

Chemical Warfare Agents - Direct SICRIT® MS Analysis

Introduction

Although chemical warfare agents (CWA) and their use are outlawed, they still are an imminent threat to people all over the world. Especially taking into account the use of CWA in the Syria conflict, the need for sufficient civil protection and early warning systems against these substances becomes obvious.



Figure 1 - Representative photograph of mobile CWA measurement training.

Unfortunately, high toxicity of these compounds makes it particularly difficult for analytical equipment, since the detection method has to be sensitive, fast and selective at the same time. For direct detection there are so far mainly ion mobility based hand-held detectors (Figure 1).

...SICRIT® MS can be even faster [than GC-MS] and allows for real-time MS based gas phase detection of CWA with unmatched sensitivity.

These instruments provide high sensitivity and a fast response (seconds), however they lack selectivity leading to false positive alarms. Mass spectrometry (MS) can overcome the poor selectivity whilst maintaining the required sensitivity. Until now, only (fast-) GC-MS systems are deployed for

these tasks, which still require about a minute of analysis time. Making the application of the additional chromatography (GC) superfluous, applying soft ionization by chemical reaction in transfer (SICRIT®) can be even faster and allows for real-time MS-based gas phase detection of CWA with unmatched sensitivity.

Setup

For generation of defined gas phase concentrations of active CWA and mimic substances a pressure assisted nanospray evaporation system was used. By constant evaporation of different CWA dilutions and dispersions in a heated nitrogen stream, concentrations ranging from 0.5 ppt up to 1 ppm were generated. These gas phase concentrations were then passed by a SICRIT® prototype source connected to a benchtop AB Sciex 3200 QTrap MS system or an Aston Labs (Purdue University, USA) Mini 10.5 hand-held and battery run MS. The Mini 10.5 uses a discontinuous atmospheric pressure inlet (DAPI) to maintain a vacuum needed for operation of the internal ion trap

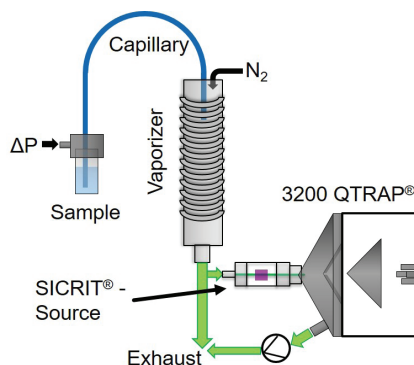


Figure 2 - Schematic sketch of the setup using the AB Sciex benchtop MS.

analyzer, enabling even MS/MS experiments. All compounds were detected and quantified using individually optimized multiple reaction monitoring (MRM) or MS² transitions, respectively. A schematic representation of the setup is depicted in figure 2.

Results

The whole set of intact nerve and blistering agents as well as related substances were investigated, including G- and V-agents as well as HD and nitrogen mustards. Efficient soft ionization was achieved for all the compounds. Figure 3 shows the SICRIT® mass spectrum for the G-agent sarin (GB) at a concentration of 5 ppb. G-agents are known to be very labile upon ionization.

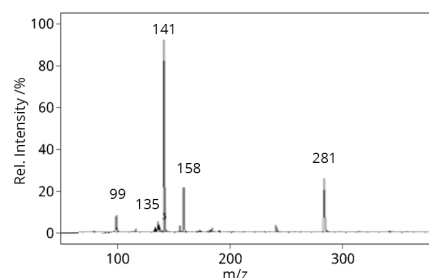


Figure 3 - Full SICRIT® mass spectrum of sarin with M+H (m/z 141), M-C₃H₆ (m/z 99), M+H₂O (m/z 158) and 2M+H (m/z 281) species acquired on the AB Sciex MS.

In APCI they mainly yield a fragment ion at m/z 99. Since this fragment is identical for GB, GF and GD agents, a discrimination based on this fragment is not possible by APCI.

In contrast, using the SICRIT® Ion source, the protonated molecular ion m/z 141 is observed as most abundant peak for GB, with little fragmentation (m/z 99) corroborating the very soft ionization.

Table 1 - Dynamic ranges and LODs for investigated CWA (AB Sciex 3200 QTrap MS).

