard for Lead (29CFR 1910.1025) and the Construction industry Standard for Lead (29CFR 1962.26). In response, the DOD has assigned a high priority to this area under the Navy's Environmental Quality R&D Requirement 2.II.2.b "Improved field analytical sensors, toxicity assays, methods, and protocols to supplement traditional sampling and laboratory analysis".

## 1.2 Official DoD Requirement Statement

Navy's Environmental Quality R&D Requirement 2.II.2.b "Improved field analytical sensors, toxicity assays, methods, and protocols to supplement traditional sampling and laboratory analysis".

## 1.3 Objectives of the Demonstration

The main objective of this project was to develop and validate a personal breathing zone (PBZ) lead analyzer/single sample ambient air monitor (AAM), which will report occupational airborne lead levels in near real time. Accomplishing this objective will significantly improve occupational safety and decrease the cost of OSHA compliance. Current OSHA protocols require sending PBZ samples to a laboratory for analysis, resulting in delayed report times (24 hours to 3 days) and an increased potential for sample integrity breaches due to shipping and handling. The AeroLead™ analyzer will provide an improved method of airborne lead and nearly instantaneous feedback, greatly enhancing workplace safety.

## 1.4 Regulatory Issues

OSHA has been designated as the governing body, monitoring the compliance of remediation sites and ammunition firing ranges to maintain airborne lead levels below the permissible exposure limit (PEL) of 30ug/m<sup>3</sup>. Rapid, on-site airborne lead measurements are therefore needed to provide a basis for immediate response to airborne lead levels that are near or exceeding EPA limits and OSHA Permissible Exposure Limits (PELs), before any significant exposure to field personnel occurs.

## **1.5 Previous Testing**

Extensive laboratory testing has been performed to validate the Anodic Stripping Voltammetry (ASV) method for lead in water and blood. A NIOSH Method for airborne lead detection has previously been established based on ASV technology (NIOSH 7701). Two field tests and a third controlled test were performed under this study; one at the indoor firing range, NAB Little Creek in Norfolk, VA, and one at an outdoor firing range, Twentynine Palms Marine Training Facility, Twentynine Palms, CA (Reference 1 and Reference 2). The third test was conducted at Oak Ridge National Laboratory (ORNL) in Oak Ridge, TN. Details regarding the Little Creek field test and the Twentynine Palms field test can be found in their respective reports (see References 1 and 2 in Section 10 of this report). The ORNL test results are presented here.

## **2. Technology Description**

### **2.1 Description**

Under the Small Business Innovative Research (SBIR) program, the Navy funded the development of an airborne sampling and analysis monitor for use at small arms ranges and lead paint abatement sites. The conceptual design and AeroLead™ prototype was established under Phase I and II. Environmental Life Support (ELS) Technology, Inc. developed the instrument based upon anodic stripping voltammetry. The selection criteria included analytical sensitivity, potential for automated operation, instrument cost, analysis time and simplicity of operation.

The AeroLead™ analyzer is the first, and currently the only portable, automatic, low-cost method to analyze airborne lead and lead dust contamination on-site and in near real-time. The analyzer's primary purposes are to provide near real time, single sample ambient air monitoring and personal breathing zone analyses during lead-based paint abatement projects. Use of the AeroLead™ instrument will result in a greater level of worker safety by providing portable, automated, on-site quantification of airborne lead concentrations to which the workers may be exposed.

The AeroLead™ analyzer has two modes of operation: single sample ambient air monitoring and personal breathing zone analyzer. Single sample air monitoring combines sampling, extraction, and analysis into one process. The personal breathing zone (PBZ) mode allows the user to analyze previously collected PBZ samples in near-real time, eliminating the need for sample storage and transportation to a laboratory for subsequent analysis. In both modes, the airborne lead is concentrated into a specially designed aqueous phase and analyzed voltammetrically. The lead concentration is analyzed by anodic stripping voltammetry (ASV), where the metal is plated onto a working electrode; the polarity of the electrode is then reversed, stripping the lead from the electrode. For a general outline of ASV, see Ashley K., *Appl. Occup. Environ. Hyg.* **13**, pp 94-98 (1998). The current consumed by the stripping step provides an accurate measurement of the lead concentration. An integrated airflow meter is used for ambient air monitoring to determine air sample volume. The volume measurement is combined with the voltammetric result to yield an accurate airborne lead concentration on-site. The instrument then automatically resets itself for the next sample and can be programmed to sample automatically throughout the

day. Data can be downloaded to a PC through an RS-232C port. Software is available to allow the user to import the data directly into MS Excel in real time, parse and graph with the touch of a button, simplifying the data reduction process.

## **2.2 Strengths, Advantages, and Weaknesses**

The advantages of this technology are faster sample turn-around and lower compliance cost. The operational costs will be reduced from \$9-20/sample (NIOSH 7105) to an estimated \$0.75/sample (AeroLead™). The total air sample volume is quantified by the AeroLead™, resulting in only 1-2% error in sampling air volume, compared to the 5% air sampling error of the belt pump and filter assembly used for NIOSH 7105. Other advantages include: (1) Provides a cost-effective method to ensure compliance with occupational exposure regulations on-site and in real-time; (2) Reduced cost of compliance compared to current NIOSH Method 7105 by reducing the personnel requirements; (3) Enhanced worker safety and cost avoidance of potential safety violations; and (4) Technological basis for a method to measure additional airborne metals used in DoD operations.

Limitations to the technology include single sample analysis at a time (one per filter vs. multiple samples to a filter) and non-validation of the technology so it can be used to satisfy legal monitoring requirements.

## **2.3 Cost and Performance Factors**

The AeroLead™ analyzer will lower the compliance cost from the currently used NIOSH 7082 method which will result in substantial cost savings for the thousands of samples that are taken each year. Current NIOSH analysis costs average approximately \$25.00 per sample, plus collection costs. The AeroLead™ instrument will provide an approved method of lead analysis for about 10% of the cost of current analysis methods, without increasing collection costs. Furthermore, the ability to receive exposure information within 10 minutes of sample collection is a significant improvement over current lead analysis techniques. Refer to section 6 of this report for a full breakdown of AeroLead™ operating costs and cost comparison information.

# **3. Site/Facility Description**

## **3.1 Background**

The majority of the development testing was performed in the laboratory at ELS Technology. Extraction efficiency and capture efficiency tests were performed at a local indoor shooting range to more accurately determine the effectiveness of each parameter using real world materials. Three field tests were conducted during the AeroLead™ Demonstration/Validation program. The sites were chosen by NFESC based on ESTCP requirements and preliminary lead level testing. The first field test was performed at an indoor shooting range at NAB Little Creek facility in Norfolk, VA on 19-21 January, 2000. The second field test took place at an outdoor range at Twentynine Palms Marine Training Facility in Twentynine Palms, CA on 6-8 June, 2000. Both facilities provided real world materials created by live fire rifle and pistol shooting exercises. The third field test was performed under controlled conditions at Oak Ridge National

Laboratory in Oak Ridge, TN on 12-14 September, 2000. Lead for the Oak Ridge field test was generated by an aerosol particle generator.

### **3.2 Site/Facility Characteristics**

#### **3.2.1 NAB Little Creek Facility**

The indoor range at NAB Little Creek is divided into two sections: a rifle range and a pistol range. There are 16 rifle shooting stations and 15 pistol shooting stations. Each station is approximately 4 feet wide. The distance between the rifle firing lines and the targets is 25 yards.



**FIGURE 3-1. RODRIGUEZ SHOOTING RANGE**

The shooting range is equipped with an open loop ventilation system. Outside air enters the range through a diffuser pipe. The diffuser pipe is located 15 feet behind the shooting positions and is attached to the ceiling. It spans the entire width of the room except for the 6-foot wide doorway in the center of the supply plenum. The doorway leads from the foyer into the range. The ceiling height is 8 feet. Direction of air flow is from rear to front (targets) of the range. Outside air is supplied by the diffuser pipe from behind the shooters, circulates toward the bullet traps, and out through the exhaust fan. The exhaust air is sent through primary, secondary, and High Efficiency Particulate Air (HEPA) filters before being exhausted to outside air.

