

ESTCP Cost and Performance Report

(CP-9507)



Measurement of Lead in Drinking Water

November 1998



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LIST OF ACRONYMS

DoD	Department of Defense
EPA	U.S. Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
GF-AA	Graphite Furnace Atomic Absorption
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
µg/L	Microgram per Liter
ml	Milliliter
NCCOSC	Naval Command, Control and Ocean Surveillance Center
NPDES	National Pollution Discharge Elimination System
NSB	Naval Submarine Base
ppb	part per billion
PSA	Potentiometric Stripping Analysis
RDTE	Research, Development, Test and Evaluation
R ²	Statistical Correlation Coefficient

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Technical material contained in this report has been approved for public release.

EXECUTIVE SUMMARY

The U.S. Department of Defense (DoD) is responsible for hundreds of sites with potential drinking water contamination. The process of measuring lead contamination at these sites is both costly and time-consuming. The purpose of this Environmental Security Technology Certification Program (ESTCP) project was to validate the field performance of the Metalyzer™ 5000, a new instrument that measures lead concentrations in water. Use of the Metalyzer™ 5000 could reduce analytical costs, speed DoD compliance with drinking water standards, and permit a more rapid, thorough sampling procedure. The Metalyzer™ 5000 has been validated for lead and a new project is underway to validate its performance in detecting other metals.

The Naval Command, Control and Ocean Surveillance Center (NCCOSC) Research, Development, Test and Evaluation (RDTE) Division demonstrated the Metalyzer™ 5000 for the measurement of lead in drinking water at the San Diego Naval Submarine Base (NSB) building 100 complex. The plumbing system for drinking water in this complex dates back to 1927, where copper piping was soldered using a high-content lead solder.

The Metalyzer™ 5000 utilizes a Potentiometric Stripping Analysis (PSA) system and performs automated lead analysis on-site in semi-real time intervals. The system is designed to quickly and cost-efficiently determine the amount of lead, if any, in drinking water. In the future, the Metalyzer™ 5000 system will be modified to handle testing for other metals, such as chromium and mercury.

The Metalyzer™ 5000 system comprises four major components: a computer, acquisition and analysis software, a computer-controlled potentiostat, and sample handling components.

The primary objectives of the ESTCP demonstration were to evaluate the PSA technology in the following areas: (1) performance compared to conventional lead analysis methods; (2) the logistical and economic resources to operate the technology; (3) data quality and conformity with accepted regulatory methods; (4) the range of usefulness in which the technology can be operated.

Generally, the PSA technology produced results that complement conventional methods for detecting the presence and amount of lead in drinking water. The data achieved a correlation coefficient (R^2) of at least 0.95 when compared with the standard graphite furnace atomic absorption spectroscopy (GF-AA) and the inductively coupled plasma mass spectrometry (ICP-MS). Also, when tested 19 times against itself for accuracy, the standard deviation for the data was 3.17%. In addition to providing results consistent with regulatory-accepted methods as well as with itself, the PSA technology provides in-field analyses and can potentially cost less than half the amount of conventional methods.

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1.0 TECHNOLOGY DESCRIPTION

1.1 TECHNOLOGY BACKGROUND

The technology demonstrated was a prototype automated laboratory lead analyzer, the Metalyzer™ 5000, based on the electrochemical technique of Potentiometric Stripping Analysis (PSA) pioneered by D. Jagner in the early 1970s. Recent advances in electronics and computer software now enable the technique to perform completely automated metals analyses, specifically lead, to 1 part per billion (ppb) in approximately five minutes. This high sensitivity can be partially attributed to the coupling effect of preconcentration steps and advanced measurement procedures.

The conventional method for detecting and analyzing lead in drinking water consists of collecting a predetermined number of samples, based on potential sources, followed by sample shipment to a certified laboratory for analysis. Turn-around time for results is typically two to four weeks and further testing, and delays, may be required if the source contamination can not be determined.

1.2 DESCRIPTION

The Metalyzer™ 5000 PSA system consists of (1) a computer; (2) custom control and data acquisition and analysis software; (3) a custom computer-controlled potentiostat and data acquisition circuitry; and (4) a custom flow-through electrochemical cell module and sampling handling components.

