

A Rapid Method for the Confirmatory Analysis of Airborne Lewisite by Solid Sorbent Sampling and Liquid Chromatography/Inductively Coupled Plasma-Mass Spectrometry.

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Introduction

- Dichloro(2-chlorovinyl)arsine was first synthesized in 1903 by Julius Arthur Nieuwland at Catholic University (Washington, D.C.) by reacting acetylene and arsenic trichloride. CPT Winford Lee Lewis optimized the synthesis and the agent was subsequently named Lewisite.
- Lewisite went into production in 1918, too late for deployment in World War I (WWI) as a blister agent. More than 45,000 tons of Lewisite are estimated to have been produced since 1903.
- Several nations have allegedly used Lewisite- or Lewisite-mustard-containing weapons in past conflicts. Therefore, concerns remain that Lewisite might be used to cause large numbers of injuries and deaths.
- In 1997, the United States implemented the Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction, committing itself to the destruction of all its chemical weapon stockpiles and production.

- In order to ensure worker and civilian safety and EPA, OSHA, State, and Local regulations compliance, air monitoring must be performed. This task is usually performed by near-real time (NRT) GC, and confirmed by an orthogonal technique, such as DAAMS.
- Any confirmatory method for Lewisite NRT alarms must be able to differentiate it from environmentally present arsenic species and quantify it and its hydrolysis/oxidation products at the Vapor Screening Limit (VSL) (0.003 mg Lewisite/m³ of air). Under plant conditions, Lewisite at the VSL will result in 15 ng Lewisite deposited on a single DAAMS tube. The State of Utah requires that the reporting level be set at 20% of the VSL alarm level or 3 ng of Lewisite per DAAMS tube.
- During a suspected agent release, confirmatory methods must be able to:
 - Rapidly support VSL NRT analysis with <3 ng Lewisite/tube sensitivity.
 - Be specific (speciation analysis).
 - Be unequivocal (no false positives/negatives).
 - Be orthogonal (completely different technology).
 - Be rugged and easily transferrable to other laboratories and instruments.

Existing NRT Monitoring for Lewisite

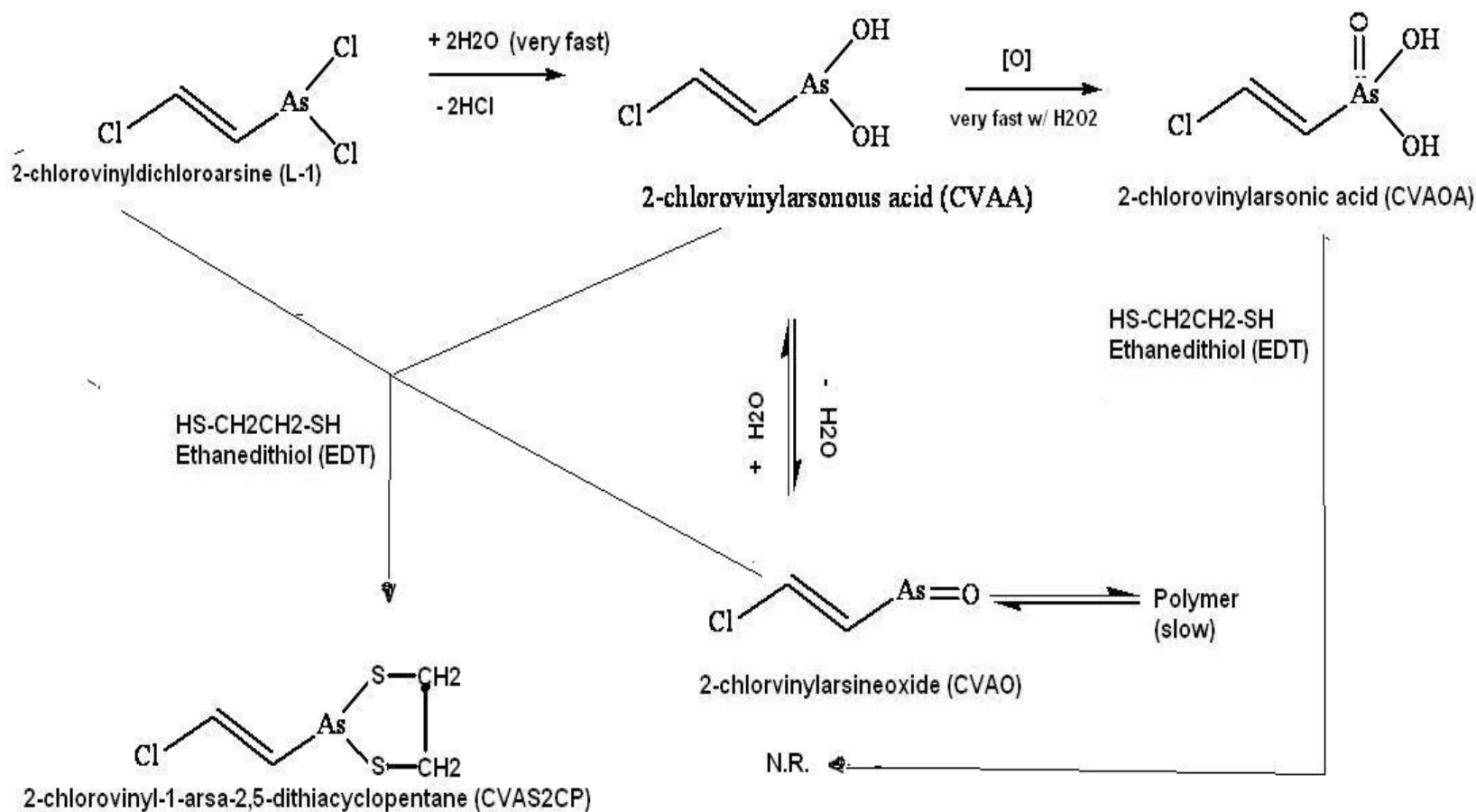
- The historical method utilized Depot Area Air Monitoring System (DAAMS) sampling equipment
 - Monitored at the WPL concentration with a twelve-hour aspiration
 - Quantification used forced SPE and LC/MS; MDL estimated at 15-20 ng.
 - The sorbent tubes had to be placed at the point of sampling, with no sample line
- The NRT method utilized a MINICAMS with a halogen-specific detector (XSD)
 - Monitored at the STEL (VSL) concentration with a ten-minute cycle time
 - Used ethanedithiol (EDT) to derivatize the L-1 to a species that increases volatility, prevents hydrolysis and oxidation to non-volatile species, and ensure effective transmission down a heated fluoro-polymer sample line ¹

