

Review of Thermal Destruction Technologies for Chemical and Biological Agents Bound on Materials



**Review of Thermal Destruction Technologies for
Chemical and Biological Agents
Bound on Materials**

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DISCLAIMER

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TABLE OF CONTENTS

LIST OF ACRONYMS	7
1 INTRODUCTION	14
1.1 Project Background	14
1.2 Quality Assurance for Sources of Secondary Data	15
1.3 Background of Chemical and Biological Agents	16
2 THERMAL TECHNOLOGIES FOR THE DESTRUCTION OF CHEMICAL AND BIOLOGICAL AGENTS BOUND ON MATERIAL SURFACES	20
2.1 Incineration/Combustion	20
2.2 Hazardous Waste Combustors	21
2.2.1 <i>Municipal Waste Combustors</i>	28
2.3 Medical Waste Incinerators	28
2.4 Chemical Weapon Demilitarization	30
2.4.1 <i>Metal Parts Furnaces</i>	30
2.4.2 <i>Liquid Incineration</i>	33
2.4.3 <i>Plasma Pyrolysis</i>	35
2.4.4 <i>Pollution Abatement of Chemical Weapon Demilitarization</i>	35
2.5 Emission and Aerosol Containment	36
2.6 Plasma Systems	41
2.6.1 <i>Thermal Plasma</i>	41
2.6.2 <i>Cold Plasma</i>	43
2.7 Microwave Irradiation	51
2.8 Autoclave	59
2.9 Landfill Flares	61
2.10 Bench-Scale Flame Mechanism Studies	62
2.11 Exothermic Intermetallic Interaction	63
2.12 Direct Heat Application	65
3 NEUTRALIZATION/HYDROLYSIS AND TREATMENT OF HYDROLYSATE	71
3.1 Neutralization/Hydrolysis	71
3.2 Treatment of Hydrolysate	72
3.2.1 <i>Incineration of Hydrolysate</i>	73
3.2.2 <i>Supercritical Water Oxidation of Hydrolysate</i>	73
3.2.3 <i>Biological Treatment of Hydrolysate</i>	76
3.2.4 <i>Treatment of Hydrolysate Using Photoactivated Periodate</i>	78
4 INCINERATOR MODELING RESULTS	80
4.1 COM Model	84
4.1.1 <i>Gas Temperature</i>	84
4.1.2 <i>Minimum Piece Temperature</i>	85
4.1.3 <i>CB Agents Remaining</i>	86
4.2 Stoker Model	87
4.2.1 <i>Gas Temperature</i>	87
4.2.2 <i>Minimum Piece Temperature</i>	88
4.3 MEDPATH Model	89
4.3.1 <i>Gas Temperature</i>	89
4.3.2 <i>Minimum Piece Temperature</i>	90
4.3.3 <i>Agent Left</i>	90

5	CREMATION OF HUMAN REMAINS FOLLOWING CHEMICAL AND BIOLOGICAL AGENT INCIDENTS.....	92
5.1	U.S. Military Protocols.....	92
5.2	UK Protocols.....	93
6	CONCLUSIONS.....	95
7	REFERENCES.....	96

LIST OF TABLES

Table 2-1.	Chemical Agent Structure and Physical Properties.....	18
Figure 2-1.	Ceiling Tile Bundle Spore Survival as a Function of Time in Kiln (Adapted with permission from Wood et al., 2006).....	23
Figure 2-2.	The Effect of Heating Temperature and Time on Reduction of <i>B. subtilis</i> Spiked on Ceiling Tile (Adapted with permission from Lemieux et al., 2005).....	24
Figure 2-3.	Log Reduction of <i>G. stearothersophilus</i> BIs in Ceiling Tile Bundles (Wet and Dry) vs. Time in RKIS (Reprinted with permission from Wood et al., Copyright 2008 American Chemical Society). 95% Confidence Interval (CI).....	25
Figure 2-4.	Histogram Showing Percent Survival of Both <i>G. stearothersophilus</i> and <i>B. atrophaeus</i> BIs Versus the Maximum Temperature Inside the Bundle (Adapted with permission from Wood et al., 2010).....	26
Figure 2-5.	Log Reduction with Time for <i>B. subtilis</i> on Wallboard at Various Initial Temperatures (Adapted with permission from Denison et al., 2002 [Reaction Engineering International]).....	27
Figure 2-6.	Comparison between Measured Data and Model Calculations of the Kiln Exit Temperature for <i>B. subtilis</i> (Adapted with permission from Denison et al., 2005 [Reaction Engineering International]).....	27
Figure 2-7.	Gas Temperature Distribution in the Afterburner of the Three-Zone MPF (Adapted with permission from Denison et al., 2002 [Reaction Engineering International]).....	31
Figure 2-8.	Comparison of HD Destruction Kinetics with Experimental Data (Adapted with permission from Denison et al., 2002 [Reaction Engineering International]).....	32
Figure 2-9.	Calculated Time Profiles for Zone 1 with 155 mm Projectiles with 5% Residual Agent Added in a Three-Zone Furnace (Adapted with permission from Denison et al., 2002 [Reaction Engineering International]).....	33
Figure 2-10.	Calculated Destruction of VX, GB, HD, and H in a Plug Flow Reactor with Two-Second Residence Time Versus Temperature (Adapted with permission from Denison et al., 2004 [Reaction Engineering International]).....	34
Figure 2-11.	LIC Primary and Secondary Chambers with VX Agent Destruction Depicted by Streamlines (Adapted with permission from Denison et al., 2004 [Reaction Engineering International]).....	34
Figure 2-12.	Comparison of Total Furan and Dioxin Emissions for Burn Barrels and Municipal Waste Incinerators (Adapted with permission from Lemieux et al., 2000).....	41
Figure 2-13.	Plot of Percent Kill Versus Target Velocity for <i>G. stearothersophilus</i> Spores on Fiberglass with and without a Lens to Block Heat from the Steam-Plasma Torch (© 2000 IEEE. Reprinted, with permission from Farrar et al.).....	43

Figure 2-14. Atmospheric Pressure Plasma Jet (APPJ) (left); Destruction of the Anthrax Surrogate <i>Bg</i> Using the APPJ Method Compared to the Dry Heat treatment (right) (Adapted from Rosocha et al., 2003 with the permission of the Los Alamos National Laboratory) ...	46
Figure 2-15. Destruction of Malathion using the APPJ Method as Compared to the Dry Heat Treatment (Adapted from Rosocha et al., 2003 with the permission of the Los Alamos National Laboratory).....	46
Figure 2-16. Residual VX Remaining on Aluminum as a Function of Exposure Time (T = 70 °C, d = 10 cm, Pressure = 30 torr, O ₂ or H ₂ at 10 % (Reproduced with permission from Herrmann et al. Copyright 2000, AIP Publishing LLC.).....	47
Figure 2-17. Residual HD Remaining on Aluminum (left) and Residual GD Remaining on Aluminum (right) Versus Time. Test Conditions: T = 70 °C, d = 10 cm, Pressure = 30 torr, O ₂ or H ₂ at 10 % (Reproduced with permission from Herrmann et al. Copyright 2000, AIP Publishing LLC.).....	47
Figure 2-18. Live Cells Versus Exposure Time for <i>B. subtilis</i> in Luria-Bertani Broth with Applied Power of 42 W (left). SEM Photograph of <i>E. coli</i> on Plasma-Exposed Sample after 30 Seconds Exposure Time (right) (© 2000 IEEE. Reprinted, with permission from Laroussi et al.).....	49
Figure 2-19. Survivors of Bacterial Cells Inoculated on Polypropylene with Time with the Application of OAUGDP (left). The Transmission Electron Micrograph of OAUGDP-treated Cells: A) Initial <i>E. coli</i> , B) <i>E. coli</i> after 30 Seconds of Exposure, C) Initial <i>S. aureus</i> , and D) <i>S. aureus</i> after 30 Seconds of Exposure (right) (© 2000 IEEE. Reprinted, with permission from Montie et al.).....	50
Figure 2-20. Airborne Exposure of <i>B. subtilis var. niger</i> , <i>P. fluorescens</i> and <i>A. versicolor</i> to Microwave Irradiation at 700, 385, and 119 W for 1.5 Minutes (Adapted from Wu and Yao, 2010 with permission from Elsevier, Inc.).....	52
Figure 2-21. Liquid-borne Exposure of <i>B. subtilis var. niger</i> to Microwave Irradiation at 700, 385, and 119 W (Adapted from Wu and Yao, 2010 with permission from Elsevier, Inc.) ..	53
Figure 2-22. SEM Images of Liquid-borne Control and Exposed <i>P. fluorescens</i> , <i>A. versicolor</i> and <i>B. subtilis var. niger</i> with 700 W and 90 Seconds Exposure Time (Reprinted from Wu and Yao, Copyright 2010, with permission from Elsevier, Inc.).....	53
Figure 2-23. Dynamic In-Flight On-Filter Disinfection of <i>B. subtilis</i> with Microwave Application Time at 250, 500, and 750 W Power Levels (Reprinted from Zhang et al., Copyright 2010 with permission from Elsevier, Inc.)	55
Figure 2-24. SEM Images of (a) TiO ₂ Nanofibers, (b) Millipore high efficiency particulate arrestance (HEPA) filter, and (c) Military HEPA (Wu et al., 2009, Published by DTIC, No Permission Required).....	56
Figure 2-25. Percent Destruction of DMMP for Different V ₂ O ₅ Catalysts (Cha et al., 2004, Published by DTIC, No Permission Required).....	57
Figure 2-26. Percent Destruction of DES for Different V ₂ O ₅ Catalysts (Cha et al., 2004, Published by DTIC, No Permission Required).....	58
Figure 2-27. Parametric Test Output for the Destruction of DES Simulant (Cha et al., 2004, Published by DTIC, No Permission Required).....	58
Figure 2-28. Effect of Second Autoclave Cycle on Spore Survivability, Temperature with Time (Adapted with permission from Lemieux et al., 2006a)	60
Figure 2-29. Effect of Packing Density for Wallboard, Temperature with Time (Adapted with permission from Lemieux et al., 2006a)	61

Figure 2-30. Dry Heat D-values and Z-values for Biological Indicators (<i>Geobacillus stearothermophilus</i> [squares], <i>B. anthracis</i> [circles], and <i>B. atrophaeus</i> [triangles]) (Adapted with permission from Wood et al., Copyright 2009 The Society for Applied Microbiology)	66
Figure 2-31. Evaporation Profiles at Different Temperatures and Drop Size for HD at an Air Flow of 175 SLPM (Reprinted from Jung and Lee, Copyright 2014 with permission from Elsevier Inc.)	68
Figure 3-1. Time Course of Strain T09 with TDG at 30 °C Grown Aerobically, Closed Circles (Residual TDG Concentrations) and Open Circles (Cellular Growth) (Reprinted from Bassi et al., Copyright 2009 with permission from Elsevier, Inc.)	78
Figure 4-1. Modeling Concept	80
Table 4-1. Experimental Design Factors for CFS Model	82
Figure 4-2. CFS COM Model Bundle Input Parameters	83
Figure 4-3. COM Model, Gas Temperature	84
Figure 4-4. COM Model, Minimum Piece Temperature	85
Figure 4-5. COM Model, Agent Left	86
Figure 4-6. Stoker Model, Gas Temperature	87
Figure 4-7. Stoker Model, Minimum Piece Temperature	88
Figure 4-8. MEDPATH Model, Gas Temperature	89
Figure 4-9. MEDPATH Model, Minimum Piece Temperature	90
Figure 4-10. MEDPATH Model, Agent Left	91
Figure 5-1. Flow Diagram for Processing Contaminated Remains (Published by US Army, 2003, No Permission Required)	93

APPENDICES

- Appendix A: Summary Table of Thermal Processes for CB Agent Destruction
Appendix B: Compiled References Worksheet

LIST OF ACRONYMS

ACF	activated carbon fiber
ANOVA	analysis of variance
APD	atmospheric plasma decontamination
APPJ	Atmospheric Pressure Plasma Jet
<i>Ba</i>	<i>Bacillus anthracis</i>
BDR	building decontamination residue
<i>Bg</i>	<i>Bacillus globigii</i>
BI	biological indicator
bp	boiling point
BWA	biological warfare agent
BW	biological weapon
CAA	Clean Air Act
CARC	chemical agent resistant coating
CAM	chemical agent monitor
CB	chemical or biological
CB	chlorobenzene
CBR	chemical, biological or radiological
CBRNIAC	Chemical, Biological, Radiological and Nuclear Information Analysis Center
CFD	computational fluid dynamics
CFS	configured fireside simulator
CFU	colony forming unit(s)
CI	confidence interval
CO ₂	carbon dioxide
COM	commercial hazardous waste burning rotary kiln
CP	chlorophenol
CWA	chemical warfare agent
CWC	Chemical Weapons Convention
DC	direct current
D/F	dioxin/furan
DES	diethyl sulfide
DFP	diisopropyl fluorophosphate
DFS	deactivation furnace system

DIMP	diisopropyl methylphosphonate
DMMP	dimethyl methylphosphonate
DMOR	Disaster Mortuary Operational Response (Team)
DNA	deoxyribonucleic acid
DoD	Department of Defense
DTIC	Defense Technical Information Center
DTP	3,3-dithiopropanol
DRE	destruction and removal efficiency
DSA	drop shape analysis
DST	decision support tool
ECDAP	enhanced corona discharge at atmospheric pressure
EPA	U.S. Environmental Protection Agency
FTCMR	flow-through catalytic membrane reactor
GA	tabun
GB	sarin
GC/MS	gas chromatograph/mass spectrometry
GD	soman
GDAP	glow discharge at atmospheric pressure
GE	ethyl sarin
GF	cyclosarin
GH	O-isopentyl sarin
GS	S-butyl sarin
<i>Gs</i>	<i>G. stearothermophilus</i>
HAP	hazardous air pollutant
HCl	hydrogen chloride
HCWA	hydrolysates of chemical warfare agents
HD	sulfur mustard
HDIAC	Homeland Defense and Security Information Analysis Center
HEPA	high efficiency particulate arrestance
HF	hydrogen fluoride
HRT	hydraulic retention time
HVAC	heating, ventilating and air conditioning
HWC	hazardous waste combustor

HWI	hazardous waste incinerator
ICB	immobilized cell bioreactor
IPE	individual protective equipment
IZAYDAS	Izmit Hazardous and Clinical Waste Incinerator
JACADS	Johnson Atoll Chemical Agent Disposal System
kW	kilowatt
LANL	Los Alamos National Laboratory
LIC	liquid incinerator
LVOH	low volatility organohalogen (compound)
MACT	maximum achievable control technology
MEDPATH	medical/pathological waste incinerator
MOPP	mission-oriented protective posture
mp	melting point
MPA	methylphosphonic acid
MPF	metals parts furnace
MPT	microwave plasma torch
MW	megawatt
MWI	medical waste incinerator
MWC	municipal waste combustor
NHSRC	National Homeland Security Research Center
NIEHS	National Institutes of Environmental Health Sciences
NTIS	National Technical Information Service
OAUGDP	one atmosphere uniform glow discharge plasma
OPC	organophosphorus compound
PAN	polyacrylonitrile
PCAPP	Pueblo Chemical Agent-Destruction Pilot Plant
PCB	Polychlorinated biphenyl
PCDD	polychlorinated dibenzo- <i>p</i> -dioxin
PCDF	polychlorinated dibenzofuran
PIC	product of incomplete combustion
PNPDPP	<i>para</i> -nitrophenyl diphenylphosphate
POHC	principal organic hazardous constituent
ppm	part(s) per million

PWC	plasma waste converter
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RF	radio frequency
RHELP	regenerative high efficiency low pressure
RKIS	rotary kiln incinerator simulator
rms	root mean square
RNA	ribonucleic acid
ROS	reactive oxygen species
SCC	secondary combustion chamber
SCWO	supercritical water oxidation
SCW	supercritical water
SEM	scanning electron microscope
SO ₂	sulfur dioxide
SRT	sludge retention time
STAATT	State Territorial Association Alternative Treatment Technologies
STO	stoker furnace
TD	thermal desorption
TDG	thiodiglycol
TEM	transmission electron micrography
TEQ	toxicity equivalent quantity
TOCDF	Tooele Chemical (Agent) Disposal Facility
TPAC	transduction-polymer and an acceptor-chromophore
TSDF	treatment, storage, or disposal facility
TTU	Texas Tech University
TX	1,4-thioxane
UK	United Kingdom
VOC	volatile organic compound
VR	Russian VX
VX	nerve agent
VXH	VX hydrolysate
W	watt
WMD	weapon of mass destruction

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ABSTRACT

There is interest in identifying appropriate operating conditions to assure that thermal destruction processes would result in complete destruction of any residual Chemical or Biological (CB) agents bound on materials removed from contaminated sites. Compiling these operating conditions, along with data on their efficacy, would greatly facilitate the management of waste generated during cleanup following a CB contamination incident.

This review report gathered available information on the thermal destruction of CB agents bound on solid materials. This review used information extracted from secondary data sources including government reports, publications in the open literature, peer-reviewed journal articles, and both published and non-published literature, including distribution limited reports. The literature search included searches in the Dialog database, Google Scholar™, and active identification of EPA research reports that were in varying stages of completion. Thermal processes reviewed in this report include incineration, thermal plasma systems, microwave irradiation, autoclaving, landfill flaring, exothermic intermetallic interaction, and direct heat application. A description of the materials tested and operating conditions such as exposure times, temperatures, and plasma flow rates and the corresponding CB reductions are included. A summary table of the operating conditions and results from the thermal processes and hydrolysate treatment discussed in this review are presented in Appendix A. In addition, a review of the containment of aerosols and emissions from the incineration of CB material is also discussed. The results of modeling of the designs of several incinerators burning CB materials are also presented in this report.

The treatment of hydrolysate wastewater from neutralization of chemical agents with supercritical water oxidation, incineration, and biological treatment are also discussed. The test conditions, contact times, concentrations of chemicals and destruction efficiencies are included.

This review also discusses the available literature on the cremation of human remains after CB contamination incidents. Specifically, literature protocols on the cremation of contaminated human remains, including the required temperature and time, are discussed.

This report reviewed literature on the destruction of CB agents and surrogates bound on various materials such as ceiling tiles, wallboard, carpet, fiberglass, aluminum, concrete, pumice, stone, wood, stainless steel, laminate, asphalt, brick, and others.

The studies showed that CB agents bound on porous materials such as ceiling tiles and carpet bundles may require more exposure time to destroy CB agents than the CB agents bound on nonporous materials. Furthermore, wet porous materials required more exposure time than dry porous materials due to the large amount of water they can hold that must be boiled off prior to heating the material beyond the boiling point of water. For example, Wood et al. (2006) reported that at 800 °C, dry ceiling tiles achieved 6 log₁₀ reduction in spores after 12 minutes for an anthrax surrogate, but up to 38 minutes was required for complete reduction with wet ceiling tiles. Farrar et al. (2000) reported only partial destruction for the biological agent surrogate *B. stearothermophilus* on a pumice block using a steam plasma torch (4,500 °F, up to 2 ft/s at a distance of 1 inch from the exit plane) whereas 99.94% destruction was achieved on fiberglass using the same test conditions.

1 INTRODUCTION

This section discusses the project background, sources of secondary data used to compile this report, the Quality Assurance (QA) of the references, and a background of Chemical or Biological (CB) agents.

1.1 Project Background

EPA is designated as a coordinating Agency, under the National Response Framework, to prepare for, respond to, and recover from a threat to public health, welfare, or the environment caused by actual or potential oil and hazardous materials incidents. Hazardous materials include chemical, biological, and radiological substances, whether accidentally or intentionally released.

Many items removed from contaminated areas either before or after contamination may be treated using incineration or thermal destruction. Whether or not these items have undergone decontamination operations, due to limitations in laboratory capacity, these items may or may not be fully characterized with respect to the presence/absence of residual CB agents. Because of this limitation, identifying packaging and incinerator or thermal destructor operating conditions to assure that thermal destruction processes would result in complete destruction of any residual CB agent bound on these items will greatly facilitate the management of the waste generated during cleanup of a CB contamination incident.

This review report gathered available information on the thermal destruction of CB agents bound on solid materials such as building materials. Results from this review will help address an identified gap related to defining conditions under which effective thermal destruction can be performed on solid materials resulting from cleanup following a CB contamination incident. Thermal processes discussed include incineration, plasma systems, microwave irradiation, autoclaving, landfill gas flaring, exothermic intermetallic interaction, and direct heat application. The containment of aerosols and emissions from the incineration of CB material is also discussed.

Neutralization and hydrolysis of chemical agents is discussed in this review. The treatment of hydrolysate wastewater from neutralization of chemical agents by supercritical water oxidation, incineration, and biological treatment is also discussed.

This review also discusses the available literature on the cremation of human remains after CB contamination incidents. Although the disposition of human remains is not part of EPA's mission in the CB response area, the environmental consequences of the disposition of those remains are part of EPA's mission to protect public health and the environment.

In addition, incineration models were conducted using EPA's Configured Fireside Simulator (CFS) tool for four CB agents (*Bacillus anthracis* [Ba], sarin [GB], VX, and mustard [HD]) and three design types of furnaces (a commercial hazardous waste-burning rotary kiln, a medical/pathological waste incinerator, and a stoker incinerator). The results from the incinerator models are presented in this report.

Chemical () and biological () icons are included in the headings of each section to represent the type of contaminant discussed in the section.

1.2 Quality Assurance for Sources of Secondary Data

This review used information extracted from secondary data sources including government reports, publications in the open literature, peer-reviewed journal articles, and both published and non-published literature, including limited distribution reports. Secondary data are defined as existing data (also termed non-direct measurements) that were not developed originally through the project to which they are being applied. Applicable secondary data were sought from the various sources of scientific literature. The literature search included searches in the Dialog database, including Energy Science & Technology (formerly DOE ENERGY) and the National Technical Information Service (NTIS), the Homeland Defense and Security Information Analysis Center (HDIAC) managed by the Defense Technical Information Center (DTIC) [formerly the Chemical, Biological, Radiological and Nuclear Information Analysis Center (CBRNIAC)], Google Scholar™, and active identification of U.S. Environmental Protection Agency (EPA) research reports that are in varying stages of completion. Battelle presented EPA with the search criteria prior to embarking on the literature search.

The literature review not only identified but also assessed the secondary data for intended use(s). After the literature searches were conducted and the results subsequently reviewed, the quality of

the secondary data was examined against the overall needs of the Task Order (TO). The quality of identified sources of secondary data was evaluated through a literature assessment factor rating. Based on the numerical rating factor score of each source of secondary data, collected information was deemed either appropriate or inappropriate for inclusion in the results. Results are listed in the Excel[®] spreadsheet grouped by relevance (as determined by the rating factor) to assist with the selection criteria for quality documents (presented in Appendix B). Articles and reports were also assessed qualitatively according to document type and documented in the Excel[®] spreadsheet. Each report or article referenced in the Excel[®] spreadsheet was identified with the appropriate document type designation. Knowledge of the document type will help EPA (or other readers/reviewers identified by EPA over the course of the TO) in understanding the range of documents obtained.

All secondary data and source information compiled underwent an independent review (at least 10% of all secondary data mined from the literature) with regard to transcriptional accuracy in the Excel[®] summary table (presented in Appendix B) by Battelle's Quality Assurance (QA) Manager. This review was conducted for initial transcription of data from the secondary data source and for each point of data transfer in process, including use of the data in the final literature review report. This review confirmed that the populated literature search included relevant information on thermal destruction of CB agents bound on different types of materials, for which the sources of information are credible, and that proper information is included in the correct categories. This review also ensured that the correct source of the data is maintained throughout all processes using the data.

1.3 Background of Chemical and Biological Agents

Chemical warfare agents (CWAs) fall into three main classes: vesicants (e.g., sulfur mustards (HD), nitrogen mustards (HN₃)), blood agents (e.g., hydrogen cyanide), and organophosphorus nerve agents (acetylcholinesterase inhibitors) of the G- type (tabun [GA], GB, soman [GD], ethyl sarin [GE], cyclosarin [GF], S-butyl sarin [GS], O-isopentyl sarin [GH]) and V (VX, VE, VG, VM). Biological warfare agents (BWAs) can be classified into at least five categories: viruses, bacteria (spore-formers and vegetative bacteria), rickettsia, biological toxins, and genetically engineered agents (Giletto et al., 2003). The physical properties of VX, mustard, and sarin are presented in Table 2-1.

Agents that are liquids at room temperature with high boiling points and low vapor pressures such as HD and VX are classified as persistent agents that generally manifest themselves as contact poisons. A persistent agent could pose long-term cutaneous and ingestion hazards, along with an inhalation hazard upon slow evaporation. GB is not typically considered to be a persistent agent, especially compared to HD and VX. HD would be difficult to remove through water washing because of its insolubility, and VX may be difficult to remove with evaporation or dispersion because of its high boiling point and low vapor pressure. All of these chemical agents interact with materials that alter the fate and transport of the contaminant. An agent can be absorbed into porous materials and drawn by capillary action into material seams and crevices. Adsorption and infiltration of an agent may result in degradation of materials and can lead to unexpected persistence of the agent, even after measures have been taken to decontaminate (Hoette et al., 2010).

Bacterial endospores (e.g., *B. anthracis*) can survive in the environment for an extended period of time and are resistant to a wide variety of treatments such as heat, desiccation, radiation, pressure and chemicals. This resistance is the result of various factors such as the thick proteinaceous spore coat, low water content in the spore core, and the a/b-type small, acid-soluble spore proteins (Rogers, 2005).

Most CB agents can be destroyed or rendered harmless by suitable chemical treatments (Giletto et al., 2003). There is no single technology that will be applicable in all situations and to all types of contamination because the nature and extent of the contamination is different at different places (Kumar et al., 2010). The optimal decontamination technology for a given application generally depends on the material that is potentially contaminated. For instance, the optimal technology for decontaminating wastewater may differ from the optimal technology for decontaminating building materials (Wilhelmi et al., 2003).

Table 2-1. Chemical Agent Structure and Physical Properties

Chemical Agent			Physical State (at 25 °C)	Vapor Pressure mm Hg (at 20 °C)	Water Solubility (g/100 g Soln.)
Name	Code	Type			
VX	VX	Nerve	liquid, mp: 39 °C, bp: 298 °C	0.0007	3.0 (at 25 °C)
Mustard	HD	Blister	liquid, mp: 14.5 °C, bp: 218 °C	0.0072	0.92 (at 22 °C), limited
Sarin	GB	Nerve	liquid, mp: -56 °C, bp: 158 °C	2.1	miscible

(Hoette et al., 2010, Sandia Report); mp: melting point; bp: boiling point.

The materials to be thermally treated may be primarily concrete or metal if CB agents are released in urban areas, although there may be large quantities of other materials as well. Concrete materials include walls, floors, ceilings, bio-shields, and fuel pools. Metallic materials include structural steel, valves, pipes, glove boxes, reactors, and other equipment. Porous materials such as concrete can be contaminated throughout their structure, although contamination in concrete normally resides in the top quarter-inch below the surface. Metals are normally only contaminated on the surface (Kumar et al., 2010). There may be varying amounts of porous materials that make up a building's contents. Further, more porous materials like ceiling tiles are much harder to decontaminate effectively than less porous materials (Wilhelmi et al., 2003).

Non-thermal processes to destroy CB agents bound on materials are prevalent in literature, and frequently the residuals resulting from application of these technologies may undergo thermal treatment as part of the waste management process. Decontamination efficiency depends on various factors: not only the characteristics of the agent, but also the weather conditions, the bio-load on the material, and the type of material that is contaminated. Smooth surfaces painted with chemical agent resistant coating (CARC) are relatively easy to clean with an effective decontaminant, whereas the same decontaminant may not be able to clean more complex structures with cracks or crevices or absorbing materials such as rubber sufficiently (Boone, 2007).

The appropriate decontamination strategy also depends on the size of the contaminated area. If a chemical or biological agent exists only in a small area (e.g., within one room), then spot decontamination methods may be appropriate; however, spot decontamination is not feasible for contamination over broad areas. The extent of the contaminated area may also affect the decision on whether to conduct decontamination activities on site or at a remote location (Wilhelmi et al., 2003).

Lemieux described I-WASTE, a web-based decision support tool (DST) developed by EPA to assist decision makers through the process of planning the disposal of residual contaminated materials. The web tool allows the user to create a decision scenario with the following input parameters: incident location, type of waste material, waste quantity estimation, contaminant/decontaminant selection, treatment specifications (including incinerators, landfills, and wastewater treatment), and transportation plan (Lemieux et al., 2006b).

A universal formulation that can decontaminate all CB threats is not available. Existing decontamination solutions are effective only against a certain class of agents. To be effective, emergency response personnel would need several types of decontaminants available on hand. For complicated treatment technologies, there will be less people available to operate them. Use of existing decontaminants under inappropriate conditions can result in the formation of dangerous by-products. The formation of these by-products may complicate a waste management facility's willingness to accept the waste. Furthermore, some chemicals such as sodium hydroxide dissolved in organic solvents are unsuitable for use under certain conditions because they corrode, etch or erode materials (Giletto et al., 2003).

Current military decontamination techniques aimed at CW agents are corrosive and can cause collateral damage to facilities and equipment. The military requires fast action (30 min or less), whereas decontamination times on the order of several hours may be sufficient for the civilian sector. Rather than speed, considerations that are more important in a civilian scenario include availability of a reagent, low maintenance, ease of application, minimal training for application, easy deployment by a variety of dispersal mechanisms and acceptable expense (Raber et al., 2002).

2 THERMAL TECHNOLOGIES FOR THE DESTRUCTION OF CHEMICAL AND BIOLOGICAL AGENTS BOUND ON MATERIAL SURFACES

This section presents a review of the following thermal processes for the destruction of CB agents bound on material surfaces: incineration/combustion, plasma systems, microwave irradiation, autoclave, landfill flare, flame mechanisms, exothermic intermetallic interactions, and direct heat sterilization.

2.1 Incineration/Combustion

This sub-section reviews the literature on the incineration of CB agents, including processes such as chemical weapons demilitarization including metals parts furnaces (MPFs), and liquid incinerators (LICs) and processes using hazardous waste combustors (HWCs), municipal waste combustors (MWCs), and medical waste incinerators (MWIs). In addition, the literature on containment of emissions and aerosols from the incineration of CB agents is discussed.

Overall, there is a dearth of information in the literature on the destruction of CB agents at MWCs and MWIs. The majority of the literature on the destruction of CB agents using incineration involves the use of hazardous waste combustors in specially designed chemical demilitarization facilities. Literature on the neutralization of stockpiled munitions and subsequent secondary treatment by an HWC is also prevalent.

Incineration is an inherently attractive approach for destruction of organic compounds since the carbon and hydrogen in the organic compound produce carbon dioxide and water when burned in the presence of oxygen. Chemical warfare agents are combustible and therefore lend themselves to destruction by incineration. The incineration products are far less toxic than the original chemical warfare agents. In principle, incineration is an environmentally safe method of toxic waste treatment provided that the temperature and residence time used are sufficient to decompose the organic chemical to simple inorganic chemicals (Pearson and Magee, 2002) and that the downstream flue gas cleaning equipment is sufficient to remove particulate matter and acid gases and all other air pollutants from the stack gases that are emitted into the atmosphere.

2.2 Hazardous Waste Combustors

Fixed hearth and rotary kiln incinerators are the most likely candidates to manage wastes containing biological and chemical agents. Advantages of using these HWCs include the fact that regulations already require these incinerators to have waste tracking mechanisms, appropriate emission controls, and employee safety training programs. Possible disadvantages include the location of most HWCs in relatively remote areas, the limited capacities of HWCs, and size limitations. Some sizes of rotary kiln HWCs can process between 50 and 175 tons of hazardous waste per day. Typically, the sizing for the feed stream to allow entry into the combustor is the rough dimensions of a 55-gallon drum (Wilhelmi et al., 2003).

The afterburner is a critical part of the incineration system as it uses an auxiliary fuel such as natural gas, propane, or fuel oil to ensure that temperatures in excess of 1,090 °C and gas-phase residence times of 2 seconds or greater are achieved to ensure that any residual agent or products of incomplete combustion are destroyed.

Spent decontamination fluids may also be injected into either the primary chamber or the afterburner to destroy any residual agent in such fluids as well as to facilitate the evaporation and discharge of the water vapor. This decontamination fluid also contains salts, which are deposited in the bottom of the primary chamber or afterburner (Pearson and Magee, 2002).

Lemieux et al. (2010) reported on the potential difficulties that exist in thermally processing waste building materials from a post-CWA event site remediation due to the refractory nature of many materials found inside and outside buildings and the potential impact that waste packaging at the site may have on the behavior of these materials and residual agent destruction in combustion systems. Although CWAs are not particularly thermally stable and are readily destroyed at typical incineration temperatures (greater than 800 °C), relatively short gas-phase residence times (greater than 2 s) and solid-phase residence times (greater than 30 min) make it possible for some of the residual agent to escape the incinerator due to bypassing the flame zones, cold spots within the waste, and incomplete penetration of heat through the combustion bed. Complete destruction of building material-bound CWAs can be achieved once the core temperature of the building materials exceeds 300 °C. However, significant time may elapse between the introduction of the material into the incinerator and the time at which the core of the

material bundles approaches equilibrium with the gas temperatures (Lemieux et al., 2010). Due to the refractory nature of some building materials such as ceiling tile, particularly if wetted, the material will remain at the boiling point of water (100 °C) until all the water has been driven off.

Lemieux et al. (2010) conducted a study to examine the thermal decomposition of a surrogate CWA (Malathion) in a laboratory reactor using heating rates similar to those found in a rotary kiln incinerator processing building materials. The experiments were performed in small constant-volume reactor vessels on the bench scale. The CWA simulant was carefully dispensed into a stainless steel pipe through a Swagelok fitting using a syringe. The initial Malathion concentration was 300,000 µg/L. The chamber was then placed into an oven, and the temperature was ramped up to 400 °C at a set rate (5 or 10 °C/min), then maintained at that temperature for 30 minutes. The Malathion concentration averaged 911 µg/L after removal from the reactor at the following test conditions, 175 °C after 30 minutes of exposure. The experiments were performed using heating rates typical of the rates found inside bundles of building materials in a pilot-scale hazardous waste incineration system and fit to a first-order Arrhenius expression. An analysis of the results was done using reactor design theory. Subsequently a scale-up of the results to a computer simulation of a full-scale commercial hazardous waste incinerator processing Malathion-contaminated ceiling tile was performed (Lemieux et al., 2010).

The decontamination of a building following release of a biological warfare agent (such as *B. anthracis*) may result in a significant quantity of building decontamination residue (BDR) consisting of non-structural components of the building (e.g., ceiling tile, carpet) and building contents. Wood et al. (2006) described experiments that were performed in a pilot-scale rotary kiln incinerator to evaluate the thermal destruction of *B. anthracis* surrogates (*Geobacillus stearothermophilus* bacterial spores) present within bundles of carpeting and ceiling tile. No spores were detected in the exhaust gas via any of the three sampling trains for the carpet burn tests. For all of the tests, average kiln exit temperatures prior to the feeding of the carpet ranged from approximately 804 to 827 °C (1,480 to 1,520 °F). For the dry ceiling tile bundles, a 1 to 2 log₁₀ reduction in the number of spores occurred sometime between 5 to 10 minutes, and complete destruction (6 log₁₀ reduction) occurred after 12 minutes. The log reduction in the number of spores is described by Equation 1.

$$\text{Log Reduction} = \log(N/N') \quad (\text{Equation 1})$$

where N is the mean number of viable organisms recovered from the control and N' is the number of viable organisms recovered from each test after decontamination (Rogers et al., 2005).

For the wet ceiling tile bundles, although the results were somewhat variable, reduction in spores (from a 1-2 \log_{10} reduction up to complete destruction) occurred between 35 to 38 minutes.

Figure 2-1 shows the spore survival as a function of time for wet and dry bundles in the kiln (Wood et al., 2006).

