



DRES Chemical Warfare Agent Literature Database of Analytical Methods

Paul A. D'Agostino
Defence Research Establishment Suffield

James R. Hancock
Defence Research Establishment Suffield

Lionel R. Provost
Defence Research Establishment Suffield

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

Suffield Special Publication

DRES SSP 2001-014

January 2001



National
Defence

Défense
nationale

Canada

20010502 183

DRES Chemical Warfare Agent Literature Database of Analytical Methods

Paul A. D'Agostino
Defence Research Establishment Suffield

James R. Hancock
Defence Research Establishment Suffield

Lionel R. Provost
Defence Research Establishment Suffield

Defence Research Establishment Suffield

Suffield Special Publication

DRES SSP 2001-014

January 2001

Author

Paul A. D'Agostino, James R. Hancock and Lionel R. Provost

Approved by

Cam Boulet
H/CBDS

Approved for release by

Robert Herring
DRP Chair

Abstract

Defence Research Establishment Suffield (DRES) is actively involved in the development and evaluation of new analytical methods for the detection and identification of chemical warfare agents, their degradation products and related compounds. These methods are used for the analysis of samples collected in support of the Canadian Forces and have application in arms control verification. DRES analytical methods are published regularly in the open literature along with the methods developed by others involved in chemical warfare agent sample preparation and analysis. DRES retains printed copies of all publications in the database and regularly updates the bibliographic information from these papers into Procite, a computer searchable bibliographic database program. The DRES Chemical Warfare Agent Literature Database of Analytical Methods contains bibliographic information for more than 260 publications, and is available on request in hardcopy form or as a Procite, Word or Wordperfect file.

Résumé

Le Centre de recherches pour la défense Suffield (CRDS) s'occupe activement du développement et de l'évaluation de nouvelles méthodes analytiques de détection et d'identification d'agents de guerre chimique, des produits de dégradation de ces derniers et des composés connexes. Ces méthodes sont utilisées pour analyser des échantillons recueillis à l'appui des Forces canadiennes et s'avèrent également utiles à la vérification du contrôle des armements. Les méthodes analytiques du CRDS sont publiées régulièrement dans des ouvrages accessibles à tous au même titre que les méthodes élaborées par d'autres chercheurs qui travaillent à la préparation et à l'analyse d'échantillons d'agents de guerre chimique. Le CRDS conserve des exemplaires de toutes les publications et saisit régulièrement les dernières informations bibliographiques tirées de ces documents dans une base de données bibliographiques consultable appelée Procite. La base de données du CRDS sur les documents relatifs aux méthodes analytiques d'agents de guerre chimique contient des informations bibliographiques tirées de 260 publications. On peut, sur demande, obtenir une copie de toutes les informations sur copie papier ou en fichier Procite, Word ou WordPerfect.

This page intentionally left blank.

Executive summary

Introduction: The Canadian Forces may be called on to perform peacekeeping or battlefield operations in regions of the world where there is a significant threat of chemical warfare agent use. To operate effectively in these theatres the Canadian Forces must be able to identify the chemical warfare agent used. Analytical methods have been developed for the identification of chemical warfare agents and Defence Research Establishment Suffield is currently investigating new approaches in fulfilment of future Canadian Forces detection and identification requirements.

Results: Defence Research Establishment Suffield has developed sample handling and analysis methods for the identification of chemical warfare agents, their degradation products and related compounds. These methods have been used for the analysis of samples collected by the Canadian Forces and have application in arms control verification. DRES analytical methods have been published regularly in the open literature along with the methods developed by others involved in chemical warfare agent sample preparation and analysis. DRES retains printed copies of these papers in a database and regularly updates the bibliographic information from these papers into Procite, a computer searchable bibliographic database program. The DRES Chemical Warfare Agent Literature Database of Analytical Methods now contains nearly twice as many entries as a prior publication and this update contains bibliographic information for the complete database.

Significance: The Canadian Forces may be deployed in regions of the world where there is a significant threat of chemical warfare agent use. Identification of the chemical warfare agent is important since the results of such analyses would contribute to the development of strategic and political positions regarding future Canadian military operations and would facilitate the dissemination of technical advice to in-theatre field commanders and medical personnel.

Future Plans: The DRES Chemical Warfare Agent Literature Database of Analytical Methods will continue to be updated on a regular basis. Use of the analytical methods is anticipated during future analyses in support of the Canadian Forces or in support of arms control verification. The complete database is available on request in hardcopy form or as a Procite, Word or Wordperfect file.

D'Agostino, P.A., Hancock, J.R. and Provost, L.R., 2001. DRES Chemical Warfare Agent Literature Database of Analytical Methods. DRES SSP 2001-014. Defence Research Establishment Suffield.

Sommaire

Introduction : Les Forces canadiennes sont susceptibles d'être appelées à effectuer des opérations de maintien de la paix ou de champ de bataille dans des régions du monde où des menaces non négligeables d'utilisation d'agents de guerre chimique existent. Afin de bien mener les opérations dans ces théâtres, les Forces canadiennes doivent être capables d'identifier les agents de guerre chimiques utilisés. Des méthodes analytiques servant à identifier les agents de guerre chimiques existent, et le Centre de recherches pour la défense Suffield est à chercher d'autres approches répondant aux besoins futurs des Forces canadiennes en matière de détection et d'identification.

Résultats : Le Centre de recherches pour la défense Suffield a créé des méthodes de prélèvement, de transport et d'analyse d'échantillon en vue de l'identification d'agents de guerre chimique, des produits de dégradation de ces derniers et des composants connexes. Ces méthodes ont servi à l'analyse d'échantillons recueillis à l'appui des Forces canadiennes et elles s'avèrent utiles à la vérification du contrôle des armements. Les méthodes analytiques du CRDS ont été publiées régulièrement dans des ouvrages accessibles à tous au même titre que les méthodes inventées par d'autres chercheurs travaillant à la préparation et à l'analyse d'échantillons d'agents de guerre chimique. Le CRDS conserve des exemplaires de ces ouvrages et saisit régulièrement les nouvelles informations bibliographiques tirées de ces documents dans une base de données bibliographiques consultable appelée Procite. La base de données du CRDS sur les documents relatifs aux méthodes analytiques d'agents de guerre chimique contient actuellement deux fois plus d'entrées qu'une publication antérieure, et la présente mise à jour met en cause des informations bibliographiques pour toute la base de données.

Signification : Les Forces canadiennes peuvent être déployées dans des régions du monde où des menaces non négligeables d'utilisation d'agents de guerre chimique existent. Il est important d'identifier les agents de guerre chimique puisque les résultats des analyses, d'une part, aideraient à l'adoption d'une position et stratégique et politique vis-à-vis des futures opérations militaires canadiennes et, d'autre part, faciliteraient la circulation de conseils techniques parmi les commandants d'unité et le personnel médical dans le théâtre.

Futurs plans : On continuera de mettre à jour, de façon régulière, la base de données du CRDS sur les documents relatifs aux méthodes analytiques d'agents de guerre chimique. On prévoit que les méthodes analytiques seront utilisées lors des futures analyses effectuées à l'appui des Forces canadiennes ou à l'appui de la vérification du contrôle des armements. On peut obtenir, sur demande, une copie de la base de données complète, sur papier ou en fichier Procite, Word ou WordPerfect.

D'Agostino, P.A., Hancock, J.R. and Provost, L.R., 2001. DRES Chemical Warfare Agent Literature Database of Analytical Methods. DRES SSP 2001-014. Defence Research Establishment Suffield.

Table of contents

Abstract.....	i
Résumé.....	i
Executive summary.....	iii
Sommaire.....	iv
Table of contents.....	v
Introduction.....	1
DRES Chemical Warfare Agent Literature Database of Analytical Methods.....	3

This page intentionally left blank.

Introduction

The Canadian Forces may be called on to perform peacekeeping or battlefield operations in regions of the world where there is a significant threat of chemical warfare agent use. To operate effectively in these theatres the Canadian Forces must be able to identify the chemical warfare agent(s) being used. Development of instrumental analytical methods for the identification and confirmation of these compounds is an important CF requirement that is being actively addressed by Defence Research Establishment Suffield (DRES) analytical researchers. Mass spectrometry and gas and liquid chromatography, core capability areas in the analytical sciences at DRES, form the basis for current analytical methods for the identification and confirmation of chemical warfare agents. In-house methods have been validated during NATO and United Nations analytical exercises with improvement continuing through the exploitation of new analytical technologies, including packed capillary liquid chromatography and electrospray mass spectrometry.

DRES analytical methods have been published regularly in the open literature along with the methods developed by others for agent sample preparation and analysis. Printed copies of these papers have been archived in a database and DRES regularly updates the bibliographic information from these papers into Procite, a computer searchable bibliographic database program. Update of the database continues as an ongoing effort and the The DRES Chemical Warfare Agent Literature Database of Analytical Methods contains more than 260 entries and is available on request in hardcopy form or as a softcopy Procite, Word or Wordperfect file. A listings of the entries follows.