The instrument provides the capability to perform on-site, discrete analyses or automatic, continuous monitoring at programmed intervals and is designed for use by non-technical personnel. The Metalyzer™ 5000 system permits near real-time tracking of lead contamination throughout a distribution system, expanded monitoring in support of remediation efforts, and lead measurements where sources must be frequently monitored over extended periods.

As may be seen in Figure 1, the Metalyzer™ 5000 system comprises two electrodes that are immersed in the test sample. The working electrode consists of a glassy carbon rod on which a thin mercury film is deposited. When the electrode is exposed to the sample, a negative voltage is applied which reduces the lead and forms an amalgam on the electrode. Depending on the lead concentration, this phase can last from one second to two minutes. For lead concentrations in the 1-30 microgram per liter ($\mu\text{g/L}$), a 30 second plating time is adequate.

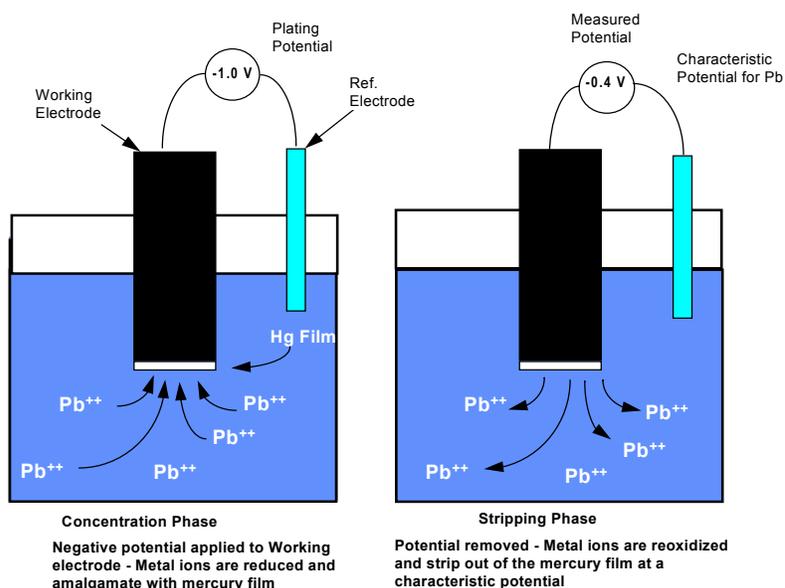


Figure 1. Potentiometric Stripping of Lead.

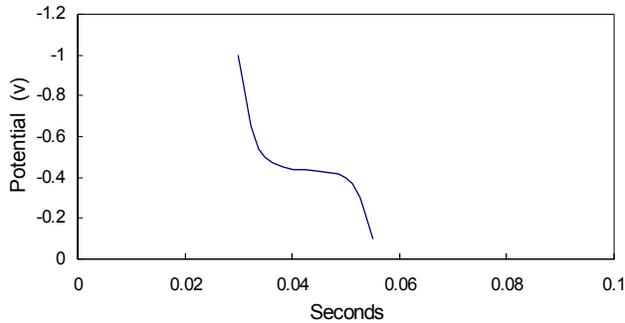


Figure 2. A Potentiometric Stripping Curve.

After plating is complete, the voltage is removed and the potential of the electrode is measured. The potential drops until it reaches the characteristic value for lead oxidation. At this voltage, the lead is oxidized and stripped out of the mercury film. The potential remains constant until all the lead is oxidized. At this point, a plateau occurs in the voltage versus time graph (see Figure 2). The width of this plateau (in seconds) is proportional to the original lead concentration in the solution.

To determine the true concentration of the lead, a standard curve is generated by adding known quantities of lead to the test sample. The measurement is then repeated. This entire process is fully automated; no operator intervention is necessary.

When the concentration of the lead has been determined (a process that typically takes less than three minutes) the instrument displays and logs the concentration and relevant measurement statistics. The instrument then pumps out the test sample, rinses the cell, and waits for either an operator command, external signal, or the next programmed sampling interval.