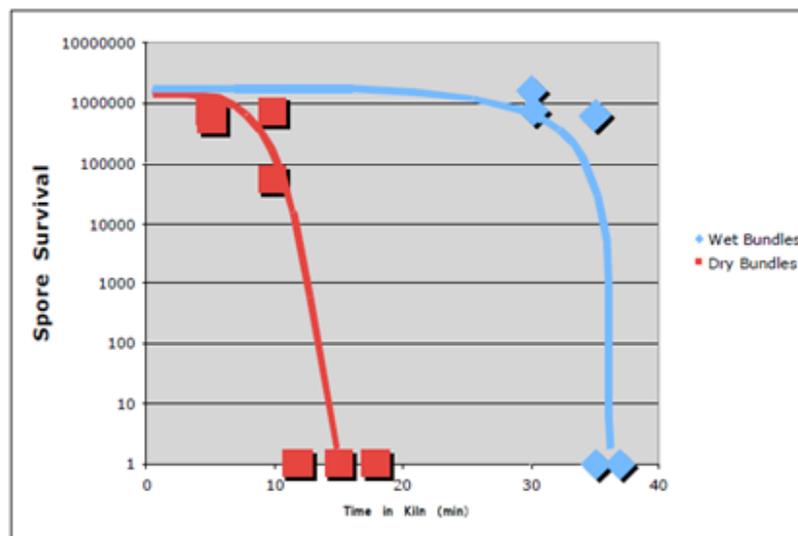


Figure 2-1. Ceiling Tile Bundle Spore Survival as a Function of Time in Kiln (Adapted with permission from Wood et al., 2006)

Lemieux et al. performed bench-scale tests on building materials. The building materials included carpet, ceiling tile, and wallboard. The ceiling tiles were Class A, standard-white, fire-retardant, texture-faced ceiling tiles composed of wood fiber (0 - 60%) and fibrous glass (0 - 13%). New drywall was used for these tests, which consisted of a gypsum core wrapped with a paper lining. The carpet was nylon 6-6 carpeting acquired directly from the manufacturer. The materials were cut into sample sizes measuring 7.62 x 3.81 cm, weighed, individually wrapped in aluminum foil and steam-sterilized by autoclaving. The sterile samples were inoculated with either 1.0 mL of a solution containing *Bacillus subtilis* spores for a final concentration of 10^8

spores/mL or 1.0 mL of a solution containing *G. stearothermophilus* spores for a final concentration of 10 spores/mL. In the thermal destruction experiments, the BDR samples were heated in a quartz reactor operating at 150, 200, 250, and 315 °C for various time intervals. Total spore destruction was predicted by the EPA simulator model to occur between 4 and 5 minutes. The time was measured at the introduction of the samples into the reactor. Figure 2-2 shows a sample set of results illustrating the destruction of *B. subtilis* inoculated onto ceiling tile (Lemieux et al., 2005).

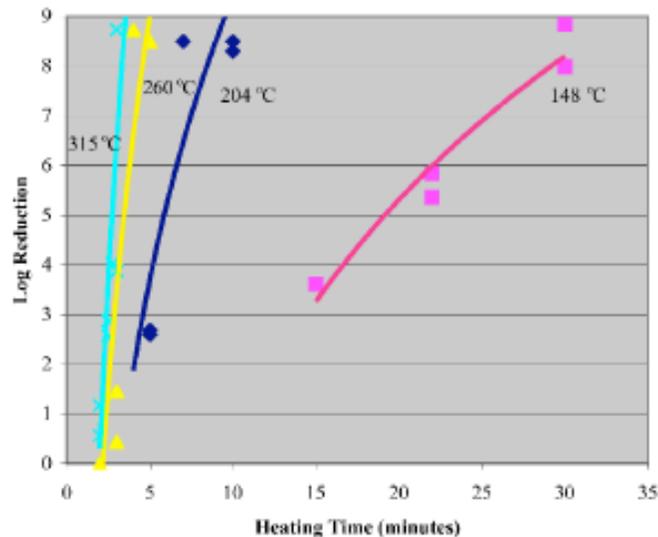


Figure 2-2. The Effect of Heating Temperature and Time on Reduction of *B. subtilis* Spiked on Ceiling Tile (Adapted with permission from Lemieux et al., 2005)

Wood et al. described experiments (primarily performed in a pilot-scale rotary kiln incinerator simulator [RKIS]) to examine the impact that bundling of material (wet and dry), exposure time, incinerator temperature, and internal bundle temperature have on the destruction of *G. stearothermophilus* biological indicator (BI) spore strips. In one test with a wet bundle, the spores survived a 38 min exposure in the RKIS. The wet ceiling tiles offered the most thermal resistance under all of the conditions tested due to the refractory materials used to produce the tiles as well as the large amounts of water the bundles could hold. This analysis showed that except for three ceiling tile tests, no *G. stearothermophilus* spores survived beyond 315 °C (600 °F) regardless of bundle material or exposure time in incinerator. Figure 2-3 shows the log

reduction of *G. stearothersophilus* in ceiling tiles with time. The high and low kiln temperatures were 1,093 °C and less than 824 °C, respectively (Wood et al., 2008).

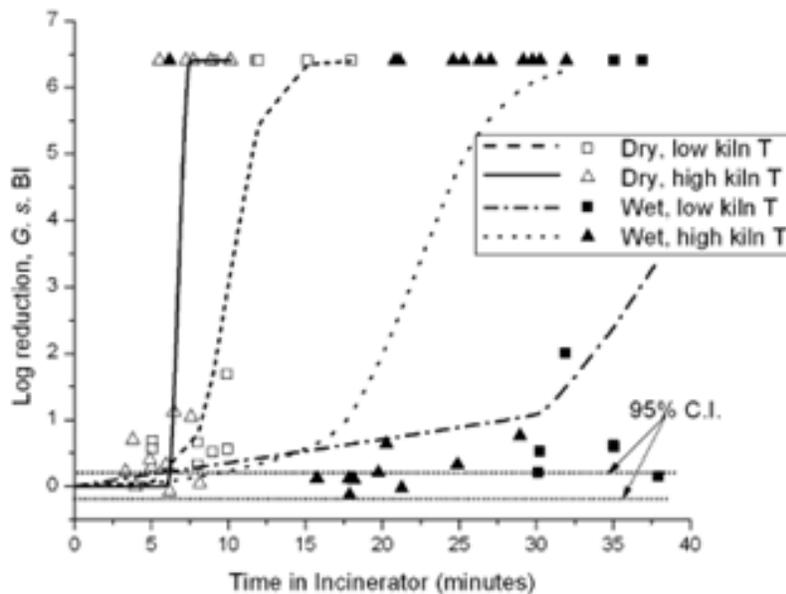


Figure 2-3. Log Reduction of *G. stearothersophilus* BIs in Ceiling Tile Bundles (Wet and Dry) vs. Time in RKIS (Reprinted with permission from Wood et al., Copyright 2008 American Chemical Society). 95% Confidence Interval (CI).

Wood et al. conducted tests in a pilot-scale incinerator utilizing biological indicators comprised of spores of *G. stearothersophilus*, *Bacillus atrophaeus* and *B. anthracis* (Sterne) embedded in building material bundles (wallboard). In the pilot-scale incinerator tests, *B. atrophaeus* and *G. stearothersophilus* demonstrated similar thermal sensitivity, but *B. anthracis* was less thermally resistant than *G. stearothersophilus*. A histogram of an average of the percent survival of the two species of spores is shown in Figure 2-4. The data provide evidence to support the use of either *G. stearothersophilus* or *B. atrophaeus* as a surrogate microorganism for conducting research to determine the dry thermal destruction requirements of *B. anthracis*-laden waste. Wood et al. reported that data from this study may assist in the selection of surrogates or indicator microorganisms to ensure that *B. anthracis* spores embedded in building materials are completely inactivated in an incinerator (Wood et al., 2010).

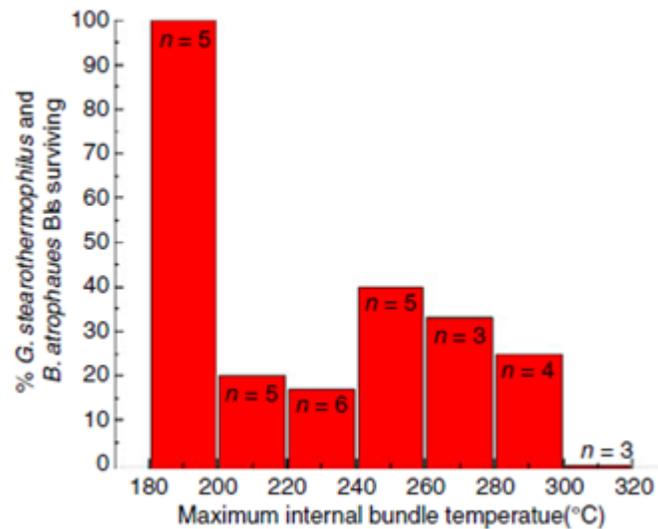


Figure 2-4. Histogram Showing Percent Survival of Both *G. stearothermophilus* and *B. atrophaeus* BIs Versus the Maximum Temperature Inside the Bundle (Adapted with permission from Wood et al., 2010)

Denison et al. investigated a transient zonal model approach for use with a computational fluid dynamics (CFD) model. Comparisons were made between the model and experimental data. The model results were compared against pilot-scale data collected by EPA to characterize the behavior. The typical gas residence times were 2 seconds in the kiln, 3 seconds in the transition between the kiln and the secondary combustion chamber and 7 to 8 seconds in the secondary combustion chamber. The bundles were fed approximately every 10.5 minutes. The bundles were approximately 50% water. The typical residence time for the solid matrix material was 10 minutes. The 6 log₁₀ reduction for *B. subtilis* on wallboard occurred at 1,700 s at 600 °F, 2,700 s at 500 °F, and 4,500 s at 400 °F, as shown in Figure 2-5. The data showed that zonal and CFD models of the laboratory scale kiln can be constructed and provide useful information on the physical processes that affect furnace performance in terms of microbiological destruction efficiency and operability. Figure 2-6 shows a comparison between the model calculations and the measured data of the kiln exit temperature and the Secondary Combustion Chamber (SCC) exit oxygen. The models predict complete destruction of the biological agent that remains in the building material matrix when the incinerators and afterburners are operated as per standard operating conditions (Denison et al., 2005).

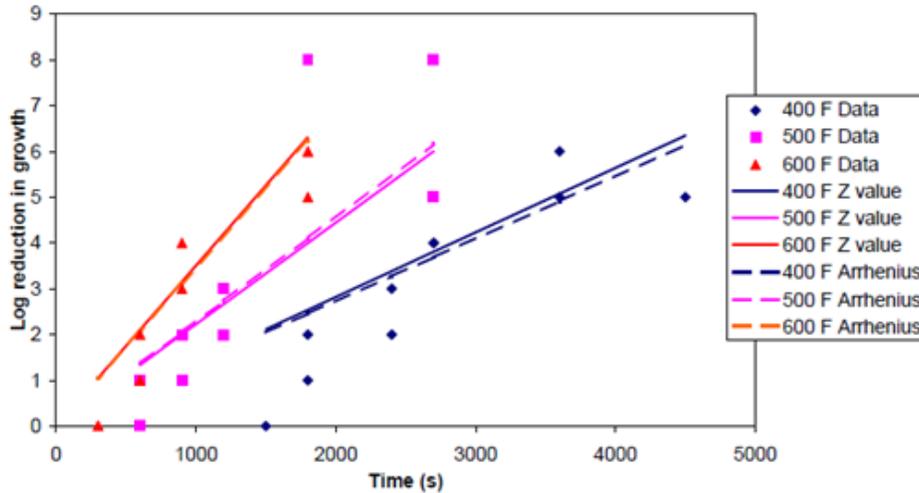


Figure 2-5. Log Reduction with Time for *B. subtilis* on Wallboard at Various Initial Temperatures (Adapted with permission from Denison et al., 2002 [Reaction Engineering International])

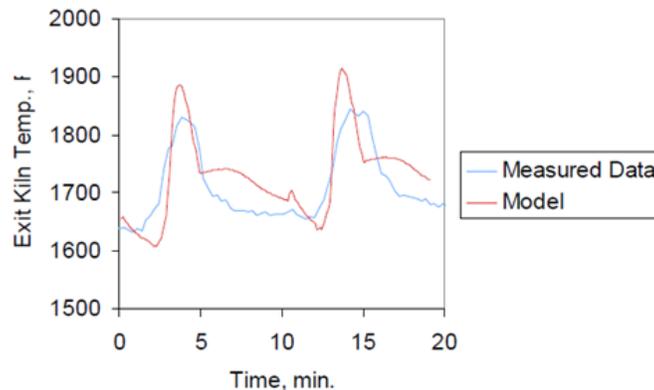


Figure 2-6. Comparison between Measured Data and Model Calculations of the Kiln Exit Temperature for *B. subtilis* (Adapted with permission from Denison et al., 2005 [Reaction Engineering International])

Fisher et al. investigated the destruction chemistry of organosulfur compounds under both pyrolytic and oxidative conditions. The focus was on the destruction of alkyl sulfides that are surrogates for chemical warfare agent related to sulfur mustard (H, HD, and HT).

Thermochemistry, reaction pathways and kinetic parameters for multiple chemical subsystems were developed using computational chemistry methods. A turbulent flow reactor with

extractive sampling was used to examine the destruction of two mustard simulants under both pyrolytic and oxidative conditions (Fisher et al., 2008).

2.2.1 *Municipal Waste Combustors*

Municipal (solid) waste combustors (MWCs), otherwise known as waste-to-energy facilities, might be able to handle wastes containing chemical and biological agents. Several potential advantages to these facilities when compared to HWCs are that waste-to-energy facilities tend to be closer to urban centers where terrorist attacks on buildings would be most likely to occur, MWCs generally have much larger processing capacities than HWCs, and MWCs are believed to have more flexibility to implement specific engineering changes. Potential disadvantages include public perception associated with incinerating special wastes near population centers and permit restrictions for these facilities. Another limitation is the fact that, while waste-to-energy facilities are designed to receive and process many thousands of tons of waste per week, they are not particularly suited for large bulky items (Wilhelmi et al., 2003). In addition, those facilities may have existing contracts to accept waste at or near their nominal capacity on a regular basis and their ability to take large quantities of unplanned material (surge capacity) may be limited.

MWCs likely could handle, and would be allowed to process, certain types of wastes containing chemical or biological agents, even though they are permitted to handle wastes primarily from clinical and research settings. Regulators might need to issue permit modifications or exemptions for MWCs to process these wastes. Watanabe et al. reported emission data during the startup of two stoker-type MWCs (two lines, 150 x 2 metric tons/day [165 tons/day] and 450 x 2 metric tons/day [495 tons/day]) (Watanabe et al., 2010). Ash is a by-product of MWC and further testing is required before disposal at an appropriate facility.

2.3 *Medical Waste Incinerators*



The State and Territorial Association on Alternate Treatment Technologies (STAATT) established a framework or guidelines that defined efficacy criteria for the destruction of microorganisms for medical waste treatment technology and delineated the components required to establish an effective state medical waste treatment technology approval process. The guidelines recommended that all medical waste treatment technologies achieve 6 logs or greater microbial inactivation of mycobacteria and 4 logs or greater reduction of spores (Lemieux et al.,

2006a). There are no federal standards related to the destruction of pathogens in incinerators and STAATT is not a government entity.

Wood et al. (2004) summarized EPA test report data on *G. stearothermophilus* (*Gs*), a heat resistant microorganism, as a worst-case surrogate bacterium for tests with medical waste incinerators (MWIs). Similar to *B. anthracis*, the surrogate is a gram-positive, endospore-forming, rod shaped bacterium. As *B. anthracis* spores are heat resistant and can survive for long periods under harsh conditions, the potential exists for viable spores to escape detection and decontamination or to survive multiple decontamination processes. The *Gs* bacterium was spiked into the medical waste feed at certain intervals throughout an emissions test. The internal pipe temperatures were above 816 °C in the small MWI. The results showed that for most of the test runs, at least a five log reduction of the spores was achieved, although viable spores were detected in 10 out of a total of 48 air emission test runs, and spores were detected in 10 out of 27 available ash samples MWIs may not completely destroy all of the spiked microorganisms because of limitations including in-bed mass transfer limitations, incomplete bed mixing, bypassing of hot zones due to poor gas phase mixing, dropping contaminated material through the grate prior to destruction in the bed, or by coming into contact with cool zones within the MWI. Coupled with complex fluid dynamics, these limitations would cause pockets within the combustion chambers that are not exposed to sufficiently high temperatures and residence times. The most notable limitation for MWCs is the size of the waste that can be processed where the typical hopper size for most MWIs is 3 feet by 5 feet by 5 feet (Wilhelmi et al., 2003). Due to the cost of complying with air emission standards and guidance developed in the 1990s, medical waste treatment has shifted from small hospital MWIs to larger commercial MWIs with state-of-the-art incinerator and air pollution control technology (Wood et al., 2004).

The Izmit Hazardous and Clinical Waste Incinerator (IZAYDAS) facility in Izmit, Turkey incinerates medical and hazardous waste. Various types of wastes such as medical wastes, plastic and lactic wastes (produced from food wastes), cosmetic wastes, used oil, petrochemical wastes and oil wastes, solvent, and dyeing wastes are disposed by incineration at IZAYDAS. The incinerator has a total area of 800,000 m², 32,000 m² of which is appropriated for incineration facilities. The capacity of the plant is 35,000 tons/year. The plant consists of five major parts:

storage, combustion, energy production system, air pollution control system, fly ash and bottom ash collection system (Cetin et al., 2003).

2.4 Chemical Weapon Demilitarization

The major portion of the literature on the destruction of CB agents using incineration involves the use of hazardous waste combustors in specially designed chemical demilitarization facilities, such as Johnson Atoll Chemical Agent Disposal System (JACADS) and Tooele Chemical Agent Disposal Facility (TOCDF). The U.S and other countries agreed to destroy their stockpiles of chemical weapons following the Chemical Weapons Convention (CWC) mainly using HWCs, MPFs, and LICs.

During the past 40 years, more than 20,000 tonnes (22,000 tons) of chemical agent have been destroyed in a number of countries and over 80 % of this material has been destroyed by incineration. There are three principal categories of chemical warfare agents in the stockpiled munitions and bulk agent storage: mustard, lewisite, and the nerve agents (GA, GB, GD, VR and VX) (Pearson and Magee, 2002).

2.4.1 *Metal Parts Furnaces*

Pearson and Magee described the destruction of metal parts that had been drained of agent (such as one-ton agent containers, bombs, spray tanks, artillery projectiles, and burster wells, which were pulled to access the agent) in a Metal Parts Furnace (MPF). Metals parts are fed by conveyor into a fuel-fired MPF and heated to 540 °C to produce metal suitable for release as scrap after deformation to comply with CWC requirements. Residual or undrained (including gelled) agent remaining in the metal parts is vaporized and burned within the furnace; the residence time in the furnace is of the order of two hours. During this period, the residual agent is vaporized (40 min), the metal parts are heated to 540 °C and maintained at that temperature for at least 15 min (heated and maintained for 40 min), and then the metal parts are allowed to cool in a cool-down zone (30 min) to minimize any fugitive emissions. This process takes additional time and can limit the throughput of the system. Gases discharged from the metal parts furnace are passed through an afterburner maintained at 1,090 °C before being treated in the pollution abatement system. The decontaminated metal parts are discharged and shipped to an approved disposal site or sold for scrap (Pearson and Magee, 2002).

Denison reported on computer modeling tools playing an important role in reducing the time, cost and technical risk of using incineration. A simulation workbench was developed to assist the chemical demilitarization community. The workbench consisted of models for an MPF. Both a transient zonal model and CFD models were prepared. In the MPF, metal parts pass intermittently through the furnace at a set point gas temperature typically at 1,600 °F and with a residence time sufficient to drive off and destroy the agent and bring the projectiles to at least 1,000 °F for at least 10 minutes. The models predict complete destruction of the chemical agent when the incinerators and afterburners are operated as per standard operating conditions. In Figure 2-7, the gas temperature distribution for the afterburner in the MPF is shown. The workbench tool being developed included the ability to study the combustion process, agent destruction and product species and concentrations for nerve agents (GB and VX) and HD. The experimental data for HD destruction are compared with the kinetic data in Figure 2-8. The calculated time profiles are shown in Figure 2-9 for the 5% of the agent remaining in the projectile shells in the MPF. The models may also be useful in simulating incineration system upset conditions and failures that could lead to an agent release, so that appropriate design and operational modifications can be made to mitigate such occurrences (Denison et al., 2002).

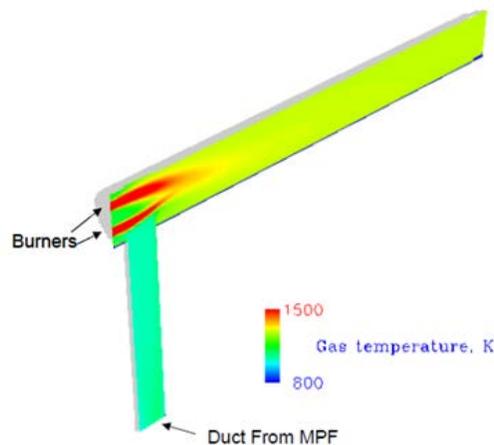


Figure 2-7. Gas Temperature Distribution in the Afterburner of the Three-Zone MPF (Adapted with permission from Denison et al., 2002 [Reaction Engineering International])

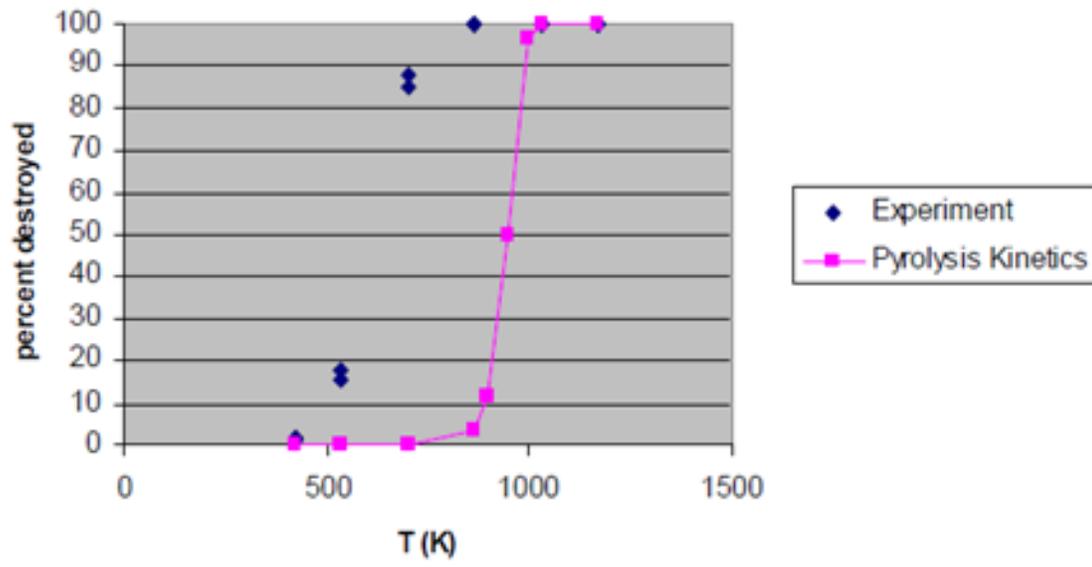


Figure 2-8. Comparison of HD Destruction Kinetics with Experimental Data (Adapted with permission from Denison et al., 2002 [Reaction Engineering International])

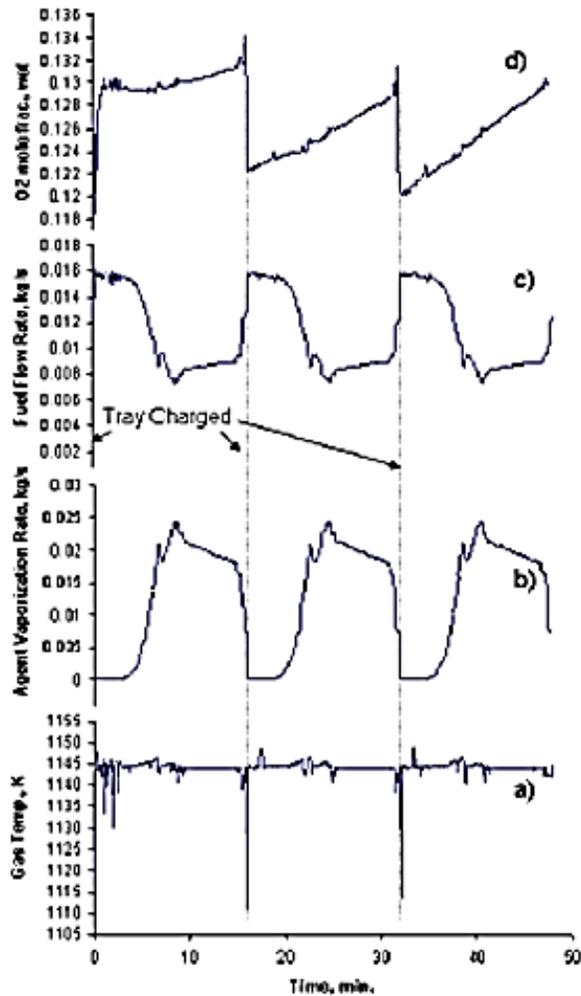


Figure 2-9. Calculated Time Profiles for Zone 1 with 155 mm Projectiles with 5% Residual Agent Added in a Three-Zone Furnace (Adapted with permission from Denison et al., 2002 [Reaction Engineering International])

2.4.2 Liquid Incineration

For warfare agent destruction, liquid chemical agent drained from the munitions and storage containers is collected in a storage tank from which it is fed into a high-temperature LIC where it is burned at a temperature of 1,480 °C. The LIC is a two-stage refractory-lined incinerator designed to destroy the nerve agents GA, GB, VX, and mustard (H, HD, and HT). The drained agent is atomized by a nozzle and mixed with combustion air. Auxiliary fuel is used to maintain combustion at or above 1,400 °C with the flue gases being passed to an afterburner maintained at a minimum temperature of 1,090 °C before ducting to the pollution abatement system (Pearson and Magee, 2002).

Denison et al. developed models for analyzing the LIC for destroying liquid chemical weapon agents (GB, HD, or VX) drained from munitions contained in the U.S. Army stockpile. The destruction profiles with time are shown in Figure 2-10. The models predict complete destruction of the chemical agents when the incinerators and afterburners are operated as per the standard operating conditions. The agent is destroyed in the primary furnace chamber shown in Figure 2-11. Both full CFD and streamlined calculations were performed for agent destruction (Denison et al., 2004).

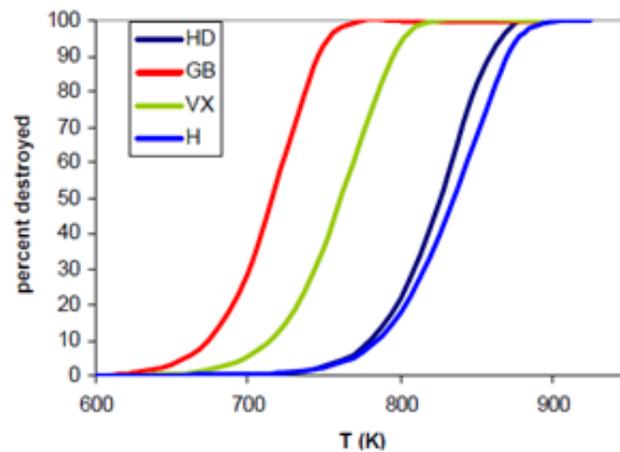


Figure 2-10. Calculated Destruction of VX, GB, HD, and H in a Plug Flow Reactor with Two-Second Residence Time Versus Temperature (Adapted with permission from Denison et al., 2004 [Reaction Engineering International])

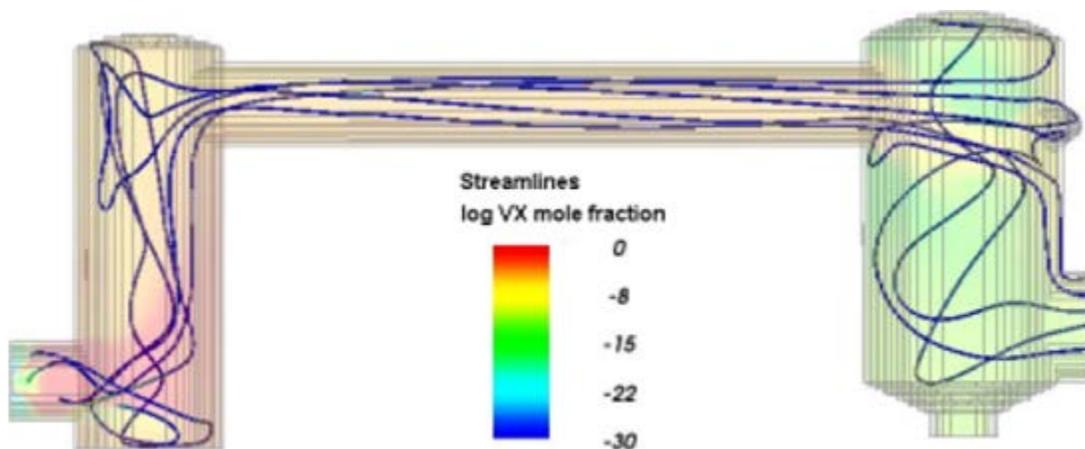


Figure 2-11. LIC Primary and Secondary Chambers with VX Agent Destruction Depicted by Streamlines (Adapted with permission from Denison et al., 2004 [Reaction Engineering International])

2.4.3 Plasma Pyrolysis

In plasma pyrolysis, components of chemical munitions, after disassembly, are introduced into a plasma environment generated by an electric arc, at temperatures approaching 15,000 °C, in a special furnace enclosure. Chemical agents are instantly decomposed, and metal parts are melted. The gaseous decomposition products are passed through a pollution abatement system to remove noxious constituents. Plasma pyrolysis can take several forms: plasma plants in which the plasma torch treats material fed into the plasma oven, and plasma waste converters (PWCs) in which a plasma torch is inserted into a chamber into which the material to be destroyed is introduced. Alternatively, plasmas can be created using two electrodes where the plasma is one electrode, and the material to be treated is at the bottom of the oven as an anode. Significantly lower temperatures are measured at the surface of the treated material (slag) depending on the melting temperature of the slag. By-products will have to be tested and disposed at an appropriate facility. Plasma pyrolysis reactors can be designed to treat all components of chemical munitions (i.e., chemical agent, fuses, bursters, propellant, metal casings, and packing materials). An explosion chamber can be used to deactivate explosive components by energetic initiation (detonation or deflagration), and the resulting debris and gas from the chamber are then treated in a high-temperature plasma (Pearson and Magee, 2002).

Of the research initiatives by the U.S. Department of Energy and the DoD over the past 10 years on plasma treatment of hazardous waste, two have reached the implementation stage: a U.S. Navy project to destroy hazardous materials on shore; and an asbestos destruction project at Port Clinton, Ohio. Other projects are still in the research phase (Pearson and Magee, 2002).

2.4.4 Pollution Abatement of Chemical Weapon Demilitarization

The liquid incinerator, the energetics deactivation furnace, and the metal parts furnace all have identical, separate, dedicated pollution abatement systems. Gases leaving the secondary chamber of the liquid incinerator or the metal parts furnace flow to these pollution abatement systems for removal of gaseous pollutants and particles to meet emission standards. Hot gases leaving the energetics deactivation furnace system kiln flow to a refractory lined cyclone separator, where large particles such as glass fibers from rocket launch tubes are removed. The gases then enter the afterburner and subsequently flow into a similar pollution abatement system (Pearson and Magee, 2002).

The exhaust gas stream enters the quench tower near the bottom, where it is cooled by contact with a countercurrent spray of brine pumped from the packed-bed scrubber sump. Acidic or acid-forming gases [such as hydrogen chloride (HCl), hydrogen fluoride (HF), nitrogen oxides (NO_x), and sulfur dioxide (SO₂)] react with the caustic brine to form salts, which remain in solution in the brine. The cooled gas stream exits from the top of the quench tower and enters a variable throat venturi where it is scrubbed to remove particulates. The venturi has a variable throat to maintain a constant pressure drop independent of the flow of exhaust gases. The brine streams from the quench and venturi scrubber are then returned to the scrubber tower sump (Pearson and Magee, 2002).

The scrubbed gases enter a candle mist-eliminator vessel. Mist-eliminator candles remove very fine mist and submicron particulate matter that were not removed in the venturi scrubber. The cooled and cleaned exhaust gases are pulled through an induced draft blower located upstream of the stack shared by the three pollution abatement systems (Pearson and Magee, 2002).

Emissions testing at JACADS and TOCDF has demonstrated the ability of these incineration systems to consistently meet all emissions standards for particulates, organic compound destruction, and emissions of dioxins/furans. Examples of recorded data were as follows: particulate emissions were on average 14.7 grains per dry standard cubic meter (gr/dsm³) (103 runs), agent destruction was complete (40 runs) in the stack gases, and dioxins and furans (36 runs) were near detectable levels (average) of 0.037 ng/dsm³. Finally, polychlorinated biphenyl (PCB) destruction in the Deactivation Furnace System (DFS) exceeded the 99.9999 % regulatory requirement (Pearson and Magee, 2002).

2.5 Emission and Aerosol Containment



Werner and Cool reported that in the highly non-uniform combustion mixtures present in furnaces, large gradients in temperatures and composition exist, which may result in incomplete chemical agent destruction. Under differing flame conditions, the presence of organophosphorus compounds may either inhibit or promote combustion. Localized pockets of the reacting mixture may exist where combustion is inhibited or incomplete; if such pyrolysis pockets escape the primary flame zone, then traces of the chemical agent may survive the primary incineration furnace. Because of this possibility, current thermal processing facilities employ an afterburner

to ensure adequate destruction and removal efficiencies for CWAs (Werner and Cool, 1999). Furthermore, modern refuse combustors have tall stacks, specially designed combustion chambers, and high-efficiency flue gas cleaning systems that serve to minimize the impact of emissions associated with waste combustion (Lemieux et al., 2000).

Emissions from all incinerators are subject to regulations promulgated through the 1990 Clean Air Act (CAA). Regulations developed under the CAA are intended to limit atmospheric concentrations of six criteria pollutants as well as the 188 hazardous air pollutants (HAPs). EPA has defined maximum-achievable-control-technology (MACT) standards for incinerators and other HAP sources. MACT standards require all pollutant sources within a category (such as incinerator sources) to attain a level of control that reflects the average of the best-performing facilities (top 12%) in that category. There are three by-product streams from an incinerator: the stack emissions, the ash residue, and the residues from the pollution control equipment. The largest volume of material released from an incinerator is the stack-gas stream, which contains mostly carbon dioxide and water vapor with small amounts of particulate matter and pollutant vapors. Many of the organic compounds in the stack and waste residue are products of incomplete combustion (PICs) whose rate of production is controlled by combustion conditions. Ideal combustion conditions are needed to maximize the destruction of PICs and minimize the partitioning of heavy metals in the vapor and particle-phase emissions that go out the stack. During startup and during transient events, ideal conditions are unattainable and pollution emissions can increase significantly (McKone, 2000). However, startup is typically performed using conventional fuels and not wastes. Minimization of transients due to feeding containerized waste can be achieved by closely monitoring the volumetric heat release by timing the introduction of containers into the combustor.