This page intentionally left blank.

DRES Chemical Warfare Agent Literature Database of Analytical Methods

1. Albaret C, Loeillet D, Auge P, Fortier P-L. Application of two dimensional ^1H - ^{31}P inverse NMR spectroscopy to the detection of trace amounts of organophosphorus compounds related to the Chemical Weapons Convention . *Anal. Chem.* 69. 1997:2694-700.
2. Albro PW, Fishbein L. Gas chromatography of sulfur mustard and its analogues. *J. Chromatogr.* 46. 1970:202-3.
3. Alfthan K, Kenttamaa H, Zukale T. Characterization and semiquantitative estimation of organophosphorus compounds based on inhibition of cholinesterases. *Anal. Chim. Acta.* 217. 1989:43-51.
4. Ali-Mattila E, Siivinen K, Kenttamaa H, Savolahti P. Mass spectrometric methods in structural analysis of some vesicants. *Int. J. Mass Spectrom. Ion Phys.* 47. 1983:371-4.
5. Andersson G. Analysis of two chemical weapons samples from the Iran/Iraq war. *NBC Defence and Technology International.* April. 1986:62-5.
6. Appler B, Christmann K. Detection of b,b'-dichloroethyl sulfide on thin-layer chromatograms. *J. Chromatogr.* 264. 1983:445-52.
7. Asbury GR, Wu C, Siems WF, Hill Jr. HH. Separation and identification of some chemical warfare degradation products using electrospray high resolution ion mobility spectrometry with mass selected detection. *Anal. Chim. Acta.* 404. 2000:273-83.
8. Avdovich HW, By A, Ethier JC, Neville GA. Spectral identification of a lachrymatory exhibit as CS. *J. Can. Soc. Forens. Sci.* 14. 1981:172-8.
9. Barcelo D. Application of thermospray liquid chromatography/mass spectrometry for determination of organophosphorus pesticides and trialkyl and triaryl phosphates. *Biomed. Environ. Mass Spectrom.* 17. 1988:363-9.
10. Barcelo D, Albaiges J. Characterization of organophosphorus compounds and phenylurea herbicides by positive and negative ion thermospray liquid chromatography-mass spectrometry. *J. Chromatogr.* 474. 1989:163-73.
11. Beck O, Holmstedt B, Lundin J, Lundgren G, Santesson J. Quantitation of free soman in nervous tissue and blood: A preliminary communication. *Fundamental & Applied Toxicology.* 1. 1981:148-53.

12. Bell AJ, Despeyroux D, Murrell J, Watts P. Fragmentation and reactions of organophosphate ions produced by electrospray ionization. *Int. J. Mass Spectrom. Ion Proc.* 165/166. 1997:533-50.
13. Benschop HP, Bijleveld EC, Otto MF, Degenhardt CEAM, Van Helden HPM, De Jong LPA. Stabilization and gas chromatographic analysis of the four stereoisomers of 1,2,2-trimethylpropyl methylphosphonofluoridate (soman) in rat blood. *Anal. Biochem.* 151. 1985:242-53.
14. Benschop HP, De Jong LPA. Nerve agent stereoisomers: Analysis, isolation, and toxicology. *Acc. Chem. Res.* 21. 1988:368-74.
15. Benschop HP, van der Schans GP, Noort D, Fidder A, Mars-Groenendijk RH, de Jong LPA. Verification of exposure to sulfur mustard in two casualties of the Iran-Iraq conflict. *J. Anal. Toxicology.* 21. 1997:249-51.
16. Bhattacharya A, Tripathi DN. Field desorption mass spectra of pyridinium oxime salts with rapid heated emitter. *Anal. Chem.* 56. 1984:2295-7.
17. Black RM. Tandem mass spectrometry: Applications in the trace analysis of chemical warfare agents. *J. Defence Sci.* 1. 1996:219-26.
18. Black RM, Brewster K, Clarke RJ, Harrison JM. The chemistry of 1,1'-thiobis(2-chloroethane) (sulphur mustard) Part II. The synthesis of some conjugates with cysteine, n-acetylcysteine and n-acetylcysteine methyl ester. *Phosphorus, Sulfur and Silicon.* 71. 1992:49-58.
19. Black RM, Brewster K, Harrison JM, Stansfield N. The chemistry of 1,1'-thiobis(2-chloroethane) (sulphur mustard) Part I. Some simple derivatives. *Phosphorus, Sulfur and Silicon.* 71. 1992:31-47.
20. Black RM, Clarke RJ, Cooper DB, Read RW, Utlely D. Application of head space analysis, solvent extraction, thermal desorption and gas chromatography-mass spectrometry to the analysis of chemical warfare samples containing sulphur mustard and related compounds. *J. Chromatogr.* 637. 1993:71-80.
21. Black RM, Clarke RJ, Harrison JM, Read RW. Biological fate of sulphur mustard: Identification of valine and histidine adducts in haemoglobin from casualties of sulphur mustard poisoning. *Xenobiotica.* 27. 1997:499-512.
22. Black RM, Clarke RJ, Read RW. Analysis of 1,1'-sulphonylbis[2-(methylsulphinyl)ethane] and 1-methylsulphinyl-2-[2-(methylthio)ethylsulphonyl]ethane, metabolites of sulphur mustard, in urine using gas chromatography-mass spectrometry. *J. Chromatogr.* 558. 1991:405-14.

23. Black RM, Clarke RJ, Read RW, Reid MTJ. Application of gas chromatography-mass spectrometry and gas chromatography-tandem mass spectrometry to the analysis of chemical warfare samples found to contain residues of the nerve agent sarin, sulphur mustard and their degradation products. *J. Chromatogr. A.* 662. 1994:301-21.
24. Black RM, Harrison JM, Read RW. Biological fate of sulphur mustard: In vitro alkylation of human haemoglobin by sulphur mustard. *Xenobiotica.* 27. 1997:11-32.
25. Black RM, Read RW. Analysis of degradation products of organophosphorus chemical warfare agents and related compounds by liquid chromatography-mass spectrometry using electrospray and atmospheric pressure chemical ionization. *J. Chromatogr. A.* 794. 1998:233-44.
26. Black RM, Read RW. Application of liquid chromatography-atmospheric pressure chemical ionization mass spectrometry, and tandem mass spectrometry, to the analysis and identification of degradation products of chemical warfare agents. *J. Chromatogr. A.* 759. 1997:79-92.
27. Black RM, Read RW. Detection of trace levels of thiodiglycol in blood, plasma and urine using gas chromatography-electron-capture negative-ion chemical ionisation mass spectrometry. *J. Chromatogr.* 449. 1988:261-70.
28. Black RM, Read RW. Improved methodology for the detection and quantitation of urinary metabolites of sulphur mustard using gas chromatography-tandem mass spectrometry. *J. Chromatogr. B.* 665. 1995:97-105.
29. Black RM, Read RW. Liquid chromatography/mass spectrometry in analysis of chemicals related to the chemicals weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:1007-25.
30. Black RM, Read RW. Methods for the analysis of thiodiglycol sulfoxide, a metabolite of sulfur mustard, in urine using gas chromatography-mass spectrometry. *J. Chromatogr.* 558. 1991:393-404.
31. Bonierbale E, Debordes L, Coppet L. Application of capillary gas chromatography to the study of hydrolysis of the nerve agent VX in rat plasma. *J. Chromatogr. B.* 688. 1997:255-64.
32. Borrett VT, Colton R, Traeger JC. The electrospray mass spectra of phosphonic acid, methyl phosphonic acid and its alkyl esters, and their complexes with alkali and alkali earth metal ions. *Eur. Mass Spectrom.* 1. 1995:131-40.
33. Borrett VT, Mathews RJ, Colton R, Traeger JC. Verification of the United Nations Chemical Weapons Convention: The application of electrospray mass spectrometry. *Rapid Commun. Mass Spectrom.* 10. 1996:114-8.