¹ US Army Chemical Materials Agency, *Final Report for Continuation of Validation Testing of Lewisite MINICAMS, DAAMS, and Organic Impinger Methods*, March 2005.

Existing Historical Monitoring for Lewisite

- Existing technology for L DAAMS ²
 - Adsorbed Lewisite can hydrolyze to CVAA, dehydrate to CVAO, and oxidize to CVAOA (refer to next slide)
 - Lewisite, CVAA, and CVAO will form a derivative with EDT; CVAOA will not
 - Consequently, if EDT and thermal desorption were used with the long sampling periods typical of DAAMS methods, the DAAMS results would be biased low by a variable amount, even when compared to the MINICAMS readings, and would not present an accurate assessment of potential human exposure.

• ² William McShane, Milan Mraz, Amber Carrillo, James Kelshiemer, James Rorie, “Rapid Confirmatory Analysis of Airborne Lewisite by DAAMS Tubes and Liquid Chromatography-Inductively Coupled Plasma-Mass Spectrometry. ”, Winter Plasma Conference, January 9-14, 2012, Tuscon, AZ.



Summary of hydrolysis, dehydration, derivatization, oxidation reactions of Lewisite and its homologues

Lewisite Confirmation DAAMS Technical Challenge

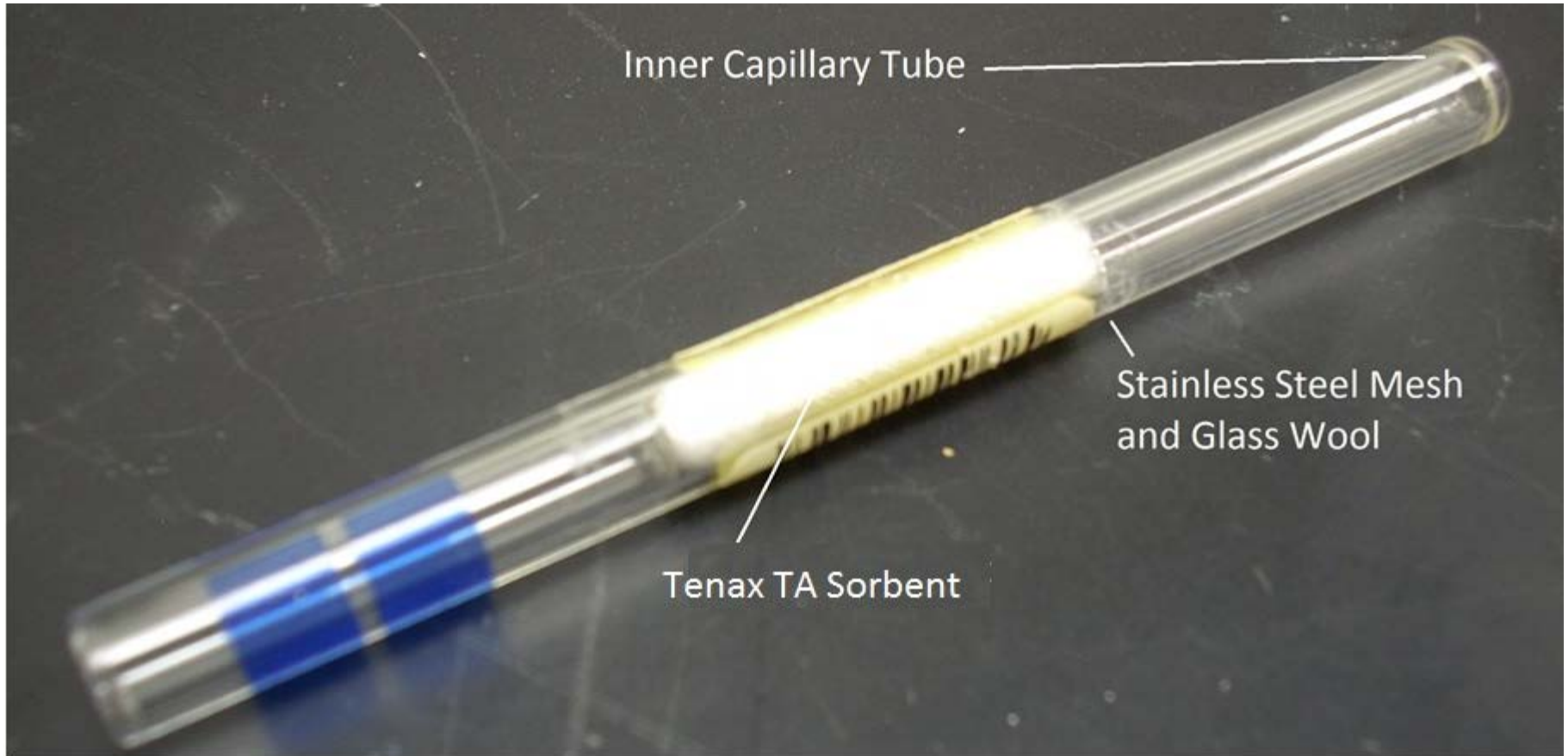
- Technical challenge
 - Must be able to quantify 3 ng of Lewisite on the collection medium
 - Must be able to speciate, at low levels, Lewisite and its hydrolysis/dehydration/oxidation products in the presence of potentially high levels of environmentally ubiquitous inorganic arsenic, both As(III) and As(V)
 - Must have a reasonable turn-around time to serve as a near-real-time confirmation method
 - Must be able to meet CMA DAAMS baseline criteria.

- Plant Design Limitations:
 - Discouraged the use of alternate-column MINICAMS units for confirmation monitoring
 - Space/Power considerations- Plant was designed with a small footprint, utilizing an existing munitions bunker and available plant electric power on the depot was near capacity.
 - DAAMS confirmation monitoring for L MINICAMS alarms used less space and consumed less electric power than alternate-column MINICAMS units.

New Technology for L DAAMS:

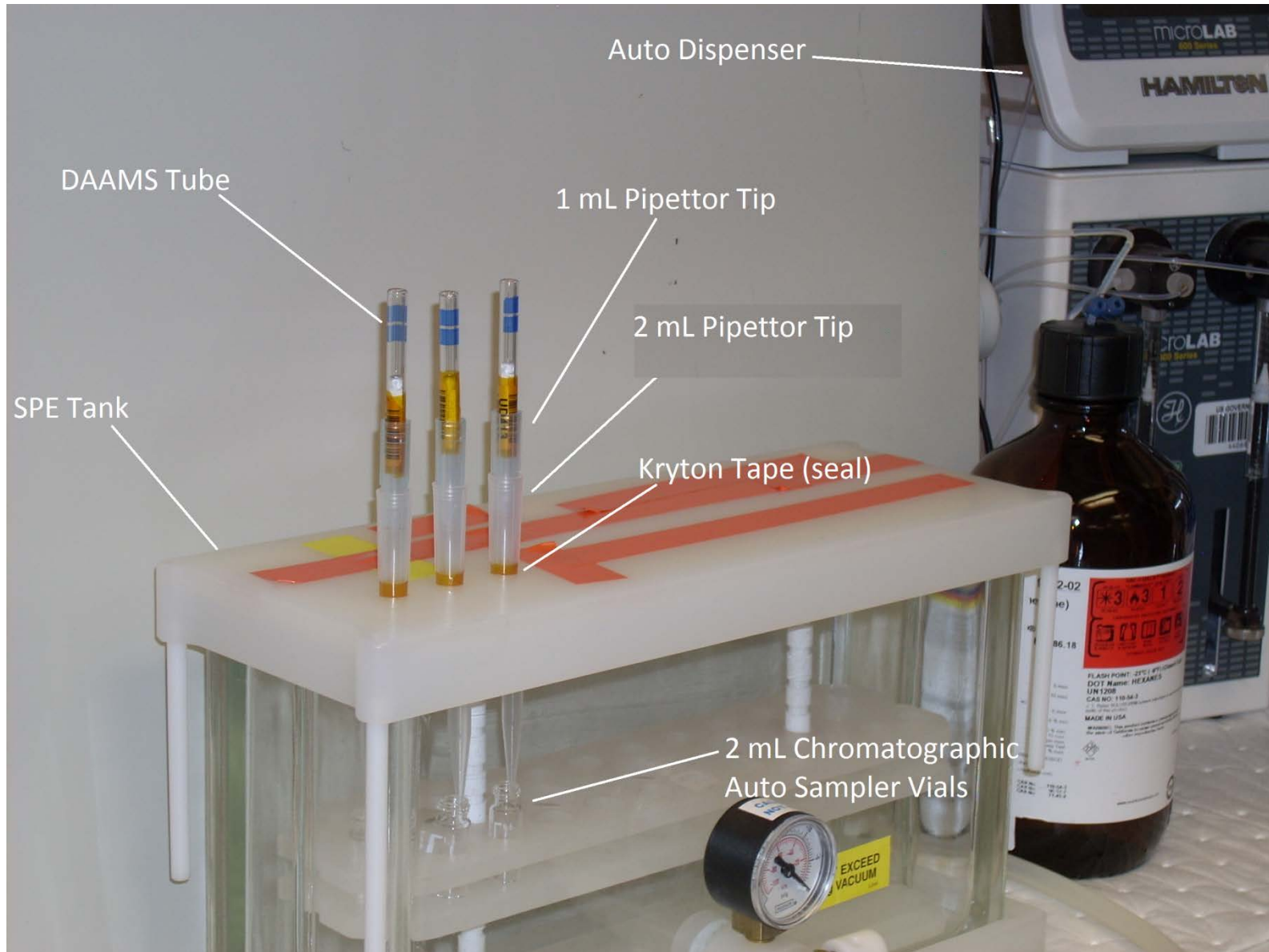
- A rapid LC/ICP-MS method to assess the threat of Lewisite to humans is presented here for the comprehensive and quantitative determination of Lewisite and its degradation homologues (as CVAOA) on DAAMS tubes.
 - This method is sensitive (ICP-MS, pg of As detected) and selective (speciation with only As detected) with no false positives ($[^{40}\text{Ar}^{35}\text{Cl}]$ isobar time resolved) in samples collected from field aspiration stations with no known exposure to Lewisite over a thirty day period
 - Method adapted from CDC Chemical Terrorism Response methodology³.
- ³Rayman Stannel, William J. McShane, Steve Pappas, Elena Dodova and Robert J. Kobelski, "Rapid Analysis of Lewisite Metabolites in Urine by High-Performance Liquid Chromatography-Inductively Coupled Plasma-Mass Spectrometry", J. Anal. Tox., 34 (2010) 122-129.

What are DAAMS Tubes?



Lewisite Challenges

- High background levels of ambient As. High levels of mining in the Western US. Commonly found in sulfidic ores, as are Cu, Ag, Au, and Hg.
- DAAMS was a legacy technology based on thermal desorption of relatively inert, semi-volatile agents. Design is not optimized for SPE. These have flow issues and can trap material between the capillary and tube wall.
- Lewisite and its degradation products are hydrolytically and oxidatively labile. Must account for four separate species, three of which are non-volatile, to accurately assess human exposure. SPE was the only method of choice.





- SPE Assembly with Solvent Reservoirs attached.