#### **3.2.2 Twentynine Palms Facility**

Range 1 at Twentynine Palms is a 50 lane outdoor shooting range used to train military personnel in high power rifle proficiency. Shooters position themselves at the 100, 200, 300, and

500 meter shooting lines with the targets located at the zero meter line. The bullet traps are located approximately 30 meters behind the zero meter line. The bullet traps are designed to capture bullet materials, upon impact, for recycle. Upon impact the bullet breaks apart, resulting in debris of various lead and copper particle sizes. The large particles are collected in bins at the base of the trap. The bullet traps are equipped with a dust collection unit (DCU) which traps and filters lead particulate generated by bullet impact on the trap. The DCU ventilation system pulls air from bullet deceleration chamber

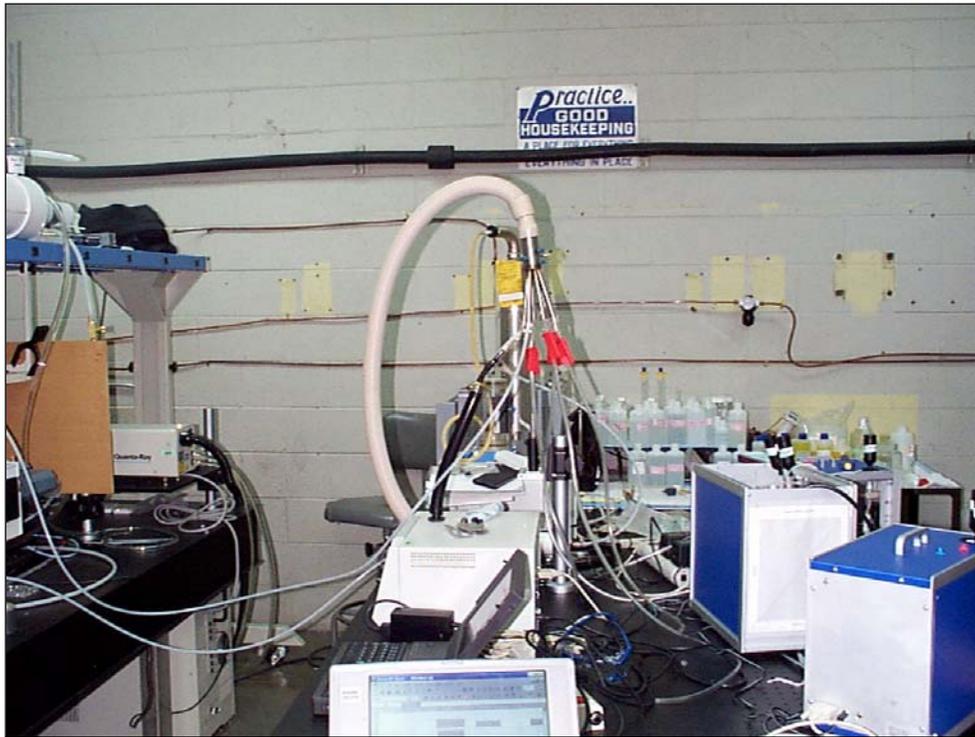
Figure 3-2 provides an illustration of the DCU on the underside of the bullet traps. Samples were collected in the vent leading from the bullet trap to the DCU, as depicted in Figure 3-2.



**FIGURE 3-2. TWENTYNINE PALMS BULLET TRAP DCU**

### **3.2.3 Oak Ridge Facility**

The Oak Ridge field test was conducted in the Aerosol Research Laboratory of the Environmental Sciences Division of Oak Ridge National Laboratory. The facility is equipped with a TSI Corporation aerosol particle generator, capable of transferring particulate from an aqueous solution to an aerosol stream. The generator can be adjusted to provide user-selectable particle sizes and concentrations. The particle generator effluent stream was attached to a six-way splitter to allow the interface of two AeroLead™ instruments, two NIOSH sampling loops, and the Laser Induced Plasma Spectrometer instrument (and one exhaust). The effluent from each instrument vented to a facility HEPA filtered vent system. An illustration of the test setup is provided in Figure 3-3.



**FIGURE 3-3: OAK RIDGE TEST SETUP**

## 4. Demonstration Approach

### 4.1 Performance Objective

The specification used to evaluate the performance of the instrument(s) throughout this Dem/Val program was ASTM-E1775. The specification outlines the performance criteria very clearly. A copy of specification ASTM-E1775 is provided in Appendix H. A breakdown of performance criteria is provided in Table 4-1 below.

**Table 4-1. ASTM-E1775 Specification Summary**

<b>Parameter</b>	<b>Specification</b>
Working Range	0.1x – 10.0x PEL
Extraction Efficiency	>80%
Capture Efficiency	100%
Precision	± 15% for primary standards ± 20% for secondary standards ± 25% for real world materials
Accuracy	± 25% (Related to AA Method)

Working range and precision parameters were evaluated in the laboratory using ELS prepared secondary standards. All other parameters were evaluated in the field with real world materials. The PEL for airborne lead is 30ug/m<sup>3</sup>.

## 4.2 Physical Setup and Operation

If properly charged, the AeroLead™ instrument requires no ancillary equipment or facilities to operate. No PPE is required to operate the unit. The instrument setup is as follows:

1. Unpack AeroLead™ analyzer and collector. Open syringe valve to run position, remove collector cap and install collector.
2. Install power supply and AeroLead™/computer interface cabling (if not using battery power).
3. Verify proper extraction solution level in analyzer (add solution as necessary).
4. Perform calibration verification (per Appendix F).
5. Perform multi-scan calibration procedure (per Appendix F) if verification failed.
6. Instrument ready for sample analyses.

### 4.2.1 General

In order to adequately validate the AeroLead™ instrument, extensive system and subsystem level testing was performed. The following chart illustrates the extent of testing performed and the timeline in which each test occurred.

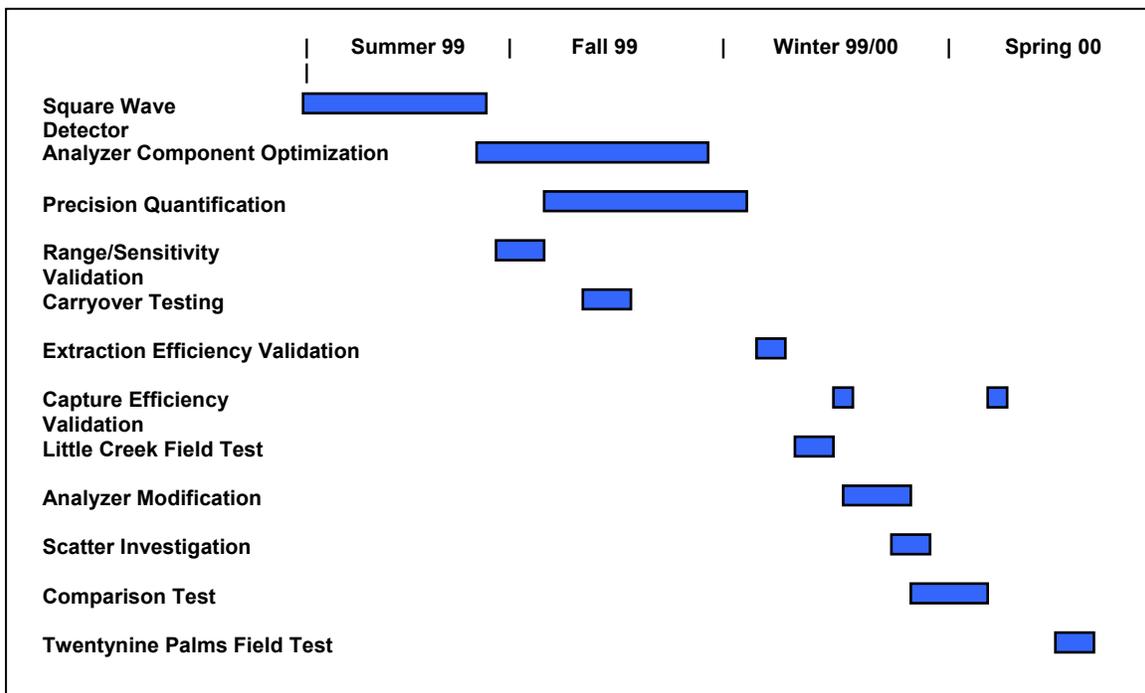


Figure 4-1. Dem/Val Test Timeline

#### 4.2.1.1 Extraction Efficiency Test

Extraction efficiency tests were performed in two parts. First, extraction efficiency tests were performed in the laboratory at ELS Technology, using secondary standards prepared by Anteon Corp. The samples were prepared by depositing lead directly to membrane filters. Lead amounts were gravimetrically determined, and amounts ranged from 0.35ug Pb to 61.47ug Pb per filter. Each sample was extracted and analyzed by an AeroLead™ instrument. The extracted membrane was then removed and sent to Reservoirs Laboratory, Inc. in Denver, CO for Pb analysis. The lead remaining on the extracted membrane was determined and compared to the initial lead concentration.

The second part of extraction efficiency testing occurred during each of the two subsequent field tests. Selected membranes extracted during these field tests were sent to Reservoirs Laboratory in Denver, CO to determine the quantity of lead remaining on the extracted membranes. This information was combined with the laboratory data to verify ASTM-E1775 conformance.

#### 4.2.1.2 Capture Efficiency Tests

A series of capture efficiency tests were performed to evaluate the collector design and verify compliance with ASTM-E1775. Both commercial-off-the-shelf (COTS) and in-house designs were tested. The capture efficiency tests were performed by placing two 0.8um (pore size), 25mm (diameter) membranes in series and drawing air through them for a period of eight hours. Collector design was deemed acceptable if the primary filter membrane captured all the lead present with none being detected on the secondary filter.

#### 4.2.1.3 Comparison Tests

Comparison tests were performed to evaluate the precision of the instruments and verify compliance with ASTM-E1775 specification. Four instruments were tested. A liquid injection method was used to introduce the lead into the detector in concentrations ranging from 0.5x to 10x the Permissible Exposure Limit (PEL). The comparison test occurred in the laboratory at ELS Technology. ELS personnel prepared all secondary standards used during comparison testing.