34. Borrett VT, Mathews RJ, Mattsson ER. Verification of the Chemical Weapons Convention: Mass spectrometry of alkyl methylphosphonofluoridates. *Aust. J. Chem.* 47. 1994:2065-74.
35. Bossle PC, Reutter DJ, Sarver EW. Analysis of alkyl methylphosphonic acids in aqueous matrices by ion-pair reverse-phase ion chromatography. *J. Chromatogr.* 407. 1987:399-404.
36. Boulet CA. Capillary electrophoresis in detection of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:909-23.
37. Braue Jr. EH, Pannella MG. Circle cell FT-IR analysis of chemical warfare agents in aqueous solutions. *Applied Spectroscopy.* 44. 1990:1513-20.
38. Brickhouse MD, Creasy WR, Williams BR, Morrissey KM, O'Connor RJ, Durst HD. Multiple-technique analytical characterization of a mixture containing chemical-weapons simulant from a munition. *J. Chromatog. A.* 883. 2000:185-98.
39. Brodskii ES, Kireev AF. Identification and determination of chemical warfare components and their decomposition products using mass chromatograms in characteristic ions and in ion mass differences. *J. Anal. Chem.* 52. 1997:801-5.
40. Camel V, Caude M, Tambute A. SFE of an organophosphorous compound from soils with capillary GC analysis. *J. Chromatogr. Sci.* 33. 1995:123-32.
41. Casselman AA, Gibson NCC, Bannard RAB. A rapid, sensitive, gas-liquid chromatographic method for the analysis of bis(2-chloroethyl)sulfide collected from air in hydrocarbon solvents. *J. Chromatogr.* 78. 1973:317-22.
42. Chaudot X, Tambute A, Caude M. Selective extraction of hydrocarbons, phosphonates and phosphonic acids from soil by successive supercritical fluid and pressurized liquid extractions. *J. Chromatogr. A.* 866. 2000:231-40.
43. Cheicante RL, Stuff JR, Durst HD. Analysis of chemical weapons degradation products by capillary electrophoresis with UV detection. *J. Cap. Elec.* 2 (4). 1995:157-63.
44. Cheicante RL, Stuff JR, Durst HD. Separation of sulfur containing chemical warfare related compounds in aqueous samples by micellar electrokinetic chromatography. *J. Chromatogr. A.* 711. 1995:347-52.
45. Chou C-C, Long SR. Chemical ionization fourier transform mass spectrometry of chemical warfare agent simulants using laser-produced metal ions. *Applied Optics.* 29. 1990:4981-6.

46. Clark AJ. Determination of organosulfur compounds and amino acid-mustard conjugates by liquid chromatography with amperometric detection. *Anal. Proceedings.* 30. 1993:355-7.
47. Claussen FA. Arsenic sepeciation of aqueous environmental samples by derivatization with thioglycolic acid methylester and capillary gas-liquid chromatography-mass spectrometry. *J. Chromatogr. Sci.* 35. 1997:568-72.
48. Cooper DB. Sampling, detection and screening of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:1071-83.
49. Creasy WR. Postcolumn derivatization liquid chromatography/mass spectrometry for detection of chemical-weapons-related compounds. *J Am. Soc. Mass Spectrom.* 10. 1999:440-7.
50. Creasy WR, Rodriguez AA, Stuff JR, Warren RW. Atomic emission detection for the quantitation of trimethylsilyl derivatives of chemical-warfare-wgent related compounds in environmental samples . *J. Chromatogr. A.* 709. 1995:333-44.
51. Creasy WR, Stuff JR, Williams B *et al.* Identification of chemical-weapons-related compounds in decontamintion solutions and other matrices by multiple chromatographic techniques. *J. Chromatogr. A.* 774. 1997:253-63.
52. D'Agostino PA. Chemical warfare agents. *Encyclopedia of Analytical Science.* 599-608. 1995.
53. D'Agostino PA. Chemical warfare agents: Chromatography. *Encyclopedia of Separation Science.* 5. 2000:2279-87.
54. D'Agostino PA, Hancock JR, Provost LR. Analysis of o-ethyl s-[2-(diisopropylamino)ethyl] methylphosphonothiolate (VX) and its degradation products by packed capillary liquid chromatography-electrospray mass spectrometry. *J. Chromatogr. A.* 837. 1999:93-105.
55. D'Agostino PA, Hancock JR, Provost LR. Packed capillary liquid chromatography-electrospray mass spectrometry analysis of organophosphorus chemical warfare agents. *J. Chromatogr. A.* 840. 1999:289-94.
56. D'Agostino PA, Hansen AS, Lockwood PA, Provost LR. Capillary column gas chromatography-mass spectrometry of tabun. *J. Chromatogr.* 347. 1985:257-66.
57. D'Agostino PA, Porter CJ. Capillary column gas chromatography/tandem mass spectrometry verification of chemical warfare agents. *Rapid Commun. Mass Spectrom.* 6. 1992:717-8.

58. D'Agostino PA, Provost LR. Analysis of irritants by capillary column gas chromatography tandem mass spectrometry . J Chromatogr. A. 695. 1995:65-73.
59. D'Agostino PA, Provost LR. Capillary column ammonia chemical ionization mass spectrometry of organophosphorus chemical warfare agents and simulants. Biomed. Environ. Mass Spectrom. 13. 1986:231-6.
60. D'Agostino PA, Provost LR. Capillary column electron impact and ammonia chemical ionization gas chromatographic-mass spectrometric and gas chromatographic-tandem mass spectrometric analysis of mustard hydrolysis products. J. Chromatogr. 645. 1993:283-92.
61. D'Agostino PA, Provost LR. Capillary column gas chromatographic-tandem mass spectrometric analysis of phosphate esters in the presence of interfering hydrocarbons. J. Chromatogr. A. 670. 1994:127-34.
62. D'Agostino PA, Provost LR. Capillary column gas chromatography-ammonia and deuterated ammonia chemical ionization mass spectrometry of sulfur vesicants. J. Chromatogr. 600. 1992:267-72.
63. D'Agostino PA, Provost LR. Capillary column isobutane chemical ionization mass spectrometry of mustard and related compounds. Biomed. Environ. Mass Spectrom. 15. 1988:553-64.
64. D'Agostino PA, Provost LR. Detection of sarin and soman in a complex airborne matrix by capillary column ammonia chemical ionization-mass spectrometry and gas chromatography-tandem mass spectrometry. J. Chromatogr. 541. 1991:121-30.
65. D'Agostino PA, Provost LR. Determination of chemical warfare agents, their hydrolysis products and related compounds in soil. J. Chromatogr. 589. 1992:287-94.
66. D'Agostino PA, Provost LR. Gas chromatographic retention indices of chemical warfare agents and simulants. J. Chromatogr. 331. 1985:47-54.
67. D'Agostino PA, Provost LR. Gas chromatographic retention indices of sulfur vesicants and related compounds. J. Chromatogr. 436. 1988:399-411.
68. D'Agostino PA, Provost LR. Mass spectrometric identification of products formed during degradation of ethyl dimethylphosphoramidocyanidate (tabun). J. Chromatogr. 598. 1992:89-95.
69. D'Agostino PA, Provost LR, Anacleto JF, Brooks PW. Capillary column gas chromatography-mass spectrometry and gas chromatography-tandem mass spectrometry detection of chemical warfare agents in a complex airborne matrix . J. Chromatogr. 504. 1990:259-68.

70. D'Agostino PA, Provost LR, Hancock JR. Analysis of mustard hydrolysis products by packed capillary liquid chromatography-electrospray mass spectrometry. *J. Chromatogr. A.* 808. 1998:177-84.
71. D'Agostino PA, Provost LR, Hancock JR, Boulet CA. Electrospray mass spectrometric characterization of six therapeutic oximes: HI-6, HS-6, obidoxime, 2-PAM, TMB-4 and HLo-7. *Rapid Commun. Mass Spectrom.* 10. 1996:805-10.
72. D'Agostino PA, Provost LR, Hansen AS, Luoma GA. Identification of mustard related compounds in aqueous samples by gas chromatography/mass spectrometry. *Biomed. Environ. Mass Spectrom.* 18. 1989:484-91.
73. D'Agostino PA, Provost LR, Looye KM. Identification of tabun impurities by combined capillary column gas chromatography-mass spectrometry. *J. Chromatogr.* 465. 1989:271-83.
74. D'Agostino PA, Provost LR, Visentini J. Analysis of o-ethyl s-[2-(diisopropylamino)ethyl] methylphosphonothiolate (VX) by capillary column gas chromatography-mass spectrometry. *J. Chromatogr.* 402. 1987:221-32.
75. Dang TA, Day RJ, Hercules DM. Laser mass spectrometry of diquatery ammonium salts. *Anal. Chem.* 56. 1984:866-71.
76. Dangi RS, Jeevaratnam K, Sugendran K, Malhotra RC, Raghuvveeran CD. Solid-phase extraction and reverse-phase high-performance liquid chromatographic determination of sulphur mustard in blood. *J. Chromatogr. B.* 661. 1994:341-5.
77. De Bisschop HC, Michiels E. Assay of the nerve agent soman in serum by capillary gas chromatography with nitrogen-phosphorus detection and splitless injection. *Chromatographia.* 18. 1984:433-6.
78. De Jong LPA, Bijleveld EC, Van Dijk C, Benschop HP. Assay of the chiral organophosphate, soman, in biological samples. *Intern. J. Environ. Anal. Chem.* 29. 1987:179-97.
79. Degenhardt CEAM, Verweij A, Benschop HP. Gas chromatography of organophosphorus compounds on chiral stationary phases. *Intern. J. Environ. Anal. Chem.* 30. 1987:15-28.
80. Degenhardt-Langelaan CEAM, Kientz ChE. Capillary gas chromatographic analysis of nerve agents using large volume injections. *J. Chromatogr. A.* 723. 1996:210-4.
81. Donovan WH, Famini GR. Using theoretical descriptions in structure activity relationships: Retention indices of sulfur vesicants and related compounds. *J. Chem. Soc., Perkin Trans. 2.* 1995:83-9.