1.3 TECHNOLOGY APPLICATIONS

The Metalyzer™ 5000 was developed in response to DoD's need, as well as a growing need in the private sector, to test for and quantify lead levels in drinking water at facilities that do not comply with federal regulations. Buildings on DoD property have been removed from service, and bottled water has been brought into many others. Within DoD, the reversion of buildings to civilian use via the Base closure process may require restoration of potable water systems. The testing requirements for these facilities will generate the need to conduct thousands of analyses at great cost in funding and time for DoD over the next few years.

The conventional method for identifying lead in drinking water, as mentioned previously, entails collecting a set number of samples and then shipping the samples to a certified laboratory for analysis. The turn-around time involved, two to four weeks, hinders quantification and efforts for a timely remediation plan. An instrument that can perform rapid, in-field analysis will have a tremendous impact in reducing both analytical costs and compliance time for all DoD facilities.

With modifications to the device, the Metalyzer™ 5000 system will also be able to test for other metals that contaminate drinking water (the system is currently capable of measuring over 40 different metals).

1.4 ADVANTAGES OF TECHNOLOGY

The Metalyzer™ 5000 system is an in-field device that is used for detecting and quantifying the amount of lead in drinking water. Though the method has not yet been accepted by regulatory agencies, it is designed to replace the conventional methods of sampling, shipping, and testing in a laboratory.

Metalyzer™ 5000 has proven a reasonable accuracy when compared with conventional methods resulting in correlation coefficients of 0.95 or higher in side-by-side tests. The Metalyzer™ 5000 apparatus exhibits low variance when measuring typical concentrations of lead in drinking water. (The median value for lead in drinking water is 3.7 µg/L in public water supplies in the 100 largest cities; the regulatory limit is 15 µg/L). Furthermore, with slight alterations to the operating procedure, measurements in the single digit ng/L range are possible. The Metalyzer™ 5000 is also extremely versatile, exhibiting the ability of in field use and near real-time delivery of data. Finally, Metalyzer™ 5000 system is relatively easy to operate and training employees takes approximately two hours.

1.5 LIMITS OF TECHNOLOGY

As with all trace metal measurement techniques, the major weakness is in matrix effects interfering with the measurement. Interference for lead measurements occurs for samples that include high concentrations of organic compounds, solids, or salts. The levels at which these begin to interfere are well above the standards set by the Safe Drinking Water Act. [Ref 1] Concentrations of thallium (I) above 100 µg/L have also been found to interfere with the measurement of samples containing 10 µg/L of lead.

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2.0 DEMONSTRATION DESIGN

2.1 PERFORMANCE OBJECTIVES

The contaminant measured by the analyzer in the demonstration at the San Diego NSB was lead ions in drinking water to a minimum level of 5 ppb. The data from the PSA apparatus should have a correlation coefficient on 0.95 when compared with the GF-AA and ICP-MS methods.

2.2 PHYSICAL SETUP AND OPERATION

The instrument requires little in terms of infrastructure. It requires a 110v electrical outlet and approximately 10 sq. ft. of table space. For this demonstration two individuals were used, a sample collector and an instrument operator. The demonstration was conducted on a Saturday starting at 9:00 a.m. and concluded at 6:00 p.m. that evening. The instrument generates process waste containing a dilute solution of acid, lead, and mercury. A single run will produce a 2.7 milliliter (ml) solution with a pH of 2. This waste solution contains approximately 300 ppb of mercuric chloride and 33 ppb of lead. From setup, sample collection to final results should take less than 15 minutes. The hazardous waste generated by the instrument (approximately 2.5 ml per run) is automatically collected in a waste container.

2.3 SAMPLING PROCEDURES

Fourteen water samples were collected from the building. The samples were then split (see Figure 3) and preserved with acid. Each sample was clearly labeled as to the location of its source, the date and time it was collected, and the name of the collector. One-half of each sample was analyzed off-site by two independent water quality testing laboratories. The other half of the sample was analyzed by the PSA system.