#### 4.2.1.4 Interference Test

To evaluate the effects of potential interference due to the presence of other metals, ELS Technology performed an interference test early in the project term. An AeroLead™ detector assembly was bench mounted and an EG&G Model 384B Polarographic Analyzer performed the functions of the current AeroLead™ electronics and software. Several solutions were prepared containing lead and several interference metals including copper and mercury. Analyses were performed to determine the effects of the interference metals on AeroLead™ detector performance.

#### 4.2.1.5 NAB Little Creek Field Test

The AeroLead™ instruments were operated in ambient air monitor mode during the Little Creek Field Test. Three analyzers were tested concurrently, along with three NIOSH sample loops to provide method comparison samples. The AeroLead™ instruments were programmed for 30minute sample times, the NIOSH loops were programmed for 8-hour sample times (in general). The AeroLead™ instruments and the NIOSH sampler were set up on a 3' table

adjacent to the first shooter lane. The NIOSH samples provided time-weighted average (TWA) and spatial distribution information to compare to the AeroLead™ data to verify compliance with ASTM-E1775 accuracy criteria. Refer to “Interim Report – Field Validation of Real Time Airborne Lead Analyzer – NAB Little Creek” for a full report of NAB Little Creek field test activities.

Four tests were performed at NAB Little Creek. Airborne lead for tests 1, 2, 3B were created by live fire of 9mm, M14, and M16 ordnance. The number of shooters present and the number of rounds fired differed for each test and test set. Test 3 airborne lead was created by manually vacuuming the rifle range floor, shooter mats, and the “wet snail.” The entire cleaning process was performed in approximately 30 minutes. Refer to Reference 1 in Section 10 for a complete account of events for the NAB Little Creek field test.

#### 4.2.1.6 Twentynine Palms Field Test

The Twentynine Palms field test was planned to evaluate the personal breathing zone analyzing function of the AeroLead™ instrument. All airborne lead samples were taken from the range trap air handling system using a combination of NFESC supplied personal breathing zone sampling pumps and ELS Technology supplied sampling pumps. Each sample pump was calibrated pretest. Samples were taken in groups of three to four per location (see Figure 3-2). Upon completion of sample collection, two samples were analyzed by the AeroLead™ instrument and one to two samples were sent to Reservoirs Laboratory in Denver, CO for analysis. This plan was developed to evaluate the AeroLead™ instrument accuracy requirements with respect to ASTM-E1775 specifications.

The AeroLead™ analyzers were set up in the range office at the start of each test day. Two analyzers were used each day and three analyzers were evaluated throughout the three days of testing. Pretest calibration was performed at the beginning of each test day on each analyzer used. Furthermore, additional calibration verification was performed on each analyzer throughout the course of testing to verify accurate analyzer performance.

#### 4.2.1.7 Oak Ridge Field Test

The purpose of the Oak Ridge field test was to evaluate the accuracy of the AeroLead™ instrument under controlled conditions using real world materials. Two AeroLead™ instruments were operated in parallel with a Laser Induced Plasma Spectrometer (LIPS) and two NIOSH sampling loops for comparison purposes. All AeroLead™ and NIOSH sample pumps were calibrated pretest using a factory calibrated float meter. The LIPS instrument was set up and operated by ORNL personnel. The AeroLead™ instruments were set up and calibrated pretest. A copy of the calibration procedure is provided in Appendix F. Additional calibration verification was performed on each analyzer throughout the course of testing to verify accurate analyzer performance. For each test point, the AeroLead™ instruments and NIOSH sampling loops were programmed for 5 minutes of sample collection, at which time the AeroLead™ instruments performed extraction and analysis operations. Upon completion of analyses the data was recorded and collectors removed in preparation for the next sample. NIOSH-sampled collection assemblies were capped, bagged and sent to Reservoirs Laboratory in Denver, CO for analysis. A copy of the test plan is provided in Appendix E.

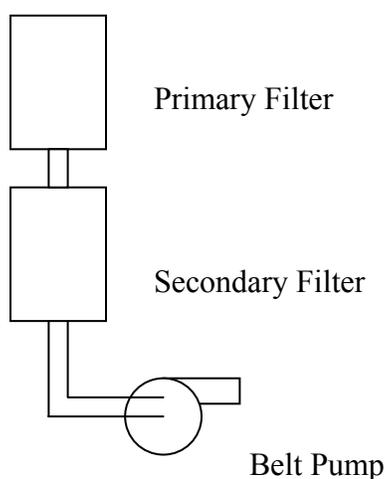
## 4.3 Sampling Procedures

### 4.3.1 Extraction Efficiency Tests

Anteon Corp. personnel prepared all samples used for the extraction efficiency tests. The samples were prepared by mixing lead salts with 325 mesh silica (Aldrich Chemical Corp.) to the desired concentration, mechanical vortex mixing, then applying a smear of the powder, by weight, to 0.8µm, 25 mm, Pall-Gelman GN-4 Metrical membranes. The samples were prepared in NFESC facilities in Port Hueneme, CA and hand carried to ELS Technology for extraction.

### 4.3.2 Capture Efficiency Tests

Sampling during the capture efficiency test was performed similar to nominal AeroLead™ operation. Two collectors were assembled in series and a belt pump was attached to draw the sample through the collectors. Each collector contained a 0.8µm, 25mm Pall-Gelman GN-4 Metrical membrane. The sample pump was set for eight-hour sample times. The test was conducted at a shooting range in Denver (near ELS facilities) to provide real world materials for the test. These tests were performed before field tests to ensure that the AeroLead™ unit was taking an adequate sample. Upon completion of the eight-hour sample time, the membranes were removed from the collector assemblies and sent to Reservoirs Laboratory in Denver, CO for analyses by NIOSH Methods 7082 and 7105.



**FIGURE 4-2. CAPTURE EFFICIENCY TEST SETUP**

### 4.3.2 NAB Little Creek Field Test

Three AeroLead™ airborne lead analyzers were operated concurrently with an automated NIOSH sampling system consisting of a belt pump and 37 mm MCE filter assemblies. The system consists of 3 parallel filter samplers (referred to as A, B, & C) used to measure airborne lead distribution and concentration. Each NIOSH sample pump was calibrated at the beginning and end of each test set to verify air flow rate through each 37mm, 0.8 micron membrane. These results were then used to determine the total sample throughput for each test set. The 37 mm cartridges were removed and capped at the completion of each test set, then bagged and sent by a third party (Anteon) to Reservoirs Environmental Services, Inc. in Denver, CO for analysis. The samples were analyzed using NIOSH 7105 and NIOSH 7082 by the laboratory.

A 25mm, 1 micron Teflon membrane was installed in the collector of each AeroLead™ analyzer prior to instrument calibration at the beginning of each test set. The same membrane was used for all samples collected in each test set (i.e., a membrane was installed prior to analyzer calibration at the start of a test set, then removed after a post test blank sample at the end of the test set). Upon the completion of each test set, the membranes were removed from each collector, separately bagged, and labeled. All AeroLead™ membranes were then sent to Reservoirs Environmental Services, Inc. in Denver, CO for analysis. The results of the analyses provided ultrasonic extraction efficiencies of the AeroLead™ analyzers. NIOSH 7082 was the method used by Reservoirs for sample analyses.

#### **4.3.3 Twentynine Palms Field Test**

Lead generation was achieved by the impact of 50mm ammunition on the bullet trap. 126 samples were collected over the 3-day test period (6 to 8 June 2000). Sample cartridges were inserted into the bullet trap dust collection unit (DCU) and air samples were acquired using calibrated sample pumps. The third party contractor (Anteon) performed sample pump calibration. Upon completion of sample collection, the cartridges were removed and transported to the range office for analyses by the AeroLead™ instruments. It should be noted that the test team expressed concern regarding sample contamination during cartridge installation (i.e., lead dust introduced on the collection membrane during installation) due to the quantity of lead particles present. Care was taken during cartridge installation to minimize the contamination potential.

Samples were taken in groups of 3 to 4 samples per location. A minimum of two locations were sampled during each test period. The sample bombs (a bundle of 3-4 sample cartridges duct-taped together) were assembled pretest, then installed into their sample location in the dust collection unit (DCU) prior to each shooting exercise. Each sample pump was programmed for sample period and start delay to insure adequate samples were collected during periods of weapons discharge. Upon completion of sample collection, the cartridges were split apart from the bundle and labeled. A minimum of one sample per location was bagged for shipment to Reservoirs Inc., in Denver, CO for NIOSH analysis. All other samples were analyzed by the AeroLead™ instruments.

#### **4.3.4 Oak Ridge Field Test**

Lead (as lead nitrate) solutions were prepared pretest by ORNL personnel. The TSI particle generator was set up for the required concentration and allowed to reach steady state by venting into the facility exhaust system. The AeroLead™ and NIOSH sampling systems were programmed for a five-minute sample time. Flow was diverted to the instruments and sampling began concurrently. Upon completion of the five-minute sample time, the flow of lead was terminated and the particle generator was disconnected from the flow splitter. This process was repeated for each test point.