The performance standards for hazardous waste incinerators consist of the following: (1) a destruction and removal efficiency (DRE) of principal organic hazardous constituents (POHCs) of 99.99%, or 99.9999% for dioxin-listed wastes; (2) particulate matter emissions not to exceed 180 milligrams per dry standard cubic meter (mg/dscm) or 0.08 grains per dry standard cubic foot (grains/dscf), corrected to 7% oxygen; and (3) gaseous hydrochloric acid (HCl) emissions not to exceed 1.8 kilograms per hour or a removal efficiency of 99%. Compliance with these performance standards is generally established through a carefully designed trial burn (40 CFR §

270.62) (EPA, 2001). These DRE standards are based upon the demonstrated capabilities of proper regulatory agencies as well as a review of organic PICs and inorganic metals emissions measured during the trial burns. Through the use of air dispersion models, the maximum likely air concentrations of these substances in surrounding communities can be predicted. Based upon the predicted level and duration of exposure at these concentrations, the degree of risk that the emission of these substances poses to the public's health can be estimated. Trial burns are typically conducted under extreme operating conditions of the unit to define the maximum operating range (or operating envelope) that assures compliance. As long as the incinerator continues to operate within the operating envelope demonstrated during a successful trial burn, the incinerator is presumed to be in compliance with the regulatory performance standards. When a risk burn involves multiple test conditions, the permit writer and facility will need to decide whether the data from each test condition should be evaluated separately, or whether the data will be combined. In addition, decisions will be needed regarding evaluation of emissions beyond those measured during the risk burn. For example, a facility may prefer to evaluate risks associated with emissions at a regulatory standard or with an emissions estimate (EPA, 2001).

The storage and treatment of bulk and chemical agents and weapons involve unique hazards of handling extremely toxic materials. Harper described the methods that have been developed to detect the presence of chemical agents in the air, and these are used to help assure worker protection and the safety of the local population. Exposure limits for all chemical agents are low, sometimes nanograms per cubic meter for worker control limits and picograms per cubic meter for general population limits. The most common detector is the flame photometric detector, in sulfur or phosphorous mode, although others, such as mass-selective detectors, also have been used. Monitoring is made more difficult by interferences from chemicals applied in pesticide spraying, busy roadways or military firing ranges (Harper, 2002).

Incineration of organic chemicals containing carbon, hydrogen, and oxygen leads to the formation of carbon dioxide and water. As chemical warfare agents also can contain fluorine, chlorine, nitrogen, phosphorus, and sulfur, incineration will produce hydrogen fluoride (from GB), hydrogen chloride (from H, HD, and HT), nitrogen dioxide (from GA, VR, and VX), phosphorus pentoxide (from GA, GB, VR, and VX), and sulfur dioxide (from H, HD, and HT). All of these can be removed by scrubbing (Pearson and Magee, 2002).

The incineration of lewisite, a blister agent which contains arsenic, requires that the arsenic products be collected and not released to the environment. The exhaust gases are typically scrubbed by passing them through countercurrent liquid absorption beds to reduce the level of pollution in the gases released to the atmosphere to an acceptable level that protects public health and the environment (Pearson and Magee, 2002).

Watanabe et al. (2010) reported that dioxins and their surrogates were continuously monitored during the startup of two stoker-type MWCs (two lines 150 x2 metric tons/day [165 tons/day] and 450 x 2 metric tons/day [495 tons/day]). The surrogates studied included low-volatility organohalogen (LVOH) compounds sampled by online systems, as well as chlorobenzenes (CBs) and chlorophenols (CPs). The changes in levels of LVOH compounds, CBs, and CPs corresponded well with the trend of the toxicity equivalent quantity (TEQ). Sampling of dioxins, CBs, and CPs began immediately after the furnace temperature reached a steady state of 900 °C. Sampling occurred at 2 h, 4 h, and 20 h intervals. An LVOH monitor operated continuously. Manual sampling was also done. The isomer analysis of the dioxins present under startup conditions showed evidence of the memory effect (where highly chlorinated isomers were emitted slowly), whereas low-chlorinated isomers and LVOH decreased rapidly as the temperature rose (Watanabe et al., 2010).

IZAYDAS is located 15 km east of Kocaeli, Turkey. Various types of wastes such as medical wastes, plastic and lactic wastes, cosmetic wastes, used oil, petrochemical wastes and oil wastes, solvents, and dyeing wastes are disposed by incineration at IZAYDAS. Mercury and its components, explosives and radioactive materials, slaughter house wastes, feces and corpses are not accepted. The waste feed rate for the incinerator is 4,100 kg/h. To start the removal process, the rotary kiln temperature is raised to 850–875 °C by fuel oil. When the rotary kiln temperature reaches 425 to 450 °C, the rotating process automatically starts and during the combustion process, the rotation speed is controlled by the control chamber operations, depending on the waste amount and properties. Removal of bottom ash occurs in 100 to 150 minute periods during the combustion of wastes at 900 to 1,100 °C. To achieve complete combustion and a good air mixture, secondary air is transferred from the bunker to the rotary kiln by using the sucking fans. Oxygen (8 %) is obtained automatically at the rotating kiln. The waste gas treatment system, consists of an electrostatic filter, a venturi scrubber, a lime scrubber, a

physical/chemical treatment plant, a flue gas on-line analysis room and a stack unit (Cetin et al., 2003).

The formation of dioxins/furans (D/Fs) in hazardous waste combustion units is highly dependent on post-combustion temperature, time, and the presence of flyash to provide a reactive surface. Even in systems achieving good combustion (with low carbon monoxide concentrations), D/F formation may occur in cooler zones downstream from the combustion chamber. Almost any combination of carbon, hydrogen, oxygen, and chlorine can yield some D/Fs, given the proper time and temperature. There could be substantial increases in D/F emissions under conditions of poor combustion and carbon monoxide levels greater than 2,000 parts per million (ppm). Some waste combustors that burn wastes containing D/F precursors, including chlorobenzenes, chlorophenols, and PCBs, have been shown to have high D/F emissions. D/F emissions could be a concern with the incineration of materials bound with CB agents if the material also contains D/F precursors. For most incineration and boiler systems, the generation of organic products of incomplete combustion is typically associated with poor combustion situations (organic emissions from cement kilns and lightweight aggregate kilns are typically dominated by organics that are volatilized from the raw materials). These conditions lead to incomplete combustion and subsequent increases in fly ash and carbon monoxide and total hydrocarbon concentrations (EPA, 2001).

Lemieux et al. (2000) conducted field studies on MWCs have shown that the amount of fly ash (and its accompanying metallic catalysts) and organic precursors that pass through the temperature window between 250 and 700 °C as well as the amount of time spent in that optimal temperature window are the primary variables affecting polychlorinated dibenzodioxins and polychlorinated dibenzofurans (PCDD/PCDF) emissions. Estimated emissions of PCDDs/PCDFs per unit mass consumed by combustion were calculated by assuming thorough mixing of air inside the burn hut and using:

$$Emissions \left(\frac{mg}{kg} \right) = \frac{Concentration \text{ Pollutant} \left(\frac{mg}{m^3} \right) \times Flow \text{ rate of Air} \left(\frac{m^3}{min} \right) \times Run \text{ Time} (min.)}{Mass \text{ of Waste Burned} (kg)} \quad (\text{Equation 2})$$

A comparison of total dioxin and furan emissions for various combustion sources is presented in Figure 2-12 (Lemieux et al., 2000).

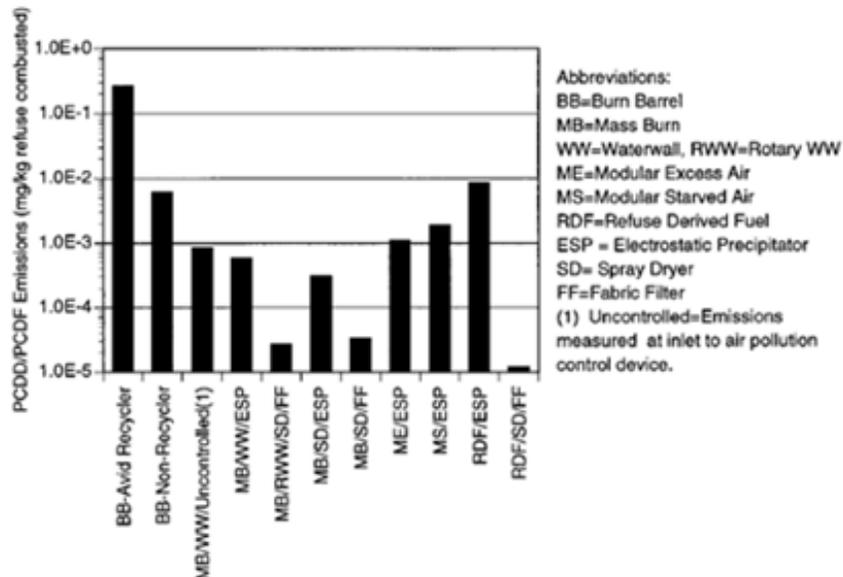


Figure 2-12. Comparison of Total Furan and Dioxin Emissions for Burn Barrels and Municipal Waste Incinerators (Adapted with permission from Lemieux et al., 2000)

2.6 Plasma Systems

This section reviews the literature on thermal plasma and cold plasma systems for the destruction of CB agents.

Plasma is defined as an energetic collection of ionized particles (electrons, ions, and radicals) that exhibit a collective behavior due to electromagnetic forces (Boone, 2007). Thermal plasma is the term used when a substantially larger fraction of the bulk gas is ionized, and can achieve bulk gas temperatures of 2,000 °C to 10,000 °C or higher (Konesky, 2008). The temperature of the gas discharge for cold plasma typically ranges from 50 °C to 300 °C, which allows for plasma processing of sensitive materials and equipment at low temperatures and accelerated processing of more robust surfaces at higher temperatures (Rosocha et al., 2003).



2.6.1 Thermal Plasma

Farrar et al. (2000) evaluated two technologies, a steam plasma torch at Montec and an arcjet thruster at Texas Tech University (TTU) to determine their efficacy to destroy biological agent

surrogates on materials. In these experiments, the post-test evaluation showed residual spore counts of a few hundred down to ten or less. The majority of the experiments were conducted using *G. stearothermophilus* spores as a simulant for anthrax spores. The *G. stearothermophilus* spores were deposited on thin 1-cm square wafers (coupons) of G-10 fiberglass, stone, and pumice. The specific types of areas investigated are representative of runways and roads, but the technologies could also be used on buildings, vehicles, and equipment (Farrar et al., 2000).

For the arcjet system, the temperature at the nozzle was estimated at 7,200 °F to 9,000 °F. At a velocity of 0.67 ft/s and at 1 inch from the exit plane, the peak for the nitrogen arc temperature was 2,300 °F. During these tests, the arcjet was operated for five to ten seconds duration. The selected bounds were 0.5 and 3.5 ft/s. Only a couple of flow rates and power settings were used for the devices, the distances between the nozzle and surface were limited to 1 to 3 inches (Farrar et al., 2000).

Montec's steam plasma torch was operated at two power levels, 60 and 90 kilowatts (kW), and produced a plume with a diameter of 4–6 inches at the sampling point. The steam-plasma temperature was calculated to be between 4,500 °F and 5,400 °F for steam-plasma torch electric input power levels of 60–90 kW. The Montec results showed that at 90-kW power, the steam plasma produced a 99.94 % or greater kill rate at velocities up to 2 ft/s at a distance of 1 inch from the exit plane. At this same power level and at a distance of 3 inches, the percent kill ranged from 97 % to 85 % as the speed increased from 0.5 to 2 ft/s. At the lower power level of 60 kW, the maximum speed that would produce 99.94 % kill at 1 inch was 1.5 ft/s. A third substrate, pumice block (a highly porous material), was also contaminated with biological agent. Only partial destruction of the biological agent was achieved over the range of operating conditions tested. These tests showed that when the agent was absorbed deeply into a very porous material, the effectiveness of the plasma was limited. UV radiation alone (when the quartz plate was placed between the plume and the target) did an impressive job of killing a large number of the spores as shown in Figure 2-13. The quartz lens allowed passage of UV from 190 to 400 nm. However, UV radiation alone did not result in a 100 % kill, except at longer exposure times. The peak temperature measured with the quartz lens in place was 270 °F. The steam torch indicated a higher value of radiation around 280 nm than did the arcjet. The percentage of kill at a given speed was slightly higher for the arcjet (Farrar et al., 2000).

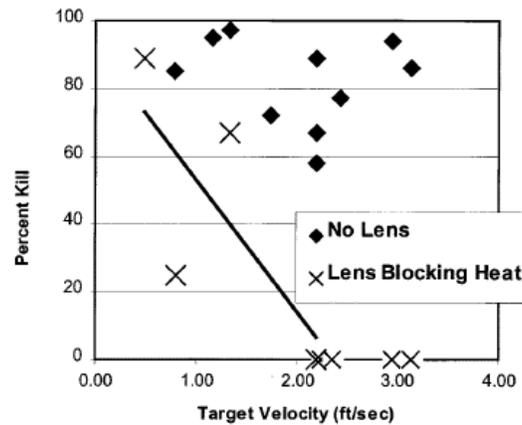


Figure 2-13. Plot of Percent Kill Versus Target Velocity for *G. stearothermophilus* Spores on Fiberglass with and without a Lens to Block Heat from the Steam-Plasma Torch (© 2000 IEEE. Reprinted, with permission from Farrar et al.)

The emission spectroscopy of an arc-seed microwave plasma torch (MPT) was examined, and the spectral line of 777.194 nm indicated relatively high atomic oxygen content in the torch. In the decontamination experiments reported by Kuo et al., *Bacillus cereus* was chosen as a simulant for *B. anthracis* spores and the airflow rate was fixed at 0.393 L/s. The results of experiments using dry samples showed that all spores were killed in less than 8 seconds at 3 cm distance, 12 seconds at 4 cm distance, and 16 seconds at 5 cm distance away from the nozzle of the torch (Kuo et al., 2005).



2.6.2 Cold Plasma

Cold plasma is a partially ionized gas where only typically 10^{-3} to 10^{-6} of the gas molecules are ionized. This range would represent strong and weak cold plasma, respectively. The term cold is a relative one, and the bulk gas can reach temperatures of 100 °C or more in a strong beam (Konesky, 2008). Cold plasmas can be generated by microwave power, direct current (DC), radio-frequency (RF), or pulsed power supplies. Among the attractive features of nonthermal discharges is the ability to control their characteristics, allowing the plasma to be tailored for each specific application (Laroussi et al., 2000).

When partially ionized, the carrier gas acts as a gaseous wire and directs the plasma to the target application area with great precision and stability. This form of cold plasma applicator, often referred to as a plasma jet, consists essentially of a carrier gas flowing over a conductor with a sharp point that is held at high voltage and high frequency. The conductor is typically made of either stainless steel or tungsten. Voltages typically range from a few kilovolts to over 10 kV, and frequencies can range from a few kilohertz to over a megahertz. Electrical currents in the plasma jet may be as low as several tens of microamperes (a weak beam) to over 100 milliamperes (a very intense beam) (Konesky, 2008).

The plasma jet configuration has many advantages over previous cold plasma applicators. Now there are two independently controllable variables, electrical power input and gas flow rate, that give the plasma jet a wide range of effects. Helium is preferred as an ionized gas for plasma applications because its high thermal conductivity helps carry away heat, and its rich UV spectral components enhance its sterilization capability (Konesky, 2008).

The overall effect of a plasma jet results from a combination of ion bombardment, electron bombardment, thermal effects, localized UV exposure, and the production of free radicals and some ozone. The production of free radicals and ozone is possible because an oscillating electric field heats mainly the electrons rather than the heavier ions, which respond much more slowly. However, these energetic electrons can transfer their energy effectively to excite and dissociate molecules, yielding reactive radicals such as oxygen atoms (Konesky, 2008). Reactive oxygen species (ROS) such as metastable oxygen, ozone, and oxygen ions can destroy just about all kinds of organic contaminants more effectively than the thermal method (Herrmann et al., 1999). This athermal destruction mechanism primarily involves the chemical reactions of ROS with nucleic acids, lipids, proteins and sugars in biological organisms. These chemical modifications result in protein cleavage, with aggregation and loss of catalytic and structural function by distorting secondary and tertiary protein structures. These oxidative proteins are irreversibly modified and cannot be repaired. This occurrence is known as protein degradation (Kuo, 2005). The plasma also generates ultraviolet radiation that can destroy many biological agents as well as enhance chemical-reaction rates (Herrmann et al., 1999).

Atmospheric plasma decontamination (APD) can be applied to the destruction of biological organisms by passing energy through air. The molecules are ionized, generating both positively and negatively charged reactive species. The interaction of these ions, along with the associated ultraviolet light, kills the microorganisms. APD is applicable to the cleaning, and perhaps the disinfection, of small areas and electronic equipment (Boone, 2007).

Rosocha et al. presented the results for decontamination of *Bacillus globigii* (*Bg*), a surrogate for anthrax spores, using both plasma and dry heat treatments. The dry heat treatment flowed hot air, or some other gas, onto the biological agent. Results indicate a seven-log kill (a factor of 10 million removal or decrease of the contaminant) of *Bg* spores in 30 s with an Atmospheric Pressure Plasma Jet (APPJ) effluent temperature of 175 °C, which was ten times faster than dry heat at the same temperature, as shown in Figure 2-14. In Figure 2-15, the destruction of Malathion is shown for APPJ and compared to the dry heat treatment (Rosocha et al., 2003).

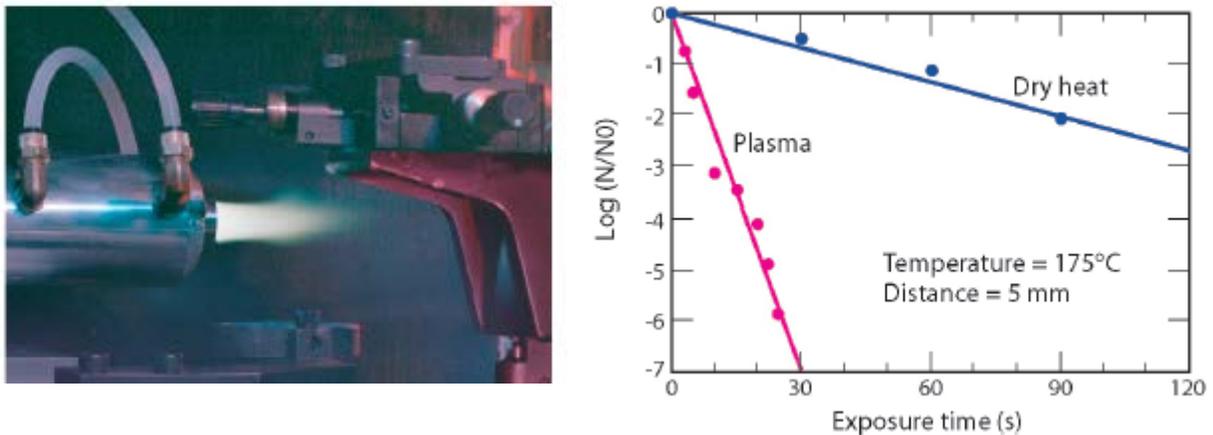


Figure 2-14. Atmospheric Pressure Plasma Jet (APPJ) (left); Destruction of the Anthrax Surrogate *Bg* Using the APPJ Method Compared to the Dry Heat treatment (right) (Adapted from Rosocha et al., 2003 with the permission of the Los Alamos National Laboratory)

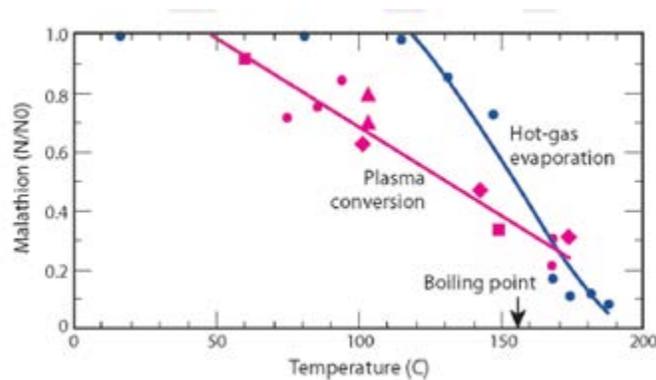


Figure 2-15. Destruction of Malathion using the APPJ Method as Compared to the Dry Heat Treatment (Adapted from Rosocha et al., 2003 with the permission of the Los Alamos National Laboratory)

Herrmann et al. reported on a plasma decontamination chamber that has been developed at Los Alamos National Laboratory (LANL), Albuquerque, NM, to study the decontamination of chemical and biological warfare agents. This technology was targeted at sensitive electronic equipment for which there is currently no acceptable nondestructive means of decontamination. Sensitive equipment is defined as equipment that cannot be exposed to aqueous decontaminants and strong oxidizing or caustic solutions without destruction, degradation in performance, or significant disruption in use. To the military, this means electronic equipment such as avionics, communications, fire control and navigational equipment and electro-optics such as range finders

and night-vision goggles. Exposures were conducted at a system pressure of 30 torr, exposure temperature of 70 °C, plasma-to-sample standoff distance of 10 cm, and 10 % addition of oxygen or hydrogen to a helium balance. The agents studied were VX and GD nerve agents and HD blister agent, as well as a thickened simulant. All agents were decontaminated off aluminum substrates to below the detection limit of 0.1 % of the initial contamination level of approximately 1 mg/cm², as shown in Figures 2-16 and 2-17. For VX, this level of decontamination was achieved in 8 to 16 min of exposure, while only 2 min were required for the more volatile HD and GD. Decontamination levels of 99.9 % were achieved in under 2 min for chemical agents HD and GD, and under 16 min for VX. Evaporation and subsequent chemical breakdown during recirculation through the plasma was believed to be the dominant decontamination process for these agents (Herrmann et al., 1999).

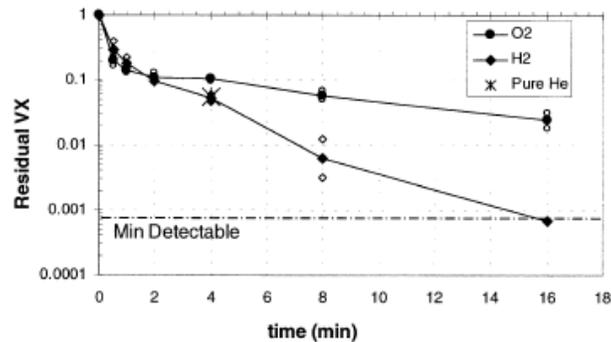


Figure 2-16. Residual VX Remaining on Aluminum as a Function of Exposure Time. Test Conditions: T = 70 °C, d = 10 cm, Pressure = 30 torr, O₂ or H₂ at 10 % (Reproduced with permission from Herrmann et al. Copyright 2000, AIP Publishing LLC.)

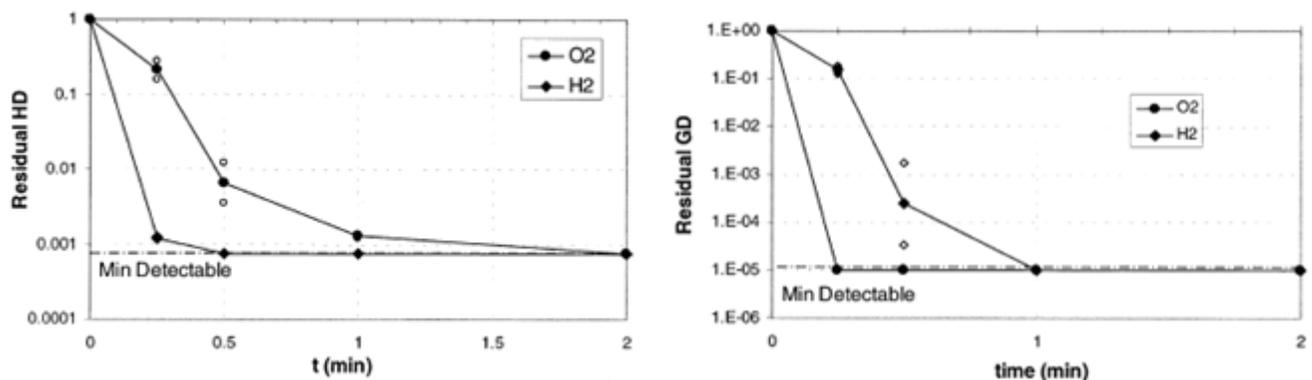


Figure 2-17. Residual HD Remaining on Aluminum (left) and Residual GD Remaining on Aluminum (right) Versus Time. Test Conditions: T = 70 °C, d = 10 cm, Pressure = 30 torr, O₂ or H₂ at 10 % (Reproduced with permission from Herrmann et al. Copyright 2000, AIP Publishing LLC.)

Laroussi et al. presented two studies on bacteria inactivation obtained by two different discharges: a glow discharge at atmospheric pressure (GDAP) and an enhanced corona discharge at atmospheric pressure (ECDAP). The plasma generated by the GDAP is a source of charged particles, free radicals ($O\cdot$ and $OH\cdot$), and radiation (infrared, visible, and ultraviolet). This environment was found to be lethal to various microorganisms. The root mean square (rms) voltage was 5 kiloVolts, the frequency was 17 kiloHertz, the gap distance was 3 cm, the gas was a mixture of helium and air, the bacteria were *Escherichia coli* (pbr 322) and *Pseudomonas aeruginosa* (frd1) (Laroussi et al., 2000).

Pseudomonas aeruginosa on a nitrocellulose filter membrane was tested. These bacteria were harder to kill since it took approximately 15 min to sterilize a sample seeded with a cell density in the 10^5 /mL range. *Pseudomonas* was even harder to kill when it was in a liquid broth since for similar experimental conditions, only half of the initial cells were killed in 15 minutes.

Therefore, the kill rate of microorganisms by the GDAP is strongly dependent on the type of microorganism, the type of medium supporting the microorganism, and the type of sterilization (surface versus volume). To understand what happens to the microorganisms after they were treated by the plasma discharge, scanning electron microscope (SEM) micrographs of the cells were taken showing the appearance of non-treated cells and cells treated for 30 s in the GDAP. The treated cells appeared to be in the process of leaking internal matter. The outer membranes of the cells appeared to have been punctured by the plasma. With a damaged outer membrane, the microorganisms became very vulnerable to the reactive environment of the discharge (Laroussi et al., 2000).

Like the glow discharge at atmospheric pressure, the ECDAP is a source of active species that can react adversely with the cells of microorganisms. For ECDAP, the power dependence on the kill rate was paramount. The power was tripled from 20 Watts (W) to 60 W, and the kill rate increased by approximately two orders of magnitude. *B. subtilis* bacteria in Luria–Bertani broth were a little harder to kill than *E. coli* since for a power of 42 W and after a 12-min exposure time, approximately 100 cells were still alive (as compared to complete kill in 8 min for *E. coli*), as shown in Figure 2-18 (Laroussi et al., 2000).

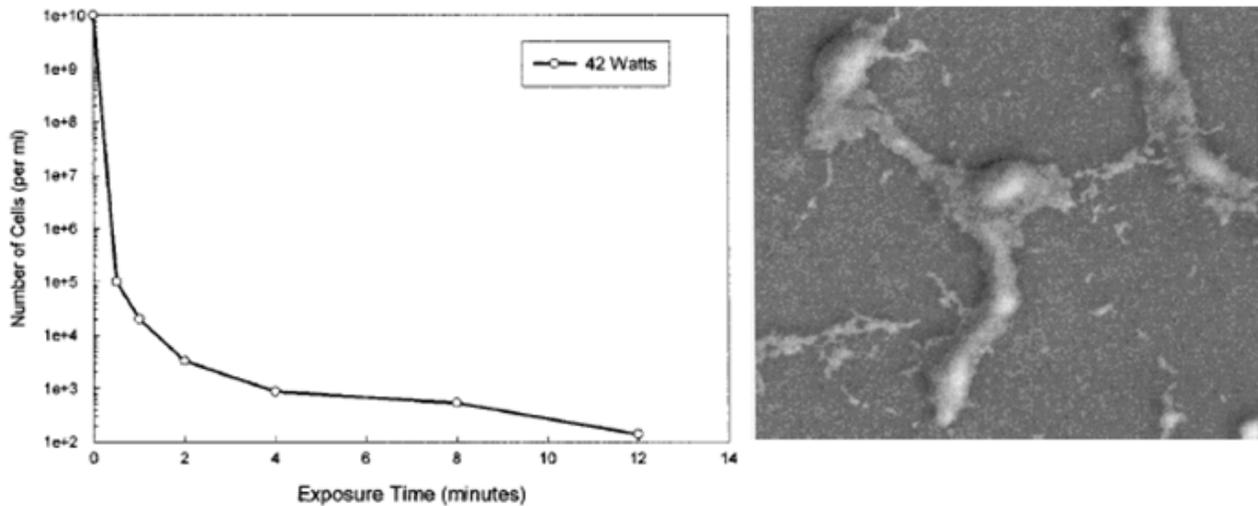


Figure 2-18. Live Cells Versus Exposure Time for *B. subtilis* in Luria-Bertani Broth with Applied Power of 42 W (left). SEM Photograph of *E. coli* on Plasma-Exposed Sample after 30 Seconds Exposure Time (right) (© 2000 IEEE. Reprinted, with permission from Laroussi et al.)

Montie et al. reported the results of a plasma source, the One Atmosphere Uniform Glow Discharge Plasma (OAUGDP), which operates at atmospheric pressure in air and produces antimicrobially active species at room temperature. The OAUGDP reactor is composed of a radio frequency (RF) power supply and a pair of water-cooled parallel plane plate electrodes, between which an atmospheric glow discharge plasma is generated, producing antimicrobially active species. These antimicrobially active species include ozone, monatomic oxygen, free radicals such as superoxide, hydroxyl, and nitric oxide, and ultraviolet photons. The nature of the surface influences the degree of lethality, with microorganisms on polypropylene being most sensitive, followed by microorganisms on glass, and cells embedded in agar. Experimental results showed at least a 5 log₁₀ colony forming unit (CFU) reduction in bacteria within a range of 50 to 90 s of exposure. After 10 to 25 s of exposure, macromolecular leakage and bacterial fragmentation were observed. *E. coli* and *Pseudomonas aeruginosa* were as susceptible to the plasma as *Staphylococcus aureus*, *B. subtilis*, and *Deinococcus radiodurans*. The latter organism is unusually resistant to drying, irradiation and ultraviolet light. Spores were more resistant, with values in the range of 1.8 to 5.5 min instead of seconds. *Bacillus stearothermophilus* spores, normally a very resistant organism, were killed to the same extent (five logs in 5.5 min) as *B. subtilis* var. *niger* spores, while only 2.5 min was required to inactivate approximately the same

number of *B. pumilus* spores. Data from Montie et al. suggest that membrane lipids may be the most vulnerable macromolecule of the cell, probably because of their location near the cell surface and their sensitivity to ROS. Gram-negative bacteria as a group would be most vulnerable because they possess a unique outer membrane in their cell envelope. By contrast, leakage from the Gram-positive *S. aureus* was delayed, and no evident fragmentation occurred, suggesting that the thick polysaccharide on the outside of the cell of *S. aureus* is resistant to chemical change but allows diffusion of ROS to the cytoplasmic membrane, which is again vulnerable to attack. When the cytoplasmic membrane lipids are altered in both groups of bacteria, this alteration results in a massive release of macromolecules. In Figure 2-19, the bacterial survivors inoculated on polypropylene are plotted with time, and the Transmission Electron Micrographs (TEM) of *E. coli* and *S. aureus* initially and after 30 seconds of exposure are presented (Montie et al., 2000).

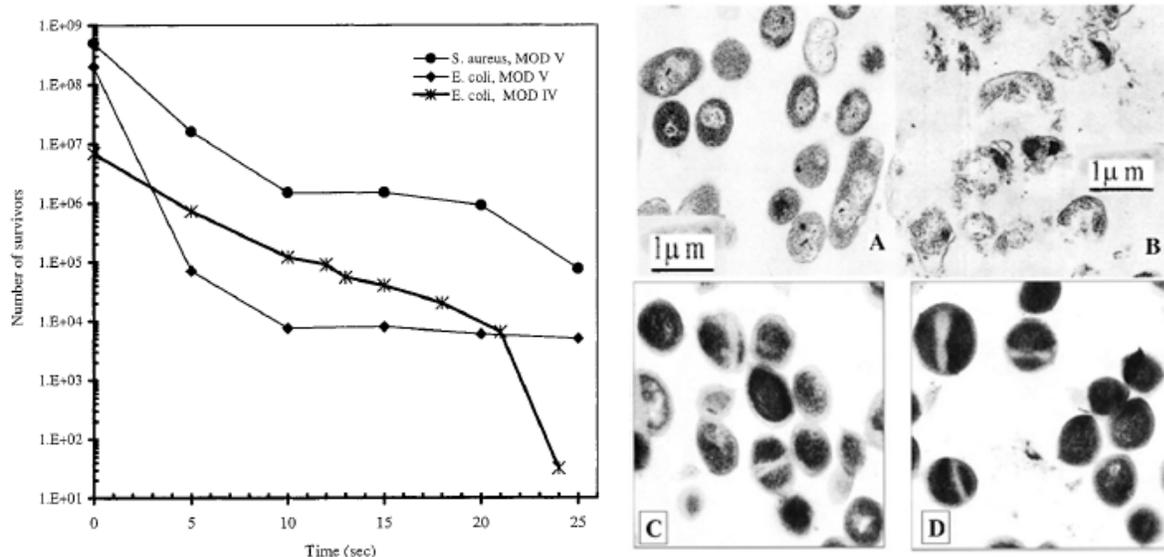


Figure 2-19. Survivors of Bacterial Cells Inoculated on Polypropylene with Time with the Application of OAUGDP (left). The Transmission Electron Micrograph of OAUGDP-treated Cells: A) Initial *E. coli*, B) *E. coli* after 30 Seconds of Exposure, C) Initial *S. aureus*, and D) *S. aureus* after 30 Seconds of Exposure (right) (© 2000 IEEE. Reprinted, with permission from Montie et al.)

2.7 Microwave Irradiation



Microwave energy is a form of electromagnetic energy that penetrates deeply into many materials, transforming energy directly into heat by exciting absorbing molecules into rapid oscillatory motion. With such unique attributes, microwave offers several practical advantages, including reduced thermal gradients, selective heating, rapid energy decomposition, and acceleration of certain chemical reactions (Cha et al., 2004).

Microwave scabbling is a new method of removing the surface of concrete which uses microwave energy to heat the moisture present in the concrete matrix. Continued heating produces steam under pressure that generates internal mechanical and thermal stresses, bursting the surface layer of the concrete. The analysis showed that the main factors affecting scarification are the pore dimensions and the evaporable water content of the cement (Kumar et al., 2010).

Wu and Yao investigated the survival of both laboratory-generated and environmental bioaerosols when these bioaerosols were exposed to microwave irradiation (2,450 MHz) for 2 min at different output power (700, 385, and 119 W), as shown in Figures 2-20 and 2-21. Three different microbial species (*B. subtilis var. niger* (hardy species, Gram-positive), *P. fluorescens* (sensitive species, Gram-negative) and fungus *A. versicolor* (hardy species) were studied as surrogates for harmful agents. The survival rates of airborne *B. subtilis var. niger* spores were shown to be approximately 35%, 44% and 35% when exposed to the microwave irradiation for 1.5 min with high, medium and low power applied. The airborne *Pseudomonas fluorescens* was shown to have lower survival rates of 5.8%, 12.2% and 21% (p-value = 0.0045). Similar patterns but higher survival rates at respective powers were observed for airborne *Aspergillus versicolor* exposure (p-value 0.0001). SEM and TEM images showed visible damage to both membrane and intracellular components of the microwave-treated microbes (Figure 2-22). In a previous study, several dark spots were also observed in the cytoplasm of both *B. subtilis* and *E. coli* through examining their TEM images, and the protein aggregation was suggested to play a role in the inactivation (Wu and Yao, 2010).

Thermal effects could result from the denaturation of enzymes, proteins and nucleic acids, as well as the disruption of membranes when the temperature reaches 50–60 °C. The athermal effect by microwave application could arise from the interference of cell metabolic activities and energy absorption and deoxyribonucleic acid/ ribonucleic acid (DNA/RNA) molecule rotation in response to microwave irradiation. The results obtained by Wu and Yao can be used to develop microwave-based air sterilization technologies especially targeted for biological aerosols. Microorganisms in wet form sustained substantial inactivation upon microwave irradiation, while those in dry or lyophilized form were not affected even by extended exposure, suggesting that the thermal effects may be responsible for the microwave inactivation. The presence of water may be necessary for the athermal effects to occur (Wu and Yao, 2010).