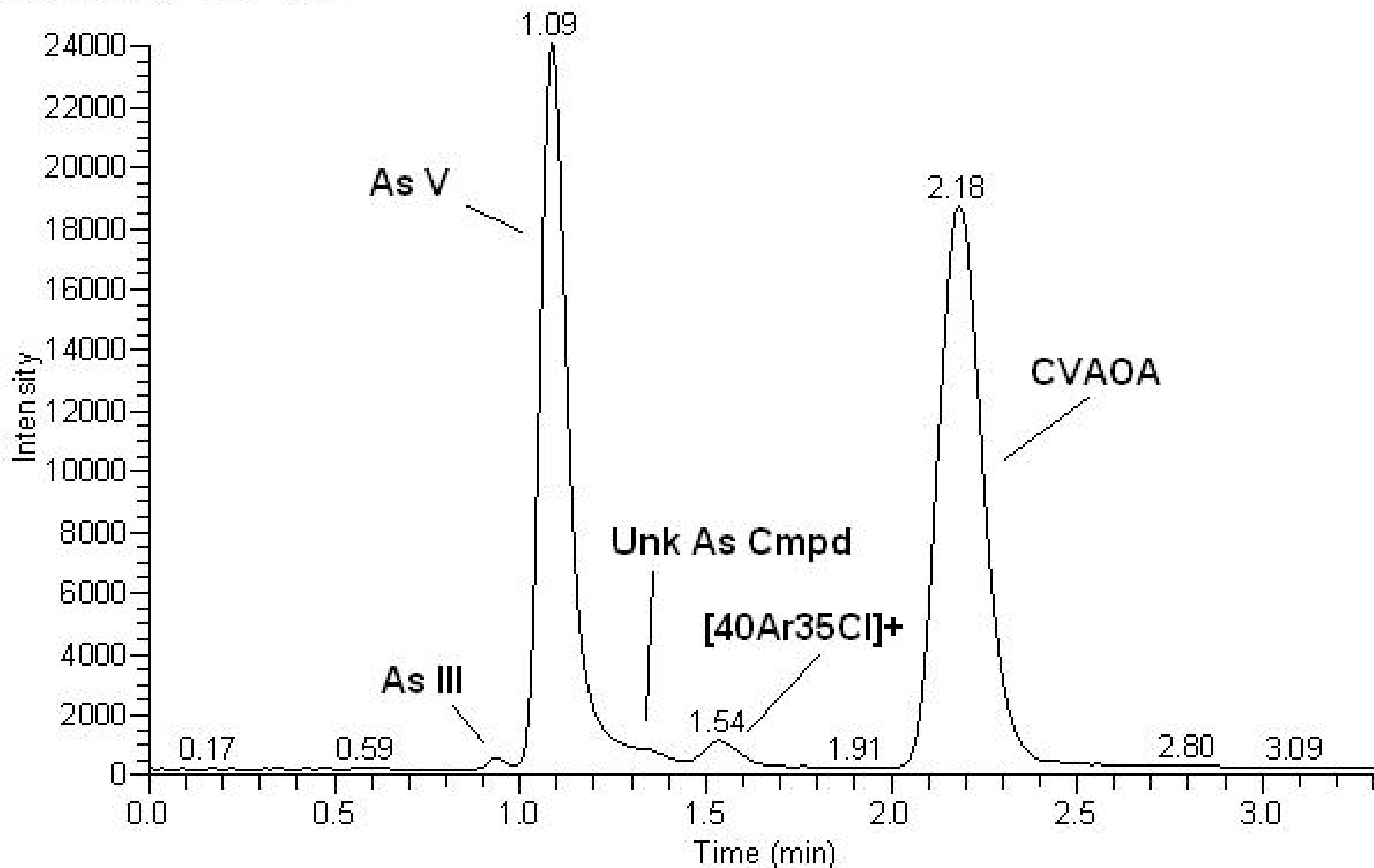
High-Sensitivity Method Developed

- LC/ICP-MS analytical technology used with significant improvements to the extractive technique used for WPL DAAMS
- Instrumentation:
 - Thermo Fisher Surveyor HPLC equipped with a C₁₈ embedded polar group, 50 x 4.6 mm, 3 μ particle size. Flow = 1 mL/min.
 - Thermo Fisher XSeries II ICP-MS equipped with Pt cones and shielded torch. RF power = 1300 W.
 - Software: Thermo Fisher PlasmaLab was used to control the ICP-MS and acquire data. Thermo Fisher Excalibur was used to control the HPLC, data reduction, and report generation. Instrumental timing coordination was accomplished via an Advantech trigger card.