#### **4.4 Analytical Procedures**

ASTM-E1775 was the guideline used to evaluate AeroLead™ performance. A copy of ASTM-E1775 is provided in Appendix H of this report. ASTM-E1775 specifies ASTM-E1613 as the basis for accuracy determination, which directs the use of Inductively Coupled Plasma Atomic

Emission Spectrometry (ICP-AES), Flame Atomic Absorption Spectrometry (FAAS) or Gas Furnace Atomic Absorption Spectrometry (GFAAS) technique as the accuracy comparator method.

The AeroLead™ Anodic Stripping Voltammetry (ASV) method was compared to NIOSH Methods 7082 (FAAS Method) and 7105 (GFAAS Method) for both field tests to determine accuracy. The results of the interference testing were compared to NIOSH 7701 for consistency. Copies of these NIOSH analytical methods are provided in Appendix G.

## **5. Performance Assessments**

### **5.1 Performance Data**

The performance data in this section is separated by test type and is not chronological. For brevity, the NAB Little Creek test data is compressed. A full report of the NAB Little Creek and Twentynine Palms field tests can be located in their respective reports (see Section 10, reference 2). All data from the Oak Ridge National Laboratory test are contained in this report, as a separate report was not prepared.

#### **5.1.1 Interference Testing**

The results of interference testing indicate copper as the primary interference material, which is consistent with NIOSH Method 7701. Copper peaks were identified to occur between  $-200\text{mV}$  and  $-500\text{mV}$  during the stripping step. Lead peaks occur between  $-450\text{mV}$  and  $-700\text{mV}$ , therefore overlap between the lead and copper peak curves is possible. Anti-interference software was incorporated into the AeroLead™ instrument to ignore the presence of copper peaks.

#### **5.1.2 Extraction Efficiency Testing**

The samples used to perform a laboratory evaluation of the AeroLead™ extraction mechanism were produced by Anteon personnel at NFESC facilities and transported to ELS Technology for extraction. All extracted membranes were sent to Reservoirs, Inc. for post extraction analyses. The analyses reported lead levels below the minimum detection limit (BDL) of  $2.5\mu\text{g}$  for all extracted membranes. NIOSH method 7082 was used for the analyses. The results of the extraction efficiency test are provided in the table below. The first column provides the sample number, the second column is the Pb quantity on each filter, by mass, as calculated during preparation, the third column provides the lead quantity remaining on the membrane after extraction as reported by NIOSH method 7082.

**Table 5-1. Extraction Efficiency Data**

Sample #	Initial Pb Conc. (ug)	Extracted Conc. (ug)
5A	0.51	BDL
4D	0.91	BDL
4C	1.09	BDL
3E	1.63	BDL
4B	1.81	BDL
3D	2.35	BDL
3A	5.95	BDL
2A	13.88	BDL
2C	15.86	BDL
1A	16.85	BDL
1E	36.68	BDL
1G	40.65	BDL

Several non-extracted samples were sent to Reservoirs, Inc. for analyses to evaluate the preparation method and verify lead quantities with respect to NIOSH method 7082. The results indicated that the actual sample lead quantities, as reported by NIOSH 7082, were 16%-60% lower than the calculated lead level (column 2 above). The results of the non-extracted membrane analyses are provided in the Table 5-2:

**Table 5-2. Non-extracted Membrane Data**

Sample #	Calculated Conc. (ug)	NIOSH Reported Conc. (ug)
2B	16.85	6.7
2D	17.85	7.6
2E	16.85	7.1
1B	40.65	34.3
1C	52.54	31.9
1D	53.53	32.3
1F	61.47	47.1

Therefore, it was concluded that the amount of lead applied to the filters was 16%-60% lower than that calculated. Plotting the data and performing linear regression, it was determined that a correction factor of 0.74 could be applied to the amount of lead on each filter. Taking this information into account, the extraction efficiency of the AeroLead™ instrument was determined to be greater than 91%, satisfying ASTM-E1775 requirements:

+

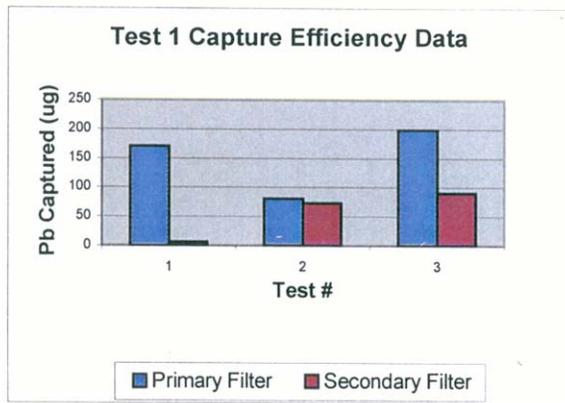
Samples 1E and 1G were extracted and analyzed and contained enough lead to evaluate extraction efficiency (due to the lower detection limit of the NIOSH method used for post extraction analyses). The correction factor of 0.74 was applied.

**Table 5-3. Adjusted Extraction Efficiency Data**

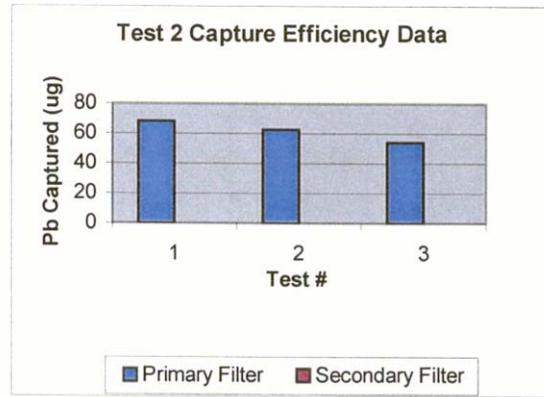
Sample #	Calculated Pb (ug)	Actual Pb (ug)	Post-extracted Pb (ug)	Efficiency (%)
1E	36.68	27.23	<2.5	>91%
1G	40.65	30.18	<2.5	>91%

### 5.1.3 Capture Efficiency Testing

Capture efficiency tests were performed at a local pistol range in Denver in order to evaluate the parameter with real world materials. Test 1, illustrated in Figure 5-1 below, indicated poor capture efficiencies for the initial collector design. The design was modified to improve the location of sealing surfaces resulting in significant improvements to capture efficiency (see Figure 5-2). ELS Technology then researched commercial-off-the-shelf products and found a NIOSH certified collector assembly, which was incorporated into the AeroLead™ design.



**Figure 5-1. Capture Efficiency Test 1**



**Figure 5-2. Capture Efficiency Test 2**

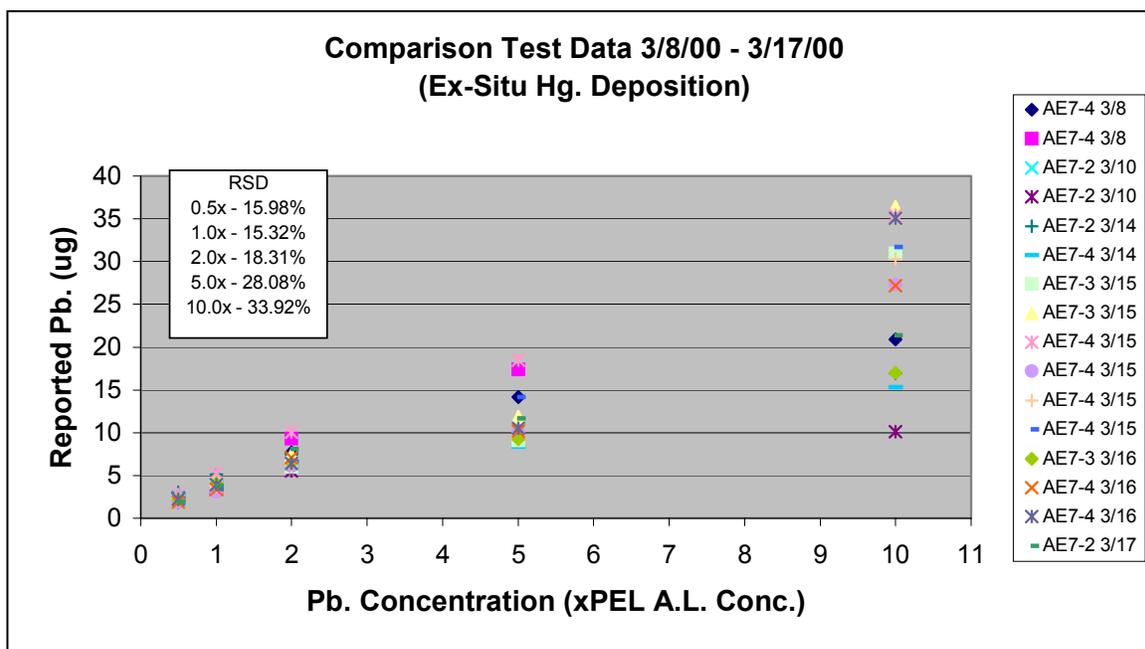
### 5.1.4 Comparison Tests

The AeroLead™ comparison tests were performed to determine the precision of the instruments. ASTM-E1775 defines acceptable instrument precision as follows:

**Table 5-4. ASTM-E1775 Precision Requirements**

Material	Specification
Secondary reference materials	<20% RSD
Primary reference materials	<15% RSD
Real world materials	<25% RSD

The comparison test was performed using secondary reference materials prepared by ELS Technology personnel. Five concentrations were analyzed in the range of 0.5x to 10.0x the Permissible Exposure Limit (PEL). The results of the tests are provided in Figure 5-2. A full set of tabular data is provided in Appendix I. This test was critical in establishing the linear range of the instrument. As summarized in Figure 5-3, the instruments fulfill the requirements outlined by ASTM-E1775 up to about 2.5x-3.0x action level concentration. Therefore, the linear range of the instrument was determined to be 0.1x to 2.5x action level concentration (0.4ug to 10ug of collected lead) in order to satisfy the precision requirement. If the user encounters lead levels above the linear range, he/she will be prompted to don PPE, reduce the sample time and collect another sample to bring the result within the linear range of the instrument. This will permit an accurate determination of the airborne lead concentration.