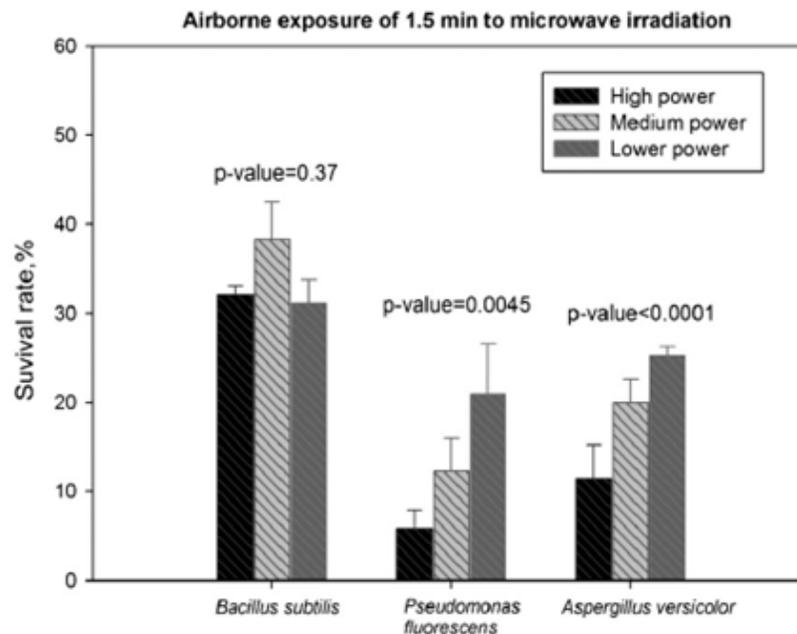


Figure 2-20. Airborne Exposure of *B. subtilis var. niger*, *P. fluorescens* and *A. versicolor* to Microwave Irradiation at 700, 385, and 119 W for 1.5 Minutes (Adapted from Wu and Yao, 2010 with permission from Elsevier, Inc.)

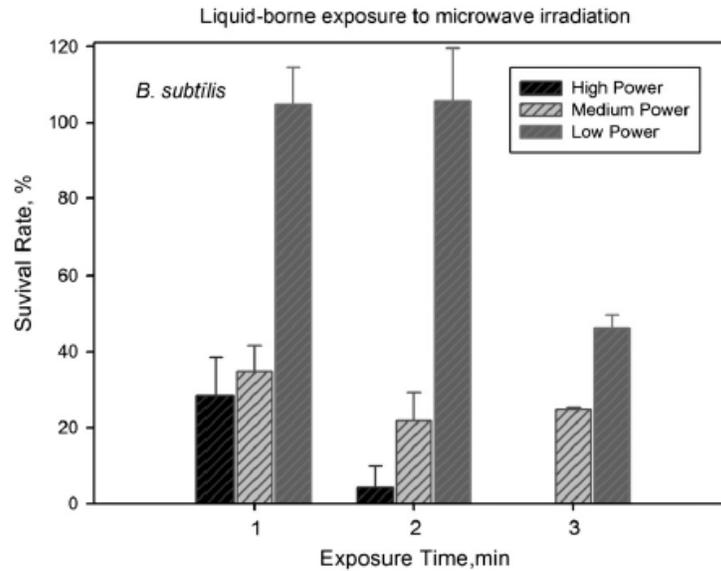


Figure 2-21. Liquid-borne Exposure of *B. subtilis* var. *niger* to Microwave Irradiation at 700, 385, and 119 W (Adapted from Wu and Yao, 2010 with permission from Elsevier, Inc.)

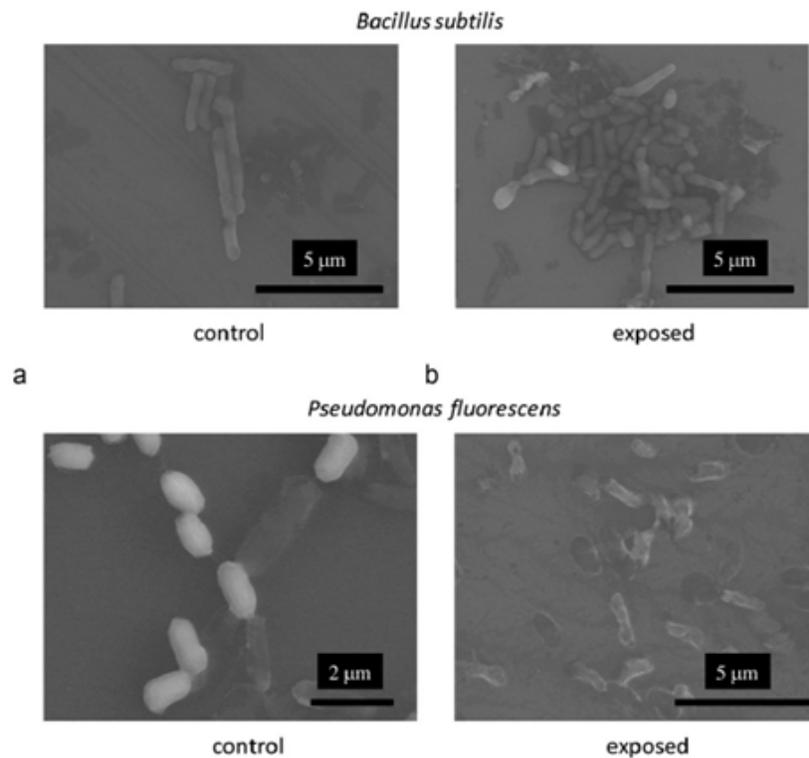


Figure 2-22. SEM Images of Liquid-borne Control and Exposed *P. fluorescens*, *A. versicolor* and *B. subtilis* var. *niger* with 700 W and 90 Seconds Exposure Time (Reprinted from Wu and Yao, Copyright 2010, with permission from Elsevier, Inc.)

Zhang et al. developed a microwave-assisted nanofibrous air filtration system (a microwave device to disinfect airborne pathogens collected on nanofibers) to disinfect air containing airborne pathogens. Aerosolized *E. coli* vegetative cells and *B. subtilis* endospores were tested as benign surrogates of pathogens and were collected on nanofibrous filters and treated by microwave irradiation. As a Gram-positive bacterium, *B. subtilis* has the ability to sporulate and has been used extensively as a benign surrogate for *B. anthracis* spores. *B. subtilis* endospores are ellipsoidal in shape, approximately 0.8–1.2 μm in length, and have an aerodynamic diameter of 0.9 μm . Both static on-filter and dynamic in-flight tests were carried out. Results showed that *E. coli* cells were efficiently disinfected in both static and in-flight tests, whereas *B. subtilis* endospores were more resistant to this treatment. The microwave power level was found to be the major factor determining the effectiveness of disinfection. Both thermal and athermal effects of microwave irradiation contributed to the disinfection. Reducing flow velocity to decrease heat loss yielded higher disinfection efficiency (Zhang et al., 2010).

Zhang et al. prepared electrospun polyacrylonitrile (PAN) nanofibers that were sandwiched between two activated carbon fiber (ACF) mats for testing. *B. subtilis* endospores were tested because of their relatively high heat resistivity compared to *E. coli*. *B. subtilis* spore tests show a similar trend in log disinfection. As shown in Figure 2-23, after irradiation at 750 W for 90 s, 2.7 logs disinfection of the spores was observed. Less powerful microwave power applications proved less effective. For 250 W, 45 s of application time was required to achieve any disinfection at all. Compared with *E. coli* tests, *B. subtilis* spores were more difficult to destroy, requiring irradiation at 750 W for 90s for 3 logs disinfection. This apparent difficulty in destroying the spores would also be observed during in-flight testing. This result is likely attributed to the heat resistivity of the endospores. Analysis of variance (ANOVA) statistical analysis indicated that microwave power, rather than application time, was the most significant factor in the reduction of viable *B. subtilis* spores on the filter (p-value 0.05) (Zhang et al., 2010).

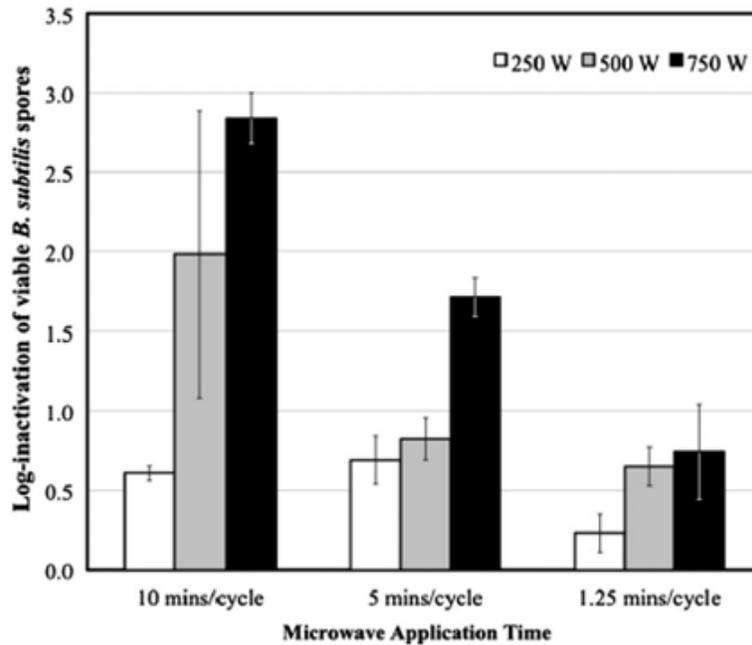


Figure 2-23. Dynamic In-Flight On-Filter Disinfection of *B. subtilis* with Microwave Application Time at 250, 500, and 750 W Power Levels (Reprinted from Zhang et al., Copyright 2010 with permission from Elsevier, Inc.)

McFarland et al. treated biological warfare agents with the transduction-polymer and an acceptor-chromophore (TPAC) compound and then exposed the treated agents to microwaves. Using this approach, significant kill of the BWAs was achieved using standard microwave equipment at moderate power. A 5.5 out of a total of 6 log kill was achieved on surrogate *B. anthracis* spores, the hardest BWA to defeat. The AC molecule is designed so that it easily penetrates the wall of the BWA and binds to surface matrix targets. Upon microwave exposure, the TP emits a blue photon that activates the AC producing saturated levels of chemical radicals that are irreversibly bound to the target spore wall, resulting in lethal failure of the spore upon germination. The TP molecule is resonant and thus responds to a given microwave frequency better than others (McFarland et al., 2001).

Microwave irradiation can be used for decontamination and regeneration with very little warmup time while generating almost none of the problematic byproducts. Wu et al. developed the RHELP (Regenerative High Efficiency Low Pressure) air purification system using a novel ceramic nanofiber on silicon carbide in a microwave oxidizer to effectively decontaminate air

containing aerosolized CB agents. Nanofiber mats of several materials (shown in Figure 2-24) were designed and fabricated: I) (PAN nanofibers on ACF mat; II) titania nanofibers; III) silicon carbide nanofibers; IV) titania carbon nanotube reinforced nanocomposite nanofibers; and V) titania silica nanocomposite nanofibers. Three microorganisms, *Escherichia coli*, MS2 bacteriophage, and *B. subtilis* endospores were tested as benign surrogates for more dangerous microbes. For static on-filter tests, all biological agents were able to be completely destroyed by microwave irradiation within two minutes, with *E. coli* being the most sensitive and *B. subtilis* endospores being the least sensitive. For the dynamic system in-flight filtration tests that coupled PAN nanofiber filtration, at 500 W of continuous microwave application, the system was able to remove over 95% of viable MS2 virus and *B. subtilis* endospores (Wu et al., 2009).

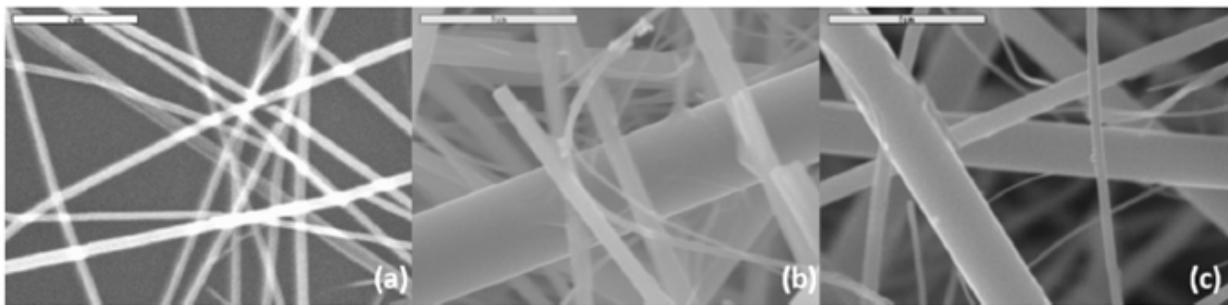


Figure 2-24. SEM Images of (a) TiO₂ Nanofibers, (b) Millipore high efficiency particulate arrestance (HEPA) filter, and (c) Military HEPA (Wu et al., 2009, Published by DTIC, No Permission Required)

Cha et al. used catalysts and microwave energy to test the destruction of simulated chemical agents including the monofunctional derivatives of mustard gas and a series of organophosphorus esters used to simulate G agents including dimethylmethyl phosphate (DMMP), diisopropyl methylphosphonate (DIMP), diisopropyl fluorophosphates (DFP), and 4-nitrophenyl diphenyl phosphate (PNPDPP). Outlet temperature and concentration measurements were taken at regular intervals from 1 to 80 minutes after flow into the reactor. During the test, the outlet simulant concentration was monitored by a Total Hydrocarbon Analyzer (accurate within 0.1 ppm) (Cha et al., 2004).

The catalyst absorbed microwave energy to perform the microwave-induced chemical reactions. Most catalyst substrates such as aluminum oxide (Al₂O₃) do not absorb microwave energy.

Since silicon carbide (SiC) is an excellent microwave absorber, commercially available catalysts were mixed with SiC to carry out microwave-induced chemical reactions. Three different substrates were used to prepare the vanadium pentoxide (V_2O_5) catalyst for a series of tests to evaluate the performance in the oxidation reactions. The first V_2O_5 catalyst was V_2O_5 on silicon carbide, and the second was V_2O_5 on 50% SiC/ Al_2O_3 support. An air stream containing either 300 ppm DMMP or 600 ppm diethyl sulfide (DES) was used to evaluate these substrates for the V_2O_5 catalyst. Air flow rates of 35 bed volume per minute and 300 W microwave power were used for these experiments (Cha et al., 2004).

In Figure 2-25, for DMMP the best DRE (>99.5%) was obtained from tests using the alumina-based vanadium catalyst. The higher catalyst surface area appears to yield greater DRE. Alumina alone does not absorb microwave energy. However, alumina impregnated with the V_2O_5 absorbs enough microwave energy to induce the oxidation reaction. Mixing a small amount of SiC with the catalyst was sufficient to initiate microwave-induced catalytic oxidation (Cha et al., 2004).

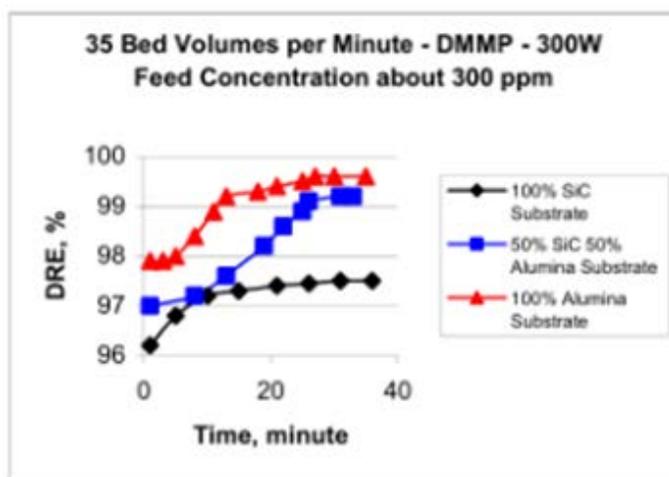


Figure 2-25. Percent Destruction of DMMP for Different V_2O_5 Catalysts (Cha et al., 2004, Published by DTIC, No Permission Required)

In Figure 2-26, the DES outlet concentration reached a steady-state concentration within 10 minutes after the experiment started. All the tests were performed using DES as the CWA simulant and using a 10% by mass V_2O_5 catalyst impregnated on alumina beads (Cha et al., 2004).

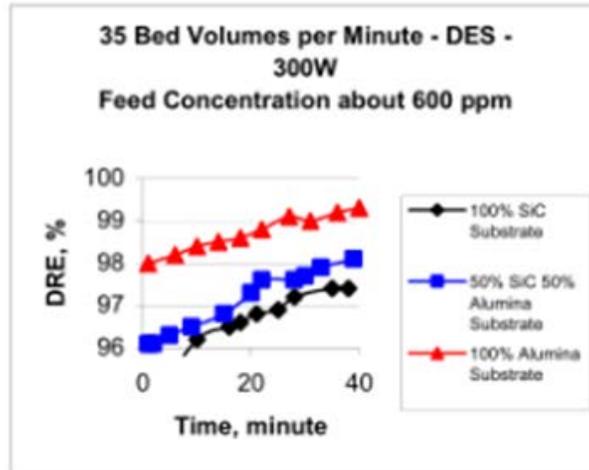


Figure 2-26. Percent Destruction of DES for Different V₂O₅ Catalysts (Cha et al., 2004, Published by DTIC, No Permission Required)

In Figure 2-27, the DRE and temperature (secondary axis) for DES are plotted versus time. The experimental results positively demonstrate that microwave catalytic oxidation is a strong candidate for the destruction of CWAs in air at low temperatures. The microwave power and inlet air flow rate are major parameters controlling the destruction and removal efficiency. The DRE is closely correlated to the combined parameter, microwave power/inlet flow rate (kJ/bed volume). For the V₂O₅ catalyst, DREs greater than 90% were obtained with the ratio of microwave power to inlet flow rate greater than approximately 0.3 kg/bed volume (ft³) (Cha et al., 2004).

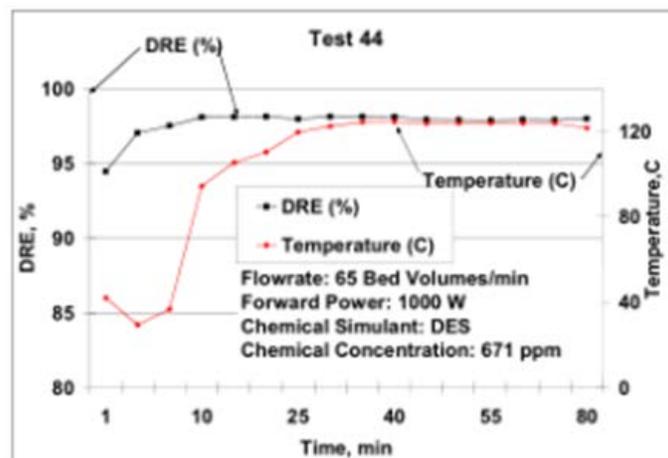


Figure 2-27. Parametric Test Output for the Destruction of DES Simulant (Cha et al., 2004, Published by DTIC, No Permission Required)

2.8 Autoclave



Autoclaves are commonly used to sterilize medical wastes using steam, heat, and pressure. Autoclaves range in size from bench-top devices to large commercial operations. These large commercial facilities can process up to 96 tons of waste per day, and some have waste inlet openings up to 8 feet in diameter. Potential advantages of using commercial autoclaves to sterilize waste include the ease with which processing conditions can be altered for specific waste streams, the ability to process large waste items, and the fact that these facilities often have testing requirements for spore destruction. Potential disadvantages include worker safety issues, packaging requirements, and the issue of disposing of decontaminated wastes (Wilhelmi et al., 2003).

The EPA conducted an experiment to evaluate the effectiveness of a commercial autoclave for treating simulated BDR. Tests were conducted at the Healthcare Environmental, Inc., facility located in Oneonta, NY. This facility can treat up to 84 tons of medical waste per day using two identical autoclaves that are 8 ft in diameter and 32 ft long, which accept large metal bins (80 in by 54 in by 69 in) on rollers. The nominal autoclave operating cycle time was 40 min plus cool down time to prepare for subsequent loads. The nominal operating conditions during the cycles are 31.5 lb/in² and 275 °F (Lemieux et al., 2006a).

The BDR (carpet, wallboard, and ceiling tile) was intended to simulate porous materials removed from a building deliberately contaminated with biological agents such as *B. anthracis* (anthrax) in a terrorist attack. The test team created simulated BDR from wallboard, ceiling tiles, carpet, and upholstered furniture, and embedded in the BDR were *G. stearothermophilus* BI strips. The purpose of the tests was to assess whether the standard operating procedure for a commercial autoclave provided sufficiently robust conditions to adequately destroy bacterial spores bound to the BDR (Lemieux et al., 2006a).

Lemieux et al. (2006a) investigated the effects of several variables related to autoclaving BDR, including time, temperature, pressure, item type, moisture content, packing density, packing orientation, autoclave bag integrity, and autoclave process sequence. The effect of a second autoclave cycle on spore survivability is shown in Figure 2-28. The results indicated that a

single standard autoclave cycle did not effectively decontaminate the BDR. Autoclave cycles consisting of 120 min at 31.5 lb/in² and 275 °F and 75 min at 45 lb/in² and 292 °F effectively decontaminated the BDR material. Two sequential standard autoclave cycles consisting of 40 min at 31.5 lb/in² and 275 °F proved to be particularly effective, probably because the evacuation step in the second cycle pulled the condensed water out of the pores of the materials, allowing better steam penetration. The results also indicated that the packing density and material type of the BDR in the autoclave could have a significant impact on the effectiveness of the decontamination process. In Figure 2-29, the effect of packing density for wallboard is presented. The most effective spore destruction was obtained with a loose packing arrangement, dry BDR material, a higher autoclave operating pressure and higher temperature, multiple autoclave cycles performed in sequence, and bags cut open prior to loading (Lemieux et al., 2006a).

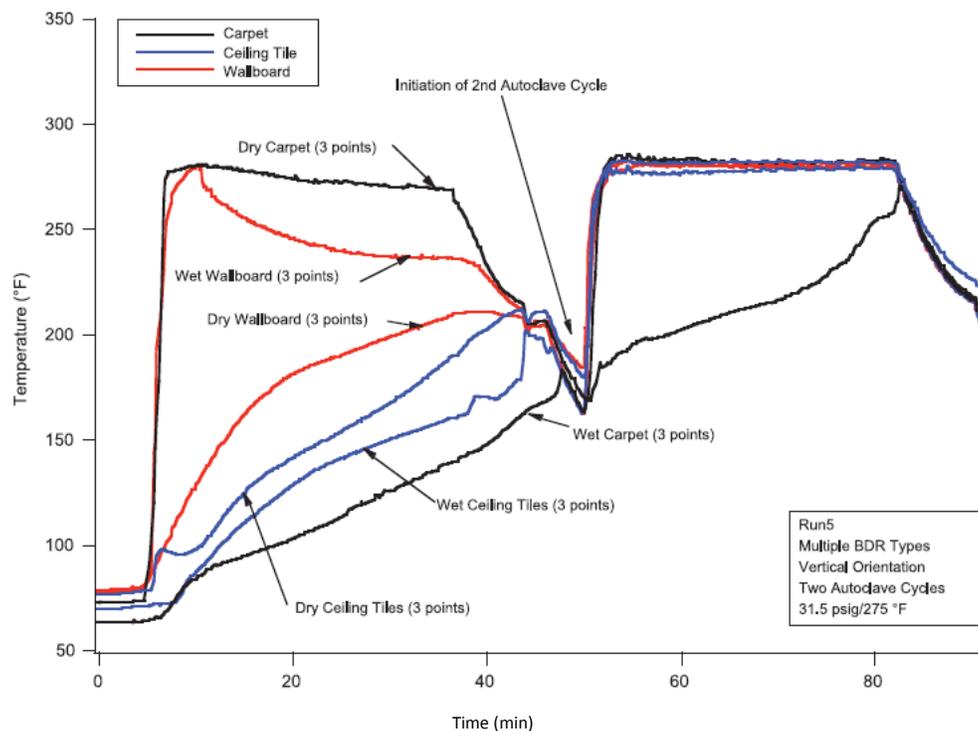


Figure 2-28. Effect of Second Autoclave Cycle on Spore Survivability, Temperature with Time (Adapted with permission from Lemieux et al., 2006a)

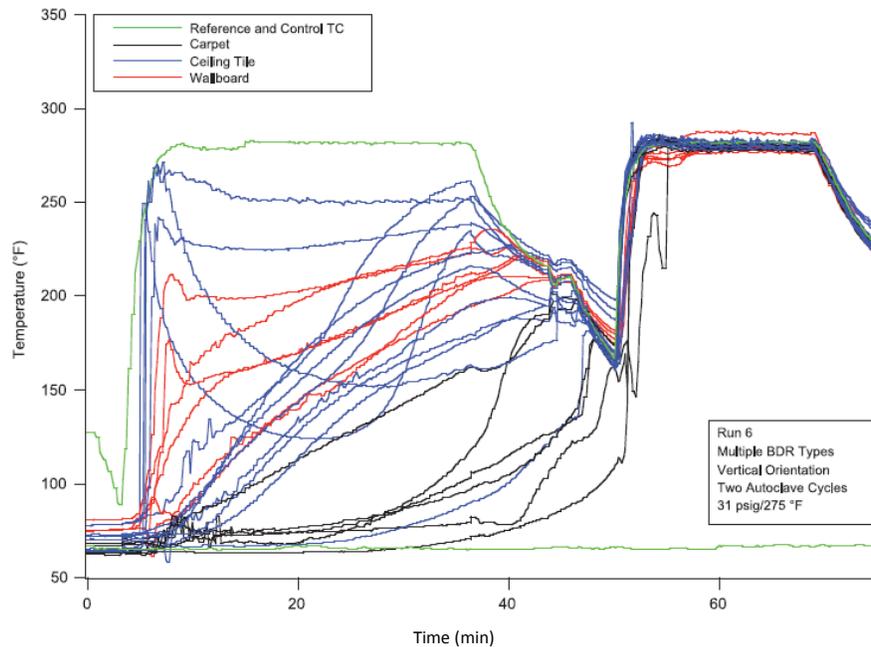


Figure 2-29. Effect of Packing Density for Wallboard, Temperature with Time (Adapted with permission from Lemieux et al., 2006a)

2.9 Landfill Flares



As organic waste decomposes inside a landfill, the decomposing waste releases a combustible gas called “landfill gas” that has a heating value on the order of half of the heating value of natural gas (EPA, 2009). This gas is commonly burned either in a boiler or engine (for energy recovery) or a flare.

Although incineration may be a preferred method to treat biologically contaminated materials, other management options would likely be required in a large-scale incident because the high volume of waste might overwhelm incineration facilities. One management option is the use of municipal solid waste (MSW) landfills. As the landfill reaches final grade, it is capped with clay and plastic to prevent water infiltration. Bacteria break down the organic wastes within each cell to produce landfill gas. Landfill gas generally consists of about half methane (CH₄), half carbon dioxide (CO₂), and <1% non-methane organic compounds as well as hydrogen sulfide and other sulfur compounds. These gases, including methane, are collected through a series of pipes and are routed by blowers to landfill flares, gas turbines, internal combustion engines, or other

devices that combust the gases and prevent the escape of methane into the atmosphere (Tufts and Rosati, 2012).

A bench-scale landfill flare system was designed by Tufts and Rosati and built to test the potential for landfilled biological spores that migrate from the waste into the landfill gas to pass through the flare and exit into the environment as viable. For the bench tests, N_2 and CH_4 were used to simulate landfill gas with combustion air. Flows were corrected to a temperature of 1,000 °C, the maximum average temperature of the flare measured at its widest point which was within the 870 to 1,037 °C operating range for an enclosed flare. *G. stearothermophilus* and *B. atrophaeus* are nonpathogenic spores that serve as surrogates for *B. anthracis*. They were investigated to determine whether these organisms would be inactivated or remain viable after passing through a simulated landfill flare (Tufts and Rosati, 2012).

High concentration spore solutions were aerosolized, dried, and sent through a bench-scale system to simulate the fate of biological weapon (BW) grade spores in a landfill gas flare. Spores were collected from the stack exhaust using a sterile BioSampler. The flare and stack residence times were estimated to be 0.2 and 0.6 sec, respectively. A comparison of the basic operating attributes (e.g., temperatures, gas-phase residence time) showed that the bench-scale system exhibited good similarity to the real-world conditions of an enclosed standard combustor flare stack with a single orifice, forced-draft diffusion burner. All spores of *G. stearothermophilus* and *B. atrophaeus* were inactivated in the flare, indicating that spores that become re-entrained in landfill gas may not escape the landfill as viable, apparently becoming completely inactivated as they exit through a landfill flare (Tufts and Rosati, 2012).

2.10 Bench-Scale Flame Mechanism Studies



Nogueira and Fisher studied the flame inhibition impact of DMMP in a premixed methane/oxygen/ N_2 -Ar flame in a flat flame burner slightly under atmospheric pressure at two different equivalence ratios: rich and slightly lean. Interest in the combustion chemistry of organophosphorus compounds was motivated by two applications: incineration of chemical warfare agents and fire suppression. DMMP addition caused all profiles except that of CH_3OH to move farther away from the burner surface, which can be interpreted as a consequence of a reduction in the adiabatic flame speed. This shift is a consequence of the flame inhibition

properties of the DMMP additive. Decreases in the overall reaction rate with doping led to flame stabilization farther from the burner surface. Experimentally, the magnitude of the shift was 50% greater for the near-stoichiometric flame than for the rich flame. Experimental CH_3OH profiles were four to seven times higher in the doped flames than in the undoped flames (Nogueira and Fisher, 2003).

Korobeinichev et al. studied the possible mechanisms for the destruction of sarin in flames. The structure of a premixed $\text{H}_2/\text{O}_2/\text{Ar}$ (0.26/0.13/0.61 by volume) flame doped with DMMP stabilized on a flat burner at 47 torr has been studied by molecular beam mass spectrometry and modeling. A study of the combustion of organophosphorus compounds (OPCs), including sarin and its simulants (phosphates and phosphonates) such as DMMP, trimethyl phosphate (TMP), and tributyl phosphate was of great interest for understanding and improving the incineration of CWAs. The hallmark of the mechanisms for the destruction of DMMP and TMP is that bimolecular reactions of either the hydroxyl radical or the free hydrogen atom are more important than unimolecular decomposition. Some conclusions on possible mechanisms for the destruction of sarin in flames can now be made. Unimolecular decomposition of sarin is likely to be less important than the substitution of $\text{C}_3\text{H}_7\text{O}$ or C_3H_7 groups by OH or H as the rate-controlling stage for the destruction of sarin in a flame (Korobeinichev et al., 2000).

Werner and Cool developed a kinetic model of the combustion chemistry of a hydrogen/oxygen-based flame, doped with dimethyl methylphosphonate, a useful simulant for nerve agents VX and GB, to assist in the controlled thermal destruction of CWA stockpiles. The kinetic model incorporated several key reaction intermediates, which included methyl metaphosphate (CH_3OPO_2), methyl dioxophosphorane (CH_3PO_2), and monomethyl methylphosphonate ($\text{PO}(\text{OH})(\text{CH}_3)(\text{OCH}_3)$) (Werner and Cool, 1999).

2.11 Exothermic Intermetallic Interaction



Zavitsanos et al. developed a thermobaric self-sustaining reactive composition method and device for destroying chemical or biological agents. The invention incorporates self-propagating high temperature reactive materials capable of self-sustaining reactions with the evolution of large quantities of thermal energy, creating an area of high temperatures (in excess of $800\text{ }^\circ\text{C}$). The method involves the interaction of metals, typically of Groups IV and V of the

periodic table, with aluminum, boron, carbon, nitrogen and silicon. Such intermetallic reactions occur pyrotechnically without requiring an outside oxidizer source (such as atmospheric oxygen). Energy levels released by these types of reactions can reach 17.6 kJ/cm^3 (Zavitsanos et al., 2012).

Wei et al. investigated electrically conducting polymers such as polyaniline to be used as coatings or fabrics on military equipment (e.g., tanks, personnel carriers, artillery pieces, etc.) and installations (e.g., buildings and other structures). These conducting polymers function as heating elements to convert applied electric energy to thermal energy, which would raise the surface temperature of the coatings and fabrics high enough to thermally decompose the chemical or biological warfare agents on the equipment or installations. Through embedded metallic (e.g., copper) wire or carbon fiber electrodes, household alternating current can be applied to the polyaniline-coated panels leading to a rapid increase in the surface temperature from 120 to 180 °C within a few minutes to degrade CB agents (Wei et al., 2004).

A new technique uses the flameless burning of powders containing aluminum, magnesium, sodium nitrate (NaNO_3), and oil. The powder is applied as a flat layer, approximately 10 mm thick, and is used to remove surface coatings from the concrete, e.g., asphalt (Kumar et al., 2010).

Motamedhashemi et al. applied the flow-through catalytic membrane reactor (FTCMR) concept to the thermal oxidation of a chemical warfare simulant (DMMP) in air. Preliminary experiments under different DMMP feed concentrations and reactor temperatures (373 to 573 K) have demonstrated the potential advantage of the FTCMR concept in the catalytic oxidation of DMMP. Complete destruction of various concentrations of DMMP in air was achieved at lower temperatures, with the FTCMR showing superior performance when compared to a wall-coated, plug-flow reactor (monolith) containing the same amount of catalytic metal. A mathematical model was also developed to provide a better understanding of the fundamental transport phenomena underpinning the FTCMR operation. The model was used for identifying the advantages of the FTCMR concept in comparison with the wall-coated catalytic monolith and also for investigating some of the limitations, which may exist in applying this concept for the complete oxidation of chemical warfare simulants. The results of the model support the

superiority of the FTCMR concept over the more conventional plug-flow monolith reactor (Motamedhashemi et al., 2011).



2.12 Direct Heat Application

This section discusses direct heat sterilization processes for spores and evaporation rates for chemical weapons on various surfaces.

The F-value is the minimum time that an organism present in or on an item has to be exposed at a certain temperature to assure sterility of that item. Sterility of medical devices is defined as finding 1 remaining viable organism in or on an item out of 10^6 present before sterilization (6 \log_{10} reduction). F-values are used to optimize sterilization processes to save time, energy, money, or to reduce the exposure time of thermo-labile products to high temperatures. For a given temperature and time, the F-value for a process can be calculated. To calculate the F-value for temperatures other than those reported in the literature, empirical models are used with the decimal reduction time (D) and the temperature resistance coefficient (Z) as parameters. The D-value (min) is the time required to reduce the number of organisms by a factor of 10. The Z-value ($^{\circ}\text{C}$) is the temperature required for one \log_{10} reduction in the D-value. The Z-value can be found by making a thermal resistance curve by plotting the logarithm of the D-value versus the temperature. The Z-value can be found by taking the reciprocal of the slope from the plot (Doornmalen and Kopinga, 2009).

The dry heat F-value, the time (in minutes) that causes the complete destruction of microorganisms at 200°C for *G. stearothermophilus* and *B. atrophaeus* is 1.3 and 1.1 min, respectively. These times are similar to the F-value of 1.2 min for *B. anthracis* at the same temperature (Wood et al., 2010). Wood et al. conducted tests in a dry heat oven to determine the destruction kinetics for *B. atrophaeus*, *B. anthracis* (Sterne) and *G. stearothermophilus*. The dry heat oven tests were conducted at 175°C , and the D-values were 0.4, 0.2 and 0.3 min for *B. atrophaeus*, *B. anthracis* (Sterne), and *G. stearothermophilus*, respectively (Wood et al., 2010). The dry heat D values and Z values are shown in Figure 2-30.