82. Durst HD, Mays JR, Ruth JL, Williams BR, Duevel RV. Micro-scale synthesis and in-situ spectroscopic characterization of some chemical weapons related organophosphate compounds. *Analytical Letters*. 31 (8). 1998:1429-44.
83. Ember L. Chemical weapons: Residues verify Iraqi use on Kurds. *Chem. Eng. News*. May. 1993:8-9.
84. Epstein J, Callahan JJ, Bauer VE. The kinetics and mechanisms of hydrolysis of phosphonothiolates in dilute aqueous solution. *Phosphorus*. 4. 1974:157-63.
85. Erickson B. The chemical weapons convention redefines "analytical challenge". *Anal. Chem.* June. 1998:397A-400A.
86. Erickson RL, Macnair RN, Brown RH, Hogan HD. Determination of bis(2-chloroethyl)sulfide in a dawsen apparatus by gas chromatography. *Anal. Chem.* 44. 1972:1040-1.
87. Ferrarolo JB, DeLeon IR, Peuler EA. Bioaccumulation of chemical markers as a means for the field detection and verification of organophosphorus warfare agents. *Environ. Sci. Technol.* 28. 1994:1893-7.
88. Ferslew KE, Orcutt RH, Hagardorn AN. Spectral differentiation and gas chromatographic/mass spectrometric analysis of the lacrimators 2-chloroacetophenone and o-chlorobenzylidene malononitrile. *J. Forensic Science*. 31. 1986:658-65.
89. Fowler WK, Smith Jr. JE. Indirect determination of o-ethyl s-(2-diisopropylaminoethyl)methylphosphonothioate in air at low concentrations. *J. Chromatogr.* 478. 1989:51-61.
90. Fowler WK, Smith Jr. JE. Solid sorbent collection and gas chromatographic determination of bis(2-chloroethyl)sulfide in air at trace concentrations. *J. Chromatogr. Sci.* 28. 1990:118-22.
91. Fowler WK, Steward DC, Weinberg DS. Gas chromatographic determination of lewisite hydrolysate, 2-chlorovinylarsonous acid, after derivatization with 1,2-ethanedithiol. *J. Chromatogr.* 558. 1991:235-46.
92. Fredriksson S-A, Hammarstrom L-G, Henriksson L, Lakso H-A. Trace determination of alkyl methylphosphonic acids in environmental and biological samples using gas chromatography/negative-ion chemical ionization mass spectrometry and tandem mass spectrometry. *J. Mass Spectrom.* 30. 1995:1133-43.
93. Frishman G, Amirav A. Fast GC-PFPD system for field analysis of chemical warfare agents. *Field Analytical Chemistry and Technology*. 4 . 2000:170-94.

94. Gandhe BR, Malhotra RC, Gutch PK. Gas chromatographic retention indices of tear gases on capillary columns. *J. Chromatogr.* 479. 1989:165-9.
95. Gibson NCC, Casselman AA, Bannard RAB. An improved gas-liquid chromatographic method for the analysis of bis(2-chloroethyl)sulfide collected from air by solvent entrapment. *J. Chromatogr.* 92. 1974:162-5.
96. Griest WH, Ramsey RS, Ho C-H, Caldwell WM. Supercritical fluid extraction of chemical warfare agent simulants from soil. *J. Chromatogr.* 600. 1992:273-7.
97. Groenewold GS, Appelhans AD, Gresham GL, Olson JE, Jeffery M, Weibel M. Characterization of VX on concrete using ion trap secondary ionization mass spectrometry. *J. Am. Soc. Mass Spectrom.* 11. 2000:69-77.
98. Groenewold GS, Appelhans AD, Gresham GL, Olson JE, Jeffery M, Wright JB. Analysis of VX on soil particles using ion trap secondary ion mass spectrometry. *Anal. Chem.* 71. 1999:2318-23.
99. Hakkinen VMA. Analysis of chemical warfare agents in water by solid phase extraction and two-channel capillary gas chromatography. *J. High Resoln. Chromatogr.* 14. 1991:811-5.
100. Hakkinen VMA. Gas chromatography/mass spectrometry in on-site analysis of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:1001-7.
101. Hancock JR, McAndless JM, Hicken RP. A solid adsorbent based system for the sampling and analysis of organic compounds in air: An application to compounds of chemical defence interest. *J. Chromatogr. Sci.* 29. 1991:40-5.
102. Hancock JR, Peters GR. Retention index monitoring of compounds of chemical defence interest using thermal desorption gas chromatography. *J. Chromatogr.* 538. 1991:249-57.
103. Harden CS, Snyder AP, Eiceman GA. Determination of collision-induced dissociation mechanisms and cross-sections in organophosphorus compounds by atmospheric pressure ionization tandem mass spectrometry. *Org. Mass Spectrom.* 28. 1993:585-92.
104. Hart KJ, Wise MB, Griest WH, Lammert SA. Design, development, and performance of a fieldable chemical and biological agent detector. *Field Analytical Chemistry and Technology.* 4. 2000:93-110.
105. Hassan SSM, Abdalla JM, Nashed NE. Characterization and determination of benzalmalonitriles using infrared, nuclear magnetic resonance and mass spectrometry. *Mikrochimica Acta.* II. 1984:27-38.

106. Hesso A, Kostianen R. Tandem mass spectrometry: A potential method for detection and identification of chemical warfare agents. Proc. 2nd Int. Symp. Protection Against Chemical Warfare Agents, Stockholm, Sweden, 15-19 June 1986. 1986:257-60.
107. Heyndrickx A, Cordonnier J, De Bock A. Chromatographic procedures for the toxicological determination of bis(2-chloroethyl) sulfide (mustard gas, yperite) in environmental and human biological samples. Arch. Belg. Med. Soc. (Toxicol.). 1984:102-9.
108. Hooijschuur EWJ, Kientz CE, Brinkman UATh. Determination of the sulfur mustard hydrolysis product thiodiglycol by microcolumn liquid chromatography coupled on-line with sulfur flame photometric detection using large-volume injections and peak compression. J. Chromatogr. A. 849. 1999:433-44.
109. Hooijschuur EWJ, Kientz CE, Hulst AG. Determination of hydrolysis products of sulfur mustard by reversed-phase microcolumn liquid chromatography coupled on-line with sulfur flame photometric detection and electrospray ionization mass spectrometry using large-volume injections and peak compression. Anal. Chem. 72. 2000:1199-206.
110. Huber JFK, Kenndler E, Reich G, Hack W, Wolf J. Optimal selection of gas chromatographic columns for the analytical control of chemical warfare agents by application of information theory to retention data. Anal. Chem. 65. 1993:2903-6.
111. Hutchinson R, Razulis J. Methodology assessment for the chemical weapons convention. Army RD&A. May-June. 1996:29-30.
112. Ingram JC, Groenewold GS, Appelhans AD, Delmore JE, Dahl DA. Detection of alkylmethylphosphonic acids on leaf surfaces by static secondary ion mass spectrometry. Anal. Chem. 67. 1995:187-95.
113. Jakubowski EM, Woodard CL, Mershon MM, Dolzine TW. Quantification of thiodiglycol in urine by electron ionization gas chromatography-mass spectrometry. J. Chromatogr. 528. 1990:184-90.
114. Jenkins AL, Uy OM, Murray GM. Polymer-based lanthanide luminescent sensor for detection of the hydrolysis product of the nerve agent soman in water. Anal. Chem. 71. 1999:373-8.
115. Kaaijk J, Frijlink C. Degradation of s-2-di-isopropylaminoethyl o-ethyl methylphosphonothioate in soil sulphur-containing products. Pestic. Sci. 8. 1977:510-4.
116. Kaipainen A, Kostianen O, Riekkola M-L. Identification of chemical warfare agents in air samples using capillary column gas chromatography with three simultaneous detectors. J. Microcol. Sep. 4. 1992:245-51.