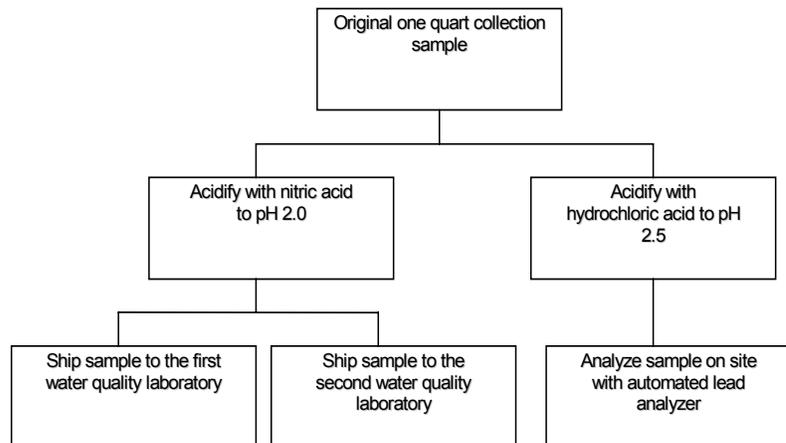


Figure 3. Flow Chart of Water Sample Splitting.

The samples that were sent to the laboratories were acidified to a pH of 2.0 using nitric acid. The remaining sample was acidified to a pH of 2.5 and brought to the instrument for analysis. The analyzer processed the samples and the data was stored on disk. These results were compared with the results from the testing laboratories.

2.4 ANALYTICAL PROCEDURES

The samples were analyzed on site using PSA, splits of the sample were preserved and analyzed using GF-AA and ICP-MS. Specifics pertaining to sampling and analysis can be found in the Demonstration Plan for the Automated Metals Analyzer [Ref. 2]

2.5 DEMONSTRATION SITE/FACILITY BACKGROUND

The four criteria used for site selection were:

1. Availability of potable water and electrical power,
2. A minimum of 10 sampling sources,
3. The ability to shut off all faucets for 24 hours preceding measurement (as per U.S. Environmental Protection Agency (EPA) sampling protocol),
4. Eight hours of unrestricted access to the facilities during testing.

The demonstration site was located at the San Diego Naval Submarine Base (NSB). The area tested was the Building 100 complex. This complex was initially built in 1927 as a naval gun battery. It has since been converted to general office use. The complex also includes other mixed use buildings containing offices and storage, and a warehouse facility that was constructed in 1988.

2.6 DEMONSTRATION SITE/FACILITY CHARACTERISTICS

The age of the drinking water plumbing system ranged from 1927 copper pipe soldered with high-content lead solder to 1988 copper piping soldered with lead free solder. The faucets tested included interior and exterior faucets, refrigerated water fountains, and two non-potable water faucets whose source of water was unknown.

3.0 PERFORMANCE ASSESSMENT

3.1 PERFORMANCE DATA

A comparison between the results obtained by ICP-MS and GF-AA are shown in Figure 4. Ideally the results would lie along a 45° line crossing at the zero axis with a correlation coefficient of 1.0. For each sample, the GF-AA instrument's values were lower than the values obtained using the ICP-MS instrument. However, a correlation coefficient (R^2) of 0.99 indicates that this discrepancy is probably due to differences in initial calibration rather than an inherent instrument error. Comparing GF-AA values with PSA (Figure 5) gives similar results, with the GF-AA generally measuring values lower than PSA again with a high correlation coefficient. Similarly, in Figure 6, the ICP-MS results are generally higher than PSA. Looking at all three measurements together in Figure 7, it can be seen that where large discrepancies between ICP-MS and GF-AA exist the PSA measurements always fall between.

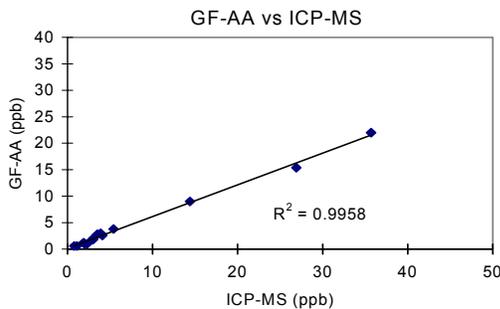


Figure 4. A Comparison of Split Sample Results between GF-AA and ICP-MS. Each data point represents one sample, the x value is the amount of lead measured by the ICP-MS, and the y axis is the amount of lead measured by the GF-AA.