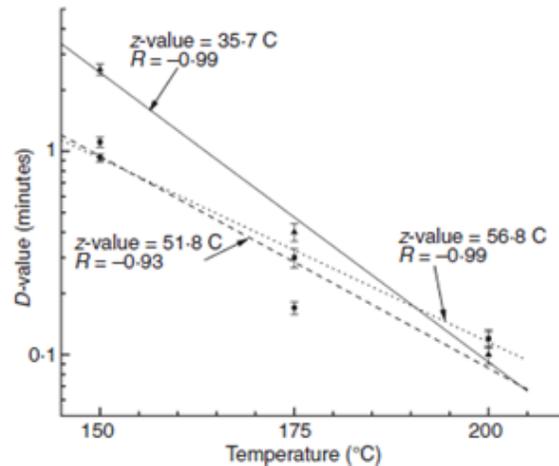


Figure 2-30. Dry Heat D-values and Z-values for Biological Indicators (*Geobacillus stearothermophilus* [squares], *B. anthracis* [circles], and *B. atrophaeus* [triangles]) (Adapted with permission from Wood et al., Copyright 2009 The Society for Applied Microbiology)

Denison et al. determined the sterilization values of *B. subtilis* spiked on ceiling tile and wallboard. The bundles were approximately 50% water. Testing was performed at the EPA's RKIS facility. The Z values were 159 and 281 K for ceiling tile and wall board, respectively (Denison et al., 2005).

Jung et al. investigated the thermal effects on bacterial bioaerosols of *Escherichia coli* and *B. subtilis* by using a thermal electric heating system in continuous air flow. The bacterial bioaerosols were exposed to a surrounding temperature that ranged from 20 °C to 700 °C for approximately 0.3 s. Both *E. coli* and *B. subtilis* vegetative cells were rendered more than 99.9% inactive at 160 °C and 350 °C of wall temperature of the quartz tube, respectively. Although the data on bacterial injury showed that the bacteria tended to sustain greater damage as the surrounding temperature increased, Gram-negative *E. coli* was highly sensitive to structural injury but Gram-positive *B. subtilis* was slightly more sensitive to metabolic injury. In addition, the inactivation of *E. coli* endotoxins was found to range from 9.2% (at 200 °C) to 82.0% (at 700 °C). However, the particle size distribution and morphology of both bacterial bioaerosols were maintained, despite exposure to a surrounding temperature of 700 °C. The results show that thermal heating in a continuous air flow can be used with short exposure time to control bacterial bioaerosols by rendering the bacteria and endotoxins to a large extent inactive (Jung et al., 2009).

Geyer et al. described a concept of applying heat to a structure to sterilize biological agents. Dry heat of 150 °C for 10 minutes effectively sterilizes most items contaminated with active biological agents, e.g., bacteria, fungi, etc. While 150 °C may be difficult to achieve when heating an entire structure, at least not without adversely affecting some architectural elements, heating a structure and its contents to 80 °C has its merits and is possible with today's technology. Moreover, holding a structure at 80 °C for 60 minutes not only kills most active biological agents, it accelerates the neutralization of many harmful toxins, accelerates vaporization of water vapor and chemicals, and oxidizes odors. If an anthrax-contaminated structure is heated so that the architectural components are 150 °C for 480 minutes, the structure should not only be free of viable anthrax spores, but some of the components may be damaged from the high temperature (Geyer et al., 2002).

Heat can be generated using thermal solar radiation, the heating ventilation and air conditioning (HVAC) system of a building, portable electric-inductive heaters, lamps, etc. Portable fuel-fired heaters (burning natural gas, propane, or kerosene) can also generate heat. The type of contamination helps to determine the degree of necessary heat penetration. If contamination occurs from airborne spores, the spores may be surficial and not deep within walls, dimensional timber, or masonry units. The heating process can therefore be surficial in design. Where materials have become moist and promote fungal growth and amplification, heating should be of sufficient duration to achieve the saturation temperature required to kill organisms deep within affected materials. Thermal desorption of CWAs can be achieved by the use of heated air that results in evaporation of the contaminant. With this method, the toxic agent is released into the atmosphere and may present an increased vapor hazard (Boone, 2007). Depending on the site, HEPA units could be used to filter and circulate air within the heated area, assisting in heat distribution; it may also be necessary to place HEPA units outside of the heated area and duct the air to the unit. Propane-fired burner-fan units have been demonstrated to be the most flexible, scalable, and cost-effective heat generators. Heating contaminated materials will not take the place of removing gross levels of contamination. This technology complements traditional remediation methods after gross removal is complete and reduces most labor-intensive detailed cleaning efforts currently performed to achieve clearance criteria (Geyer et al., 2002).

The evaporation rates and reaction mechanism for a droplet of distilled sulfur mustard agent from stainless steel and aluminum substrates are reported by Jung and Lee. For systematic analysis, we used a laboratory-sized wind tunnel, thermal desorption (TD) connected to a gas chromatograph/mass spectrometer (GC/MS) and droplet shape analysis (DSA). Jung and Lee found that the evaporation rates (mg/m^3) of HD from stainless steel and aluminum increased with temperature as shown in Figure 2-31. The rates were also linearly proportional to droplet size. The time-dependent contact angle measurement showed that the evaporation of the droplet of HD proceeded only by a constant contact area mechanism from stainless steel surface. The evaporation of HD from aluminum proceeded by a combined mechanism of constant contact area mode and constant contact angle mode. The experimental data sets and analysis could be used to predict vapor and contact hazard persistence of CWAs in the air and on exterior surfaces with chemical releases, which assists the military decision influencing personnel safety and decontamination of the site upon a chemical attack event (Jung and Lee, 2014).

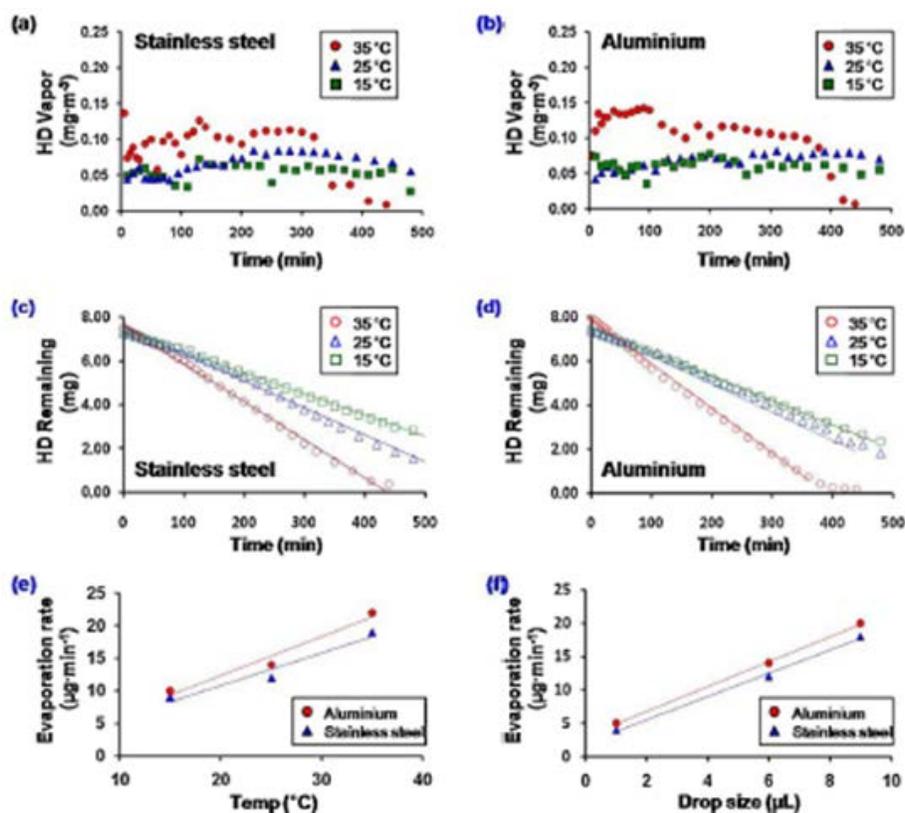


Figure 2-31. Evaporation Profiles at Different Temperatures and Drop Size for HD at an Air Flow of 175 SLPM (Reprinted from Jung and Lee, Copyright 2014 with permission from Elsevier Inc.)

Rowland et al. developed methods for testing off-gassing from selected military-relevant surfaces and to establish a model for predicting off-gassing from a broad range of such surfaces. Vapor-contaminated surfaces were investigated by exposing representative field materials to CWA simulants and then monitoring the off-gassing concentration as a function of time. Concrete, plastic, wood, steel and latex paint surfaces were contaminated with triethyl phosphate, 4-chlorobutyl acetate, 3-hepten-2-one, trimethyl phosphate, and 2-isobutyl-3-methoxypyrazine. The testing process and simple analysis model provided test and analysis methods that were used to test agent off-gassing and served as a standard for vapor hazard testing following vapor exposure. Use of the simple model was justified, based on analyses of the measured off-gassing trends and the predicted trends of interaction between each compound and each surface (Rowland et al., 2010).

A model for evaporation of chemical warfare agents on the ground was developed by Westin et al. The process of evaporation is described in three steps: 1) the immediate drop enlargement due to impact momentum is modeled using an empirical correlation from the technical literature; 2) further enlargement caused by capillary spreading upon the surface and the simultaneous sorption into the substrate, modeled in three dimensions; and 3) subsequent drying and redistribution of the sorbed material is described as a one-dimensional vertical process. The formulation of the flux in the soil takes into account vapor, liquid, solute, and adsorbed phases. The evaporation from the surface was determined by the vapor concentration at the surface and the conditions in the atmospheric viscous sub-layer close to the droplet spots on the surface. Model results agreed with the limited experimental data found in the literature. The model showed a very rapid sorption and redistribution of chemical warfare droplets on sand. This effect gives a rapid decrease of the evaporation, except for a shorter initial period. However, a small residual evaporation from liquid exists for a rather long time when the liquid has penetrated down into the soil (Westin et al., 1998).

Steam cleaning, which combines the solvent action of hot water with the kinetic energy effect of blasting, is recommended for removing contamination from complex shapes and large surfaces, even if grease or similar substances are present, and for removing contaminated soil particles from earth moving and drilling equipment. Secondary waste volumes produced by the process

are relatively low as the steam can be collected by vacuum extraction or similar means and condensed (Kumar et al., 2010).

3 NEUTRALIZATION/HYDROLYSIS AND TREATMENT OF HYDROLYSATE



This section reviews neutralization/hydrolysis of chemical agents and treatment of hydrolysate.

3.1 Neutralization/Hydrolysis

Neutralization employs process conditions that are specific for each type of agent. Thus, a neutralization process for destroying a specific agent or class of agents would not be suitable for treating a wide range of other wastes (e.g., commercial hazardous wastes). Variations in the process may be needed when treating different types of the same agent such as H, HD, and HT. A particular benefit from neutralization is that it detoxifies the mustard agent rapidly at low temperature and low pressure. Batch or semi-batch processing allows retention of the products from neutralization until testing can verify destruction of the chemical agent (Pearson and Magee, 2002).

Two methods of neutralization of mustard through hydrolysis have been demonstrated: hot water at 90 °C and a caustic solution. The Pueblo Chemical Agent-Destruction Pilot Plant (PCAPP) used hot water hydrolysis to neutralize the mustard agent. However, because sulfonium ions (SR_3^+) present after water hydrolysis can cause a false positive in the analytical gas chromatographic method for testing the hydrolysate to establish that the hydrolysate is clear of mustard agent, a heated caustic hydrolysis step (using sodium hydroxide (caustic) at pH >10) follows the hot water hydrolysis reaction. The caustic hydrolysis removes the interference due to SR_3^+ where R is an organic substitute such as methyl (CH_3) attached to sulfur (Nurdogan et al., 2012).

The hydrolysis process results in an irreversible chemical reaction in which the mustard agents are destroyed and a byproduct called hydrolysate is formed. In the hot water reaction, HD is converted to TDG ($HOCH_2CH_2SCH_2CH_2OH$), a readily biodegradable compound, and HCl. The reaction proceeds to completion with no detectable agent (< 4 ppb) remaining in the product (Nurdogan et al., 2012).

Many kinetic and mechanistic studies have been done on the hydrolysis of G-type chemical agents, which include tabun (GA), GB, and GD. Hydrolysis in basic media works well for these agents but less well with sulfur mustard (H or HD). Direct base hydrolysis is not effective for V agents, an example of which is VX. However, oxidation of the sulfur in VX in an aqueous acid medium is rapidly followed by hydrolysis to non-toxic products. An acidic medium also causes protonation of the amine nitrogen, both increasing the solubility of VX and enhancing the oxidation of sulfur (Raber and McGuire, 2002).

3.2 Treatment of Hydrolysate

Chemical agents can be disposed of with technologies based on chemical neutralization. This destruction process results in the production of a solution called hydrolysate that retains some undesirable characteristics and requires further treatment to comply fully with the requirements of the CWC (Pearson and Magee, 2002).

Although neutralization of HD detoxifies the agent, the resulting hydrolysate needs further treatment prior to final disposal. Treatment of the hydrolysate has to destroy both thiodiglycol, which is the major residual in the hydrolysate, and any chlorinated volatile organic compounds (VOCs) that result from impurities in the HD. Management of hydrolysate from HD neutralization may be either on site, through additional treatment following the neutralization process, or off site, by shipping the hydrolysate to a permitted waste-management facility (Pearson and Magee, 2002).

On-site treatment of the hydrolysate requires substantially more complex processing than does the neutralization process alone. The primary process considered for on-site treatment of mustard agent hydrolysate is biodegradation. Aqueous effluent from an on-site biodegradation process could potentially be discharged to the existing publicly or federally owned treatment works or, alternatively, the water could be recycled if zero liquid effluent discharge is desired (Pearson and Magee, 2002).

The hydrolysate produced by the neutralization of mustard is a turbid amber liquid that is approximately 90% water and salts (mainly sodium chloride and iron salts). HD mustard is hydrolyzed to an organic chemical called thiodiglycol (TDG), while HT mustard is hydrolyzed to TDG and a similar compound, T-alcohol (an ethyl ether compound) (Nurdogan et al., 2012).

3.2.1 *Incineration of Hydrolysate*

Ember reported on the incineration of VX hydrolysate (VXH) from the destruction of VX chemical weapons in Newport, Indiana. The VXH was transported to the Veolia Environmental Services incineration facility in Port Arthur, Texas. By March of 2008, 84% of the VHX was incinerated (Ember, 2008).

Notman reported that following pressure from the international community, the Syrian government joined the Chemical Weapons Convention (CWC) and in doing so, agreed to destroy their chemical weapon stockpiles. In September 2014, the Syrian government declared approximately 1,000 tonnes (1,100 tons) of chemical weapons, mostly precursors, and approximately 290 tonnes (319 tons) of raw materials. The blister agent sulfur mustard was the only complete chemical weapon declared. The plan was to chemically neutralize approximately 560 tonnes (616 tons) of sulfur mustard at sea aboard the US Navy ship Cape Ray. The effluent from the Cape Ray hydrolysis operation was incinerated in Germany. The mustard would be hydrolyzed using a batch process facilitated by the titanium reactor at a ratio of approximately 13.5 parts 95 °C water to one part ambient mustard. The mustard breaks down in hot water to hydrochloric acid and thiodiglycol. The second step was to adjust the pH of the effluent to neutral using sodium hydroxide. The neutralization process generates hazardous waste effluent in volumes of five to 13.5 times the volume of the chemical warfare material being treated (Notman, 2014).

3.2.2 *Supercritical Water Oxidation of Hydrolysate*

A one-component fluid is loosely defined to be supercritical when its temperature and pressure exceed its critical temperature and pressure, respectively, while it is not far from its critical state. Supercritical water oxidation (SCWO) is the oxidation of organics with air or oxygen, in the presence of a high concentration of water, under temperatures and pressures above the critical point values of water, 374 °C and 22 MPa (218 atmospheres) (Yesodharan, 2002).

As a waste destruction process, SCWO has several advantages over conventional processes and even some of the relatively modern processes such as wet-air oxidation and incineration. These advantages arise mainly from the properties of supercritical water (SCW) itself. The gas-like low viscosity promotes mass transfer. The liquid-like density promotes solvation. The low

dielectric constant promotes dissolution of nonpolar organic materials. The high temperature increases thermal reaction rates. These properties provide a reactor medium in which mixing is fast, organic materials dissolve well and react quickly with oxygen, and the salts precipitate (Yesodharan, 2002).

The oxidation reaction is complete when carbon goes to carbon dioxide, hydrogen to water, nitrogen compounds to nitrogen or nitrous oxide. Heteroatoms form the corresponding oxyacids or salts if cations are present in the waste or added to the feed. Under supercritical conditions, the salt may remain dissolved in the SCW medium or condense as a concentrated brine solution or as a solid particulate. Heavy metals may form oxides or carbonates, which may or may not precipitate, depending on their volatility. Inert solids will largely be unaffected by the medium and remain as solids. Time required to complete the reactions is short. Reactor residence time ranging from a few seconds to a few minutes is sufficient for complete decomposition of most waste materials. Shorter reactor residence time means higher waste throughput (Yesodharan, 2002).

SCWO was originally selected for the treatment of the hydrolysate from the nerve agent VX stored at the Newport, Indiana, storage site. The SCWO system is a hydrothermal process for the oxidation of hydrolysate that yields a wastewater stream and salts. In a typical chemical agent destruction process, agent would be drained from the weapon or container, hydrolyzed in a well-stirred reactor, tested to verify agent destruction, and then released to the SCWO process unit. The hydrolysate is heated and pumped into an SCWO reactor along with an oxidizing agent (air or oxygen), and the heat of reaction increases the temperature to 600 to 650 °C under about 275 bar pressure. In the course of approximately 30 s, the organic components are largely (approximately 99.99 %) oxidized to water and sodium salts, as well as gaseous nitrogen containing products (e.g., N₂ and NO_x). This mixture of materials is cooled by adding quench water and through heat exchange and then released from the SCWO reactor through a pressure reduction system. The resulting effluent is a mixture of gases (O₂, N₂, CO₂), a concentrated aqueous salt solution, and entrained solid salts. Trace concentrations of partially oxidized organic constituents may also be present. The aqueous products from the SCWO reactor, including entrained solids, are then fed to the evaporation unit, where the mixture is heated to distill excess water. At this point, the salts that have crystallized from solution are filtered and

packaged for disposal in a secure landfill. A large portion of the water distilled from the SCWO effluent is recycled back to the process. All gases reduced during the SCWO treatment step are filtered prior to release (Pearson and Magee, 2002). The Newport site decided to use incineration for hydrolysate treatment at Veolia in Port Arthur, TX (hydrolysate was shipped there).

DMMP is a simulant for VX. DMMP can readily be hydrolyzed to methylphosphonic acid (MPA) during the preheating stage of the SCWO process. Laboratory-scale, continuous-flow reactor tests were conducted to confirm the destruction efficiency of MPA and the effect of sodium hydroxide on MPA destruction efficiency under SCWO conditions. The reaction temperatures ranged from 400 to 594 °C; the reactor residence times varied from 3 to 83 s; and the oxygen concentrations varied from 110 to 200% of stoichiometric requirements. Fixed parameters included: (1) a nominal pressure of 27.6 MPa (4,000 psi); (2) a MPA feed concentration of 1,000 mg/L; (3) a feed flow rate of 25 g/min; and (4) a NaOH to MPA molar ratio of 2:1. MPA was effectively destroyed, as indicated by the C-P bond cleavage, within the selected SCWO conditions. Specifically, greater than 99% DE of MPA was achieved at a temperature of 550 °C, pressure of 27.6 MPa, oxygen concentration of 200% of stoichiometric requirements, and reactor residence times of less than 20 s. In addition to the oxidation end product of CO₂, CO and CH₄ were major gaseous byproducts. Methanol was the only liquid organic byproduct detected. Data derived from these limited MPA/NaOH experiments indicated that the formation of salts did not affect the overall effectiveness of SCWO for destroying MPA. Eventually, means to remove precipitated salts from the reactor should be incorporated into the overall design of an SCWO facility for treating the VX/NaOH hydrolysate (Bianchetta et al., 1999).

Kim et al. reported that in 2003, neutralization followed by SCWO was selected as the technology to destroy the chemical weapons stockpile at the Blue Grass Army Depot. After neutralization and chemical analysis, the hydrolysate was transferred with oxidizing agent (air or oxygen) to the SCWO. The SCWO reaction mechanism generally follows free radical chain pathways that involve important oxidative radicals such as •OH and •OOH. Within approximately 30 s, the organic components were largely oxidized to water and sodium carbonate, phosphate, and sulfate, as well as gaseous nitrogen-containing products (e.g., N₂ and

N₂O). After cooling with quench water, the mixture from the SCWO reactor was released through a pressure reduction system. The resulting effluent was a mixture of gases (O₂, N₂, and CO₂), a concentrated aqueous salt solution, and entrained solid salts. The aqueous salts underwent distillation to remove water in the evaporating section. Salts crystallized from this solution were filtered and packaged for landfill disposal. The disadvantage of second-stage technology is the corrosion of heating and cooling elements on either side of the supercritical water reactor. Frequent replacement of the reactor liner was planned for the SCWO units at the Blue Grass Chemical Agent Destruction Plant (Kim et al., 2011).

3.2.3 Biological Treatment of Hydrolysate

Biodegradation exploits the ability of certain microorganisms—bacteria or fungi—to degrade hazardous organic materials to innocuous materials such as carbon dioxide, methane, water, inorganic salts, and biomass. Microorganisms can derive the carbon and energy required for growth through biodegradation of organic contaminants. The biodegradation of organic constituents in agent destruction process streams can be carried out either on site in coordination with the agent destruction process or off site at a permitted commercial TSDf (treatment, storage, or disposal facility) (Pearson and Magee, 2002).

The bioreactor design for aerobic treatment needs to solve two problems. First, the bacteria must be in contact with the contaminants for extended periods of time to complete the biochemical reactions. Secondly, the design needs to ensure oxygen transfer to the bacteria. Energy requirements for oxygen transfer usually constitute the main operating cost of a bioreactor, other than manpower costs. Designs for biological treatment of hydrolysate are based on systems designed to treat wastewater. Bioreactors for treating contaminated water can be separated into several main types:

- *Suspended-growth reactors.* The bacteria are grown in the water and mixed with the organic contaminants in the water. Oxygen is supplied through a surface aerator or air diffusers.

- *Fixed-film reactors.* The bacteria are grown on an inert support medium within the reactor. The contaminated water passes over the attached bacteria and forms a thin water film into which the contaminants and oxygen diffuse.
- *Submerged fixed-film reactors.* In this version of the fixed-film reactor, the water is in constant contact with the bacterial film, as opposed to passing through in thin water films.
- *Reactors based on activated carbon.* The combination of powdered activated carbon adsorbs organic contaminants and acts as an attachment site for bacteria (Pearson and Magee, 2002).

In an aqueous solution, sulfur mustard spontaneously hydrolyzes and generates TDG. Thus, TDG as a hydrolyzate of sulfur mustard will accumulate in soil and remain in nature for long periods. Nocardioforms of bacterium such as *Rhodococcus* and *Gordonia* are frequently isolated from soil and have been shown to exhibit a wide range of degradative and/or oxidative functions, including hydroxylation, sulfoxidation, or dehalogenation. Cultivation and resting cell reactions are carried out aerobically at 30 °C. The reaction was started by adding the substrate TDG aqueous solution to the cell suspension. Among the tested strains, strain T09 showed the highest degradation activity as shown in Figure 3-1 where cell growth increased with time and TDG concentration decreased (Bassi et al., 2009).

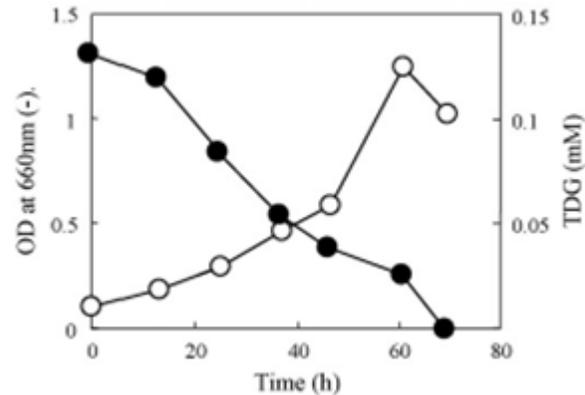


Figure 3-1. Time Course of Strain T09 with TDG at 30 °C Grown Aerobically, Closed Circles (Residual TDG Concentrations) and Open Circles (Cellular Growth) (Reprinted from Bassi et al., Copyright 2009 with permission from Elsevier, Inc.)

Nurdogan et al. described the design of an Immobilized Cell Bioreactor (ICB) for treatment of hydrolysate at the PCAPP in Pueblo, Colorado. The design was based on laboratory and pilot testing results, which defined organic loading rates, hydraulic retention times (HRTs), aeration and nutrient requirements, and operational parameter ranges and controls (temperature, dissolved oxygen, and pH). PCAPP was expected to generate an estimated 8,400,000 gallons of mustard hydrolysate. After the caustic addition and hydrolysis, the agent hydrolysate was between 10 and 12. After neutralization, the pH of the hydrolysate was treated by the ICB, an aerobic fixed-film bioreactor packed with 2-inch polyurethane foam cubes and plastic spacers (bio-rings). The hydrolysate was pumped into aerated treatment tanks containing a mixed culture of microorganisms that digest and break down the complex organic compounds into simpler forms. The influent and effluent concentration of TDG from the bioreactor was measured weekly for six months. The effluent TDG concentration was below detection for much of the test. The treated water from the ICBs was evaporated and recovered for recycling in the plant. Various salts and biosolids left behind were dewatered and sent offsite for disposal. The PCAPP ICBs were designed for 4-5 days of HRT and 120-200 days of sludge retention time SRT (Nurdogan et al., 2012).

3.2.4 Treatment of Hydrolysate Using Photoactivated Periodate

Tang and Weavers reported on the kinetics and mechanism of periodate and photoactivated periodate oxidation of the hydrolysates of chemical warfare agents, TDG, 3,3-dithiopropanol

(DTP), and 1,4-thioxane (TX). These hydrolysates were investigated at pH 3, pH 7, and pH 10 under dark and monochromatic UV light irradiation. The presence of monochromatic UV light at 220 nm, 240 nm, or 254 nm made insignificant improvements in hydrolysates of chemical warfare agents HCWA degradation at low pH (Tang and Weavers, 2007).

4 INCINERATOR MODELING RESULTS



Systematic evaluation of the effectiveness of incineration of CB agents bound on building materials in a full-scale incineration system is not practical. The chemical demilitarization incinerators that process CWAs on a routine basis are tightly regulated facilities that have strict operating permits, in addition to the international agreements that define their operations. These facilities would not be amenable to a performance test where there may be suboptimal operating conditions as part of the test matrix. Testing CB agents on conventional incinerators would be difficult at best, due to community relations and shareholder issues with the facility that would likely arise, even if the permitting hurdles could be overcome. In addition, performing such a test on a full-scale facility that potentially would require tens to hundreds of tons of feed material per day would be prohibitively expensive.

Rather, an approach has been taken to perform bench- and pilot- scale testing using surrogates, combined with computer simulations of full-scale incineration facilities that use the data derived through the sub-scale experiments and other sources to provide the required kinetic mechanistic information. Figure 4-1 illustrates this concept.

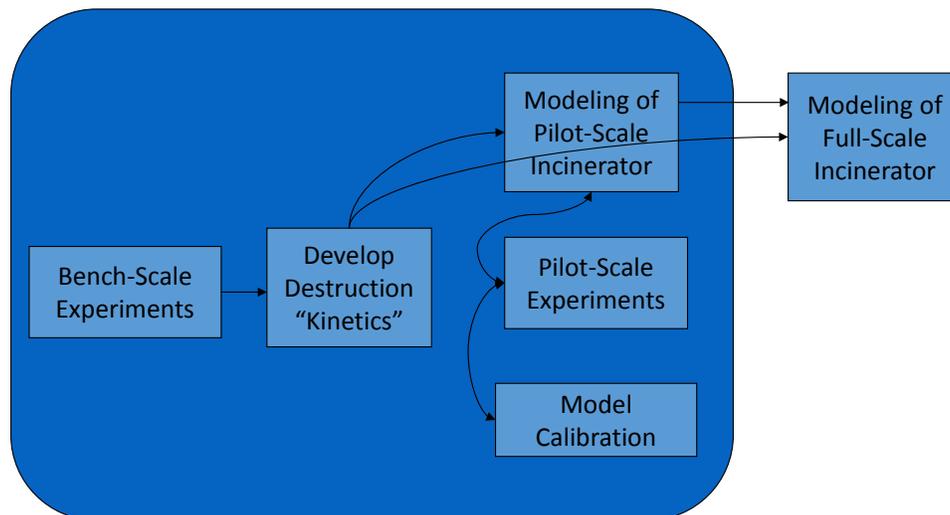


Figure 4-1. Modeling Concept

To achieve this goal, a computer simulation was developed that was based on a simulation developed for the U.S. Department of Defense (DoD) to predict the behavior of CWA-containing munitions in the various furnaces used in the chemical demilitarization program (Denison et al., 2004). This simulation was adapted to model conventional full-scale incinerators feeding solid fuel mixed with arbitrary solid materials with user-defined amounts of chemical and biological agents bound on the solid materials. This simulator was called “The Configured Fireside Simulator” or CFS. The kinetic data for CWA destruction were the same mechanisms used in the previous work for the DoD (Denison et al., 2004). The kinetic data for the BWA destruction was derived from the bench- scale experiments described earlier (Lemieux et al., 2005).

This section discusses the results from the incinerator models using EPA’s CFS tool to model the destruction of three chemical agents (GB, VX, and HD) and one f (*Ba*) with three types of furnaces: a commercial hazardous waste burning rotary kiln (COM), a medical/pathological waste incinerator (MEDPATH), and a stoker furnace (STO).

In 2005, Lemieux evaluated thermal processing of BDR material in commercial incinerators by using an incinerator modeling tool developed by EPA. The simulator included a range of models, from time-dependent process models to detailed Computational Fluid Dynamics (CFD) models. Using computational chemistry methods, detailed chemical kinetic mechanisms were developed that describe the incineration of mustard blister agent and the nerve agents GB and VX. The first unit, the EPA RKIS facility, is a simulated pilot-scale rotary kiln incinerator located at the EPA research facilities in RTP, NC. The EPA RKIS facility has a primary and secondary burner, each rated at 73 kW. The second combustion unit is a commercial dual-chamber starved-air modular medical/pathological waste incinerator that is currently being operated jointly by the EPA and National Institutes of Environmental Health Sciences (NIEHS) on their RTP, NC campus. This facility has a nominal firing rate of 1 megawatt MW and is capable of processing approximately 400 kg/h of wastes, which consist mostly of animal bedding. The third combustion unit is a commercial hazardous waste-burning rotary kiln system currently in operation in East Liverpool, OH. This unit has a nominal firing rate of 35 MW and processes approximately 8,100 kg/h of hazardous waste from various sources. Data available for interrogation from the CFD model include gas temperature, velocity, agent concentration, combustion products (major and minor species), pressure as well as wall and equipment surface

temperatures and incident heat fluxes. Pilot-scale experiments were used to calibrate the models (Lemieux et al., 2005).

In 2015, EPA ran incinerator models following the design factors in Table 4-1 with three furnace types, four CB agents, and three bundle bed locations in the furnace. The bed location was the percent of the bundle exposed to hot gas in the furnace. The high bed location corresponds to 70% of the bundle exposed to the hot gas. For the mid and low conditions, 45% and 20% of the bundle was exposed to the hot gas in the furnace, respectively. Therefore, the low bed condition simulated bundles buried in the furnace. In Table 4-2, the simulator model test parameters are presented.

Table 4-1. Experimental Design Factors for CFS Model

Factor Level	A	B	C
	Furnace	Agent	Bed Location
1	Stoker	GB	low
0	Med/Path	VX	mid
-1	Rotary Kiln	HD	high
0.5		<i>Ba</i>	

Nine net files were created for each furnace model with inputs for the type of agent, bundle moisture content, and bed location. A total of 36 net files were created. After the net files were created, the net files were entered into the CFS simulator and executed in transient mode. The bundle parameters (density, conductivity, specific heat, moisture mass fraction, surface emissivity, dimensions, and Z value [for biological agents]) in the CFS simulator are shown in Figure 4-2. Group A is for the furnace type, group B for the agent, and group C for the bed location.

Table 4-2. Simulator Model Table of Test Parameters

Test ID	Furnace	Agent	Bed Location
1	A ₋₁	B ₁	C ₋₁
2	A ₋₁	B ₁	C ₁
3	A ₀	B ₁	C ₀
4	A ₁	B ₁	C ₋₁
5	A ₁	B ₁	C ₁
6	A ₋₁	B ₀	C ₀
7	A ₀	B ₀	C ₋₁
8	A ₀	B ₀	C ₀
9	A ₀	B ₀	C ₁
10	A ₁	B ₀	C ₀
11	A ₋₁	B ₋₁	C ₋₁
12	A ₋₁	B ₋₁	C ₁
13	A ₀	B ₋₁	C ₀
14	A ₁	B ₋₁	C ₋₁
15	A ₁	B ₋₁	C ₁
16	A ₀	B _{0.5}	C ₋₁
17	A ₋₁	B _{0.5}	C ₀
18	A ₀	B _{0.5}	C ₀
19	A ₁	B _{0.5}	C ₀
20	A ₀	B _{0.5}	C ₁

74 transientCom_0

Zones \ Natural Gas \ Bundle \ Bundle (cont.)

General Properties

Agent Mass Fraction | 0.0001

Density (kg/m³) | 534.0

Conductivity (W/mK) | 0.6

Specific Heat (J/kg-K) | 835.0

Furnace view factor/bundle surface emissivity | 0.2

Critical moisture mass fraction | 0.08

Length (m)

X Dimension | 0.3

Y Dimension | 0.075

Z Dimension | 0.075

Number of Nodes

X Dimension | 3

Y Dimension | 3

Z Dimension | 3

Bio Destruction

A or C, 1/s | 30.01

E/R or Z, K | 3568.3

Arrhenius

Z Value

Only apply when agent is BIO

Help Execute

Figure 4-2. CFS COM Model Bundle Input Parameters

4.1 COM Model

This section discusses the CFS COM model results. The CFS simulator allows the user to plot furnace parameters against time. The gas temperature, the minimum temperature of pieces of bundle, and fraction of agent remaining were plotted against time in the furnace.

4.1.1 Gas Temperature

In Figure 4-3, the gas temperature for *Ba*, GB, HD, and VX are plotted versus time for the COM model. The gas temperature is the highest (approximately 1,200 °C) for the low bed condition for all the agents, which is expected as the bundle is buried in the furnace. The gas temperature is the lowest (approximately 1,125 °C) for the high bed location condition (bundles are not buried in the furnace and are exposed to hot gas) for GB, HD, and VX. For GB, HD, and VX the gas temperatures are fairly stable for all bed conditions.