**FIGURE 5-3. COMPARISON TEST RESULTS**

**5.1.5 NAB Little Creek Field Test**

All performance data for the NAB Little Creek field test can be found in that interim report (see reference 1 in Section 10). An assessment of the Little Creek data is included in Section 5.2 of this report.

**5.1.6 Twentynine Palms Field Test**

All performance data for the Twentynine Palms field test can be found in that final report (see reference 2 in Section 10). An assessment of the Twentynine Palms data is included in Section 5.2 of this report.

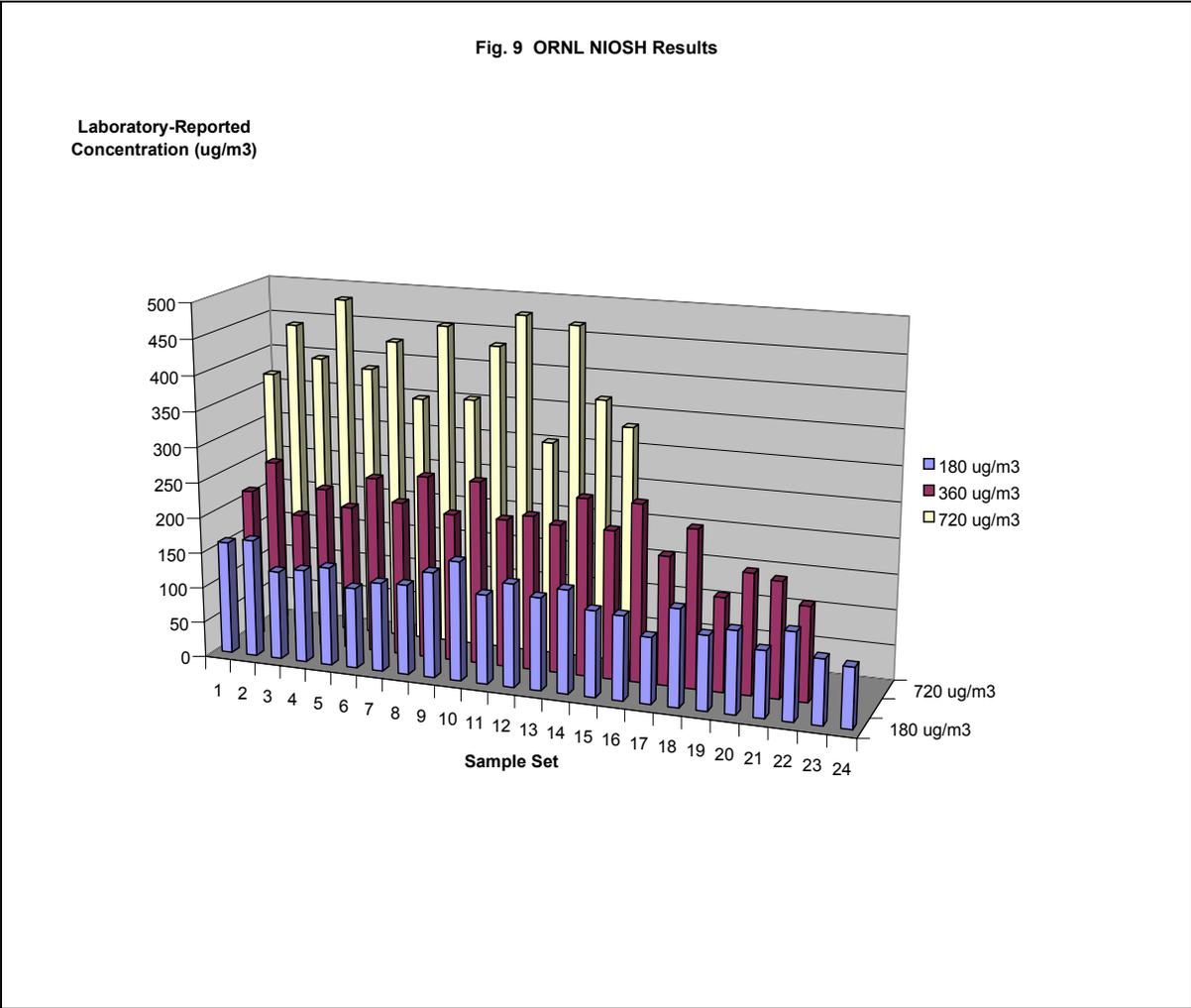
**5.1.7 Oak Ridge Field Test**

To evaluate instrument performance throughout the linear range of the detector, three lead concentrations were provided by the particle generator, 180ug/m<sup>3</sup>, 360ug/m<sup>3</sup> and 720ug/m<sup>3</sup>. The

high sample concentrations were chosen to allow for five-minute sample times to expedite the test process. The generator was fitted with a manifold with four sampling ports. In addition, a Laser Induced Plasma Spectrometer was connected to the particle generator to independently determine the lead concentration generated. The high sample concentrations were chosen to allow for five-minute samples to maximize the sample throughput for the time allocated on the particle generator. Fourteen samples were taken by the AeroLead™ instruments at each concentration. The data is summarized in Table 5-5. Null fields in the Table 5-5 indicate that only one AeroLead™ was operated at that test point (typically due to operator error or malfunctioning of the instrument). Twenty-seven test points were conducted. Two instruments were operated during each test point, though instruments were occasionally exchanged during the test for electrode changeout and troubleshooting (three AeroLead™ instruments were used during the tests). Data are presented graphically in Figure 5-4, and a complete set of peak current graphical data is provided in Appendices B-D.

**Table 5-5. Oak Ridge Field Test Data**

Test Point Date-Sequence	Aerosol Particle Generator Pb Target Pb Conc. (ug/m3)	AeroLead™ AE7- 2 Pb Conc. (ug/m3)	AeroLead™ AE7- 3 Pb Conc. (ug/m3)	AeroLead™ AE7- 4 Pb Conc. (ug/m3)
9/12 – 1	ambient air		467	351.5
9/12 – 2	ambient air		554.17	568.25
9/12 – 3	180		366.48	162
9/13 – 1	ambient air		525.5	86.8
9/13 – 2	180			92.64
9/13 – 3	360			78.82
9/13 – 4	360			230.69
9/13 – 5	360		478.23	210.66
9/13 – 6	360		847.9	70.06
9/13 – 7	720		790.97	306.29
9/13 – 8	720		194.37	337.2
9/13 – 9	720	261.13	1440.23	
9/13 – 10	720	635.08	439.33	
9/13 – 11	720	319.55	652.05	
9/13 – 12	720	384.66	773.72	
9/14 – 1	720	251.93	385.31	
9/14 – 2	180	BDL	121.26	
9/14 – 3	180	113.44	BDL	
9/14 – 4	180	Error	231.73	
9/14 – 5	180	100.01	189.89	
9/14 – 6	180	136	183.56	
9/14 – 7	180	139.15	213.8	
9/14 – 8	360	103.91	229.4	
9/14 – 9	360	79.11	316.81	
9/14 – 10	360	635.08	439.33	
9/14 – 11	360	375		
9/14 – 12	360	91.61	423.7	



**FIGURE 5-4. ORNL NIOSH RESULTS**

Samples were also collected for analysis by NIOSH Method 7082. A total of 18 to 26 filter samples were prepared for each of the three lead concentrations. Samples were split (unequally) between two laboratories to determine inter-laboratory precision.

A summary of results of filters analyzed by NIOSH Method 7082 is presented in Table 5-6.