Substance	Mass (m/z)	Calibration range (ppt)	LOD (ppt)	LOD ($\mu\text{g}/\text{m}^3$)	LCT ₅₀ ($\mu\text{g min}/\text{m}^3$)	MED ($\mu\text{g min}/\text{m}^3$)
GB (sarin)	182	11-5271	1.2	0.009	35000	500
GD	182	10-4866	11	0.079	35000	200
GA	162	9-4565	12	0.077	70000	500
GF	180	8-4086	6.2	0.044	35000	200
RVX	267	6-552	10	0.106	-	-
VX	267	6-552	6.3	0.065	15000	90
HN1	170	10-18964	4.7	0.032	-	-
HN2	156	9-17200	54	0.332	-	-
HN3	204	7-14573	9.5	0.077	-	-
HD (dry)	159	27-2760	40	0.254	900000	-

Results and parameters for the direct detection of all the investigated CWA acquired on the AB Sciex benchtop MS, as well as some toxicological and safety limits, are presented in table 1.

For a better comparison, limit values and limits of detection (LODs) are presented in parts per trillion (ppt) and $\mu\text{g per m}^3$. Sensitivity for all compounds is extraordinary high, resulting in LODs (3s blank) between 1.2 ppt to 54 ppt.

Linearity is preserved at least for three to four orders of magnitude.

Comparing the minimal effect dose (MED) and median, lethal vapor or aerosol (LCT₅₀) values, which correspond to the product of toxic dose by inhalation and exposure time, it can be seen that all the detection limits are more than six orders of magnitude lower than LCT₅₀ and at least three orders of magnitude lower than the MED, even for the most toxic V-agents.

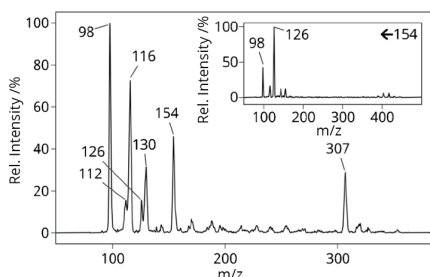


Figure 4 - Full SICRIT[®] mass spectrum and MS² transition (154 to 126; see inset) of DEPA measured on the Mini 10.5 MS.

For the experiments with the portable Mini 10.5 MS equipped with the SICRIT[®] ion source, LODs from 1.0 $\mu\text{g}/\text{m}^3$ to 6.3 $\mu\text{g}/\text{m}^3$ were achieved for CWA related substances.

Even if these values are three orders of magnitude higher than the LODs for the lab-based MS, they are still more than sufficient for a direct on site monitoring and identification of CWA far below the minimal effect dose. As expected, the resolution of the portable instrument cannot compete with lab equipment. Yet, due to the MS² capability, an unambiguous identification of the substances is possible. Figure 4 depicts an MS and MS² spectrum (insert) for 85 $\mu\text{g}/\text{m}^3$ of Diethylphosphoramidate (DEPA).

Conclusions

SICRIT[®] enables the ultrasensitive and selective direct MS-based gas-phase detection of various CWA. The very soft ionization enables MS² experiments for highly sensitive and selective identification and quantification. Detection capabilities are as low as 0.01 $\mu\text{g}/\text{m}^3$ to 0.33 $\mu\text{g}/\text{m}^3$ on lab based instruments and 1.0 $\mu\text{g}/\text{m}^3$ to 6.3 $\mu\text{g}/\text{m}^3$ on the portable MS.

SICRIT[®] CWA Detection Benefits

- Direct gas phase detection of CWA (< 1s response time)
- Higher sensitivity (low ng/m³)

- Low power consumption
- Soft ionization for MS² or high resolution identification
- No consumables (noble gases, solvents, etc.)
- Miniature ion source and electronics

SICRIT[®] Technology Advantages

The SICRIT[®] ionization technology enables high-sensitive 24/7 MS-analysis not only for CWA but for a broad range of analytes.

The plug&play ion source can be easily mounted to any type of atmospheric pressure MS giving them "ambient" detection capabilities and enhanced sensitivity (femtogram range). Furthermore, SICRIT[®] add-on modules allow for coupling with classical sample pretreatment and separation techniques (HPLC, GC, SPME, LA).

Acknowledgements

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References

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Further Reading

Technical Note

TN_01 SICRIT[®]: Soft Ionization by Chemical Reaction in Transfer

Product Notes

PN_02 SICRIT[®] SC-20X Ionization Set
 PN_03 SICRIT[®] GC/SPME Module