DAAMS SPE and Analysis

- Tubes extracted first using hexane and followed by H₂O₂/Methanol (3% H₂O₂/7% H₂O/90% Methanol, v/v); elution was gravity driven.
- Collected eluents were evaporated to about 0.2-0.25 mL
- Diluted to 1.0 mL with mobile phase
- Mobile phase was aqueous 11.6 mM Tetrabutyl ammonium hydroxide/5 mM Succinic Acid/2% Isopropanol.
- HPLC: flow was 1.0 mL/min.; used a C₁₈ Embedded Polar Group Column, 50x4.6 mm, 3 μm column packing size; 20 μL injection
- ICP-MS monitored ⁷⁵As ion; CCT not required
- 1 VSL Recoveries (QP and QL) – averaging 100.5%; MDL = 0.29 ng
 - Note that this MDL is equivalent to **6 pg** of Lewisite on-column mass
- Extraction and analysis turn-around routinely performed in under two hours

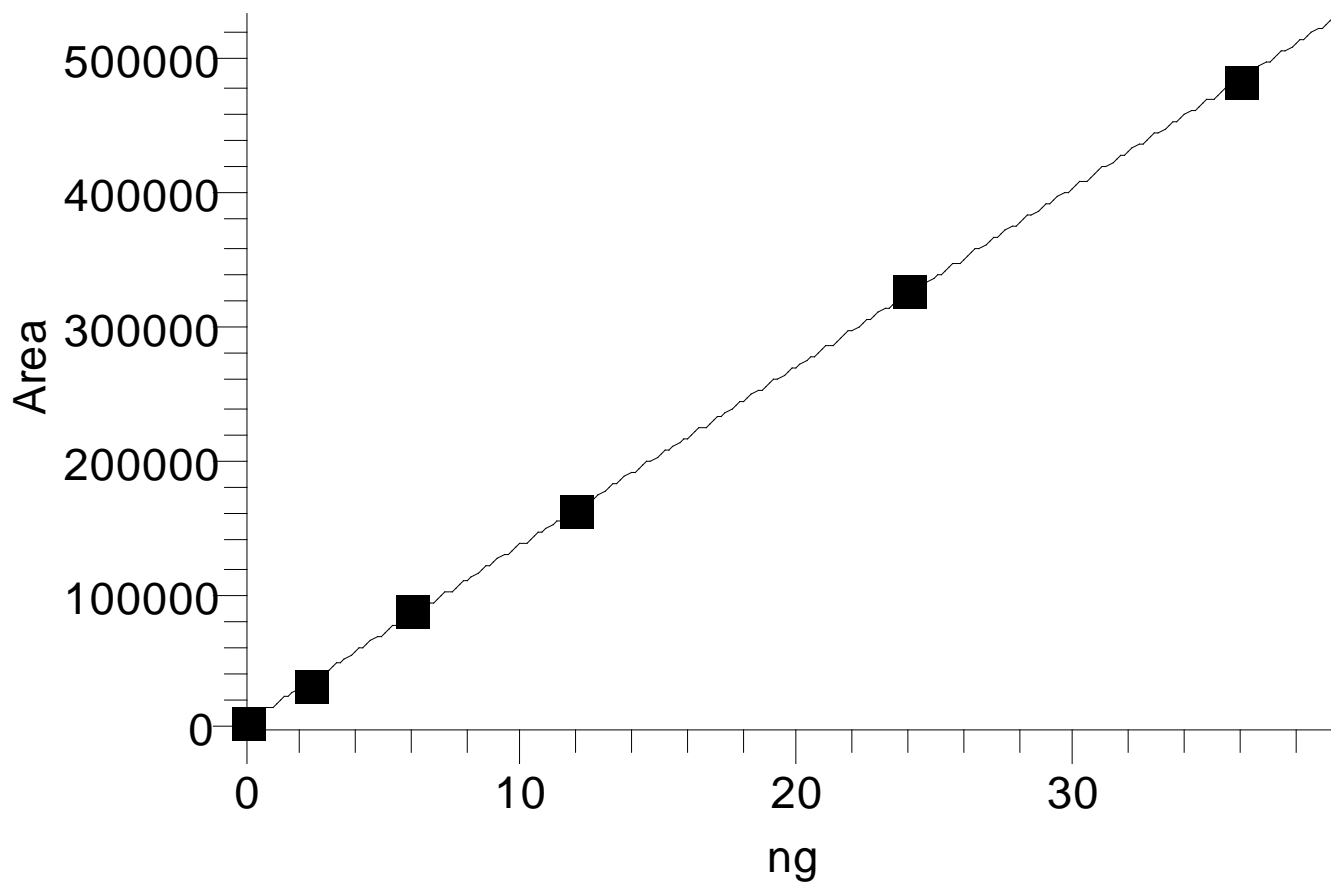
Spiked DAAMS Tube Extract Chromatogram



Calibration Curve for CVAOA / Lewisite

L-1

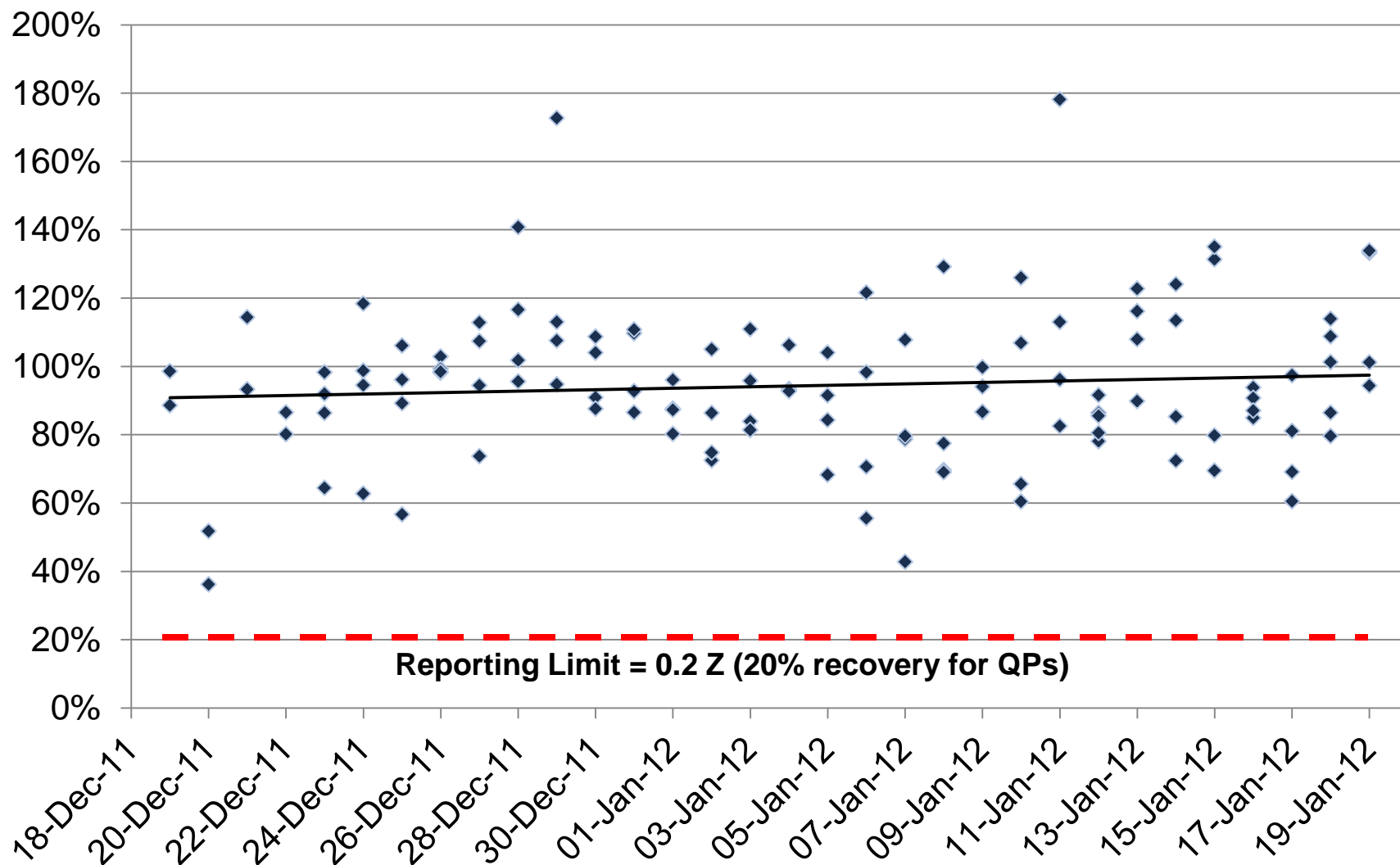
$$Y = 3573.78 + 13371.1 * X \quad R^2 = 0.9997 \quad W: \text{Equal}$$