**Table 5-6. Analytical Laboratory Results of Non-Extracted Filters Using NIOSH Method 7082**

Pb Concentration	No. of Samples	Mean	Standard Deviation	95% Confidence Level
180 ug/m3	24	126.4	23.0	9.70
360 ug/m3	22	210.8	37.6	16.7
720 ug/m3	15	402.5	56.5	31.3

One data point from the 720ug/m3 set was omitted as an anomalous outlier (reported as BDL) and two others were omitted due to particle generator orifice clogging. As can be seen in Table 5-6, the mean concentrations for each of the 180, 360 and 720ug/m3 data sets were significantly lower (at the 95% confidence level) than that calculated to be delivered by the particle generator. The mean error between the calculated amount of lead and the actual amount of lead deposited based on NIOSH Method 7082, expressed as a percentage for each concentration, is as follows:

$$(126.4-180)/180 \times 100 = -29.8\%$$

$$(210.8-360)/360 \times 100 = -41.4\%$$

$$(402.5-720)/720 \times 199 = -50.6\%$$

## 5.2 Data Assessment

In general, the data presented in Section 5.1 provides an adequate assessment of AeroLead™ instrument performance. The assessment is summarized in Table 5-7. The interference materials, found through laboratory testing, agree with materials found to interfere with similar methods. The extraction efficiency and capture efficiency tests followed protocols identical to nominal instrument operation, and performance analyses were conducted in an accredited laboratory by comparative technologies recognized by OSHA. Comparison testing provided an adequate evaluation of instrument precision. However, additional test points would be helpful in providing a more complete evaluation of precision.

**Table 5-7. Data Assessment Summary**

Parameter	ASTM-E1775 Specification	AeroLead™ Performance	Satisfied Spec. (YES/NO)
Capture Efficiency	100%	99.9999-100%	YES
Extraction Efficiency	>80%	>91%	YES
Precision	± 20%	+75% <sup>1</sup>	NO
Accuracy	± 25%	+49.4 <sup>1</sup>	NO
Working Range	0.1x-10.0x PEL	0.1x-2.5x PEL	NO

DND – Did Not Determine

PEL – Permissible Exposure Limit

<sup>1</sup> Based on Results from Oak Ridge Testing

Of the three field tests, the most reliable data resulted from the tests carried out at Oak Ridge National Laboratory since these tests were carried out under controlled laboratory conditions. The two field tests carried out at the firing ranges, Little Creek NAB and Twentynine Palms MCAGCC, were compromised by a lack of airborne lead at Little Creek NAB and an excess, uncontrolled amount of lead at Twentynine Palms MCAGCC. Thus, for the three field tests, accuracy and precision determinations can be best determined using the Oak Ridge data, presented below.

The accuracy data collected during the three field tests conducted during this program did not adequately satisfy ASTM-E1775 specifications. The first field test conducted at Little Creek

NAB resulted in non-detectable levels of lead in all NIOSH filter samples. Thus, accuracy cannot be determined for this test. The cause(s) of the discrepancies are inconclusive at this time. Spatial distribution, sampling protocols, software development issues, and calibration methods have all been attributed to various issues, particularly during the Little Creek field test.

### **Little Creek Field Test**

Consistent analytical data were observed within each analyzer during the Little Creek field test. The automated sampling, extraction, and analysis functions of the AeroLead™ instruments were demonstrated under field conditions to be effective and reliable. A marked response to range activity was also observed, i.e. increases and decreases in firing rates correlated directly with AeroLead™ reported lead concentration. There was not however, good general agreement among the three analyzers. More significantly, there was not good agreement between the NIOSH samples analyzed by the certified laboratory (all NIOSH samples were below detection level). Post-test data analysis indicated that the single-point, single scan calibration technique used in the original AeroLead™ instruments allowed too much variability in sample results. This is primarily due to a new configuration of the detector cell (to provide increased electrode operational life) which results in more variable mass transfer of analyte from the filter to the detector cell than has been observed previously. This problem was addressed by incorporating a quadruplicate calibration procedure followed by a quality control calibration check after calibration.

### **Twentynine Palms Field Test**

Consistent analytical data were observed for each AeroLead™ analyzer during the Twentynine Palms field test. The automated extraction and analysis functions of the AeroLead™ instruments were found to be effective and reliable. The software modifications made after the Little Creek field test proved to enhance the performance of the instrument. Low level concentrations were detected and accurate calibration was achieved reliably. Software modifications to allow personal breathing zone analyses operated appropriately.

There was good general agreement among the AeroLead™ analyzed samples. Samples collected in the same location for the same sample period resulted in similar reported lead concentrations. However, in general the NIOSH data generated by Reservoirs Laboratory did not agree with the AeroLead™ data. The disparity of results is believed to be attributed to one of the following: sample contamination during cartridge installation and handling, inaccurate air flow measurements or mis-prepared calibration solution and instrument variance using real-world samples. To eliminate the possibility of mis-prepared calibration solution, three samples of the calibration solution used during the 29 Palms field test were sent to Reservoirs Laboratory for NIOSH analysis (Flame AA). The results are provided in Table 5-8.

**Table 5-8. Calibration Solution NIOSH Analysis**

Sample #	Prepared Concentration	Reported Concentration
Pb-1	1000 ug/l	1167 ug/l
Pb-2	1000 ug/l	1000 ug/l
Pb-3	1000 ug/l	1158 ug/l

The results indicate that the solution was prepared correctly and that the NIOSH method and the AeroLead™ instrument have good analytical agreement on analyses of laboratory prepared aqueous samples. The same solution was used during calibration verification process at 29 Palms. The AeroLead™ instruments reported the correct lead concentration ( $\pm 20\%$ ) with respect to the prepared lead solution, which further confuses the results of the 29 Palms collected samples. Aqueous samples when analyzed provide better results than corresponding airborne samples. Analyzer modifications were successfully completed and tested prior to the second field test to correct calibration and software issues. From analyzing the pretest laboratory data, it is believed that the instruments were performing properly during the Twentynine Palms field test, therefore, sample contamination, pump calibration or spatial distribution issues are believed to be the case of data discrepancy.

Specific observations made during test and data analysis are outlined below. Course(s) of action(s) required to improve AeroLead™ analyzer performance are also addressed.

- AeroLead™ software upgrades to incorporate personal breathing zone analyses functioned well.
- The modified calibration procedure, which includes quadruple scan calibration and triple scan verification steps, significantly improved calibration reliability. Performing occasional calibration verification during sample analyses effectively verifies analyzer performance.
- Ex-situ mercury deposition is advantageous as it eliminates the occurrence of data scatter experienced during the NAB Little Creek field test. Furthermore, the user is not exposed to mercury while calibrating and maintaining the instrument.
- Although the AeroLead™ and NIOSH data displayed similar trends, there was not good overall agreement between the NIOSH data and the AeroLead™ data. The fact that the AeroLead™ and NIOSH analyses reported similar concentrations for the calibration solution raises questions regarding sample collection. The large disparity between many of the samples indicates that sample contamination could have occurred or that flow rate measurements may have been inaccurate.

### **Oak Ridge Field Test**

Averaged results reported by each of the three AeroLead™ instruments at each of the three lead concentrations generated by the particle generator are presented in Table 5-9.

**Table 5-9. Averaged Results for Individual AeroLead™ Instruments**

Pb Conc. (NIOSH consensus)	Analyzer 2			Analyzer 3			Analyzer 4		
	No. of Samples	Mean	Std. Dev.	No. of Samples	Mean	Std. Dev.	No. of Samples	Mean	Std. Dev.
126.4 ug/m3	4	122.1	18.7	6	317.8	208.7	2	130.3	53.3
210.8 ug/m3	4	162.4	142.1	5	459.2	237.6	4	147.5	84.9
355.6 ug/m3	5	331.3	80.4	7	716.4	364.5	2	250.3	79.1

A summary of results for all 3 analyzers combined yields the averaged data presented in Table 5-10. The results are also presented graphically in Figure 5-5.