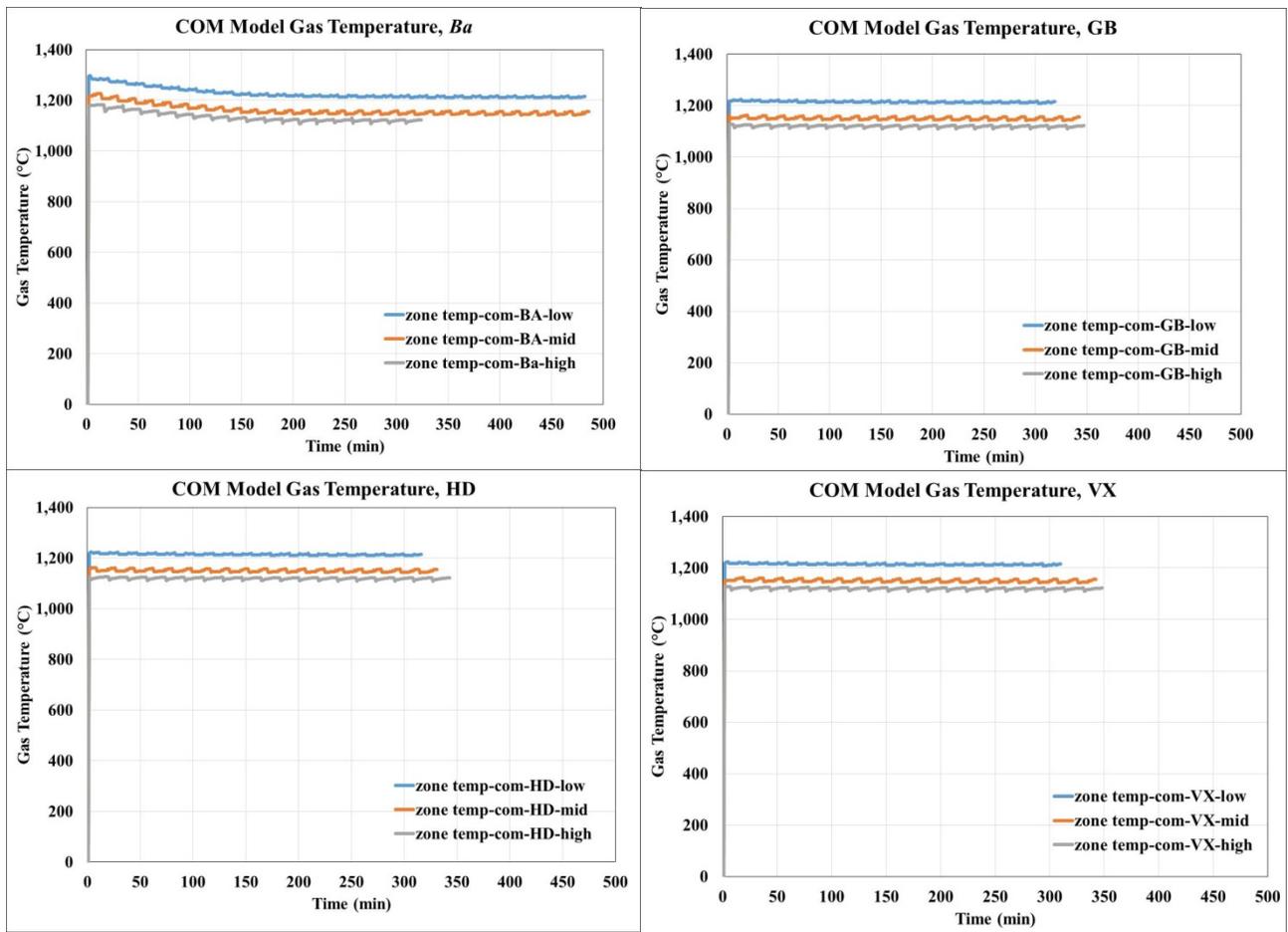


Figure 4-3. COM Model, Gas Temperature

4.1.2 Minimum Piece Temperature

In Figure 4-4, the minimum piece temperatures for *Ba*, GB, HD, and VX are plotted versus time for the COM model. In the plots, the temperature remains at 100 °C for approximately 50 minutes as the water in the bundles vaporizes. Then, the bundle temperature starts to increase again. The high and medium bed locations reach 100 °C before the buried bundles in the low condition. For all the agents, the temperature in the bundle for the low bed condition does not increase above 450 °C at the end of the heating cycle, whereas for the high and medium bed conditions, temperatures climb to approximately 600 °C. For *Ba*, the temperature reaches 450 °C after 475 minutes at the low bed condition, but it takes approximately 300 minutes to reach the same temperature for GB, HD, and VX.

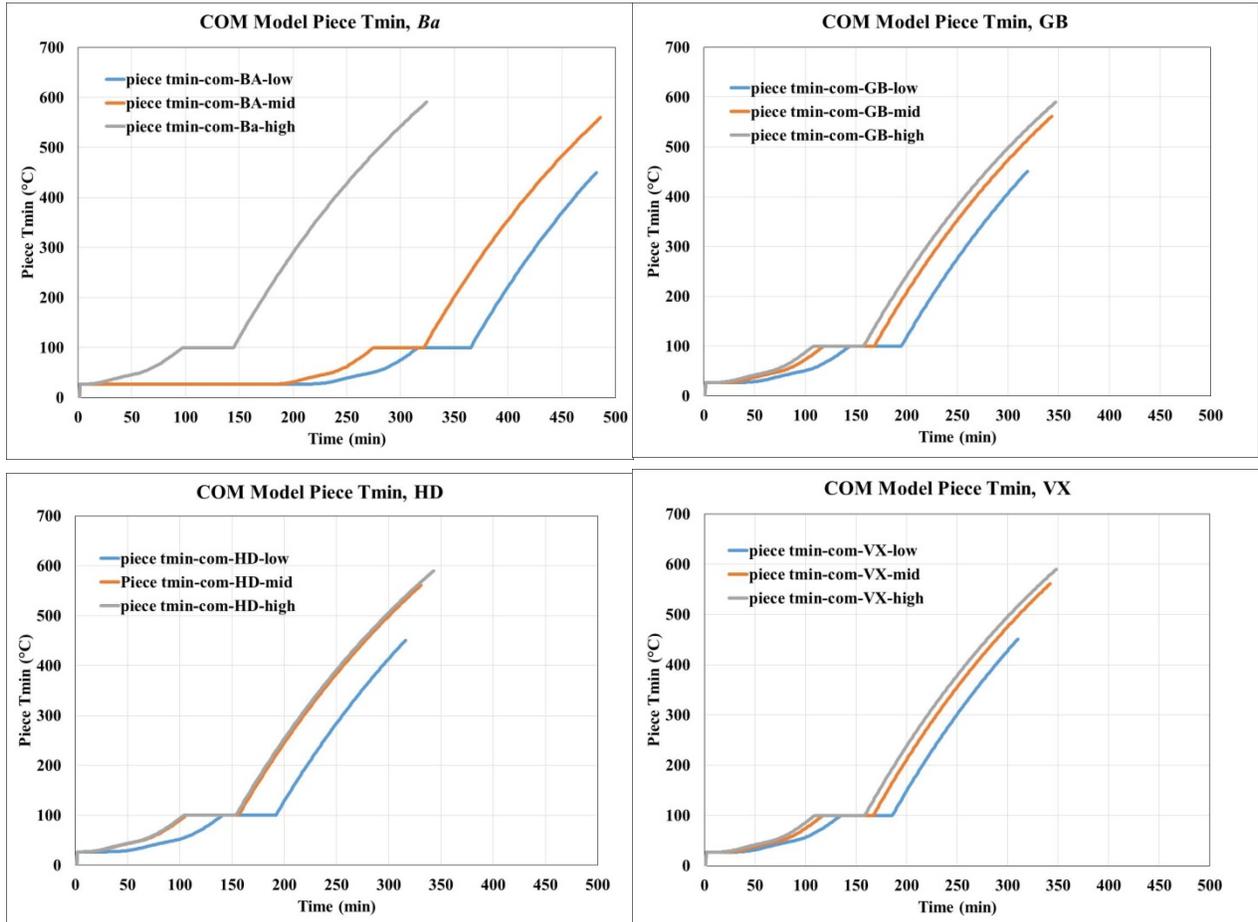


Figure 4-4. COM Model, Minimum Piece Temperature

4.1.3 CB Agents Remaining

In Figure 4-5, the fraction of agent left for *Ba*, GB, HD, and VX is plotted versus time for the COM model. For all the agents, the low bed condition requires the most time for all of the agent to be destroyed. For *Ba*, no agent remains after 45 minutes for the high bed condition, but approximately 350 and 400 minutes, respectively, are required for all the agent to be destroyed for the medium and low bed conditions. For GB, HD, and VX, no agent remains for the high bed condition after 175, 180, and 220 minutes, respectively. VX required the most time to destroy all the agent as it has a higher boiling point (298 °C) than HD (218 °C) and GB (158 °C).

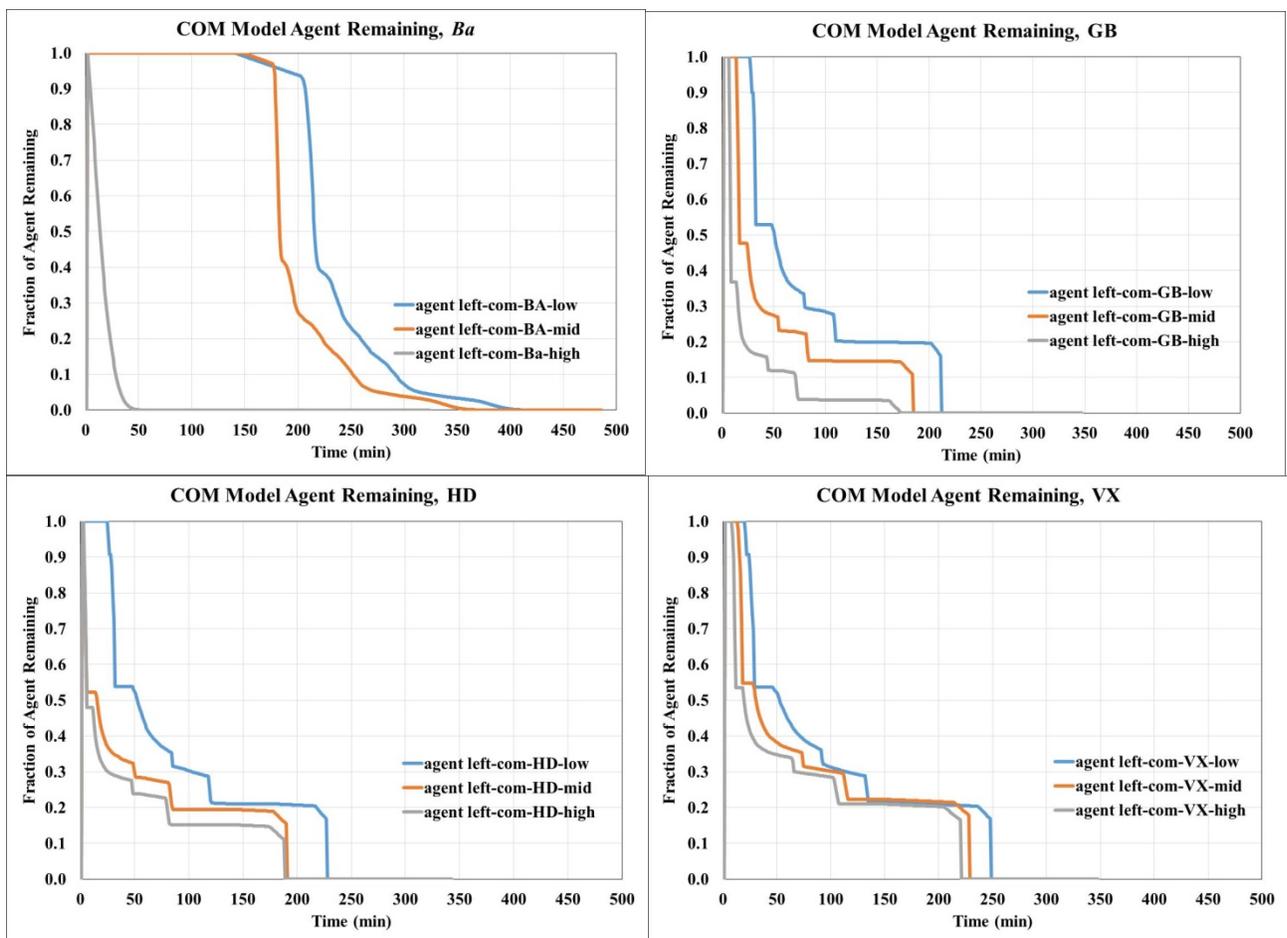


Figure 4-5. COM Model, Agent Left

4.2 Stoker Model

This section discusses the stoker model results. The gas temperature and the minimum piece temperature are plotted with time for *Ba*, GB, HD, and VX.

4.2.1 Gas Temperature

In Figure 4-6, the gas temperature for *Ba*, GB, HD, and VX is plotted with time. For all the CB agents and bed conditions, the gas temperature profiles are similar. The gas temperature rises quickly to 200 °C, then climbs to 1,200 °C after approximately 360 minutes.

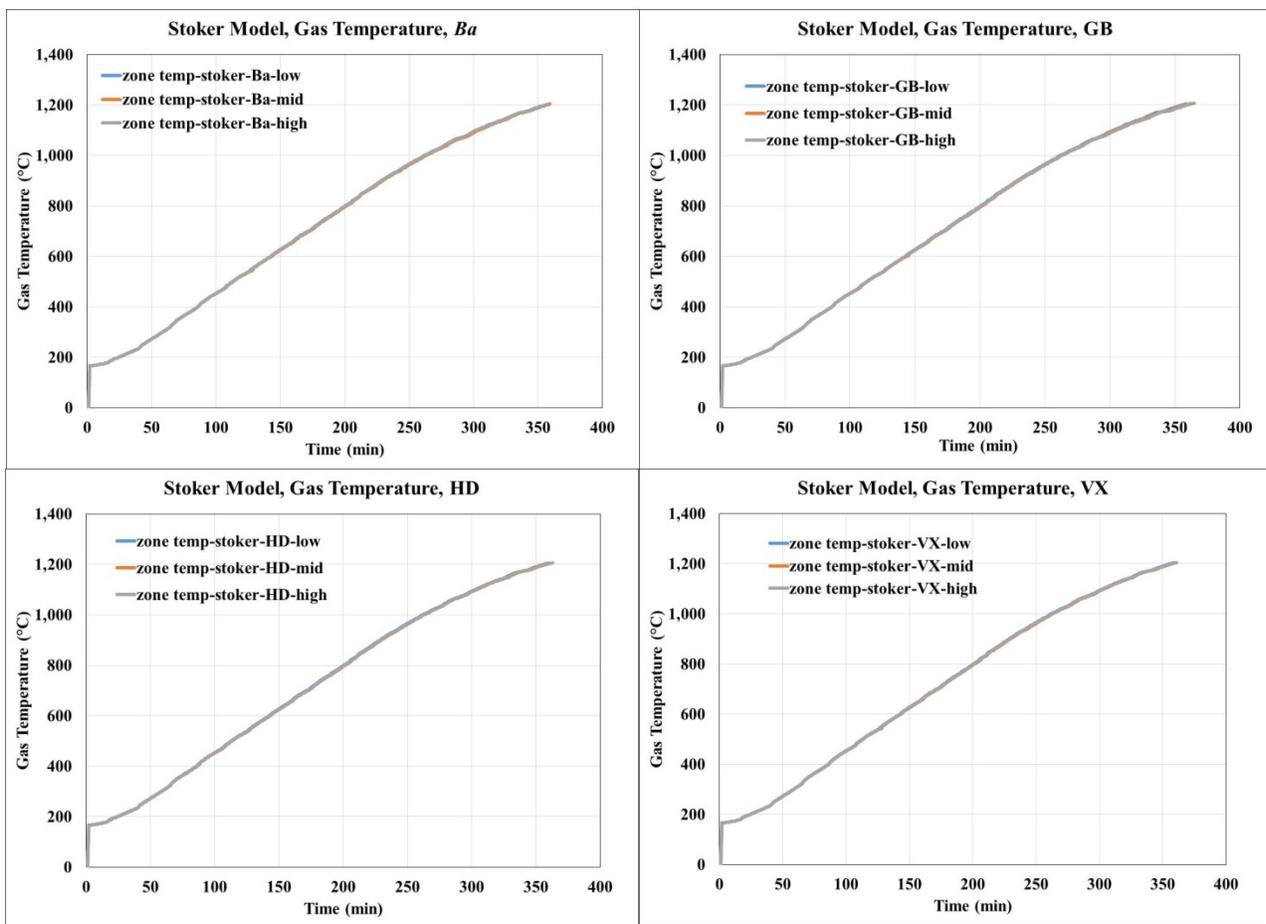


Figure 4-6. Stoker Model, Gas Temperature

4.2.2 Minimum Piece Temperature

In Figure 4-7, the minimum piece temperature for *Ba*, GB, HD, and VX is plotted with time for the stoker model. For all the CB agents, the minimum temperature for the low bed condition does not raise above 100 °C. The high bed condition reaches 100 °C before the other bed conditions. The medium and high bed conditions remain at 100 °C for approximately 70 minutes for all the agents. The minimum temperature for the medium bed location rises to approximately 300 °C for all the agents. For all the agents, the minimum piece temperature reaches approximately 400 °C for the high bed condition.

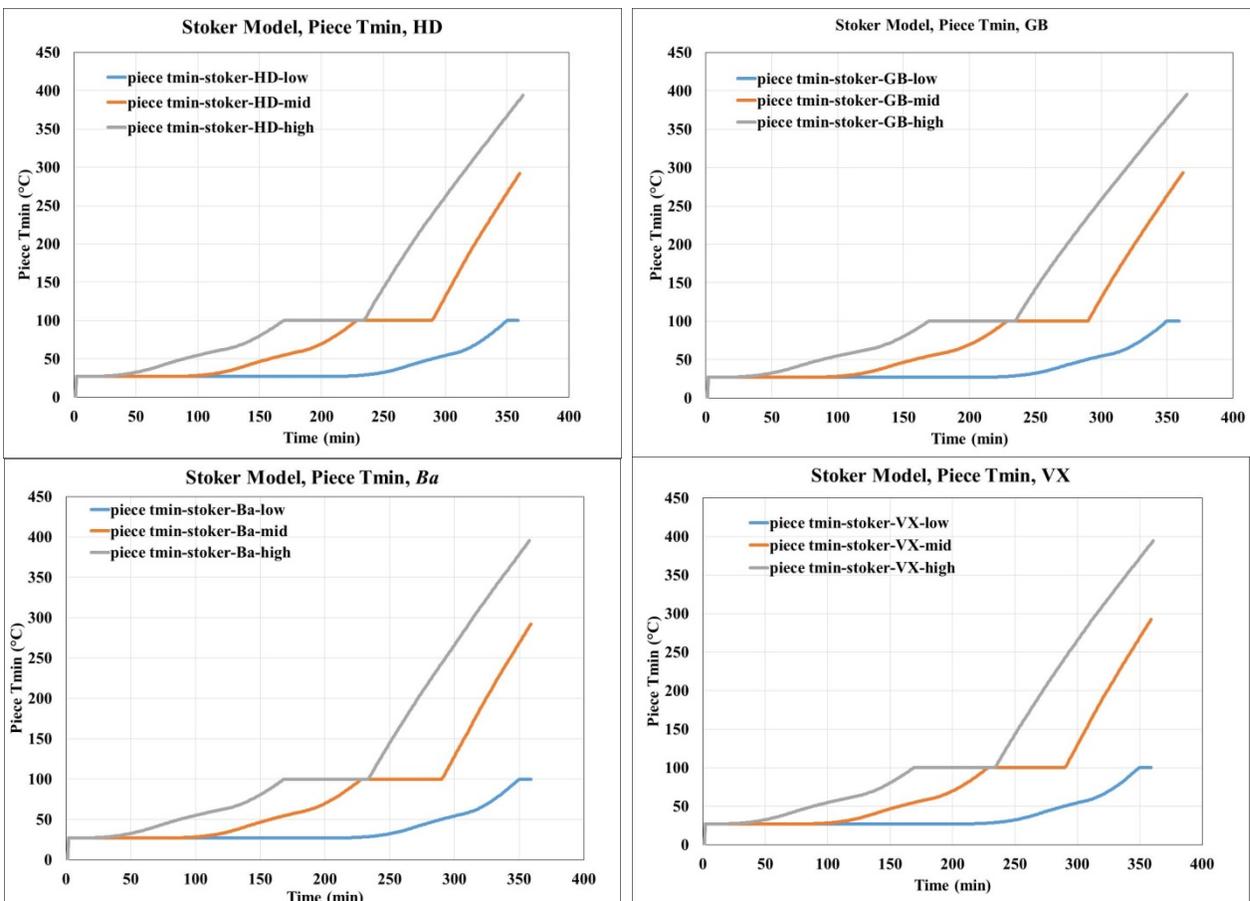


Figure 4-7. Stoker Model, Minimum Piece Temperature

4.3 MEDPATH Model

This section discusses MEDPATH model results. The gas temperature, the minimum temperature of a piece of bundle, and the fraction of agent remaining are plotted against time for *Ba*, GB, HD, and VX.

4.3.1 Gas Temperature

In Figure 4-8, the temperatures rise quickly to 850 °C for the first cycle and peak at approximately 1,100 °C before dropping. The peak temperatures for the subsequent cycles are lower, approximately 1,025 °C for all the agents. For the third cycle in the plots, the temperature of the lower bed condition rises before the other bed conditions.

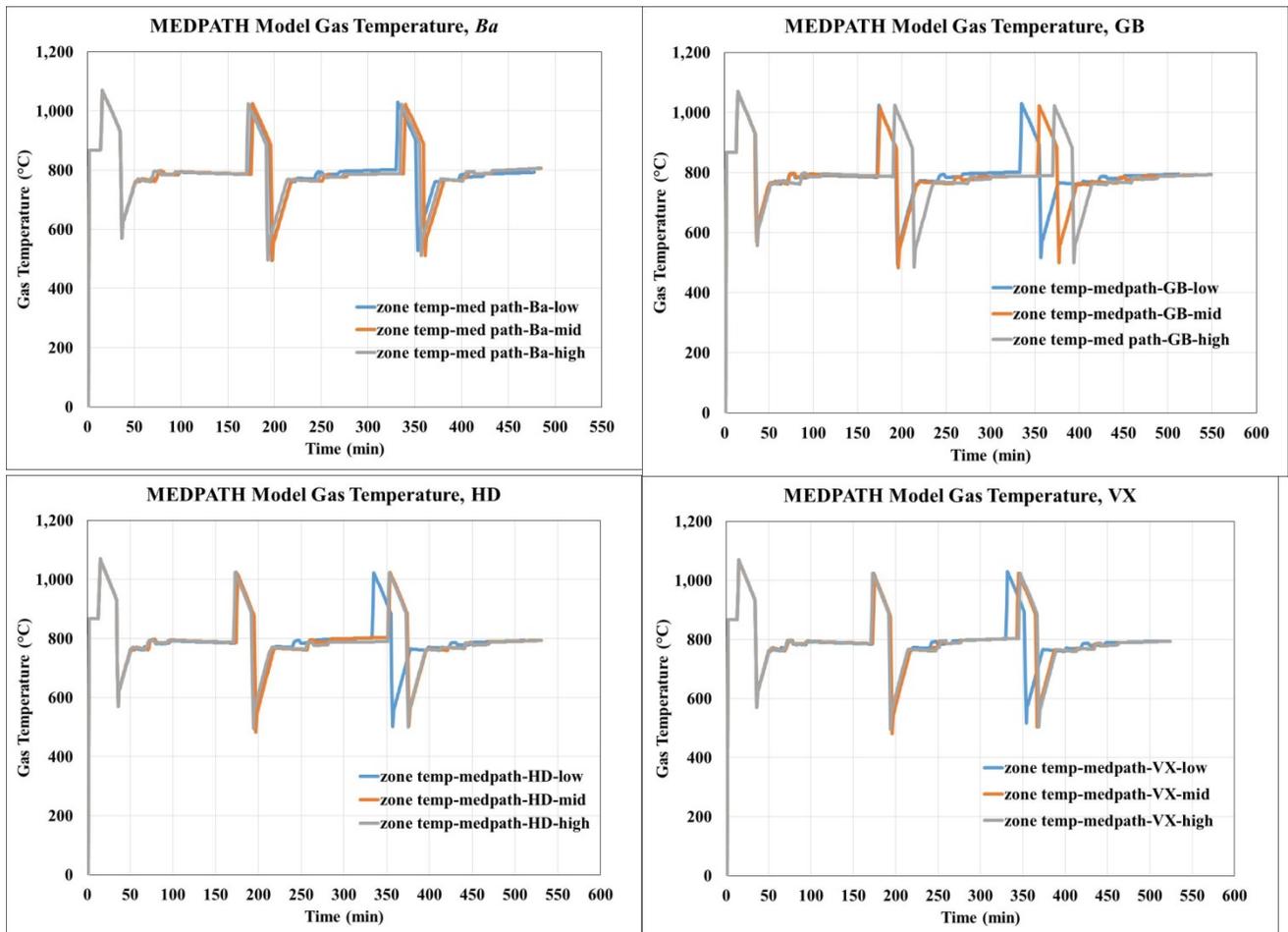


Figure 4-8. MEDPATH Model, Gas Temperature

4.3.2 Minimum Piece Temperature

In Figure 4-9, the minimum piece temperature is plotted for *Ba*, GB, HD, and VX with time. For all the agents the high bed condition reaches 100 °C before the other bed conditions and climbs to approximately 725 °C after approximately 500 minutes. Approximately 60 minutes is required to boil off the water in the bundles. For all the agents, the low bed condition reaches a maximum temperature of 650 °C.

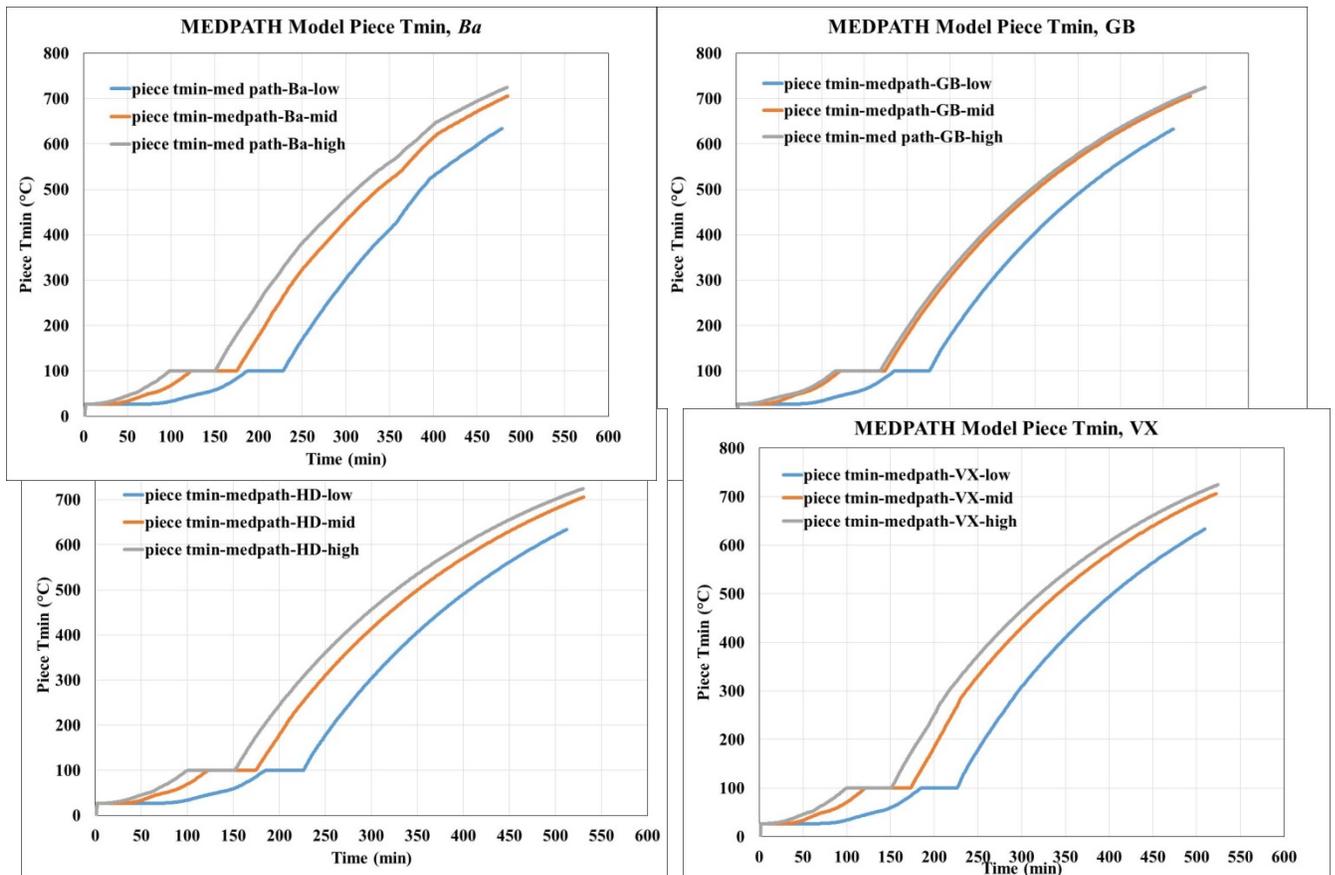


Figure 4-9. MEDPATH Model, Minimum Piece Temperature

4.3.3 Agent Left

In Figure 4-10, the fraction of agent remaining is plotted for *Ba*, GB, HD, and VX against time. The low bed condition required the most time to destroy all the agent. For VX at the low bed condition, approximately 480 minutes was required to have no agent remaining, but for *Ba*, approximately 425 minutes was required to destroy all the agent.

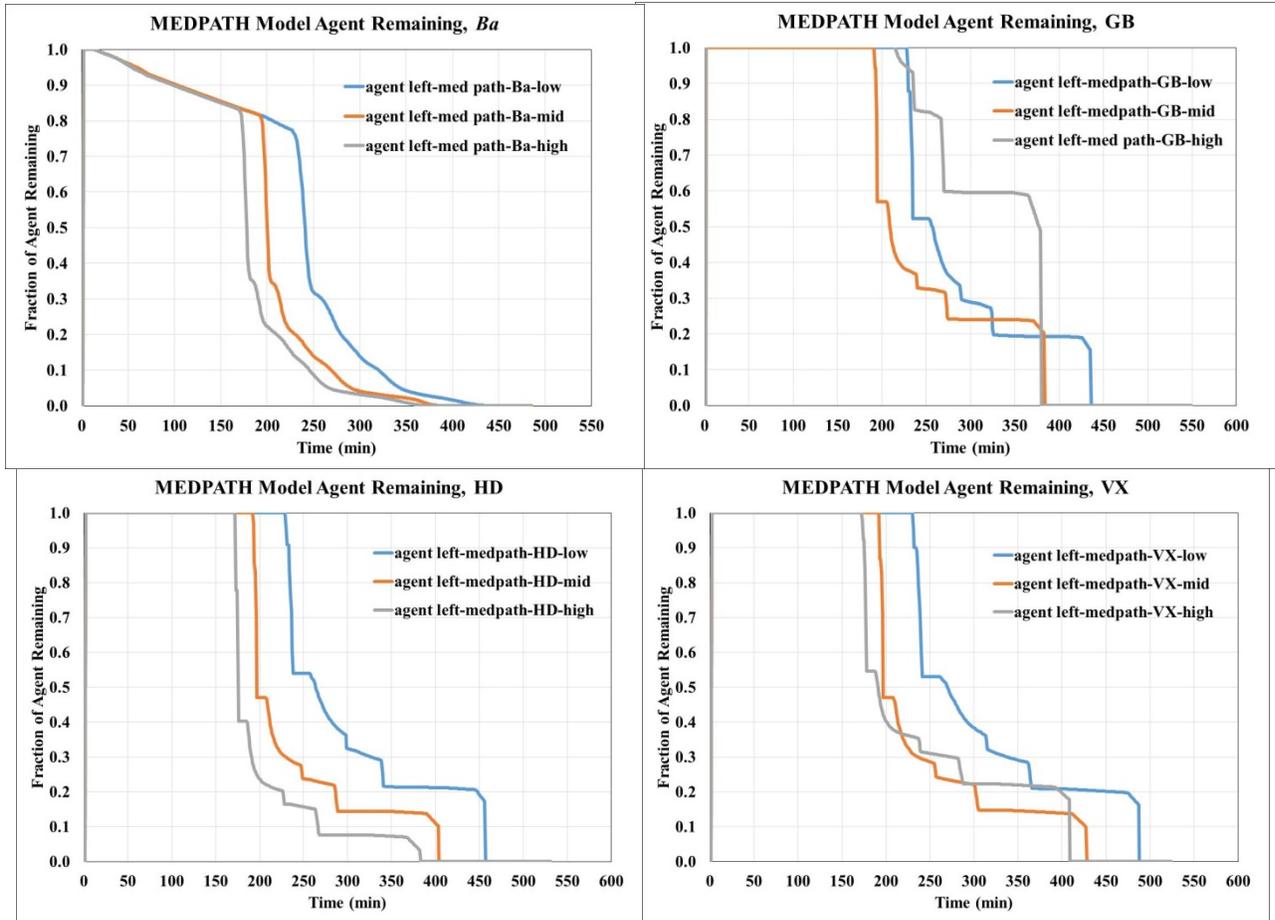


Figure 4-10. MEDPATH Model, Agent Left

5 CREMATION OF HUMAN REMAINS FOLLOWING CHEMICAL AND BIOLOGICAL AGENT INCIDENTS



This section describes the US and UK protocols for cremation of human remains contaminated with CB agents.

5.1 U.S. Military Protocols

Ryder described the decontamination process for remains of military personnel contaminated with CB agents. Mortuary Affairs defines contaminated remains as ‘remains of personnel which have absorbed or upon which have been deposited radioactive material, or biological, or chemical agents’. Mortuary doctrine for decontamination remains much the same as it has been for the last 20 years and depends upon sodium hypochlorite (5% solution) and water in sufficient amounts to wash away and/or dilute the presence of chemicals. The decontamination efforts are carried out in full individual protective equipment (IPE), most likely worn at the highest mission-oriented protective posture (MOPP) levels. Decontamination of remains is done using nearly the same methods used in decontaminating equipment. Therefore, the decontamination process just cleans the exterior surface. Men and women killed by biological or chemical weapons will most likely have ingested or absorbed the agents in some way, making their remains contaminated on the inside. The outside and inside levels of contamination will vary. In 2002, Mortuary Affairs ordered a re-evaluation of existing mortuary policy to assess the policy that cremation is not an option for contaminated remains (Ryder, 2003).

The U.S. Army prepared a report to assist emergency managers, medical examiners, and coroners to better prepare for and determine the best course of action for responding to a mass fatality situation following a chemical weapon of mass destruction (WMD) incident. At the federal level, the Disaster Mortuary Operational Response Team (DMORT) is the only response organization prepared to handle large numbers of fatalities. Time, effort, and resources may dictate a blanket policy to mass incinerate all animal remains resulting from a chemical WMD incident. To ensure that human remains are free from contamination, the medical examiner should monitor human remains before releasing them to the community for final disposition. Two main types of chemical agent monitors exist. The Chemical Agent Monitor (CAM) provides high level monitoring capability, which technicians use to monitor levels of agent. The

second type of monitoring is mass spectrometer monitoring. This type of monitor is used for low level monitoring. Army Regulations (AR 385-61) state that all chemical warfare agents are nullified when exposed to temperatures of 1,000 °F for fifteen minutes. United States crematoria set their cremation temperature higher than 1,000 °F, so cremation will nullify all chemical agents. Cremation of human remains requires temperatures approximately 650 °C for sufficient lengths of time (usually 2.5–3 hours) for complete burning (Morgan, 2004). When contamination cannot be mitigated with decontamination efforts, involuntary individual cremation may be the only remaining option. The emergency plan of a jurisdiction should reflect the location and capability of area crematoria. Medical examiners should consider preparing remains for cremation even if authorities have not determined their final disposition. The appropriate time to prepare remains for possible cremation is before they are embalmed. Personnel should scan and remove all internal devices such as automatic defibrillators and internal pacemakers before embalming, and personnel should be wearing PPE. A flow diagram for processing contaminated remains is shown in Figure 5-1 (US Army, 2003).

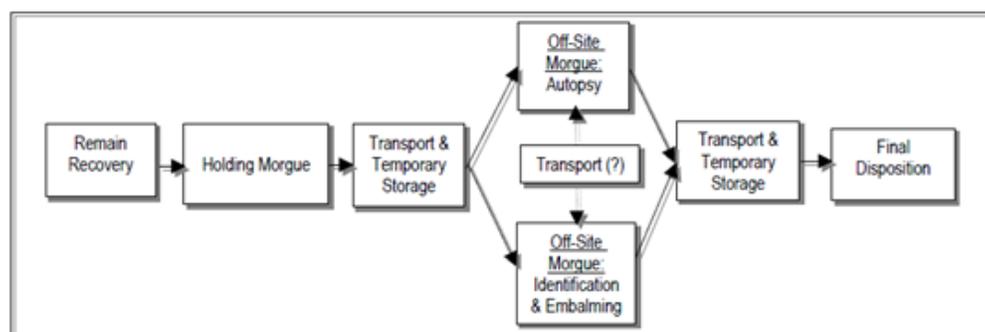


Figure 5-1. Flow Diagram for Processing Contaminated Remains (Published by US Army, 2003, No Permission Required)

5.2 UK Protocols

The UK Home Office recommended that if cremation were chosen as the disposition option for victims contaminated with CB agents, the victim must first be placed in a chemical resistant body bag. The crematorium should be located in a remote area to reduce the number of potential human receptors. The crematorium should be fitted with regulation air filters to reduce emissions. Ashes should be collected and sealed in an air tight container. All personnel

involved with the disposal should wear the correct PPE. Decontamination of the crematorium may also be necessary after cremation (Home Office and Cabinet Office, 2004).