Mass values are expressed as ng of Lewisite extracted

Baseline Performance

Recovery of Lewisite QPs Analyzed on LC/ICP-MS



WPL vs VSL

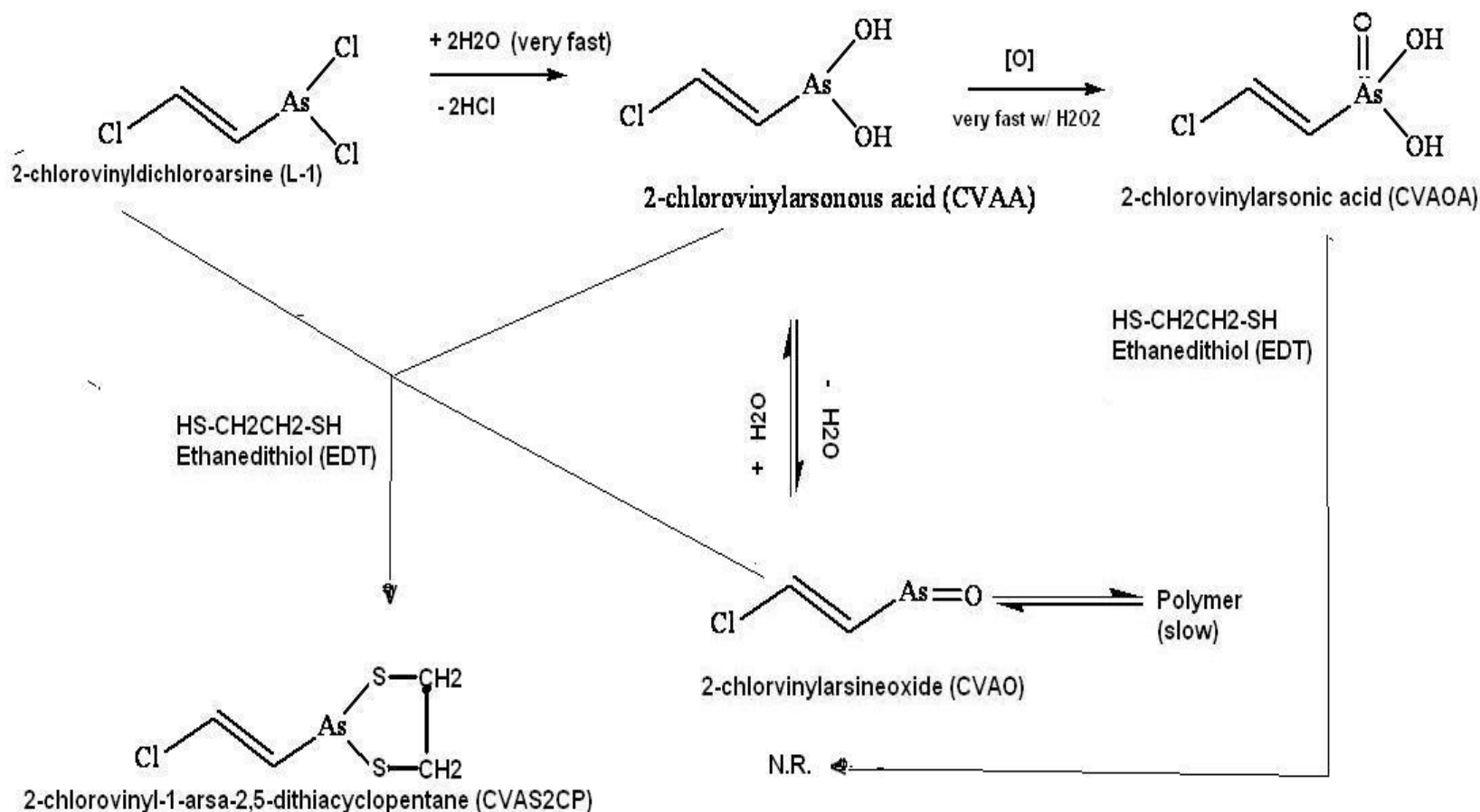
- VSL extraction, a post-exposure spike procedure, used only H₂O₂/Methanol originally.
- When applied to WPL, a pre-exposure spike procedure, low recoveries resulted.
- Hexane extraction was incorporated and recoveries improved:

	Mean % Recovery	Recovery Standard Deviation	Recovery %RSD
No Hexane Extraction	67.8	24.3	35.9
Hexane Extraction	89.8	15.6	17.3

- Why?

Arsine Oxide Formation

- Literature refers to CVAA dehydration to the CVAO as “slow”.
- This interpretation arises from studies performed on macro quantities of Lewisite in non-aqueous solvents.
- When applied to WPL, Lewisite is widely dispersed on a high surface medium exposed to constant dry air flow.
- CVAO (and other arsine oxides) are not readily dissolved by polar solvents such as methanol or water.



Summary of hydrolysis, dehydration, derivatization, oxidation reactions of Lewisite and its homologues

Conclusions

- To address the need for Lewisite NRT confirmation DAAMS analysis, a new analytical method was developed, utilizing the LC/ICP-MS analytical platform.
- This method was shown to be highly selective, extraordinarily sensitive, and fast enough for its intended purpose.
- Implementation of the method successfully supported the Lewisite processing campaign at TOCDF, with no false-positive or false-negative readings observed.

Acknowledgements

- **James Rorie**, GA/L Laboratory Manager, responsible for forming the laboratory, including staff hiring, analytical method identification and development, instrumentation and equipment purchases, and overall configuration