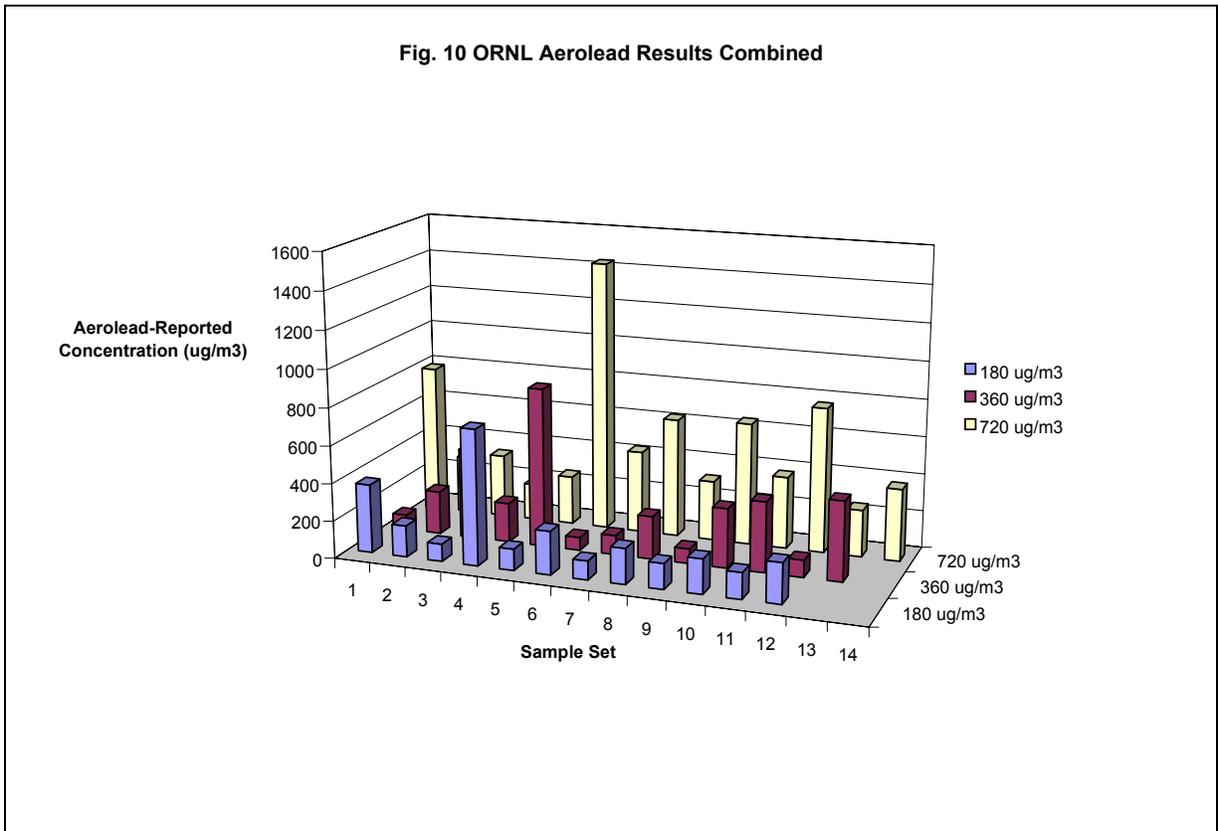
**Table 5-10. Averaged Combined Results for AeroLead™ Instruments**

Pb conc. (NIOSH consensus)	No. of Samples	Mean	Std. Dev.	95% Confidence Level
126.4 ug/m3	12	221.3	174.1	110.6
210.8 ug/m3	13	272.0	222.3	134.4
355.6 ug/m3	14	512.3	330.7	190.9

Precision for each analyzer can be expressed in terms of the coefficient of variation (relative standard deviation, RSD) which is the standard deviation divided by the mean, times 100 (%). Precision for each analyzer at each of the three concentrations is presented in Table 5-11. Accuracy (bias) can be determined by dividing the AeroLead™ result by the actual Pb concentration (i.e. the NIOSH average at each concentration range), as presented in Table 5-12.

**Table 5-11. Precision of Each AeroLead™ Instrument Based on Mean Result Compared to NIOSH Method 7082 Mean Result**

Pb conc. (NIOSH consensus)	Analyzer 2			Analyzer 3			Analyzer 4		
	Precision (±%)	Mean	Std. Dev.	Precision (±%)	Mean	Std. Dev.	Precision (±%)	Mean	Std. Dev.
126.4 ug/m3	15.3	122.1	18.7	16.8	317.8	208.7	40.9	130.3	53.3
210.8 ug/m3	87.5	162.4	142.1	51.7	459.2	237.6	57.5	147.5	84.9
355.6 ug/m3	24.3	331.3	80.4	50.9	716.4	364.5	31.6	250.3	79.1



**FIGURE 5-5. ORNL AEROLEAD™ RESULTS COMBINED**

Accuracy (bias) can be determined by dividing the AeroLead™ result by the actual Pb concentration (i.e. the NIOSH average at each concentration range), as presented in Table 5-12.

**Table 5-12. Accuracy (Bias) for Each AeroLead™ Instrument Compared to NIOSH Method 7082**

Pb conc. (NIOSH consensus)	Analyzer 2				Analyzer 3			Analyzer 4		
	Precision (±%)	Mean	Accuracy (Bias)	Precision (±%)	Mean	Accuracy (Bias)	Precision (±%)	Mean	Accuracy (Bias)	
126.4 ug/m3	15.3	122.1	-3.50%	16.8	317.8	+251%	40.9	130.3	+3.01%	
210.8 ug/m3	87.5	162.4	-29.8%	51.7	459.2	+218%	57.5	147.5	-30.0%	
355.6 ug/m3	24.3	331.3	-7.33%	50.9	716.4	+201%	31.6	250.3	-29.6%	

A summary of results for all three analyzers combined in the ORNL field test is presented in Table 5-13.

**Table 5-13. Precision and Accuracy (Bias) for All AeroLead™ Instruments Combined Compared to NIOSH Method 7082**

Pb conc. (NIOSH consensus)	Precision (±%) (Coefficient of Variation)	Mean	Std. Dev.	Accuracy (Bias)
126.4 ug/m3	78.7	221.3	174.1	+75.1%
210.8 ug/m3	81.7	272.0	222.3	+29.0%
355.6 ug/m3	64.6	512.3	330.7	+44.1%

### 5.3 Technology Comparison

Several NIOSH methods were used for comparison during the AeroLead™ Dem/Val project including: NIOSH 7082, NIOSH 7105 and NIOSH 7701. For easy comparison, technical performance information for each method is summarized in Table 5-14:

**Table 5-14. Technical Performance Comparison**

Parameter	AeroLead™	NIOSH 7082	NIOSH 7105	NIOSH 7701
Technology	ASV	Flame AAS	GFAAS	ASV
Low Detect Limit	0.25 ug	2.5 ug	0.001 ug	0.31ug
Accuracy	49.4%	±17.6%	not determined	±19.3%
Precision	75%	0.072	not determined	0.094
Interferences	Cu			Cu
Sampling	Automatic AAM Separate PBZ	Separate Step	Separate Step	Separate Step
Extraction	Automatic 92% Efficient	Separate Step	Separate Step	Separate Step
Analysis Time	7-10 minutes	24 hrs.	24 hrs.	not determined
Portability	YES	NO	NO	NO

AAM-Ambient Air Monitor

PBZ-Personal Breathing Zone

GFAAS- Graphite Furnace AAS

ASV-Anodic Stripping Voltammetry

AAS-Atomic Absorption Spectrometry

Complete evaluation sheets are provided for the NIOSH methods listed above in Appendix G.

## 6. Cost Assessment

### 6.1 Cost Performance

The estimated cost of purchasing, operating, and maintaining the AeroLead instrument is provided in Table 6.1 below. The estimate assumes an instrument life of 5 years and two 8-hour monitoring events per week with 20 samples taken during the event. Labor costs are assumed to be \$25.00/hr.; 4 hours per day of labor is estimated to be required to maintain, calibrate and operate the AeroLead instrument. The cost of an instrument is \$9600. The 5-year amortized per sample cost given these assumptions can be thusly calculated:

$$\$9600 / (20 \text{ samples/event} * 2 \text{ events/week} * 52 \text{ weeks/year} * 5 \text{ years}) = \$0.923/\text{sample}$$

**Table 6-1. AeroLead™ User Cost Estimate**

<i>Cost Data Table for the AeroLead™ Airborne Lead Analyzer</i>					
Costs by Category					
Startup		Operation & Maintenance		Demobilization	
Activity	\$	Activity	\$	Activity	\$
Capital Equipment	\$9600.00	Labor (calibration/operation – 4 hours @ \$25/hr)	\$100.00 per day	Removal of Equipment	\$0.00
<b>5-year Amortized Equipment Cost per Sample</b>	<b>\$0.92 per sample</b>	<b>Labor (20 samples per day)</b>	<b>\$5.00 per sample</b>		
Site Preparation	\$0.00	Analytical Services	\$0.00	Site Restoration	\$0.00
		Facility Modifications	\$0.00		
		Utilities	\$0.00		
		Operation Training (1 hr. per person)	\$20.00		
		<b>Consumables &amp; Supplies</b>	<b>\$2.77 (per sample)</b>		
		Ancillary Equipment	\$0.00		

The total per sample cost is then \$0.092 + \$2.50 + \$2.77= \$8.69.

The consumable & supplies cost estimate is based on electrode life, ion exchange life, and membrane price information gathered during the evaluation phase of the project. The supplies cost requirements are broken down in the following Table 6-2.

**Table 6-2. AeroLead™ Consumables Cost Estimate**

Component	User Cost (\$)	Sample Life	Cost per Sample
Reference Electrode	\$25.00	40*	\$0.625
Auxiliary Electrode	\$20.00	100*	\$0.20
Working Electrode	\$25.00	20	\$1.25
Membrane	\$0.57	1	\$0.57
Electrode Solution	10.00	100	\$0.10
Ion Exchange Assembly	\$10.00	500	\$0.02
<b>Total Cost per Sample</b>			<b>\$2.77</b>

**6.2 Cost Comparisons to Conventional and Other Technologies**

The technologies most commonly used to analyze airborne lead are Flame Atomic Absorption Spectrometer (FAAS) and Graphite Furnace Atomic Absorption Spectrometer (GFAAS). These methods require costly equipment and highly trained personnel. It is assumed here that a user would send samples to a certified laboratory for 3-5 day turnaround time analysis. The total cost per sample assumes 20 samples/day, a 5-yr. Instrument life, instrument in use two 8-hour days/week, and labor at \$25/hr. The 5-year amortized per sample cost given these assumptions is:

$\$400.00 / (20 \text{ samples/event} * 2 \text{ events/week} * 52 \text{ weeks/year} * 5 \text{ years}) = \$0.04/\text{sample}$ . The total cost per sample is then  $\$0.04 + \$2.50 + \$25.00 + \$1d.00 = \$28.54$ .