Baker et al. reported that crematoria are carefully regulated to prevent environmental hazards from emissions. Current UK regulations state that crematoria must be a minimum distance from dwellings (100 yards in London or 200 yards elsewhere in the United Kingdom (UK)). The cremation process works at temperatures in excess of 600 °C. A crematorium can function continuously for a period of several days or weeks, should the demand to cremate a large number of fatalities arise. However, only one body may be cremated at any one time in each crematorium. Coffins awaiting cremation require temporary storage in the committal room; therefore, the necessary space and ventilation may present problems. In the UK, it is doubtful whether a cremation order would be available quickly from the appropriate legal authority (the coroner) for all fatalities following a chemical, biological or radiological (CBR) release. Therefore, a storage facility at 4 °C would be required. A coffin alone may not provide sufficient containment for a contaminated body, due to the likelihood of offgassing, aerosolized agents, or leakage of fluids. Double-bagging of the body will be necessary, preferably in a body bag specifically designed for CBR-contaminated bodies. Equipment that minimizes the time that crematorium personnel spend near the coffin, or the resultant ash, should be utilized (catafalque, hearth type) (Baker et al., 2008).

6 CONCLUSIONS

This report reviewed literature on the destruction of CB agents and surrogates bound on materials such as ceiling tiles, wallboard, carpet, fiberglass, aluminum, concrete, pumice, stone, wood, stainless steel, laminate, asphalt, brick, and others. A summary table of the operating conditions and results from the thermal and hydrolysis treatments discussed in this review are presented in Appendix A. The log reduction, destruction efficiencies, F-, D- and Z-values, and spore survivability are included in the summary table.

Incineration of materials contaminated with CB agents is widely reported in the literature. Incomplete combustion of CB agents should not occur, provided that the temperature and exposure time used are sufficient to decompose the organic chemicals to simple inorganic chemicals. There is not a significant amount of literature on the destruction of CB agents at MWCs and MWIs. The majority of the literature on the destruction of CB agents using incineration involves the use of HWCs.

For the incinerator modeling presented, the incinerator models are calibrated using empirical data collected from pilot-scale experiments, mechanistic data from experiments, or derived using molecular modeling techniques. Denison et al. (2002) found that models are useful in simulating incineration system upset conditions and failures that could lead to an agent release, so that appropriate design and operational modifications can be made to mitigate such occurrences.

CB agents can readily be absorbed into porous materials and can lead to unexpected persistence of the agent, even after measures have been taken to decontaminate. The results from this review found that more porous materials are much harder to treat effectively than less porous materials using thermal destruction methods. Compiling the operating conditions in this review could facilitate the management of the waste generated during cleanup following a CB contamination incident.

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Appendix A
Summary Table of Thermal
Processes for CB Agent Destruction

Table A1. Summary of Test Conditions and Results for Thermal Processes

Test Conditions	Results	Reference
Incineration		
Bench scale study with CWA simulant, Malathion at an initial concentration of 300,000 µg/L. Tested in an oven ramped up to 400 °C (following hazardous waste incinerator (HWI) temperature increases) then maintained at that temperature for 30 minutes.	The Malathion concentration averaged 911 µg/L at 175 °C after 30 minutes of exposure (99.7% destruction).	Lemieux et al., 2010
Pilot-scale rotary kiln incinerator, <i>G. stearothersophilus</i> spiked on dry and wet ceiling tile bundles. The incinerator temperature was 804 – 827 °C.	Dry ceiling tile bundles had a 1 to 2 log ₁₀ reduction at 5 to 10 minutes and 6 log ₁₀ reduction after 12 minutes. Wet ceiling tile bundles 35 – 38 minutes for 6 log ₁₀ reduction.	Wood et al., 2006
<i>B. subtilis</i> ceiling tile samples were heated in a quartz reactor operating at 150, 200, 250, and 315 °C, for various time intervals.	6 log ₁₀ reduction at 2.5, 3, 6, and 21 min at 315, 260, 204, and 148 °C, respectively.	Lemieux et al., 2005
<i>G. stearothersophilus</i> spiked on wet and dry ceiling tile bundles tested in a pilot-scale rotary kiln incinerator.	6 log ₁₀ reduction in 6 and 30 min at 1,093 °C for dry and wet ceiling tile, respectively. 6 log ₁₀ reduction in 13 and 38 min at 824 °C for dry and wet ceiling tile, respectively.	Wood et al., 2008
Dry heat oven tests conducted at 175 °C with wallboard spiked with <i>B. atrophaeus</i> , <i>B. anthracis</i> (Sterne) and <i>G. stearothersophilus</i> .	The D-values were 0.4, 0.2 and 0.3 min for <i>B. atrophaeus</i> , <i>B. anthracis</i> (Sterne) and <i>G. stearothersophilus</i> , respectively, on wallboard	Wood et al., 2009
<i>B. subtilis</i> spiked on wallboard and ceiling tile tested in the pilot-scale rotary kiln incinerator	For <i>B. subtilis</i> , the Z values were 159 and 281 K for ceiling tile and wall board, respectively. The 6 log ₁₀ reduction for <i>B. subtilis</i> on wallboard occurred at 1,700 sec at 600 °F, 2,700 sec at 500 °F, and 4,500 sec at 400 °F.	Denison et al., 2002
Test data compared to incineration model for HD destruction.	A furnace temperature of 850 °C was required for complete destruction of HD, which was comparable to the model output.	Denison et al., 2002
<i>B. stearothersophilus</i> spiked on medical waste feed in the small medical waste incinerator operating at 816 °C.	At least a five log reduction of the spores was achieved, although viable spores were detected in 10 out of a total of 48 air emission test runs, and spores were detected in 10 out of 27 available ash samples.	Wood et al., 2004
Plasma Systems		
Thermal plasma test with the Montec steam torch with <i>B. stearothersophilus</i> spiked on fiberglass and other substrates.	At 90 kW power, the steam plasma produced a 99.94% or greater kill rate for <i>B. stearothersophilus</i> on fiberglass substrates at velocities up to 2 ft/s at a distance of 1inch from the exit plane. At this same power level and at a distance of 3 in, the percent kill ranged from 97% to 85% as the speed increased from 0.5 to 2 ft/s. At the lower power level of 60 kW, the maximum speed that would produce 99.94% kill at 1 in was 1.5 ft/s.	Farrar et al., 2000

Table A1. Summary of Test Conditions and Results for Thermal Processes (Continued)

Test Conditions	Results	Reference
Atmospheric Pressure Plasma Jet (APPJ) effluent temperature of 175 °C tested with <i>Bacillus globigii</i> .	Results indicate a seven-log kill of <i>Bacillus globigii</i> spores in 30 s at 5 mm distance, which was ten times faster than dry heat at the same temperature.	Rosocha et al., 2003
Cold plasma test; exposures were conducted at a system pressure of 30 torr, exposure temperature of 70 °C, plasma-to-sample standoff distance of 10 cm, and 10% addition of oxygen or hydrogen to a helium balance. The agents studied were VX, HD, and GD on aluminum.	VX decontamination (99.9%) was achieved in 8 to 16 min of exposure, while under 2 min was required for the more volatile HD and GD.	Herrmann et al., 1999
Glow discharge at atmospheric pressure and enhanced corona discharge at atmospheric pressure with <i>Pseudomonas aeruginosa</i> on nitrocellulose filter membrane and in a liquid broth. <i>B. subtilis</i> in Luria–Bertani and <i>E. coli</i> .	15 min was required to sterilize a sample of <i>Pseudomonas aeruginosa</i> on nitrocellulose filter membrane. For <i>Pseudomonas</i> in a liquid broth, only half of the initial cells were killed in 15 min. For <i>B. subtilis</i> in Luria–Bertani broth at 42 W and after a 12-min exposure time, about 100 cells were still alive as compared to complete kill in 8 min for <i>E. coli</i> using ECDAP.	Laroussi et al., 2000
OAUGDP testing <i>B. stearothermophilus</i> spores on nitrocellulose, <i>B. subtilis</i> var. <i>niger</i> , <i>B. pumilus</i> spores on paper, <i>B. subtilis</i> on glass, and <i>E. coli</i> on glass and polypropylene.	<i>B. stearothermophilus</i> spores on nitrocellulose, were killed to five logs in 5.5 min. <i>B. subtilis</i> var. <i>niger</i> spores took 4 min (to 4 log ₁₀ reduction), while it took only 2.5 min to inactivate approximately the same number of <i>B. pumilus</i> spores on paper. <i>B. subtilis</i> on glass, 3 log ₁₀ reduction after 60 seconds (D1 at 13 sec, D2 at 10 sec). <i>E. coli</i> on glass 70 seconds for 2 log ₁₀ (D1 33 sec, D2 7 sec), <i>E. coli</i> on polypropylene, 24 sec 5 log ₁₀ , D1 6 sec, D2 2 sec.	Montie et al., 2000
Microwave Irradiation		
Microwave treatment for airborne <i>B. subtilis</i> var. <i>niger</i> , <i>Pseudomonas fluorescens</i> , and <i>Aspergillus versicolor</i> at 750 W, 385 W and 119 W for 1.5 minutes.	The survival rates of airborne <i>B. subtilis</i> var. <i>niger</i> spores were shown to be about 35%, 44% and 35% when exposed to the microwave irradiation for 1.5 min with 750 W, 385 W and 119 W power applied, respectively. The airborne <i>Pseudomonas fluorescens</i> was shown to have lower survival rates of 5.8%, 12.2% and 21%. 12%, 20%, 25% rates at respective powers were observed for airborne <i>Aspergillus versicolor</i> exposure	Wu and Yao, 2010
Microwave at 750 W for <i>B. subtilis</i> on PAN nanofibers.	For <i>B. subtilis</i> at 750 W for 90 s, 2.7 log disinfection on PAN nanofibers.	Zhang et al., 2010
TPAC compound with anthrax-type spores with standard microwave equipment at moderate power.	A 5.5 out of a total of 6 log kill was achieved with TPAC compound and anthrax type spores.	McFarland et al., 2001
<i>E. coli</i> , MS2 bacteriophage, and <i>B. subtilis</i> static on-filter tests and dynamic system test with microwave irradiation.	Biological agents were able to be completely destroyed by microwave irradiation within 2 minutes, with <i>E. coli</i> being the most sensitive and <i>B. subtilis</i> endospores being the least sensitive. For the dynamic system in-flight filtration coupled PAN nanofiber filtration at 500 W of continuous microwave application, the system was able to remove over 95% of viable MS2 virus and <i>B. subtilis</i> .	Wu et al., 2009

Table A1. Summary of Test Conditions and Results for Thermal Processes (Continued)

Test Conditions	Results	Reference
Microwave and catalysts tested with DMMP initially at 300 ppm and DES at 600 ppm.	The best DRE (>99.5%) was obtained from tests using the alumina-based vanadium catalyst after 35 min at 300 W. DES removal was at steady state after 10 minutes, 99% DRE at 300 W with the alumina substrate.	Cha et al., 2004
Autoclave		
BDR material (carpet, wallboard, and ceiling tile) spiked with <i>G. stearothermophilus</i> tested with an autoclave at various packing arrangements.	Autoclave cycles consisting of 120 min at 31.5 lb/in ² and 275 °F and 75 min at 45 lb/in ² and 292 °F effectively decontaminated the BDR material. The most effective spore destruction was obtained with a loose packing arrangement, dry BDR material, a higher autoclave operating pressure and higher temperature, multiple autoclave cycles performed in sequence, and bags cut open prior to loading.	Lemieux et al., 2006a
Landfill Flare		
Bench tests with N ₂ and CH ₄ were used to simulate landfill gas with combustion air at 870 to 1,037 °C with aerosolized <i>G. stearothermophilus</i> and <i>B. atrophaeus</i> .	At a 0.2 and 0.6 second residence times, all spores were inactivated in the flare.	Tufts and Rosati, 2012
Direct Heat Application		
F-value determination for <i>G. stearothermophilus</i> , <i>B. atrophaeus</i> , and <i>B. anthracis</i> .	The F-value at 200 °C for <i>G. stearothermophilus</i> and <i>B. atrophaeus</i> is 1.3 and 1.1 min. The F-value is 1.2 min for <i>B. anthracis</i> . Dry heat oven tests were conducted at 175 °C, the D-values were 0.4, 0.2 and 0.3 min for <i>B. atrophaeus</i> , <i>B. anthracis</i> (Sterne), and <i>G. stearothermophilus</i> , respectively	Wood et al., 2010
Z-value determination for <i>B. subtilis</i> spiked on wet ceiling tile and wallboard.	The Z values for <i>B. subtilis</i> spiked on wet ceiling tile and wallboard were 159 and 281 K, respectively	Denison et al., 2005
A thermal electric heating system in continuous air flow with <i>E. coli</i> and <i>B. subtilis</i> bioaerosols.	<i>E. coli</i> and <i>B. subtilis</i> bioaerosols were rendered more than 99.9% inactive at 160 °C and 350 °C wall temperature of the quartz tube.	Jung et al., 2009
SCWO and Bioremediation of Hydrolysate		
VX hydrolysate treated with SCWO with air at temperatures to 600 to 650 °C under about 275 bar pressure about 30 seconds.	The organic (about 99.99 %) was oxidized to water and sodium salts as well as gaseous nitrogen.	Pearson and Magee, 2002
MPA, a VX hydrolysate simulant treated with SCWO.	Greater than 99% DRE of MPA was achieved at a temperature of 550 °C, pressure of 27.6 MPa, oxygen concentration of 200% stoichiometric requirements, and reactor residence times of less than 20 s.	Bianchetta et al., 1999
Bioremediation of TDG (hydrolysate of sulfur mustard) with Strain T09 bacteria in an aqueous solution with at 30 °C.	70 h required to degrade TDG with Strain T09.	Bassi et al., 2009
Immobilized Cell Bioreactor to treat TDG mustard hydrolysate.	The effluent concentration from the bioreactor was below detection for much of the test with 5 days of HRT and 120-200 days of SRT.	Nurdogan et al., 2012

Appendix B
Compiled References Worksheet
(Excel Attachment)

Document Type Legend

- A Technical Report, U.S. Government
- B Technical Report, Contractor for U.S. Government
- C Translated Foreign-Language Document
- D Translated Foreign-Language Abstract
- E Untranslated Foreign-Language Document
- F Untranslated Foreign-Language Abstract
- G Peer-Reviewed English Language Literature, post-1975
- H Peer-Reviewed English Language Literature, 1925-1975
- I Peer-Reviewed English Language Literature, pre-1925
- J Government Website, with citations
- K Government Website, without citations
- L Non-Government Website, with citations
- M Non-Government Website, without citations
- N Book Chapter or Book, with peer-review and/or editorial oversight
- O Book Chapter or Book, no peer-review nor editorial oversight
- P Book Chapter or Book, peer review and editorial oversight unknown
- Q Patent (United States)
- R Patent (International)
- S Thesis/Dissertation
- T News Article
- U Other
- V Analysis Pending

Search Terms

Chemical or biological agents	Cremation	Environmental impact	Hydrolysate
Thermal destruction	Warfare agents	Risk	Incineration
	Remains	Warfare agents	Warfare agents
Chemical or biological agents		Destruction	
Destruction			
		Biosafety	
Chemical or biological agents		Warfare agents	
Incineration		Destruction	
Chemical or biological agents		Incinerator	
Autoclave		Emissions	
		Warfare agents	
Destruction or Decomposition or Incineration			
Thermal or Heating or (Hot (w) (Temperature or Air))		aerosol containment	
Chemical or Biological Agent		warfare agents	
Anthracis or Anthrax or Stearothermophilus		incineration	
HD or Mustard			
Building or Soil or Carpet or (Ceiling (w) Tile)			
Concrete or Asphalt			

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
A	High	43	NA	Y	Thermal Destruction of <i>Bacillus Anthracis</i> Surrogates in a Pilot-Scale Incinerator	The decontamination of a building following a biological warfare agent (such as <i>Bacillus anthracis</i>) release may result in a significant quantity of building decontamination residue (BDR). This BDR would consist of various materials such as ceiling tile, carpet, wallboard, concrete, and wood, which would be removed from the building either before or after decontamination efforts. Although the BDR is likely to have been decontaminated, the possibility exists for the presence of trace amounts of biological agent. Although a likely disposal technique for the BDR is high temperature incineration, complete destruction of microbiological organisms in an incinerator environment is not a certainty, due to heat transfer limitations and matrix effects. This paper describes experiments that were performed in a pilot-scale rotary kiln incinerator to evaluate the thermal destruction of <i>B. anthracis</i> surrogates (bacterial spores) present within bundles of carpeting and ceiling tile. Another purpose of the experiments was to evaluate sampling and analytical techniques to measure spores in the exhaust gas and material bundles. No spores were detected via any of the three sampling trains in the exhaust gas for the carpet burn tests conducted in July and August 2005, although the detection limit was determined to be 22 spores/dry standard ft ³ . Combustion of the nylon-6 carpet resulted in increased nitrogen oxide (NOx) emissions, with short-term spikes in emissions levels from approximately 30 ppm baseline to roughly 150 ppm with each carpet bundle charged. The use of biological indicator strips to quantify thermal destruction of spores embedded within carpet and ceiling tile bundles was successful. Spores embedded within wet ceiling tile bundles took at least 35 minutes to completely destroy, possibly exceeding typical incinerator solid waste residence times. The absence of viable spores from residues of spore-forming bacteria was not confirmed.	Pilot-scale rotary kiln incinerator.	Building decontamination residue (BDR), <i>B. anthracis</i> surrogates (bacterial spores) present within bundles of carpeting and ceiling tile.	Thermal Destruction of <i>Bacillus Anthracis</i> Surrogates in a Pilot-Scale Incinerator	Google Scholar		chemical or biological agents, destruction
U	High	43	2005	Y	Thermal Destruction of CB Contaminants Bound on Building Materials: Experiments and Modeling	An experimental and theoretical program has been initiated by the U.S. EPA to investigate issues of chemical/biological agent destruction in incineration systems when the agent in question is bound on common porous building interior materials. This program includes 3-dimensional computational fluid dynamics modeling with matrix-bound agent destruction kinetics, bench-scale experiments to determine agent destruction kinetics while bound on various matrices, and pilot-scale experiments to scale-up the bench-scale experiments to a more practical scale. Finally, model predictions are made to predict agent destruction and combustion conditions in two full-scale incineration systems that are typical of modern combustor design.	Chemical/biological agent destruction in incineration systems. An experimental and theoretical program.	Common porous building interior materials.	Thermal Destruction of CB Contaminants Bound on Building Materials Experiments and Modeling	Google Scholar	Conference paper.	chemical or biological agents, destruction
G	High	41	2011	Y	Destruction and Detection of Chemical Warfare Agents	NA	Overview of chemical warfare agent decontamination, ease of technology application, and compatibility with treated objects.	Contaminated objects, indoor, concrete, construction surfaces.	Destruction and Detection of Chemical Warfare Agents	Google Scholar		chemical or biological agents, thermal destruction
U	High	41	2010	Y	The Use of Experiments and Modeling to Evaluate Incineration of Chemical Warfare Agent Simulants Bound on Building Materials	In the event of a terrorist attack with chemical warfare agents (CWAs), large quantities of materials, both indoor and outdoor, may be treated by thermal incineration during the site remediation process. CWAs in general are not particularly thermally stable and decompose readily in a high temperature combustion environment. Potential difficulties exist, however, in thermally processing waste building materials from a post-CWA event site remediation due to the refractory nature of many materials found inside and outside buildings, and the potential impacts that waste packaging at the site may have on the behavior of these materials and residual agent destruction in combustion systems. This paper reports on a study to examine the thermal decomposition of surrogate CWAs (in this case, Malathion) in a laboratory reactor, analysis of the results using reactor design theory, and subsequent scale-up of the results to a computer simulation of a full-scale commercial hazardous waste incinerator processing ceiling tile contaminated with residual Malathion. The heating rates that the reactor was subjected to were based on previously determined heating rates of wet ceiling tile in a pilot-scale rotary kiln incinerator simulator, and are intended to simulate the thermal processing of building materials containing trace amounts of CWAs.	Thermal incineration.	Indoor and outdoor materials with a surrogate CWAs (in this case, Malathion) in a laboratory reactor.	The Use of Experiments and Modeling to Evaluate Incineration of Chemical Warfare Agent Simulants Bound on Building Materials	Google Scholar	IT3 Conference, San Francisco, CA	chemical or biological agents, destruction
U	High	41	2006	Y	A Decision Support Tool (DST) for Disposal of Residual Materials Resulting from National Emergencies	AFTER A BUILDING OR WATER TREATMENT/DISTRIBUTION FACILITY HAS GONE THROUGH DECONTAMINATION ACTIVITIES FOLLOWING A CONTAMINATION EVENT WITH CHEMICAL/BIOLOGICAL WARFARE AGENTS OR TOXIC INDUSTRIAL CHEMICAL, THERE WILL BE A SIGNIFICANT AMOUNT OF RESIDUAL MATERIAL AND WASTE TO BE DISPOSED. A CONTAMINATION EVENT COULD OCCUR FROM TERRORIST ACTIVITY OR FROM A NATURAL DISASTER SUCH AS THE RECENT HURRICANE EVENTS IN THE GULF COAST WHERE MOLD AND POLLUTANTS FROM DAMAGED CHEMICAL AND INDUSTRIAL FACILITIES HAVE RESULTED IN SIGNIFICANT QUANTITIES OF CONTAMINATED MATERIALS. IT IS LIKELY THAT MUCH OF THIS MATERIAL WILL BE DISPOSED OF IN PERMITTED LANDFILLS OR HIGH TEMPERATURE THERMAL INCINERATION FACILITIES. DATA HAS BEEN COLLECTED FROM THE OPEN LITERATURE, FROM STATE AND FEDERAL REGULATORY AGENCIES, AND FROM WASTE MANAGEMENT AND WATER UTILITY INDUSTRY STAKEHOLDER GROUPS, TO DEVELOP TECHNICAL GUIDANCE FOR DISPOSAL OF THESE RESIDUES. THE INFORMATION BECOMES AVAILABLE, AND OLD INFORMATION (SUCH AS CONTACT INFORMATION FOR KEY PERSONNEL) CHANGES. THE PRIMARY AUDIENCE FOR THIS TOOL WILL BE: 1) EMERGENCY RESPONSE AUTHORITIES WHO HAVE TO DECIDE THE MOST APPROPRIATE DECONTAMINATION METHODS AND DISPOSAL OF THE RESULTING RESIDUES; 2) STATE AND LOCAL PERMITTING AGENCIES, WHO HAVE TO MAKE DECISIONS ABOUT WHICH FACILITIES WILL BE ALLOWED TO DISPOSE OF THE MATERIALS; AND 3) THE WASTE MANAGEMENT AND WATER UTILITY INDUSTRY, THAT NEEDS TO SAFELY DISPOSE OF DECONTAMINATION RESIDUES WITHOUT AFFECTING THE OPERATION OF THEIR FACILITIES AND MATERIALS PLANT AND RELEVANT ENVIRONMENTAL FEATURES.	DATA HAS BEEN COLLECTED FROM THE OPEN LITERATURE, FROM STATE AND FEDERAL REGULATORY AGENCIES, AND FROM WASTE MANAGEMENT AND WATER UTILITY INDUSTRY STAKEHOLDER GROUPS, TO DEVELOP TECHNICAL GUIDANCE FOR DISPOSAL OF THESE RESIDUES.	CONTAMINATED MATERIALS.	A DECISION_SUPPORT_TOOL_FOR_DISP_OSAF_OF_RESIDUAL_BUILDING_MATERIALS	Google Scholar	Conference paper.	chemical or biological agents, thermal destruction
G	High	41	2006	Y	Destruction of Spores on Building Decontamination Residue in a Commercial Autoclave	The U.S. Environmental Protection Agency conducted an experiment to evaluate the effectiveness of a commercial autoclave for treating simulated building decontamination residue (BDR). The BDR was intended to simulate porous materials removed from a building deliberately contaminated with biological agents such as <i>Bacillus anthracis</i> (anthrax) in a terrorist attack. The purpose of the tests was to assess whether the standard operating procedure for a commercial autoclave provided sufficiently robust conditions to adequately destroy bacterial spores bound to the BDR. In this study we investigated the effects of several variables related to autoclaving BDR, including time, temperature, pressure, item type, moisture content, packing density, packing orientation, autoclave bag integrity, and autoclave process sequence. The test team created simulated BDR from wallboard, ceiling tiles, carpet, and upholstered furniture, and embedded in the BDR were <i>Geobacillus stearothermophilus</i> biological indicator (BI) strips containing 106 spores and thermocouples to obtain time and temperature profile data associated with each BI strip. The results indicated that a single standard autoclave cycle did not effectively decontaminate the BDR. Autoclave cycles consisting of 120 min at 31.5 lb/in ² and 275°F and 75 min at 45 lb/in ² and 292°F effectively decontaminated the BDR material. Two sequential standard autoclave cycles consisting of 40 min at 31.5 lb/in ² and 275°F proved to be particularly effective, probably because the second cycle's evacuation step pulled the condensed water out of the pores of the materials, allowing better steam penetration. The results also indicated that the packing density and material type of the BDR in the autoclave could have a significant impact on the effectiveness of the decontamination process.	Commercial autoclaves.	Simulated building decontamination residue (BDR). The BDR was intended to simulate porous materials removed from a building deliberately contaminated with biological agents such as <i>Bacillus anthracis</i> (anthrax) in a terrorist attack.	Destruction of Spores on Building Decontamination Residue in Commercial Autoclave	Google Scholar		chemical or biological agents, thermal destruction
U	High	41	2005	Y	U.S. EPA R&D Program for Disposal of Building Decontamination Residue	In the event of a terrorist attack on buildings, transportation hubs, or other structures where chemical or biological agents are used, significant quantities of building decontamination residue (BDR) can be generated during cleanup and restoration activities. This BDR primarily consists of porous materials formerly contained within the building, and although it has undergone decontamination, current sampling limitations prevent assurances that no remaining traces of the contamination agent is present in the BDR. In addition, the BDR could contain residual decontamination chemicals and decomposition by-products from the contaminating agent. The completion of the restoration process requires that the BDR be disposed. Likely disposal options include high temperature thermal incineration, landfilling, and steam autoclaving. This paper describes EPA's current program to 1. consolidate available information and lessons learned for building decontamination residue disposal into technical guidance for responders, permitting agencies, and the disposal industry; and 2. perform experimental research to help close existing data gaps.	This paper describes EPA's current program to 1. consolidate available information and lessons learned for building decontamination residue disposal into technical guidance for responders, permitting agencies, and the disposal industry; and 2. perform experimental research to help close existing data gaps.	Building decontamination residue (BDR).	U_S_EPA_R_D_PROG_RAM_FOR DISPOSAL_OF_BUILD_DECON_RESIDUE_LEMIEUX_SYM_PAPER	Google Scholar	Conference paper.	chemical or biological agents, thermal destruction
G	High	41	2000	Y	The Chemistry of the Destruction of Organophosphorus Compounds in Flames III: The Destruction of DMMP and TMP in a Flame of Hydrogen and Oxygen	The structure of a premixed H ₂ /O ₂ /Ar (0.26/0.13/0.61 by volume) flame doped with dimethyl methyl phosphonate (DMMP) stabilized on a flat burner at 47 Torr has been studied by molecular-beam mass spectrometry and modeling. Using previous experimental measurements, the mechanism for the destruction of trimethyl phosphate (TMP) in H ₂ /O ₂ /Ar flames was refined. The present experiments with Warowski's reaction mechanism for hydrogen, oxygen, and phosphorus and Werner and Cool's mechanism for the destruction of DMMP, enabled updated kinetic mechanisms for the destruction of both DMMP and TMP in a flame to be developed. Based on the available thermochemical data and using the computer codes PREMIX and CHEMKIN-II, the computer modeling of the destruction of DMMP and TMP in a flame was achieved. Matching the experimental and calculated concentration profiles for all the species found in flames allowed the rate constants for the reactions of intermediates to be evaluated and refined. The final result is that the calculated and measured concentration profiles are in satisfactory agreement for DMMP, TMP, H ₂ , O ₂ , H ₂ O, OH, O, H, PO, PO ₂ , HPO, and HPO ₂ . The results provide an understanding of important regularities of the destruction of organophosphorus compounds, used here as simulants of sarin in flames.	H ₂ /O ₂ /Ar (0.26/0.13/0.61 by volume) flame.	Dimethyl methyl phosphonate (DMMP) and trimethyl phosphate (TMP) in H ₂ /O ₂ /Ar flames.	The Chemistry of the Destruction of Organophosphorus Compounds in Flames III: The Destruction of DMMP and TMP in a Flame of Hydrogen and Oxygen	Google Scholar		chemical or biological agents, thermal destruction

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
	High	40	2012	Y	Thermal Inactivation of <i>Bacillus anthracis</i> Spores in a Bench-Scale Enclosed Landfill Gas Flare	A bench-scale landfill flare system was designed and built to test the potential for landfilled biological spores that migrate from the waste into the landfill gas to pass through the flare and exit into the environment as viable. The residence times and temperatures of the flare were characterized and compared to full-scale systems. <i>Geobacillus stearothermophilus</i> and <i>Bacillus atrophaeus</i> , nonpathogenic spores that may serve as surrogates for <i>Bacillus anthracis</i> , the causative agent for anthrax, were investigated to determine whether these organisms would be inactivated or remain viable after passing through a simulated landfill flare. High concentration spore solutions were aerosolized, dried, and sent through a bench-scale system to simulate the fate of biological weapons (BW) grade spores in a landfill gas flare. Sampling was conducted downstream of the flare using a bioaerosol collection device containing sterile white mineral oil. The samples were cultured, incubated for seven days, and assessed for viability. Results showed that the bench-scale system exhibited good similarity to the real-world conditions of an enclosed standard combustor flare stack with a single orifice, forced-draft diffusion burner. All spores of <i>G. stearothermophilus</i> and <i>B. atrophaeus</i> were inactivated in the flare, indicating that spores that become re-entrained in landfill gas may not escape the landfill as viable, apparently becoming completely inactivated as they exit through a landfill flare.	Simulated landfill flare.	<i>Geobacillus stearothermophilus</i> and <i>Bacillus atrophaeus</i> , nonpathogenic spores that may serve as surrogates for <i>Bacillus anthracis</i> , the causative agent for anthrax, were investigated to determine whether these organisms would be inactivated or remain viable after passing through a simulated landfill flare.	Google Scholar		chemical or biological agents, thermal destruction	
G	High	40	2011	Y	A Systematic Methodology for Selecting Decontamination Strategies Following a Biocontamination Event	Decontamination and recovery of a facility or outdoor area after a wide-area biological incident involving a highly persistent agent (eg. <i>Bacillus anthracis</i> spores) is a complex process that requires extensive information and significant resources, which are likely to be limited, particularly if multiple facilities or areas are affected. This article proposes a systematic methodology for evaluating information to select the decontamination or alternative treatments that optimize use of resources if decontamination is required for the facility or area. The methodology covers a wide range of approaches, including volumetric and surface decontamination, monitored natural attenuation, and seal and abandon strategies. A proposed trade-off analysis can help decision makers understand the relative appropriateness, efficacy, and labor, skill, and cost requirements of the various decontamination methods for the particular facility or area needing treatment—whether alone or as part of a larger decontamination effort. Because the state of decontamination knowledge and technology continues to evolve rapidly, the methodology presented here is designed to accommodate new strategies and materials and changing information.	The methodology covers a wide range of approaches, including volumetric and surface decontamination, monitored natural attenuation, and seal and abandon strategies.	A facility or outdoor area after a wide-area biological incident.	A systematic methodology for selecting decontamination strategies following a biocontamination event	Google Scholar		chemical or biological agents, thermal destruction
B	High	40	2009	Y	Decontamination Strategy for Large Area and/or Equipment Contaminated with Chemical and Biological Agents using a High Energy Arc Lamp (HEAL)	A strategy for the decontamination of large areas and/or equipment contaminated with Biological Warfare Agents (BWAs) and Chemical Warfare Agents (CWAs) was demonstrated using a High Energy Arc Lamp (HEAL) photolysis system. This strategy offers an alternative that is potentially quicker, less hazardous, generates far less waste, and is easier to deploy than those currently fielded by the Chemical and Defense (CD). For example, for large frame aircraft the United States Air Force still relies on the combination of weathering (stand alone in environment), air washing (fly aircraft) and finally washing the aircraft with Hot Soapy Water (HSW) in an attempt to remove any remaining contamination. This method is laborious, time consuming (upwards of 12+ hours not including decontamination site preparation), and requires large amounts of water (e.g., 1,600+ gallons for a single large frame aircraft), and generates large amounts of hazardous waste requiring disposal. The efficacy of the HEAL system was demonstrated using diisopropyl methyl phosphonate (DIMP) a G series CWA simulant, and <i>Bacillus globigii</i> (BG) a simulant of <i>Bacillus anthracis</i> . Experiments were designed to simulate the energy flux of a field deployable lamp system that could stand-off 17 meters from a 22m ² target area and uniformly expose a surface at 1,360 W/m ² . The HEAL system in the absence of a catalyst reduced the amount of <i>B. globigii</i> by five orders of magnitude at a starting concentration of 1.63 x 10 ⁷ spores. In the case of CWA simulants, the HEAL system in the presence of the catalyst TiO ₂ effectively deradated DIMP sprayed onto a 100 mm diameter Petri dish in 5 minutes.	High Energy Arc Lamp (HEAL) photolysis system.	The efficacy of the HEAL system was demonstrated using diisopropyl methyl phosphonate (DIMP) a G series CWA simulant, and <i>Bacillus globigii</i> (BG) a simulant of <i>Bacillus anthracis</i> .	Decontamination Strategy for Large Area and/or Equipment Contaminated with Chemical and Biological Agents using a High Energy Arc Lamp HEAL	Google Scholar		chemical or biological agents, thermal destruction
G	High	40	2009	Y	Dry Thermal Resistance of <i>Bacillus anthracis</i> (Sterne) Spores and Spores of Other <i>Bacillus</i> Species: Implications for Biological Agent Destruction via Waste Incineration	Methods and Results: Tests were conducted in a pilot-scale incinerator utilizing biological indicators comprised of spores of <i>Geobacillus stearothermophilus</i> , <i>Bacillus atrophaeus</i> and <i>B. anthracis</i> (Sterne) and embedded in building material bundles. Tests were also conducted in a dry heat oven to determine the destruction kinetics for the same species. In the pilot-scale incinerator tests, <i>B. atrophaeus</i> and <i>G. stearothermophilus</i> demonstrated similar thermal sensitivity, but <i>B. anthracis</i> (Sterne) was less thermally resistant than <i>G. stearothermophilus</i> . For the dry heat oven tests conducted at 175 °C, the D-values were D=4, D=2 and D=3 min for <i>B. atrophaeus</i> , <i>B. anthracis</i> (Sterne) and <i>G. stearothermophilus</i> , respectively. Conclusions: <i>Bacillus anthracis</i> (Sterne) possesses similar or less dry heat resistance compared to <i>B. atrophaeus</i> and <i>G. stearothermophilus</i> . Significance and Impact of the Study: Previous studies have demonstrated conditions under which bacterial spores may survive in an incinerator environment. The data from this study may assist in the selection of surrogates or indicator micro-organisms to ensure <i>B. anthracis</i> spores embedded in building materials are completely inactivated in an incinerator.	Pilot-scale incinerator utilizing biological indicators comprised of spores of <i>Geobacillus stearothermophilus</i> , <i>Bacillus atrophaeus</i> and <i>B. anthracis</i> (Sterne)	Building material bundles.	Dry thermal resistance of <i>Bacillus anthracis</i> (Sterne) spores and spores of other <i>Bacillus</i> species implications for biological agent destruction via waste incineration	Google Scholar		chemical or biological agents, thermal destruction
U	High	40	2008	N	Large-Area Chemical and Biological Decontamination Using a High Energy Arc Lamp (HEAL) System	Methods for quickly decontaminating large areas exposed to chemical and biological (CB) warfare agents can present significant logistical, manpower, and waste management challenges. Oak Ridge National Laboratory (ORNL) is pursuing an alternate method to decompose CB agents without the use of toxic chemicals or other potentially harmful substances. This process uses a high energy arc lamp (HEAL) system to photochemically decompose CB agents over large areas (12 m ²). Preliminary tests indicate that more than 5 decades (99.999%) of an Anthrax spore simulant (<i>Bacillus globigii</i>) were killed in less than 7 seconds of exposure to the HEAL system. When combined with a catalyst material (TiO ₂) the HEAL system was also effective against a chemical agent simulant, diisopropyl methyl phosphonate (DIMP). These results demonstrate the feasibility of a rapid, large-area chemical and biological decontamination method that does not require toxic or corrosive reagents or generate hazardous wastes.	High energy arc lamp (HEAL) system to photochemically decompose CB agents.	Rapid, large-area chemical and biological decontamination method (12 m ²).	NA	Google Scholar	Conference paper.	chemical or biological agents, destruction
G	High	40	2008	Y	Pilot-Scale Experimental and Theoretical Investigations into the Thermal Destruction of a <i>Bacillus anthracis</i> Surrogate Embedded in Building Decontamination Residue Bundles	<i>Bacillus anthracis</i> (<i>B. anthracis</i>) spores were released through the U.S. mail system in 2001, highlighting the need to develop efficacious methods of decontaminating and disposing of materials contaminated with biological agents. Incineration of building decontamination residue is a disposal option for such material, although the complete inactivation of bacterial spores via this technique is not a certainty. Tests revealed that under some circumstances, <i>Geobacillus stearothermophilus</i> (<i>G. stearothermophilus</i> ; a surrogate for <i>B. anthracis</i>) spores embedded in building materials remained active after 35 min in a pilot-scale incinerator and survived with internal material bundle temperatures reaching over 500 °C. A model was also developed to predict survival of a bacterial spore population undergoing thermal treatment in an incinerator using the thermal destruction kinetic parameters obtained in a laboratory setting. The results of the pilot-scale incinerator experiments are compared to model predictions to assess the accuracy of the model.	Pilot-scale incinerator.	Building decontamination residue.	Pilot-Scale Experimental and Theoretical Investigations into the Thermal Destruction of a <i>Bacillus anthracis</i> Surrogate Embedded in Building Decontamination Residue Bundles	Google Scholar		chemical or biological agents, destruction
G	High	40	2005	Y	Decontamination Assessment of <i>Bacillus anthracis</i> , <i>Bacillus subtilis</i> , and <i>Geobacillus stearothermophilus</i> Spores on Indoor Surfaces Using a Hydrogen Peroxide Gas Generator	Aims: To evaluate the decontamination of <i>Bacillus anthracis</i> , <i>Bacillus subtilis</i> , and <i>Geobacillus stearothermophilus</i> spores on indoor surface materials using hydrogen peroxide gas. Methods and Results: <i>Bacillus anthracis</i> , <i>B. subtilis</i> , and <i>G. stearothermophilus</i> spores were dried on seven types of indoor surfaces and exposed to 1,000 ppm hydrogen peroxide gas for 20 min. Hydrogen peroxide exposure significantly decreased viable <i>B. anthracis</i> , <i>B. subtilis</i> , and <i>G. stearothermophilus</i> spores on all test materials except <i>G. stearothermophilus</i> on industrial carpet. Significant differences were observed when comparing the reduction in viable spores of <i>B. anthracis</i> with both surrogates. The effectiveness of gaseous hydrogen peroxide on the growth of biological indicators and spore strips was evaluated in parallel as a qualitative assessment of decontamination. At 1 and 7 days postexposure, decontaminated biological indicators and spore strips exhibited no growth, while the nondcontaminated samples displayed growth. Conclusions: Significant differences in decontamination efficacy of hydrogen peroxide gas on porous and nonporous surfaces were observed when comparing the mean log reduction in <i>B. anthracis</i> spores with <i>B. subtilis</i> and <i>G. stearothermophilus</i> spores. Significance and Impact of the Study: These results provide comparative information for the decontamination of <i>B. anthracis</i> spores with surrogates on indoor surfaces using hydrogen peroxide gas.	Hydrogen peroxide gas.	<i>Bacillus anthracis</i> , <i>B. subtilis</i> , and <i>G. stearothermophilus</i> spores were dried on seven types of indoor surfaces and exposed to 1,000 ppm hydrogen peroxide gas for 20 min.	Decontamination assessment of <i>Bacillus anthracis</i> , <i>Bacillus subtilis</i> , and <i>Geobacillus stearothermophilus</i> spores on indoor surfaces using a hydrogen peroxide gas generator	Google Scholar		chemical or biological agents, thermal destruction
U	High	40	2004	Y	Destruction Efficiency of Microbiological Organisms in Medical Waste Incinerators: A Review of Available Data	After a building has undergone a terrorist attack using a biological weapon such as <i>B. anthracis</i> , many of the interior building materials will need to be disposed. Although it is likely that these materials will be decontaminated prior to their removal, officials may decide to remove the potentially bio-contaminated materials without first fumigating them. In either scenario, the possibility exists that some of the building materials will retain viable contaminating agent spores. Incineration may be the best option for the disposal of such building materials to completely destroy all potentially remaining bio-contaminants. In the early 1990s, the US Environmental Protection Agency (EPA) conducted microbial survivability tests at several medical waste incinerators (MWIs); these data have now been examined to evaluate microbiological destruction performance. Microorganisms were spiked into the waste feed and in test pipes, and subsequently analyzed for viability in the emissions, residue, and pipes using EPA conditional test methods. The results showed that for the most of the test runs, at least a five log reduction of the spores was achieved, although viable spores were detected in 10 out of a total of 48 air emission test runs, and spores were detected in 10 out of 27 available ash samples.	Medical waste incinerators (MWIs).	Microorganisms were spiked into the waste feed and in test pipes.	DESTRUCTION EFFICIENCY OF MICROBIOLOGICAL ORGANISMS IN MEDICAL WASTE INCINERATORS - REVIEW OF AVAILABLE DATA	Google Scholar	Conference paper.	chemical or biological agents, thermal destruction