117. Katagi M, Nishikawa M, Tatsuno M, Tsuchihashi H. Determination of the main hydrolysis product of o-ethyl s-2-diisopropylaminoethyl methylphosphonothiolate, ethyl methylphosphonic acid, in human serum. *J. Chromatogr. B.* 689. 1997:327-33.
118. Katagi M, Tatsuno M, Nishikawa M, Tsuchihashi H. On-line solid-phase extraction liquid chromatography-continuous flow frit fast atom bombardment mass spectrometric and tandem mass spectrometric determination of hydrolysis products of nerve agents alkyl methylphosphonic acids by p-bromophenacyl derivatization. *J. Chromatogr. A.* 833. 1999:169-79.
119. Kataoka M, Tsuge K, Seto Y. Efficiency of pretreatment of aqueous samples using a macroporous strong anion-exchange resin on the determination of nerve gas hydrolysis products by gas chromatography-mass spectrometry after tert.-butyldimethylsilylation. *J. Chromatogr. A.* 891. 2000:295-304.
120. Ketkar SN, Penn SM, Fite WL. Real-time detection of parts per trillion levels of chemical warfare agents in ambient air using atmospheric pressure ionization tandem quadrupole mass spectrometry. *Anal. Chem.* 63. 1991:457-9.
121. Kientz CE, Hooijschuur EWJ, Brinkman UATh. Capillary electrophoresis coupled on-line with flame photometric detection: Determination of alkylphosphonic acids. *J. Microcol. Sep.* 9. 1997:253-9.
122. Kientz CE, Langenberg JP, Brinkman UATh. Microcolumn liquid chromatography with thermionic detection of the enantiomers of o-ethyl s-2-diisopropylaminoethyl methylphosphonothiolate (VX). *J. High Resol. Chromatogr.* 17. 1994:95-7.
123. Kientz CE, Verweij A, de Jong GJ, Brinkman UATh. Verification of nonproduction of chemical warfare agents: I. Determination of organophosphorus compounds by microcolumn liquid chromatography with flame photometric or thermionic detection. *J. Microcol. Sep.* 4. 1992:465-75.
124. Kientz CE, Verweij A, de Jong GJ, Brinkman UATh. Verification of nonproduction of chemical warfare agents: II. Large volume injections in microcolumn liquid chromatography using flame photometric detection. *J. Microcol. Sep.* 4. 1992:477-83.
125. Kientz ChE. Chromatography and mass spectrometry of chemical warfare agents, toxins and related compounds: State of the art and future prospects. *J. Chromatogr. A.* 814. 1998:1-23.
126. Kingery AF, Allen HE. The environmental fate of organophosphorus nerve agents: A review. *Toxicol. and Environ. Chem.* 47. 1995:155-84.

127. Kingery AF, Allen HE. Ion chromatographic separation of closely related nerve agent degradation products using an organic modifier to provide selectivity. *Anal. Chem.* 66. 1994:155-9.
128. Kokko M. Effects of variations in gas chromatographic conditions on the linear retention indices of selected chemical warfare agents. *J. Chromatogr.* 630. 1993:231-49.
129. Kolla P. Detecting hidden explosives. *Anal. Chem.* 67. 1995:184A-9A.
130. Kostiainen O. Gas chromatography in screening of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:963-79.
131. Kostiainen R, Bruins AP, Hakkinen VMA. Identification of degradation products of some chemical warfare agents by capillary electrophoresis-ion spray mass spectrometry. *J. Chromatogr.* 634. 1993:113-8.
132. Kuitunen M-L. Sample preparation for analysis of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:1055-71.
133. Kuitunen M-L, Hartonen K, Riekkola M-L. Analysis of chemical warfare agents in soil samples by off-line supercritical fluid extraction and capillary gas chromatography. *J. Microcol. Sep.* 3. 1991:505-12.
134. Kunkel GJ, Busch KL, Dunphy R *et al.* Liquid secondary ion mass spectra and fast atom bombardment mass spectra of diquatery pyridinium oxime salts. *J. Mass Spectrom.* 30. 1995:282-9.
135. Lacorte S, Molina C, Barcelo D. Temperature and extraction voltage effect on fragmentation of organophosphorus pesticides in liquid chromatography-atmospheric pressure chemical ionization mass spectrometry. *J. Chromatogr. A.* 795. 1998:13-26.
136. Lakkisto U-M. Retention spectrometry - A new method for rapid and reliable detection and identification of chemical warfare agents. *Proc. 2nd Int. Symp. Protection Against Chemical Warfare Agents, Stockholm, Sweden, 15-19 June 1986.* 1986:245-50.
137. Lakso H-A, Ng WF. Determination of chemical warfare agents in natural water samples by solid-phase microextraction. *Anal. Chem.* 69. 1997:1866-72.
138. Leadbeater L, Sainsbury GL, Utley D. Ortho-chlorobenzylmalononitrile: A metabolite formed from ortho-chlorobenzylidenemalononitrile (CS). *Toxicology and Applied Pharmacology.* 25. 1973:111-6.
139. Lightenstein DA, Wils ERJ, Kossen SP, Hulst AG. Identification of two metabolites of the cholinestase reactivator HI-6 isolated from rat urine. *J. Pharm. Pharmacol.* 39. 1987:17-23.

140. Logan TP, Smith JR, Jakubowski EM, Nielson RE. Verification of lewisite exposure by the analysis of 2-chlorovinyl arsonous acid in urine. *Toxicology Methods*. 9. 1999:275-84.
141. Loke WK, Karlsson B, Waara L, Nyberg AG, Cassel GE. Enzyme-based microassay for accurate determination of soman in blood. *Anal. Biochem*. 257. 1998:12-9.
142. Ludemann WD, Stutz MH, Sass S. Qualitative thin-layer chromatography of some irritants. *Anal. Chem*. 41. 1969:679-81.
143. Machata G, Vycudilik W. Detection of mustard gas in biological material. *Arch. Belg. Med. Soc. (Toxicol.)*. 1984:53-5.
144. Maisonneuve A, Callebat I, Debordes L, Coppet L. Specific and sensitive quantitation of 2,2'-dichlorodiethyl sulphide (sulphur mustard) in water, plasma and blood: Application to toxicokinetic study in the rat after intravenous intoxication. *J. Chromatogr*. 583. 1992:155-65.
145. Marsh C. Nerve agent sensor. *Trends in Anal. Chem*. 18. 1999:v-vi.
146. Martz RM, Reutter DJ, Lasswell III LD. A comparison of ionization techniques for gas chromatography/mass spectroscopy analysis of dye and lachrymator residues from exploding bank security devices. *J. Forensic Sci*. 28. 1983:200-7.
147. Massil SE, Ovadia D. Determination of phosgene as its n,n,n',n'-tetraethylurea derivative by gas chromatography. *J. Chromatogr*. 538. 1991:435-40.
148. Matsuda Y, Nagao M, Takatori T *et al*. Detection of the sarin hydrolysis product in formalin-fixed brain tissues of victims of the Tokyo subway terrorist attack. *Toxicol. and Applied Pharmacol*. 150. 1998:310-20.
149. Matz G, Hunte T, Schroeder W. Hand-portable gas-detector array (GDA) for rapid field detection and identification of chemical threat. *Field Analytical Chemistry and Technology*. 4. 2000:195-203.
150. Mazurek M, Witkiewicz Z. The analysis of organophosphorus warfare agents in the presence of pesticides by overpressure thin layer chromatography. *J. Planar Chromatogr*. 4. 1991:379-84.
151. McAndless JM, Hancock JR. An automated air sampling and analysis system based on miniature solid-sorbent tubes (minitubes). *Proc. 2nd Int. Symp. Protection Against Chemical Warfare Agents, Stockholm, Sweden, 15-19 June 1986*. 181-7.

152. Mercier J-P, Morin P, Dreux M. Combination of LC-MS and CE-MS analysis for the separation and the identification of phosphonic acids. *Chimia*. 53. 1999:511-4.
153. Mercier J-P, Morin Ph, Dreux M, Tambute A. Capillary electrophoresis analysis of chemical warfare agent breakdown products I. Counterelectroosmotic separation of alkylphosphonic acids and their monoester derivatives. *J. Chromatogr. A*. 741. 1996:279-85.
154. Mercier J-P, Morin Ph, Dreux M, Tambute A. Capillary electrophoresis separation of alkylphosphonic acid monoesters with indirect ultraviolet detection. *J. Chromatogr. A*. 779. 1997:245-52.
155. Mesilaakso M, Niederhauser A. Nuclear magnetic resonance spectroscopy in analysis of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry*. 2000:1026-55.
156. Mesilaakso M, Rautio M. Verification of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry*. 2000:899-909.
157. Mesilaakso M, Tolppa E-L. Detection of trace amounts of chemical warfare agents and related compounds in rubber, paint, and soil samples by ^1H and ^{31}P $\{^1\text{H}\}$ NMR spectroscopy. *Anal. Chem.* 68. 1996:2313-8.
158. Miki A, Katagi M, Tsuchihashi H, Yamashita M. Determination of alkylmethylphosphonic acids, the main metabolites of organophosphorus nerve agents, in biofluids by gas chromatography-mass spectrometry and liquid-liquid-solid-phase-transfer-catalyzed pentafluorobenzoylation. *J. Anal. Toxicology*. 23. 1999:86-93.
159. Minami M, Hui D-M, Katsumata M, Inagaki H, Boulet CA. Method for the analysis of the methylphosphonic acid metabolites of sarin and its ethanol-substituted analogue in urine as applied to the victims of the Tokyo sarin disaster. *J. Chromatogr. B*. 695. 1997:237-44.
160. Mulchandani A, Kaneva I, Chen W. Biosensor for direct determination of organophosphate nerve agents using recombinant *Escherichia coli* with surface-expressed organophosphorus hydrolase. 2. Fiber-optic microbial biosensor. *Anal. Chem.* 70. 1998:5042-6.
161. Mulchandani A, Mulchandani P, Chen W, Wang J, Chen L. Amperometric thick-film strip electrodes for monitoring organophosphate nerve agents based on immobilized organophosphorus hydrolase. *Anal. Chem.* 71. 1999:2246-9.
162. Mulchandani A, Mulchandani P, Kaneva I, Chen W. Biosensor for direct determination of organophosphate nerve agents using recombinant *Escherichia coli* with surface-expressed organophosphorus hydrolase. 1. Potentiometric microbial electrode. *Anal. Chem.* 70. 1998:4140-5.