**Table 6-3. Comparative Methods Cost Estimate**

<i>Cost Data Table for NIOSH Method 7105 or 7082</i>					
Costs by Category					
Startup		Operation & Maintenance		Demobilization	
Activity	\$	Activity	\$	Activity	\$
Capital Equipment	\$400.00	Labor (sample collection)	\$25.00 per hr	Removal of Equipment	\$0.00
Site Preparation	\$0.00	Analytical Services (per sample)	\$25.00	Site Restoration	\$0.00
5-year Amortized Equipment Cost per Sample	\$0.04 per sample	Labor (20 samples per day)	\$2.50 per sample		
		Facility Modifications	\$0.00		
		Utilities	\$0.00		
		Operation Training (1 hr. per person)	\$20.00		
		Consumables & Supplies (per sample)	\$1.00		
		Ancillary Equipment	\$0.00		

Therefore, the overall realized savings according to NFESC estimations:

- Assuming 170,000 DoD LBP sites (50%)
- Assume 32 samples per site (\$913.28 vs. \$278.08)
- Cost savings of \$635.20 per site
- **DoD Savings = \$107,984,000**

## **7. Regulatory Issues**

### **7.1 Approach to Regulatory Compliance and Acceptance**

Under this program, the AeroLead™ was compared against standard reference materials using standard regulatory approved analytical methods. The specification used to evaluate the performance of the instrument was ASTM E1775. The specification outlines the performance criteria very clearly. Had the AeroLead™ met the required performance criteria, the method would have been eligible for full regulatory acceptance.

## **8. Technology Implementation**

### **8.1 DOD Need**

DOD real estate records indicate that there are more than 2,600 munitions related sites containing lead, and there are over 101 million square feet of Army buildings that were built before the 1978 ban on lead-based paint (LBP). DOD is responsible for maintaining 166,000 family housing units; 65% of which are estimated to contain LBP and require abatement. Environmental responses at these sites require EPA-mandated monitoring (40 CFR 50) as well as verification of worker safety according to OSHA regulations.

### **8.2 Transition**

The AeroLead™ instrument will require additional demonstration & validation testing to determine instrument accuracy before it can be considered a commercially viable product. A method must also be developed and accepted by NIOSH, which describes the operation and illustrates compliance with specification ASTM-E1775. The manufacturer has conducted additional field and laboratory tests during 2001 to try and resolve precision and accuracy deficiencies. The issues are not completely resolved at this time.

Currently, design improvements to the AeroLead™ are being made by the manufacturer and will be field tested by interested commercial users. It would be helpful to perform a third method of lead analysis to allow the research team to evaluate the validity of both the AeroLead™ and the comparative data. The AeroLead™ instrument has proven reliable in the laboratory in terms of operation, accuracy, and precision using aqueous samples, but has not been proven reliable for real-world or artificially-produced airborne lead determination.

Throughout the extensive development and field testing of the AeroLead™ instrument, many sectors of commercial industry provided comments, including lead abatement supervisors and shooting range managers. Their response to the instrument was overwhelmingly positive. All those interviewed were interested in using the AeroLead™ instrument upon successful completion of the demonstration process. Potential users are particularly interested in the ability to improve employee safety and reduce potential litigation by having occupational lead concentrations reported in near-real time.

## 9. Lessons Learned

The rigorous conduct of each field and laboratory test showed variability of results that did not surface in preliminary testing of the instrument. From this, several valuable lessons can be passed on:

- Perform additional testing using real world materials under controlled laboratory conditions prior to additional field tests. Do not rely on dissolved lead solutions to determine the reliability of the instrument; instead use known concentrations of lead particles.
- Choose the comparative method and laboratory conducting the comparative sample analyses carefully. Use methods which provide detection levels commensurate with the samples collected (i.e., low detection limits for sites with low lead levels)
- When sampling in air handling systems, choose sample locations which allow the sample cartridge to be installed inverted to eliminate the potential for sample contamination during installation.
- Perform airborne lead controlled tests early in the demonstration phase when possible to more easily identify issues.

## 10. References

1. *Interim Report Field Validation of Real Time Airborne Lead Analyzer, NAB Little Creek Field Test*, Naval Facilities Engineering Service Center / Environmental and Life Support Technology, 25 February 2000.
2. *Interim Report Field Validation of Real Time Airborne Lead Analyzer, Twentynine Palms Field Test*, Naval Facilities Engineering Service Center / Environmental and Life Support Technology, 9 August 2000.
3. *Lead by Flame AAS: Method 7082, Issue 2*, NIOSH Manual of Analytical Methods, 4<sup>th</sup> Edition, 15 August 1994.

4. *Lead by GFAAS: Method 7105, Issue 2*, NIOSH Manual of Analytical Methods, 4<sup>th</sup> Edition, 15 August 1994.
5. *Lead by Ultrasound/ASV: Method 7701*, NIOSH Manual of Analytical Methods, 4<sup>th</sup> Edition, 15 January 1998.
6. *Standard Guide for Evaluating Performance of On-Site Extraction and Field-Portable Electrochemical or Spectrophotometric Analysis for Lead: Designation ASTM-E1775-96*, 1996

# **APPENDIX A**

## **Points of Contact**

**Contracting Organization:** Environment and Life Support Technology (ELS)  
6600 E. Lookout Drive  
Parker, CO 80138  
303-840-4221

**ELS Principal Investigator:** Clifford D. Jolly  
6600 E. Lookout Drive  
Parker, CO 80138  
303-840-4221 (phone)  
303-792-2353 (fax.)

**ELS Test Engineer:** David G. Staat  
6600 E. Lookout Drive  
Parker, CO 80138  
303-840-4221 (phone)  
303-792-2353 (fax.)

**NFESC PI:** Leslie Karr  
Naval Facilities Engineering Service Center  
1100 23<sup>rd</sup> Avenue ESC411  
Port Hueneme, CA 93043  
805-982-1618

**NFESC Test Engineers:** Bryan Harre  
Naval Facilities Engineering Service Center  
1100 23<sup>rd</sup> Avenue ESC411  
Port Hueneme, CA 93043  
805-982-1795

Barbara Sugiyama  
Naval Facilities Engineering Service Center  
1100 23<sup>rd</sup> Avenue ESC411  
Port Hueneme, CA 93043  
805-982-1668

**Third Party Oversight:** John Kornuc, PhD.  
Anteon Corporation  
1701 Pacific Ave.  
Oxnard, CA 93033  
805-982-1615

**Appendix B**  
**Oak Ridge Field Test - Day 1**  
**AeroLead™ Graphical Data**

**Appendix C**  
**Oak Ridge Field Test - Day 2**  
**AeroLead™ Graphical Data**

**Appendix D**  
**Oak Ridge Field Test - Day 3**  
**AeroLead™ Graphical Data**

**Appendix E**  
**Oak Ridge Field Test**  
**Test Plan & Tabular Data**

**Appendix F**  
**AeroLead™ Calibration Procedure**

**AeroLead™ Preparation/Calibration Procedure**  
Revision B 6/1/00

**Preparation**

1. Remove analyzer and collector from container. Plug in power supply if required and install communication cabling from the analyzer to a computer (if required).
2. Open file AECollect.xls in Microsoft Excel to prepare to collect data.
3. Remove side panel of instrument - open syringe valve to run position and remove collector cap – replace side panel.
4. Install collector on analyzer and turn power ON.
5. Verify proper extraction solution level by pressing ALT+5 on front panel of the analyzer. Allow syringe to push solution into detector until motor stops. The extraction solution should reach the fill line on the collector. If not, add solution as necessary using a syringe.
6. Once proper solution level is achieved, press ALT+4 and allow the syringe to fully retract. The analyzer is now ready for calibration.

**Calibration**

1. Press the CAL1 button twice. The instrument will begin the calibration process. Follow the instructions on the instrument display to perform calibration.
2. Upon completion of successful calibration, record the peak current and voltage shown on laptop.
3. Press CAL2 twice. The analyzer will now check the calibration performed in step 2.
4. Upon completion of verification, note the lead value shown on the display. The value must be between 3.2ug-4.8ug to consider the verification step successful.
5. If the verification fulfills the requirements in step 4, the analyzer is ready to sample. If it does not, repeat the verification step by pressing CAL2.
6. If a successful verification cannot be achieved in two attempts, return to step 1 to re-calibrate.

**Appendix G**  
**Comparative Methods**  
**(NIOSH 7082, 7105 & 7701)**

# **Appendix H**

## **ASTM-E1775 Specification**

# **Appendix I**

## **Comparison Test Data**