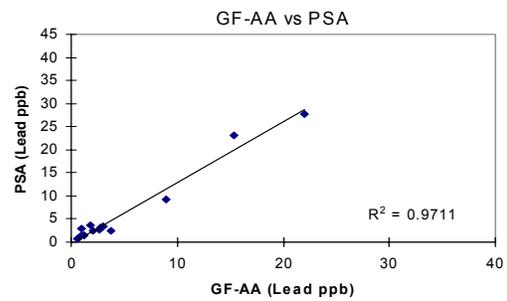


Figure 5. A Comparison of Split Sample Results between GF-AA and PSA. Each data point represents one sample, the x value is the amount of lead measured by the GF-AA, and the y axis is the amount of lead measured by PSA.

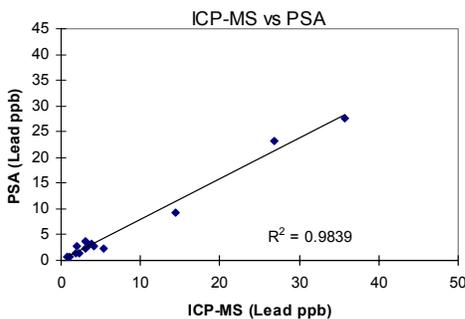


Figure 6. A Comparison of Split Sample Results between ICP-MS and PSA. Each data point represents one sample, the x value is the amount of lead measured by the ICP-MS, and the y axis is the amount of lead measured by PSA.

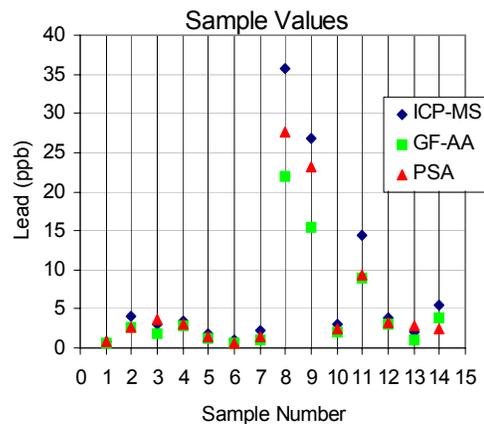


Figure 7. The Lead Levels for Each Sample Measured by ICP-MS, GF-AA, and PSA Methods.

These results indicate that within experimental error, field measurements using PSA will give equivalent results as those of traditional methods. It has been past experience that the discrepancies between the GF-AA and IPC-MS laboratory results are not unusual when conducting comparisons between laboratories. What should be emphasized is the excellent linearity (>0.97) between all three methods. More consistent calibration protocols between the laboratories would likely produce lead levels with less spread.

3.2 DATA ASSESSMENT

A series of laboratory tests were conducted to assess the performance of PSA in measuring lead quantities in drinking water. The water was collected from various sources within the Las Cruces, New Mexico Water Utility District. This area uses ground water as a source. A single sample was measured 19 times by the PSA system. Figure 8 shows the relative standard deviation of all measurements, amounting to less than 3.2%. Figure 9 is a correlation between PSA and GF-AA of a single sample spiked to 15 different levels (see Table 1) of lead and measured 3 times. This analysis resulted in a correlation between PSA and GF-AA of 95%. The linearity of the instrument range was tested from 0 to 300 ppb lead concentrations. To avoid biasing the results with the data manipulation software built-in to the instrument, which outputs a running average of the signal counts, the actual unaveraged analog to digital counts were collected. Using the running average of the signal counts would have lowered the signal to noise ratio improving the linearity at the lower concentrations. The unaveraged voltages that were within the characteristic stripping potential (see Figure 2) were summed and that value was plotted for each of the concentrations measured. Within the 0-300 ppb range, a correlation of 99% was calculated indicating excellent linearity.