163. Munavalli S, Jakubowski EM, Durst HD. Liquid chromatography/thermospray mass spectrometry of mustard and its metabolites. *J. Mass Spectrom.* 30. 1995:1716-22.
164. Munavalli S, Pannella M. Thin-layer chromatography of mustard and its metabolites. *J. Chromatogr.* 437. 1988:423-8.
165. Nagao M, Takatori T, Matsuda Y, Nakajima M, Iwase H, Iwadate K. Definitive evidence for the acute sarin poisoning diagnosis in the Tokyo subway. *Toxicology and Applied Pharmacology.* 144. 1997:198-203.
166. Nasser A-EF, Lucas SV, Hoffland LD. Determination of chemical warfare agent degradation products at low-part-per-billion levels in aqueous samples and sub-part-per-million levels in soils using capillary electrophoresis. *Anal. Chem.* 71. 1999:1285-92.
167. Nasser A-EF, Lucas SV, Jones WR, Hoffland LD. Separation of chemical warfare agent degradation products by the reversal of electroosmotic flow in capillary electrophoresis. *Anal. Chem.* 70. 1998:1085-91.
168. Nasser A-EF, Lucas SV, Myler CA, Jones WR, Campisano M, Hoffland LD. Quantitative analysis of chemical warfare agent degradation products in reaction masses using capillary electrophoresis. *Anal. Chem.* 70. 1998:3598-604.
169. Nieuwenhuizen MS. Detection and screening of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:923-40.
170. Noort D, Hulst AG, Platenburg DHJM, Polhuijs M, Benschop HP. Quantitative analysis of o-isopropyl methylphosphonic acid in serum samples of Japanese citizens allegedly exposed to sarin: Estimation of internal dosage. *Arch. Toxicol.* 72. 1998:671-5.
171. Noort D, Hulst AG, Trap HC, de Jong LPA, Benschop HP. Synthesis and mass spectrometric identification of the major amino acid adducts formed between sulphur mustard and haemoglobin in human blood. *Arch. Toxicol.* 71. 1997:171-8.
172. Nowicki J. Analysis of chemical protection sprays by gas chromatography/mass spectrometry. *J. Forensic Sciences.* 27. 1982:704-9.
173. Occolowitz JL, White GL. The mass spectrometry of esters of phosphorous and phosphonic acids. *Anal. Chem.* 35. 1963:1179-82.
174. Oehrle SA, Bossle PC. Analysis of nerve agent degradation products using capillary ion electrophoresis. *J. Chromatogr. A.* 692. 1995:247-52.

175. Pedersen SN, Francesconi KA. Liquid chromatography electrospray mass spectrometry with variable fragmentor voltages gives simultaneous elemental and molecular detection of arsenic compounds. *Rapid Commun. Mass Spectrom.* 14. 2000:641-5.
176. Pianetti GA, Taverna M, Baillet A, Mahuzier G, Baylocq-Ferrier D. Determination of alkylphosphonic acids by capillary zone electrophoresis using indirect UV detection. *J. Chromatogr.* 630. 1993:371-7.
177. Polhuijs M, Langenberg JP, Benschop HP. New method for retrospective detection of exposure to organophosphorus anticholinesterases: Application to alleged sarin victims of Japanese terrorists. *Toxicology and Applied Pharmacology.* 146. 1997:156-61.
178. Preston JM, Karasek FW, Kim SH. Plasma chromatography of phosphorus esters. *Anal. Chem.* 49. 1977:1746-50.
179. Purdon JG, Pagotto JG, Miller RK. Preparation, stability and quantitative analysis by gas chromatography and gas chromatography-electron impact mass spectrometry of tert-butyl dimethylsilyl derivatives of some alkylphosphonic and alkyl methylphosphonic acids. *J. Chromatogr.* 475. 1989:261-72.
180. Raghuvveeran CD, Malhotra RC. Reversed-phase high-performance liquid chromatography of some irritants. *J. Chromatogr.* 240. 1982:243-6.
181. Raghuvveeran CD, Malhotra RC, Dangi RS. Reversed-phase high-performance liquid chromatography of sulphur mustard in water. *J. Liq. Chromatogr.* 16. 1993:1615-24.
182. Read RW, Black RM. Rapid screening procedures for the hydrolysis products of chemical warfare agents using positive and negative ion liquid chromatography-mass spectrometry and atmospheric pressure chemical ionization. *J. Chromatogr. A.* 862. 1999:169-77.
183. Rezai MA, Famigliini G, Cappiello A. Enhanced detection sensitivity by large volume injection in reversed-phase micro-high-performance liquid chromatography. *J. Chromatogr. A.* 742. 1996:69-78.
184. Robins WH, Wright BW. Capillary electrophoretic separation of organophosphonic acids using borate esterification and direct UV detection. *J. Chromatogr. A.* 680. 1994:667-73.
185. Rohrbaugh DK. Characterization of equimolar VX-water reaction product by gas chromatography-mass spectrometry. *J. Chromatogr. A.* 809. 1998:131-9.
186. Rohrbaugh DK. Methanol chemical ionization quadrupole ion trap mass spectrometry of O-ethyl S-[2-(diisopropylamino)ethyl] methylphosphonothiolate (VX) and its degradation products. *J. Chromatogr. A.* 893. 2000:393-400.

187. Rohrbaugh DK, Berg FJ, Szafraniec LJ, Rossman DI, Durst HD, Munavalli S. Synthesis and mass spectral characterization of diisopropylamino-ethanethiol, -sulfides and -disulfides and vinyl sulfides. *Phosphorus, Sulfur and Silicon*. 149. 1999:95-106.
188. Rohrbaugh DK, Sarver EW. Detection of alkyl methylphosphonic acids in complex matrices by gas chromatography-tandem mass spectrometry. *J. Chromatogr. A*. 809. 1998:141-50.
189. Rohrbaugh DK, Yang Y-C. Liquid chromatography/electrospray mass spectrometry of mustard-related sulfonium ions. *J. Mass Spectrom.* 32. 1997:1247-52.
190. Samcova E, Kvasnicova V, Urban J, Jelinek I, Coufal P. Determination of thioglycolic acid in urine by capillary electrophoresis. *J. Chromatogr. A*. 847. 1999:135-9.
191. Sass S, Fisher TL. Chemical ionization and electron impact mass spectrometry of some organophosphonate compounds. *Org. Mass Spectrom.* 14. 1979:257-64.
192. Sass S, Fisher TL, Steger RJ, Parker GA. Gas chromatographic methods for the analysis of trace quantities of isopropyl methylphosphonofluoridate and associated compounds, in situ and in decontamination effluent. *J. Chromatogr.* 238. 1982:445-56.
193. Sass S, Ludemann WD. Thin-layer chromatography of phosphonic acids. *J. Chromatogr.* 187. 1980:447-52.
194. Sass S, Parker GA. Structure-response relationship of gas chromatography-flame photometric detection of some organophosphorus compounds. *J. Chromatogr.* 189. 1980:331-49.
195. Sass S, Steger RJ. Gas chromatographic differentiation and estimation of some sulfur and nitrogen mustards using a multidetector technique. *J. Chromatogr.* 238. 1982:121-32.
196. Sass S, Stutz MH. Thin-layer chromatography of some sulfur and nitrogen mustards. *J. Chromatogr.* 213. 1981:173-6.
197. Schoene K, Bruckert H-J, Jurling H, Steinhanses J. Derivatization of 10-chloro-5,10-dihydrophenarsazine (adamsite) for gas chromatographic analysis. *J. Chromatogr. A*. 719. 1996:401-9.
198. Schoene K, Steinhanses J, Bruckert HJ, Konig A. Speciation of arsenic-containing chemical warfare agents by gas chromatography analysis after derivatization with thioglycolic acid methyl ester. *J. Chromatogr.* 605. 1992:257-62.