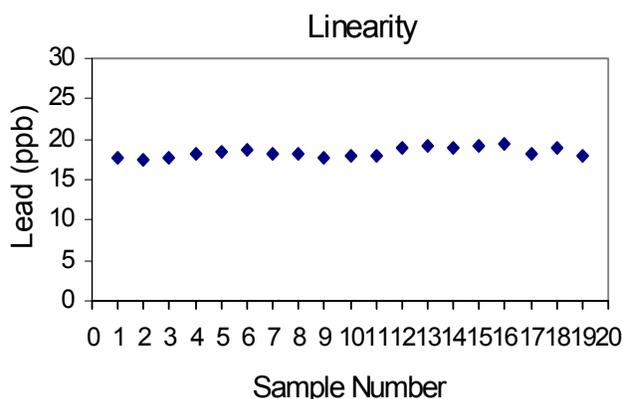


Figure 8. A Single Sample of Drinking Water Measured 19 Times. (The relative standard deviation for this data set is 3.17%.)

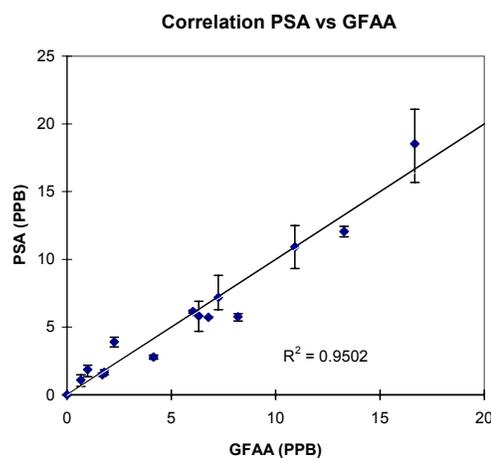


Figure 9. Correlation of Drinking Water Samples Spiked to Different Levels of Lead. (Each sample was measured three times, the high low and average values are plotted.)

Table 1. Correlation of GF-AA and PSA with a Spiked Sample of Lead.
(All values are in parts per billion.)

Correlation PSA vs. GF-AA			
Sample	Spike	GFAA	PSA
blank	0.0	0.04	0.02
1	1.0	0.66	1.09
2	1.0	0.99	1.86
3	1.5	1.69	1.48
4	1.7	1.79	1.66
5	3.0	2.26	3.90
6	3.0	4.14	2.78
7	6.0	6.03	6.15
8	6.0	6.31	5.82
9	6.5	6.78	5.72
10	7.0	8.19	5.77
11	7.0	7.25	7.19
12	11.0	10.92	10.92
13	12.0	13.28	12.05
14	17.0	16.67	18.52

An interference study of 15 metals at 50 and 100 ppb concentrations was conducted. Concentrations of metals typically found in drinking water systems are listed in Table 2. The original sample, for each metal ion tested, was spiked to 10 ppb lead and split three ways. Aliquots two and three were spiked with the interfering ion to 50 and 100 ppb concentrations respectively. Each sample was measured twice. The variance within each aliquot was calculated and the variance of the data from both aliquots together was calculated. For example, with the 10 ppb interfering ion, if the variance of the data from aliquots one and two combined was greater than the largest variance within aliquots one or two, that ion can be considered to be an interferent. The results of this test are shown in Table 3.

Table 2. Range in Quality of Finished Water in Public Water Supplies of the 100 Largest Cities. (ND means non detect, NA means not available.)

Metal	Maximum (µg/L)	Median µg/L)	Minimum (µg/L)	Reg. Level (µg/L)
Aluminum	1,500	54	3.3	NA
Antimony	NA	NA	NA	6
Arsenic	NA	NA	NA	50
Cadmium	NA	NA	NA	5
Calcium	145	26	0	NA
Copper	250	8.3	0.6	1,300
Chromium	35	.43	ND	100
Iron	1,700	43	1.9	NA
Lead	62	3.7	ND	15
Manganese	1,100	5.0	ND	NA
Nickel	34	2.7	ND	100
Thallium	NA	NA	NA	2

From Table 3 it can be seen that thallium appears to be an interfering ion at both 50 and 100 ppb concentrations. At 100 ppb, cadmium is a possible interferent. This is not caused by any chemical interaction but is due to the close proximity of the oxidation voltage of the two metals. At high concentrations, the cadmium and lead potentiometric curves begin to merge making it difficult to separate the two. Table 2 indicates that for typical levels of seen in drinking water, interference from either thallium or cadmium should not be a problem in typical drinking water supplies. Nickel and indium appear to cause a slight interference at a 50 ppb concentration. This may be an anomaly which would not appear with a larger data set since nickel and indium at 100 ppb do not act as interferents. Antimony and aluminum in the 100 ppb-range, and calcium in the 50 ppb-range case were only measured once. The variance in the two measurements in these three cases was below 0.20 and the corresponding concentration test showed no interference indicating that these ions are not interferents at 50 or 100 ppb concentrations.