199. Sega GA, Tomkins BA, Griest WH. Analysis of methylphosphonic acid, ethyl methylphosphonic acid and isopropyl methylphosphonic acid at low microgram per liter levels in groundwater. *J. Chromatogr. A.* 790. 1997:143-52.
200. Shih ML, Ellin RI. Determination of toxic organophosphorus compounds by specific and nonspecific detectors. *Anal. Letters.* 19. 1986:2197-205.
201. Shih ML, Smith JR, McMonagle JD, Dolzine TW, Gresham VC. Detection of metabolites of toxic alkylmethylphosphonates in biological samples. *Bio. Mass Spectrom.* 20. 1991:717-23.
202. Shimizu N, Inoue Y, Daishima S, Yamaguchi K. Liquid chromatography-mass spectrometry of arsenic compounds using the electrospray ionization with postcolumn addition of methanol. *Anal. Sciences.* 15. 1999:685-7.
203. Singh AK, Zeleznikar Jr. RJ, Drewes LR. Analysis of soman and sarin in blood utilizing a sensitive gas chromatography-mass spectrometry method. *J. Chromatogr.* 324. 1985:163-72.
204. Sipponen KB. Detector for organophosphorus compounds in liquid chromatography based on the cholinesterase inhibition reaction. *J. Chromatogr.* 389. 1987:87-94.
205. Slobodnik J, van Baar BLM, Brinkman UATH. Column liquid chromatography-mass spectrometry: Selected techniques in environmental applications for polar pesticides and related compounds. *J. Chromatogr. A.* 703. 1995:81-121.
206. Smith JR, Schlager JJ. Gas chromatographic separation of the stereoisomers of organophosphorus chemical warfare agents using cyclodextrin capillary columns. *J. High Resol. Chromatogr.* 19. 1996:151-4.
207. Smith SJ. Detection methods for highly toxic organophosphonates. *Talanta.* 30. 1983:725-39.
208. Sng MT, Ng WF. In-situ derivatisation of degradation products of chemical warfare agents in water by solid-phase microextraction and gas chromatographic-mass spectrometric analysis. *J. Chromatogr. A.* 832. 1999:173-82.
209. Soderstrom MT. Fourier transform infrared in on-site and off-site analysis of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:943-63.

210. Soderstrom MT, Bjork H, Hakkinen VMA, Kostianen O, Kuitunen M-L, Rautio M. Identification of compounds relevant to the chemical weapons convention using selective gas chromatography detectors, gas chromatography-mass spectrometry and gas chromatography-fourier transform infrared spectroscopy in an international trial proficiency test. *J. Chromatogr. A.* 742. 1996:191-203.
211. Soderstrom MT, Ketola RA. Identification of nerve agents and their homologues and dialkyl methylphosphonates by gas chromatography/fourier transform infrared spectroscopy (GC-FTIR) Part I: Spectral interpretation. *Fresenius J. Anal. Chem.* 350. 1994:162-7.
212. Sokolowski M, Rozylo JK. TLC analysis of warfare agents under battlefield conditions. *J. Planar Chromatogr.* 6. 1993:467-71.
213. Sokolowski M, Witkiewicz Z. Gas chromatography-mass spectrometry analysis of products of o-isopropyl methylphosphonofluoridate transformation in aliphatic alcohols. *Chem. Anal. (Warsaw).* 38. 1993:139-47.
214. Stan'kov IN, Polyakov VS, Sergeeva AA, Lanin SN. Gas-chromatographic analysis of o-isobutyl s-2-(n,n-diethylamino)ethyl methylthiophosphonate and concomitant impurity substances. *J. Anal. Chem.* 54. 1999:194-7.
215. Stan'kov IN, Sergeeva AA, Tarasov SN. Gas-chromatographic determination of trace amino alcohols in water, air, and bitumen-salt masses forming in the detoxification of chemical warfare agents. *J. Anal. Chem.* 55. 2000:150-4.
216. Stan'kov IN, Tarasov SN, Polyakov VS. Gas-chromatographic determination of phosphorus and phosphoric acid chlorides in thionyl chloride. *J. Anal. Chem.* 54. 1999:191-3.
217. Stan'kov IN, Yarova VA, Sergeeva AA, Potashova IV, Tarasov SN, Samofalova NN. Gas-chromatographic determination of monoethanolamine and its salts of inorganic and organophosphorus acids present in combination. *J. Anal. Chem.* 55. 2000:155-9.
218. Steinhanses J, Schoene K. Thermal desorption-gas chromatography of some organophosphates and s-mustard after trapping on tenax. *J. Chromatogr.* 514. 1990:273-8.
219. Stuff JR, Cheicante RL, Durst HD, Ruth JL. Detection of chemical warfare agents bis-(2-chloroethyl)ethylamine (HN-1) and tris-(2-chloroethyl)amine (HN-3) in air. *J. Chromatogr. A.* 849. 1999:529-40.
220. Stuff JR, Cheicante RL, Morrissey KM, Durst HD. Trace determination of isopropyl methylphosphonofluoridate (GB) and bis (2-chloroethyl) sulfide (HD) in chemical neutralization solutions by gas chromatography-mass spectrometry. *J. Microcol. Sep.* 12. 2000:87-92.

221. Stuff JR, Creasy WR, Rodriguez AA, Durst HD. Gas chromatography with atomic emission detection as an aid in the identification of chemical warfare related material. *J. Microcol. Sep.* 11. 1999:644-51.
222. Syage JA. Real-time detection of chemical agents using molecular beam laser mass spectrometry. *Anal. Chem.* 62. 1990:505A-9A.
223. Szostek B, Aldstadt JH. Determination of organoarsenicals in the environment by solid-phase microextraction-gas chromatography-mass spectrometry. *J. Chromatogr. A.* 807. 1998:253-63.
224. Tingfa D. Gas chromatographic determination of o-ethyl s-(n,n-diisopropylamino)ethyl methylphosphonothiolate and o,o-diisopropyl s-benzyl phosphorothiolate as corresponding phosphonofluoridate and phosphorofluoridate. *Intern. J. Environ. Anal. Chem.* 27. 1986:151-8.
225. Tomkins BA, Griest WH, Hearle DR. Determination of small dialkyl organophosphonates at microgram/L concentrations in contaminated groundwaters using multiple extraction membrane disks. *Anal. Letters.* 30. 1997:1697-717.
226. Tornes AF. Identification of some alkyl methylphosphonic acids by thermospray tandem mass spectrometry. *Rapid Commun. Mass Spectrom.* 10. 1996:878-82.
227. Tornes JA, Johnsen BA. Gas chromatographic determination of methylphosphonic acids by methylation with trimethylphenylammonium hydroxide. *J. Chromatogr.* 467. 1989:129-38.
228. Tornes JA, Opstad AM, Johnsen BA. Use of solid-phase extraction in determination of chemical warfare agents. Part I Evaluation of the solid-phase extraction technique. *Intern. J. Environ. Anal. Chem.* 44. 1991:209-25.
229. Tornes JA, Opstad AM, Johnsen BA. Use of solid-phase extraction in determination of chemical warfare agents. Part II Determination of chemical warfare agents in samples from a battlefield environment. *Intern. J. Environ. Anal. Chem.* 44. 1991:227-32.
230. Trap HC, Langenberg JP. Semi-continuous high speed gas analysis of generated vapors of chemical warfare agents. *J. High Resol. Chromatogr.* 22. 1999:153-8.
231. Tripathi DN. Mass spectrometric identification of methylphosphonic acid: The hydrolysis product of isopropyl methylphosphonofluoridate and pinacolyl methylphosphonofluoridate. *Anal. Chem.* 64. 1992:823-4.