In conclusion, PSA compares very favorably to current standard methods with excellent linearity up to 300 ppb. Interference with other metals likely to be found in drinking water are minimal. This data indicates that PSA is an appropriate method for measurement of lead in drinking water.

Table 3. Interference Study of 15 Metals at 50 and 100 ppb Concentrations.

(a) 50 ppb interference results

Ion	Measurement Variance of Lead Samples		
	Aliquot with 10 ppb Lead	Aliquot with 10 ppb Lead and 50 ppb Interfering Ion	Both Aliquots
Cd (II)	0.06	0.05	0.04
Tl (I)	2.64	1.18	3.26
Cu (II)	0.14	0.09	0.08
Zn (II)	0.41	1.09	0.57
Bi (III)	1.07	0.76	0.65
Sb (III)	1.28	1.74	1.24
Sn (IV)	1.41	0.67	0.73
In (III)	0.02	0.02	0.12
Al (III)	1.03	0.10	0.38
Ca (II)	*	*	0.03
As (III)	1.00	0.23	0.41
Fe (III)	1.12	1.76	1.04
Ni (II)	0.08	0.10	0.19
Cr (VI)	0.96	2.71	1.26
Mn (II)	0.11	0.11	0.07

(b) 100 ppb interference results

Ion	Measurement Variance of Lead Samples		
	Aliquot with 10 ppb Lead	Aliquot with 10 ppb Lead and 50 ppb Interfering Ion	Both Aliquots
Cd (II)	0.05	0.04	0.33
Tl (I)	0.42	0.14	2.59
Cu (II)	0.17	0.41	0.38
Zn (II)	0.18	0.36	0.18
Bi (III)	1.65	1.72	1.13
Sb (III)	*	*	0.20
Sn (IV)	0.64	2.40	1.35
In (III)	0.55	1.05	0.63
Al (III)	*	*	0.04
Ca (II)	0.68	0.33	0.40
As (III)	1.76	2.15	1.46
Fe (III)	0.01	0.20	0.17
Ni (II)	0.63	1.38	0.72
Cr (VI)	0.11	0.01	0.11
Mn (II)	0.64	0.16	0.27

* sample was measured only once

3.3 TECHNOLOGY COMPARISON

For drinking water PSA compares very favorably to ICP-MS and GF-AA. Correlation of data (Figures 4, 5, and 8) always results in coefficients above 0.95. The Metalyzer™ 5000 has several advantages over ICP-MS and GF-AA instruments. The Metalyzer™ 5000 is portable and capable of unattended field operation and requires a minimal technical level to operate. In contrast GF-AA and ICP-MS instruments are large laboratory instruments requiring a very high level of expertise and substantial infrastructure to support plus they are not well suited to automated long term monitoring.

4.0 COST ASSESSMENT

4.1 COST PERFORMANCE

Table 4 is an estimate of the costs incurred over an expected 10-year life span of the instrument assuming a processing rate of 100 samples per month. The labor rate was fixed at \$50 per hour resulting in a total life cycle cost of \$207K.

Table 4. Cost Performance Table for the Metals Analyzer over a 10 Year Life Span.

Cost Performance					
Cost by Category					
Start-up		Operation & Maintenance		Demobilization	
Activity	\$K	Activity	\$K	Activity	\$K
Capital Equipment	25.0	Labor	150.0	Disposal (just throw it away)	0.0
		Consumables & supplies	18.0		
		Effluent disposal	12.0		
		Training required to operate equipment	2.0		

4.2 COST COMPARISONS

Costs are best compared with current practice for determining lead levels in drinking water (Table 5). Typically samples are collected and preserved by acidifying the sample with nitric acid, the samples are packed in ice and shipped over-night to a trace metal laboratory. Cost for the laboratory analysis can vary from \$20 to \$75 per sample depending on the laboratory and the volume of samples. Even at the lower \$20 per sample PSA compares very favorably at less than half the cost of conventional methods. Typically the turnaround time for conventional methods is 2-4 weeks verses 15 minutes with PSA, this allows immediate resampling if results warrant it. Using traditional methods resampling time could take over a month. GF-AA and ICP-MS costs are similar.