232. Tripathi DN, Bhattacharya A, Vaidyanathaswamy R. Mass spectral identification of bis(2-chloroethyl)sulfide and related compounds. *Can. Soc. Forens. Sci. J.* 17. 1984:55-7.
233. Tripathi DN, Kaushik MP, Bhattacharya A. Gas chromatographic-mass spectrometric identification of a mixture of isopropyl methylphosphonofluoridate, pinacolyl methylphosphonofluoridate and diisopropyl fluoro phosphate. *Can. Soc. Forens. Sci. J.* 2. 1987:151-3.
234. Tripathi DN, Malhotra RC, Bhattacharya A. Gas chromatographic-mass spectrometric identification of w-chloroacetophenone, o-chlorobenzylidenemalononitrile and dibenz[b,f]-1:4-oxazepine. *J. Chromatogr.* 315. 1984:417-9.
235. Verweij A, Boter HL. Degradation of s-2-diisopropylaminoethyl o-ethyl methylphosphonothioate in soil: Phosphorus containing products. *Pestic. Sci.* 7. 1976:355-62.
236. Verweij A, Burghardt E, Koonings AW. Gas chromatographic separation of diastereoisomeric alkyl methylphosphonofluoridates and related compounds. *J. Chromatogr.* 54. 1971:151-6.
237. Verweij A, Degenhardt CEAM, Boter HL. The occurrence and determination of PCH3 - containing compounds in surface water. *Chemosphere.* 3. 1979:115-24.
238. Verweij A, Dekker WH, Beck HC, Boter HL. Hydrolysis of some methylphosphonites and methylphosphinates. *Analytica Chimica Acta.* 151. 1983:221-5.
239. Vincze A, Busch KL, Cooks RG. Secondary ion mass spectra of quaternary pyridine aldoximes. *Anal. Chim. Acta.* 136. 1982:143-53.
240. Vycudilik W. Detection of bis(2-chloroethyl)-sulfide (yperite) in urine by high resolution gas chromatography-mass spectrometry. *Forensic Sci. Intern.* 35. 1987:67-71.
241. Wang QS, Zhang L, Zhang M, Xing XD, Tang GZ. A system for predicting the retentions of o-alkyl, n-(1-methylthioethylidenamino) phosphoramidates on RP-HPLC. *Chromatographia.* 49. 1999:444-8.
242. Ward JR, Hovanec JW, Albizo JM, Szafraniec LL, Beaudry WT. Decomposition of phosphonofluoridates on glass. *J. Fluorine Chem.* 51. 1991:277-82.
243. Waters WA, Williams JH. Hydrolysis and derivatives of some vesicant arsenicals. *J. Chem. Soc.* 1950:18-22.

244. Weimaster JF, Beaudry WT, Bossle PC *et al.* Chemical analysis of environmental samples collected in Iraq: Analysis for the presence of chemical warfare agents. *J. Chem. Tech. Biotechnol.* 64. 1995:115-28.
245. Wensing MW, Snyder AP, Harden CS. Energy resolved mass spectrometry of dialkyl methylphosphonates with an atmospheric pressure ionization tandem mass spectrometer. *Rapid Commun. Mass Spectrom.* 10. 1996:1259-65.
246. Wensing MW, Snyder AP, Harden CS. Energy resolved mass spectrometry of diethyl alkyl phosphonates with an atmospheric pressure ionization tandem mass spectrometer. *J. Mass Spectrom.* 30. 1995:1539-45.
247. Wils ERJ. Gas chromatography/mass spectrometry in analysis of chemicals related to the chemical weapons convention. *Encyclopedia of Analytical Chemistry.* 2000:979-1001.
248. Wils ERJ. Mass spectral data of precursors of chemical warfare agents. *Fresenius J. Anal. Chem.* 338. 1990:22-7.
249. Wils ERJ, Hulst AG. Determination of o-ethyl s-2-diisopropylaminoethyl methylphosphonothioate (VX) by thermospray liquid chromatography-mass spectrometry. *J. Chromatogr.* 523. 1990:151-61.
250. Wils ERJ, Hulst AG. Determination of organophosphorus acids by thermospray liquid chromatography-mass spectrometry. *J. Chromatogr.* 454. 1988:261-72.
251. Wils ERJ, Hulst AG. Gas chromatographic-mass spectrometric identification of tear-gases in dilute solutions using large injection volumes. *J. Chromatogr.* 330. 1985:379-82.
252. Wils ERJ, Hulst AG. Mass spectra of some derivatives of 2,2'-dichlorodiethyl sulphide (mustard gas). *Fresenius Z. Anal. Chem.* 321. 1985:471-4.
253. Wils ERJ, Hulst AG. Mass spectra of some derivatives of the irritant o-chlorobenzylidenemalononitrile. *Fresenius Z. Anal. Chem.* 320. 1985:357-60.
254. Wils ERJ, Hulst AG. Mass spectra of some pinacolyl-containing organophosphorus compounds. *Org. Mass Spectrom.* 21. 1986:763-5.
255. Wils ERJ, Hulst AG. Thermospray mass spectrometry of diquaternary pyridinium oxime salts. *Biomed. Environ. Mass Spectrom.* 17. 1988:155-9.
256. Wils ERJ, Hulst AG. The use of thermospray-liquid chromatography/mass spectrometry for the verification of chemical warfare agents. *Fresenius J. Anal. Chem.* 342. 1992:749-58.

257. Wils ERJ, Hulst AG, de Jong AL. Determination of mustard gas and related vesicants in rubber and paint by gas chromatography-mass spectrometry. *J. Chromatogr.* 625. 1992:382-6.
258. Wils ERJ, Hulst AG, de Jong AL, Verweij A, Boter HL. Analysis of thiodiglycol in urine of victims of an alleged attack with mustard gas. *J. Anal. Toxicology.* 9. 1985:254-7.
259. Wils ERJ, Hulst AG, van Laar J. Analysis of thiodiglycol in urine of victims of an alleged attack with mustard gas, part II. *J. Anal. Toxicology.* 12. 1988:15-9.
260. Wils ERJ, Hulst AG, Verwiël PEJ, van Krimpen SH, Niederhauser A. Identification of an octyl methylphosphonofluoridate mixture in chemical industry samples. *Fresenius J. Anal. Chem.* 343. 1992:297-303.
261. Witkiewicz Z, Mazurek M, Szulc J. Chromatographic analysis of chemical warfare agents. *J. Chromatogr.* 503. 1990:293-357.
262. Woloszyn TF, Jurs PC. Quantitative structure-retention relationship studies of sulfur vesicants. *Anal. Chem.* 64. 1992:3059-63.
263. Xie Y, Popov BN. Catalyzed hydrolysis of nerve gases by metal chelate compounds and potentiometric detection of the byproducts. *Anal. Chem.* 72. 2000:2075-9.
264. Yang Y-C. Chemical reactions for neutralising chemical warfare agents. *Chemistry and Industry.* 1995:334-7.
265. Yang Y-C, Baker JA, Ward JR. Decontamination of chemical warfare agents. *Chem. Rev.* 92. 1992:1729-43.
266. Zerba EN, Ruveda MA. Gas chromatographic determination of riot-control agents. *J. Chromatogr.* 68. 1972:245-7.

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
 (highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for who the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in Section 8.) Defence Research Establishment Suffield	2. SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable) Unclassified	
3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title). DRES Chemical Warfare Agent Literature Database of Analytical Methods		
4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.) D'Agostino, Paul A., Hancock, James R., Provost, Lionel R.		
5. DATE OF PUBLICATION (month and year of publication of document) January 2001	6a. NO. OF PAGES (total containing information, include Annexes, Appendices, etc) 32	6b. NO. OF REFS (total cited in document) 0
7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)		
8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)		
9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)	
10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRES SSP 2001-014	10b. OTHER DOCUMENT NOs. (Any other numbers which may be assigned this document either by the originator or by the sponsor.)	
11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification) <input checked="" type="checkbox"/> Unlimited distribution <input type="checkbox"/> Distribution limited to defence departments and defence contractors; further distribution only as approved <input type="checkbox"/> Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved <input type="checkbox"/> Distribution limited to government departments and agencies; further distribution only as approved <input type="checkbox"/> Distribution limited to defence departments; further distribution only as approved <input type="checkbox"/> Other (please specify):		
12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally corresponded to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected).		

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM

13. **ABSTRACT** (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C) or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

Defence Research Establishment Suffield (DRES) is actively involved in the development and evaluation of new analytical methods for the detection and identification of chemical warfare agents, their degradation products and related compounds. These methods are used for the analysis of samples collected in support of the Canadian Forces and have application in arms control verification. DRES analytical methods are published regularly in the open literature along with the methods developed by others involved in chemical warfare agent sample preparation and analysis. DRES retains printed copies of all publications in the database and regularly updates the bibliographic information from these papers into Procite, a computer searchable bibliographic database program. The DRES Chemical Warfare Agent Literature Database of Analytical Methods contains bibliographic information for more than 260 publications, and is available on request in hardcopy form or as a Procite, Word or Wordperfect file.

14. **KEYWORDS, DESCRIPTORS or IDENTIFIERS** (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifies, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Chemical warfare agents
Database
Analytical methods
Chromatography
Mass spectrometry

The Defence Research
and Development Branch
provides Science and
Technology leadership
in the advancement and
maintenance of Canada's
defence capabilities.

Leader en sciences et
technologie de la défense,
la Direction de la recherche
et du développement pour
la défense contribue
à maintenir et à
accroître les compétences
du Canada dans
ce domaine.



www.crad.dnd.ca