Table 5. Cost Breakdown per Sample between Traditional Laboratory GF-AA Analysis and On Site PSA Analysis.

Cost Breakdown Per Sample			
GF-AA		PSA	
Activity	Cost (\$)	Activity	Cost (\$)
Sample Collection (\$50/hr)		Sample Collection (\$50/hr)	
– 5 min collection	4.17	– 5 min collection	4.17
– 10 min preservation, labeling packing	8.34	– 10 min operator time	8.34
– shipping	1.86		
Sample Analysis (contract with Laboratory)	50.00	Consumables	
		– Reagents	1.25
		– Electrodes	0.25
		Capital Cost of Instrument	
		– \$25k/40,000 samples	0.63
		Haz/Mat Disposal (3ml)	1.00
Total	64.37		15.64

5.0 IMPLEMENTATION ISSUES

5.1 COST OBSERVATIONS

As indicated in the previous section, the PSA system compares very favorably against the conventional methods when comparing costs. The major issue involved with keeping the price-per-sample costs to a minimum with the PSA device is how often it will be utilized. Because DoD had over 250,000 violations of the Safe Water Drinking Act between 1991 and 1992 and over 300,000 violations for 1993 and 1994, there is a potential for this device to perform enough samples to compensate for the relatively large capital investment for the PSA system.

5.2 PERFORMANCE OBSERVATIONS

In summary, the PSA system met or exceeded all the levels of performance listed in the Demonstration Design section. Specifically, the data for the PSA had at least a 0.95 correlation coefficient when compared with both the GF-AA and the ICP-MS methods. Also, it proved its consistency during an accuracy test where after testing the same sample 19 times, it achieved only a 3.17% standard deviation for the entire data set.

5.3 REGULATORY ISSUES

EPA Cincinnati has developed a protocol for nationwide approval of new or revised methods for inorganic analyses in national primary drinking water regulations monitoring. They were contacted early in the project. EPA's estimate of approval of a new standard was \$375K requiring 3 years for final acceptance. Based on this, it was realized that ESTCP would not be able to fund full acceptance. It was agreed that EPA will pursue regulatory acceptance using data provided by this project. Due to the high costs and lengthy approval process, EPA is now developing a streamlined approval of analytical method protocol in response to the current Administration's Environmental Technology Initiative. The goal of the proposed protocol is to promote the use of innovative techniques while ensuring equivalency with approved methods. This holds promise of a much more rapid and less expensive approval of PSA for drinking water in the near future.

Currently, the PSA system is pursuing regulatory acceptance outside of ESTCP by incorporating the instrument into monitoring requirements stipulated in National Pollution Discharge Elimination System (NPDES) permits. There is current work with the Norfolk Naval Shipyard to incorporate use of the instrument to monitor trace metal for NPDES. Discussions with Puget Sound Naval Shipyard are underway for the use of the instrument for their NPDES monitoring requirements.

5.4 LESSONS LEARNED

As regulatory certification proceeds, it has become apparent that the initial cost estimate and timetable were wildly optimistic. This initial estimate was based on literature published by the EPA. Furthermore, the acceptance path is not clearly laid out and is subject to the latitude given regulatory personnel by the agency. Different and sometimes conflicting answers will come from different sources. Gaining a clear picture of the exact steps necessary to acquire EPA's approval would assist in transforming the PSA system from an innovative technology to a way to save money when testing drinking water for lead.

6.0 END-USER ISSUES

The Metalyzer™ 5000 is licensed and commercial production began in 1998.

7.0 REFERENCES

1. Safe Drinking Water Act, 1974 (and Amendments). <http://www.epa.gov/OGWDW/sdwa/sdwa.html>.
2. ESTCP Demonstration Plan for Automated Metals Analyzed, 3/12/1996.

APPENDIX A

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