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
B	High	40	2003	Y	Verification of Formaldehyde Vapor Technologies for Decontaminating Indoor Surfaces Contaminated with Biological or Chemical Agents	To support the Nation's Homeland Security Program, this U.S. Environmental Protection Agency (EPA) Environmental Technology Verification (ETV) project is conducted to verify the performance of commercially available products, methods, and equipment for decontamination of hard and porous indoor surfaces contaminated with biological or chemical warfare agents. Due to the continuing threat of additional sudden and unexpected chemical and biological terrorist attacks, the Agency first responders and building decontamination teams must be prepared to rapidly mitigate harm to the public and the environment. The main targets of future terrorist attacks include public- and private-sector buildings that house the Nation's workforce and business activities. To fulfill the responsibility for protecting human health and the environment from accidental and intentional releases of hazardous and toxic materials, the Agency must identify and evaluate the tools for decontaminating surfaces on a variety of matrices including hard and porous indoor surfaces. A Blanket Purchase Agreement was established with Battelle to conduct laboratory-scale efficacy tests to evaluate the performance of technologies that can potentially decontaminate large surfaces and hard-to-reach corners and crack-and-crevices. The first phase tests include fumigation technologies such as hydrogen peroxide vapor, chlorine dioxide gas, and formaldehyde gas. An ETV report will be issued for each technology tested.	Fumigation technologies such as hydrogen peroxide vapor, chlorine dioxide gas, and formaldehyde gas.	Hard and porous indoor surfaces.	Test QA Plan for Verification of Formaldehyde Vapor Technologies for Decontaminating Indoor Surfaces Contaminated with Biological or Chemical Agents	Google Scholar	Test/Quality Assurance Plan	chemical or biological agents, thermal destruction
G	High	39	2010	Y	Inactivation of Bacteria and Fungus Aerosols Using Microwave Irradiation	This study investigated the survival of both lab-generated and environmental bioaerosols when exposed to the microwave irradiation (2,450 MHz) for 2 min at different output powers (700, 385 and 119 W). Control and exposed bioaerosols were collected by a BioSampler or a mixed cellulose ester (MCE) filter, and the air samples were further cultured. As a comparison, liquid-borne exposure for one species was also conducted. Environmental scanning electron microscope (ESEM) and transmission electron microscope (TEM) were used to study the membrane surface morphologies and intracellular components of the microwave-treated and untreated microbes. The survival rates of airborne <i>Bacillus subtilis</i> var <i>niger</i> spores were shown to be about 35%, 44% and 35% when exposed to the microwave irradiation for 1.5 min with high, medium and low power applied, respectively (p-value=0.37). In contrast, the airborne <i>Pseudomonas fluorescens</i> were shown to have lower survival rates of 5.8%, 12.2% and 21% (p-value=0.0045). Similar patterns but higher survival rates at respective powers were observed for airborne <i>Aspergillus versicolor</i> exposure (p-value 0.0001). For environmental bacterial and fungal bioaerosols, 30–40% of them were shown to survive the high power microwave irradiation for 1.7 min. Outdoor bioaerosols were shown to have stronger survival than the indoor bioaerosols when exposed to the microwave irradiation. ESEM and TEM images showed visible damages to the microwave-irradiated microbes. The results obtained here can be used to develop microwave-based air sterilization technologies especially targeted for biological aerosols.	Microwave irradiation (2,450 MHz).	Lab-generated and environmental bioaerosols.	Inactivation of bacteria and fungus aerosols using microwave irradiation	Google Scholar		chemical or biological agents, destruction
G	High	38	2002	Y	Oxidative Decontamination of Chemical and Biological Warfare Agents Using L-Gel	A decontamination method has been developed using a single reagent that is effective both against chemical warfare (CW) and biological warfare (BW) agents. The reagent, "L-Gel", consists of an aqueous solution of a mild commercial oxidizer, Oxone™, together with a commercial fumed silica gelling agent, Cab-O-Sil EH-5. L-Gel is non-toxic, environmentally friendly, relatively non-corrosive, maximizes contact time because of its thixotropic nature, clings to walls and ceilings, and does not harm carpets or painted surfaces. The new reagent also addresses the most demanding requirements for decontamination in the civilian sector, including availability, low maintenance, ease of application and deployment by a variety of dispersal mechanisms, minimal training and acceptable expense. Experiments to test the effectiveness of L-Gel were conducted at Lawrence Livermore National Laboratory and independently at four other locations. L-Gel was tested against all classes of chemical warfare agents and against various biological warfare agent surrogates, including spore-forming bacteria and non-virulent strains of real biological agents. Testing showed that L-Gel is as effective against chemical agents and biological materials, including:	L-Gel consists of an aqueous solution of a mild commercial oxidizer, Oxone™, together with a commercial fumed silica gelling agent, Cab-O-Sil EH-5.	Walls and ceilings, carpets or painted surfaces.	Oxidative decontamination of chemical and biological warfare agents using L-Gel	Google Scholar		chemical or biological agents, destruction
A	High	38	1992	Y	Decontamination of Chemical Agent Contaminated Structures and Equipment	Operations involving chemical agents such as manufacture, loading, storage, and demilitarization have resulted in the contamination of buildings and a wide variety of processing equipment. The contamination has been caused by a number of chemical agents with the most persistent being mustard. Materials that are contaminated include concrete (in floors and walls), metals (in piping, and process equipment), and wood. All of these materials exist in both painted and unpainted forms. Many of the contaminated facilities have potential reuses or monetary value as excess property if they can be properly decontaminated. Much of the contaminated process equipment also has monetary value as scrap material if properly decontaminated. Currently this value cannot be realized since the only acceptable decontamination method involves destruction and incineration of the contaminated material. Past efforts at resolving this situation have identified some "5c" concepts which could be utilized with few having been evaluated under laboratory conditions. These concepts include thermal, abrasive, chemical, and extractive removal schemes. Each of these technologies was evaluated based on destruction efficiency, mass transfer, safety, damage to existing materials, penetration depth, applicability to complex surfaces, cost, and waste management. Based on these comparisons hot gas technology was identified as the most suitable methodology. Currently a full scale demonstration is in the design phase for implementation at Rocky Mountain Arsenal. The chosen site was originally contaminated with mustard and mustard degradation by-products from past demilitarization activities. The building contains concrete approximately eighteen inches thick, large metal storage tanks, process piping, motors, and pumps.	Flashblast, microwave heating, solvent soak/burn, burning, contact heating, infrared heating, flaming, hot plasma, hot gases, CO2 laser	concrete, metals, wood	Decontamination of Chemical Agent Contaminated Structures and Equipment.pdf	DTIC		chemical or biological agents, thermal destruction
G	High	37	2011	N	Efficacy of Liquid and Foam Decontamination Technologies for Chemical Warfare Agents on Indoor Surfaces	Bench-scale testing was used to evaluate the efficacy of four decontamination formulations on typical indoor surfaces following exposure to the liquid chemical warfare agents sarin (GB), soman (GD), sulfur mustard (HD), and VX. Residual surface contamination on coupons was periodically measured for up to 24h after applying one of four selected decontamination technologies (0.5% bleach solution with trisodium phosphate, Allen Vanguard Surface Decontamination Foam (SDF™), U.S. military Decon Green™, and Modex Inc. and EnviroFoam Technologies Sandia Decontamination Foam (DF-200)). All decontamination technologies tested, except for the bleach solution, performed well on nonporous and nonpermeable glass and stainless-steel surfaces. However, chemical agent residual contamination typically remained on porous and permeable surfaces, especially for the more persistent agents, HD and VX. Solvent-based Decon Green™ performed better than aqueous-based bleach or foams on polymeric surfaces, possibly because the solvent is able to penetrate the polymer matrix. Bleach and foams outperformed Decon Green for penetrating the highly porous concrete surface. Results suggest that the different characteristics needed for an ideal and universal decontamination technology may be incompatible in a single formulation and a strategy for decontaminating a complex facility will require a range of technologies.	Chemical agents, 0.5% bleach solution with trisodium phosphate, Allen Vanguard Surface Decontamination Foam (SDF™), U.S. military Decon Green™, and Modex Inc. and EnviroFoam Technologies Sandia Decontamination Foam (DF-200).	Typical indoor surfaces.	NA	Google Scholar		chemical or biological agents, destruction
G	High	37	2007	N	Decontamination of VX, GD, and HD on a Surface Using Modified Vaporized Hydrogen Peroxide	Vaporized hydrogen peroxide (VHP) has proven efficacy for biological decontamination and is a common gaseous sterilant widely used by industry. Regarding chemical warfare agent decontamination, VHP is also effective against HD and VX, but not GD. Simple addition of ammonia gas to VHP affords reactivity toward GD, while maintaining efficacy for HD (and bioagents) and further enhancing efficacy for VX. Thus, modified VHP is a broad-spectrum CB decontaminant suitable for fumigant-type decontamination scenarios, i.e., building, aircraft, and vehicle interiors and sensitive equipment. Finally, as an interesting aside to the current study, commercial ammonia-containing cleaners are also shown to be effective surface decontaminants for GD, but not for VX or HD.	Vaporized hydrogen peroxide (VHP).	Modified VHP is a broad-spectrum CB decontaminant suitable for fumigant-type decontamination scenarios, i.e., building, aircraft, and vehicle interiors and sensitive equipment.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	High	37	2004	Y	Determination of the Efficacy of Two Building Decontamination Strategies by Surface Sampling with Culture and Quantitative PCR Analysis	The efficacy of currently available decontamination strategies for the treatment of indoor furnishings contaminated with bioterrorism agents is poorly understood. Efficacy testing of decontamination products in a controlled environment is needed to ensure that effective methods are used to decontaminate domestic and workplace settings. An experimental room supplied with materials used in office furnishings (i.e., wood laminate, painted metal, and vinyl tile) was used with controlled dry aerosol releases of endospores of <i>Bacillus atrophaeus</i> (" <i>Bacillus subtilis</i> subsp. <i>niger</i> ", also referred to as BG), a <i>Bacillus anthracis</i> surrogate. Studies were performed using two test products, a foam decontaminant and chlorine dioxide gas. Surface samples were collected pre- and post-treatment with three sampling methods and analyzed by culture and quantitative PCR (QPCR). Additional aerosol releases with environmental background present on the surface materials were also conducted to determine if there was any interference with decontamination or sample analysis. Culture results indicated that 105 to 106 CFU per sample were present on surfaces before decontamination. After decontamination with the foam, no culturable <i>B. atrophaeus</i> spores were detected. After decontamination with chlorine dioxide gas, no culturable <i>B. atrophaeus</i> was detected in 24 of 27 samples (89%). However, QPCR analysis showed that <i>B. atrophaeus</i> DNA was still present after decontamination with both methods. Environmental background material had no apparent effect on decontamination, but inhibition of the QPCR assay was observed. These results demonstrate the effectiveness of two decontamination methods and illustrate the utility of surface sampling and QPCR analysis for the evaluation of decontamination strategies.	foam decontaminant and chlorine dioxide gas.	Domestic and workplace settings (i.e., wood laminate, painted metal, and vinyl tile) contaminated with dry aerosol releases of endospores of <i>Bacillus atrophaeus</i> (" <i>Bacillus subtilis</i> subsp. <i>niger</i> r", also referred to as BG), a <i>Bacillus anthracis</i> surrogate.	Determination of the Efficacy of Two Building Decontamination Strategies by Surface Sampling with Culture and Quantitative PCR Analysis	Google Scholar		chemical or biological agents, thermal destruction

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
G	High	37	2002	Y	Chemical Warfare Agent Decontamination Studies in the Plasma Decon Chamber	A "plasma decon chamber" has been developed at Los Alamos National Laboratory (LANL), Albuquerque, NM, to study the decontamination of chemical and biological warfare agents. This technology is targeted at sensitive electronic equipment for which there is currently no acceptable, nondestructive means of decontamination. Chemical reactivity is provided by a downstream flux of reactive radicals such as atomic oxygen and atomic hydrogen, produced in a capacitively coupled plasma. In addition, the decon chamber provides an environment that accelerates the evaporation of chemical agents from contaminated surfaces by vacuum, heat, and forced convection. Once evaporated, agents and agent byproducts are recirculated directly through the plasma where they undergo further chemical breakdown. Preliminary studies on actual chemical agents were conducted at the U.S. Army Dugway Proving Ground, Dugway, UT. Exposures were conducted at a system pressure of 30 torr, exposure temperature of 70 °C, plasma-to-sample standoff distance of 10 cm, and 10% addition of oxygen or hydrogen to a helium balance. This exposure condition was based on optimization studies conducted at LANL on agent simulants. The agents studied were VX and soman (GD) nerve agents and sulfur mustard (HD) blister agent, as well as a thickened simulant. All agents were decontaminated off aluminum substrates to below the detection limit of 0.1% of the initial contamination level of approximately 1 mg/cm ² . For VX, this level of decontamination was achieved in 8-16 min of exposure, while only 2 min were required for the more volatile HD and GD. Evaporation and subsequent gas-phase chemical breakdown in the plasma appears to be the dominant decontamination mechanism for all of the agents. However, an observed difference in the decontamination process between oxygen and hydrogen indicates that chemical reactivity in the liquid phase also plays an important role.	Plasma decon chamber.	The decon chamber provides an environment that accelerates the evaporation of chemical agents from contaminated surfaces by vacuum, heat, and forced convection. Once evaporated, agents and agent byproducts are recirculated directly through the plasma where they undergo further chemical breakdown.	Chemical Warfare Agent Decontamination Studies in the Plasma Decon Chamber	Google Scholar	chemical or biological agents, thermal destruction	
G	High	37	2000	Y	Rapid Decontamination of Large Surface Areas	The effectiveness of the decontamination of biological agents (spores) on surfaces by two thermal plasma systems is reported here. Using existing systems, operating at nonoptimum conditions, a steam plasma decontaminated surfaces at a maximum speed of 1.4 mph and a nitrogen plasma decontaminated at a maximum of 2.4 mph.	Thermal plasma systems.	Decontaminated surfaces contaminated with biological agents.	Rapid Decontamination of Large Surface Areas	Google Scholar	chemical or biological agents, thermal destruction	
G	High	36	2008	Y	CBRN Decontamination using a Large-Area Cold Plasma Applicator	The Medical community has used cold plasma for several years. A cold plasma is an ionized gas in which only a small fraction of the gas molecules are ionized, and is formed by passing an inert gas, such as argon or helium, over a sharp conductive point that is held at high voltage and high frequency. An additional benefit in the Medical application of this technology is enhanced wound healing due to the destruction of infectious microbial agents without damaging healthy tissue. By expanding the cold plasma applicator to an area of a square meter or more, a general purpose decontamination device results with uses in the destruction of biological and chemical agents, and in assisting in the removal of radiological agents, while causing minimal or no damage to the contaminated substrate material. This approach is especially useful on porous surfaces. The use of large-area low cost applicators, utilizing numerous simultaneous independent plasma emitters for CBRN decontamination applications is considered.	Cold plasma applicator.	Large areas, porous surfaces.	CBRN Decontamination using a Large-Area Cold Plasma Applicator	Google Scholar	chemical or biological agents, thermal destruction	
G	High	36	2005	N	Evaluation of Hydrogen Peroxide Vapour as a Method for the Decontamination of Surfaces Contaminated with Clostridium botulinum Spores	The aim of this study was to evaluate the efficacy of hydrogen peroxide vapour (HPV) against spores of <i>Clostridium botulinum</i> , for use as a method for decontaminating environments where this pathogen has been handled. Spores were dried onto stainless steel slides and exposed to HPV in a sealed glovebox enclosure, transferred to a quenching agent at timed intervals during the exposure period, before survivors were cultured and enumerated. D_{10} values were calculated from graphs of log10 survivors plotted against time and were found to range from 1.41 to 4.38 min. HPV was found to be effective at deactivating spores of toxigenic <i>C. botulinum</i> , non-toxicogenic <i>Clostridium spp.</i> and <i>Geobacillus stearothermophilus</i> dried onto stainless steel surfaces. HPV could be used to decontaminate cabinets and rooms where <i>C. botulinum</i> has been handled. The cycle parameters should be based on studies carried out with relevant spores of this organism, rather than based on <i>Geobacillus stearothermophilus</i> spores, which have been used in the past as a standard biological challenge for disinfection and sterilisation procedures. HPV could provide an attractive alternative to other decontamination methods, as it was rapid, residue-free and did not give rise to the health and safety concerns associated with other gaseous decontamination systems.	Hydrogen peroxide vapour (HPV).	Stainless steel surfaces, cabinets and rooms where <i>C. botulinum</i> has been handled.	NA	Google Scholar	chemical or biological agents, thermal destruction	
Q	High	36	2003	N	Portable Mail Sterilizer Which Counters Biological and Chemical Warfare Agents	A process for sterilizing mail and/or packages of biological warfare agents, which will also mineralize chemical warfare agents. A machine for sterilizing mail and/or packages of biological warfare agents, which will also mineralize chemical warfare agents, having a horizontally arranged cylindrical housing with openings provided in the sidewall through which a user can insert his hands and can view the interior of the housing, a door at one end which covers a portion of one end of the housing, a UV light source, and a photocatalytic coating. An electro-mechanical door interlock prevents the door from opening during the sterilization cycle.	Portable mail sterilizer.	A machine for sterilizing mail and/or packages of biological warfare agents, which will also mineralize chemical warfare agents.	NA	Google Scholar	chemical or biological agents, thermal destruction	
G	High	35	2014	N	Factors Influencing Recovery and Restoration Following a Chemical Incident	Chemicals are an important part of our society. A wide range of chemicals are discharged into the environment every day from residential, commercial and industrial sources. Many of these discharges do not pose a threat to public health or the environment. However, global events have shown that chemical incidents or accidents can have severe consequences on human health, the environment and society. It is important that appropriate tools and technical guidance are available to ensure that a robust and efficient approach to developing a remediation strategy is adopted. The purpose of remediation is to protect human health from future exposure and to return the affected area back to normal as soon as possible. There are a range of recovery options (techniques or methods for remediation) that are applicable to a broad range of chemicals and incidents. Recovery options should be evaluated according to their appropriateness and efficacy for removing contaminants from the environment; however economic drivers and social and political considerations often influence decision makers on which remedial actions are implemented during the recovery phase of a chemical incident. To date, there is limited information in the literature on remediation strategies and recovery options that have been implemented following a chemical incident, or how successful they have been. Additional factors that can affect the approach taken for recovery are not well assessed or understood by decision makers involved in the remediation and restoration of the environment following a chemical incident. The identification of this gap has led to the development of the UK Recovery Handbook for Chemical Incidents to provide a framework for choosing an effective recovery strategy. A compendium of practical evidence-based recovery options (techniques or methods for remediation) for inhabited areas, food production systems and water environments has also been developed and is included in the chemical handbook. This paper presents the key factors that should be considered when developing a recovery strategy with respect to how these may impact on its effectiveness. The paper also highlights the importance of these factors through an evaluation of recovery strategies implemented following real chemical incidents that have been reported in the literature.	Compendium of practical evidence-based recovery options (techniques or methods for remediation).	Inhabited areas, food production systems and water environments.	NA	Google Scholar	chemical or biological agents, thermal destruction	
G	High	35	2013	Y	Study on Plasma Agent Effect of a Direct-Current Atmospheric Pressure Oxygen-Plasma Jet on Inactivation of E. coli Using Bacterial Mutants	Biosensors of single-gene knockout mutants and physical methods using mesh and quartz glass are employed to discriminate plasma agents and assess their lethal effects generated in a Direct-Current atmospheric-pressure oxygen plasma jet. Radicals generated in plasma are determined by optical emission spectroscopy, along with the O3 density measurement by UV absorption spectroscopy. Besides, thermal effect is investigated by an infrared camera. The biosensors include three kinds of <i>Escherichia coli</i> (<i>E. coli</i>) K-12 substrains with their mutants, totalling 8 kinds of bacteria. Results show that oxidative stress plays a main role in the inactivation process. Rather than superoxide O ₂ ⁻ , neutral reactive oxygen species such as O3 and O2 (Δ g) are identified as dominant sources for oxidative stress. In addition, DNA damage caused by oxidation is found to be an important destruction mechanism.	Direct-Current atmospheric-pressure oxygen plasma jet.	Inactivation of <i>Escherichia coli</i> (<i>E. coli</i>) K-12 substrains with their mutants, totalling 8 kinds of bacteria.	Study on Plasma Agent Effect of a Direct-Current Atmospheric Pressure Oxygen-Plasma Jet on Inactivation of E. Coli Using Bacterial	Google Scholar	chemical or biological agents, thermal destruction	
G	High	35	2010	N	Thermal Inactivation of Airborne Viable Bacillus subtilis Spores by Short-Term Exposure in Axially Heated Air Flow	In this investigation, an experimental facility was developed for quantifying the inactivation of viable bioaerosol particles in a controlled axially heated air flow. The tests were conducted with <i>Bacillus subtilis</i> var. <i>niger</i> endospores. The thermal inactivation of aerosolized spores was measured based on the loss of their culturability that resulted from a short-term exposure to air temperatures ranging from ~150 to ~1,000 °C. The cross-sectional and longitudinal temperature profiles in the test chamber were determined for different heating and flow conditions. The characteristic exposure temperature (Te) was defined using a conservative approach to assessing the spore inactivation. Experimentally determined inactivation factors (IF) were corrected to account for the temperature profiles in the axially heated air flow. The reported IF-values serve as the lower approximation of the actual inactivation. Two data sets obtained at different flow rates, Q=18 and 36 L min ⁻¹ , represent different exposure conditions. In both cases, the thermal exposure of aerosolized spores produced no effect or only a moderate inactivation when the Te remained below ~200 °C for 18 L min ⁻¹ and ~250°C for 36 L min ⁻¹ . The IF-values increased exponentially by about four orders of magnitude as the temperature rose by 150 °C. Depending on the flow rate, IF exceeded ~104 at Te=320 °C (Q=18 L min ⁻¹) or >360 °C (Q=36 L min ⁻¹). At Te=375-400 °C, the spore inactivation obtained at both flow rates reached the limit of quantification established in this study protocol, which translates to approximately 99.999% viability loss. The findings were attributed primarily to the heat-induced damage of DNA and denaturation of essential proteins. Up to a certain level of the thermal exposure, these damages are repairable; however, the self-repair capability diminishes as the heat rises and then the damage becomes totally irreversible. The data generated in this study provide an important reference point for thermal inactivation of stress-resistant spores in various biodefence/counterterrorism and air quality control applications.	Axially heated air flow.	<i>Bacillus subtilis</i> var. <i>niger</i> endospores in air.	NA	Google Scholar	chemical or biological agents, thermal destruction	
U	High	35	2009	N	Dwell Time Considerations for Large Area Cold Plasma Decontamination	Atmospheric discharge cold plasmas have been shown to be effective in the reduction of pathogenic bacteria and spores and in the decontamination of simulated chemical warfare agents, without the generation of toxic or harmful by-products. Cold plasmas may also be useful in assisting cleanup of radiological "dirty bombs." For practical applications in realistic scenarios, the plasma applicator must have both a large area of coverage, and a reasonably short dwell time. However, the literature contains a wide range of reported dwell times, from a few seconds to several minutes, needed to achieve a given level of reduction. This is largely due to different experimental conditions, and especially, different methods of generating the decontaminating plasma. We consider these different approaches and attempt to draw equivalencies among them, and use this to develop requirements for a practical, field-deployable plasma decontamination system. A plasma applicator with 12 square inches area and integral high voltage, high frequency generator is described.	Atmospheric discharge cold plasmas. A plasma applicator with 12 square inches area and integral high voltage, high frequency generator is described.	Field-deployable plasma decontamination system.	NA	Google Scholar	Proceedings from SPIE: The International Society for Optical Engineering.	chemical or biological agents, thermal destruction
G	High	35	2008	N	Surface Decontamination Using Atmospheric Oxygen-Argon Plasma	This study reports on the efficacy of atmospheric oxygen-argon plasma for bio-decontamination or surface sterilization of infectious agents, such as <i>Bacillus anthracis</i> [Sterne] (Anthrax), MS-2 bacteriophage, and <i>E. coli</i> . A 10-second exposure [RF power 77 W, 29.5 mL O ₂ /min, 28 L Ar/min] on the B. a. spores revealed an average post-exposure log reduction (LR) value of 2.7, whereas a 20-second treatment yielded a log 9.9 kill. The effectiveness of the oxygen-argon plasma is believed to be attributed to the generation of free radicals, specifically highly reactive oxygen atom or hydroxyl radicals. The mechanism of radical attack of the microorganisms is	Atmospheric oxygen-argon plasma [a 10-second exposure [RF power 77 W, 29.5 mL O ₂ /min, 28 L Ar/min]].	Surface sterilization of infectious agents, such as <i>Bacillus anthracis</i> [Sterne] (Anthrax), MS-2 bacteriophage, and <i>E. coli</i> .	NA	Google Scholar	chemical or biological agents, thermal destruction	

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
G	High	35	2007	Y	Study on Photolytic and Photocatalytic Decontamination of Air Polluted by Chemical Warfare Agents (CWAs)	Photolytic and photocatalytic reactions of sarin (GB), soman (GD), sulfur mustard (HD), cyanogen chloride (CK) and perfluorobutylene (PFIB) vapors in air were carried out. It was shown that vapors of GB, GD, HD and PFIB could be efficiently eliminated by UV light from germicidal lamp through either photolysis or photocatalysis, but CK could hardly be done through photodegradation. It was demonstrated that GB, GD and HD might possibly undergo a photo-induced polymerization under UV light irradiation. Photocatalytic reaction would lead to a cleavage of these molecules into small inorganic compounds at TiO ₂ surface. The experimental results strongly suggested that both photolysis and photocatalysis of GB vapor at static conditions were kinetically slowed down and possibly limited by a low diffusion rate of GB molecule. It has been testified that the static photolysis approach could be applicable for decontamination of GB vapor in an indoor space. And that, a dynamic photocatalysis approach for decontamination of GB vapor was proved to be much more efficient than that through photolysis, and it was also considered to be feasible for decontamination of air polluted by GB vapor.	UV light from germicidal lamp through either photolysis or photocatalysis.	Sarin (GB), soman (GD), sulfur mustard (HD), cyanogen chloride (CK) and perfluorobutylene (PFIB) vapors in air were carried out.	Study on photolytic and photocatalytic decontamination of air polluted by chemical warfare agents (CWAs)	Google Scholar		chemical or biological agents, thermal destruction
G	High	35	2004	N	Effects of Chemical and Biological Warfare Remediation Agents on the Materials of Museum Objects	In the fall of 2001, anthrax-contaminated letters were sent to public figures in the United States. Chemical and radiation treatments were employed to decontaminate exposed buildings, objects, and materials. These treatments are effective, but potentially damaging to exposed objects and materials. The recommended surface chemical treatments include solutions, gels, and foams of oxidizing agents such as peroxides or chlorine bleaching agents. Such oxidizing agents are effective against a wide range of hazardous chemical and biological agents. Knowing how these reagents affect various substrates would help to anticipate and to minimize any potential damage. We are examining the effects on typical museum materials of reagents likely to be used, including hydrogen peroxide, sodium hypochlorite, and potassium permanganate. Results so far show significant changes in a number of materials. Surface corrosion was observed on metals such as copper, silver, iron, and brass. Color changes occurred with at least one reagent in about one-fourth of the dyed fabric swatches tested, and about half of the inks. Samples of aged yellowed paper are bleached. Effects varied with both the substrate and the tested reagent. The observed changes were generally less drastic than might have been expected. Enough materials were affected, though, to preclude the use of these reagents on museum objects unless no less drastic alternative is available. It appears that many objects of lesser intrinsic value can be treated without severe loss of properties or usefulness. For example, most documents should remain legible if the appropriate reagent is used. This work will provide a basis for determining which treatment is most appropriate for a specific situation and what consequences are to be expected from other treatments.	The recommended surface chemical treatments include solutions, gels, and foams of oxidizing agents such as peroxides or chlorine bleaching agents.	Chemical and radiation treatments were employed to decontaminate exposed buildings, objects, and materials.	NA	Google Scholar		chemical or biological agents, thermal destruction
A	High	35	2003	Y	Report on the Homeland Security Workshop on Transport and Disposal of Wastes from Facilities Contaminated with Chemical or Biological Agents	NA	Medical waste incinerators (MHWIs), autoclaves, hazardous waste incinerators (HWIs).	Wastes contaminated with chemical and biological agents.	Report on the Homeland Security Workshop on Transport and Disposal of Wastes from Facilities Contaminated with Chemical and Biological Agents	Google Scholar	This report summarizes discussions from the "Homeland Security Workshop on Transport and Disposal of Wastes from Facilities Contaminated with Chemical or Biological Agents." The workshop was held on May 28-30, 2003, in Cincinnati, Ohio, and its objectives were to: Document the current understanding of the challenges faced when handling, storing, transporting, and disposing of wastes from public and private facilities contaminated with chemical and biological agents. Identify research needs and opportunities for improving coordination between federal, state, and local government agencies and other stakeholders in order to fill gaps in the current understanding of these waste management challenges.	chemical or biological agents, thermal destruction
G	High	35	2002	N	Surface Decontamination of Simulated Chemical Warfare Agents Using a Nonequilibrium Plasma with Off-Gas Monitoring	InnovaTek is developing a surface decontamination technology that utilizes active species generated in a nonequilibrium corona plasma. The plasma technology was tested against DMMP, a simulant for the chemical agent Sarin. GC-MS analysis showed that a greater than four log10 destruction of the DMMP on an aluminum surface was achieved in a 10 minute treatment. An ion-trap mass spectrometer was utilized to collect time-resolved data on the treatment off-gases. These data indicate that only non-toxic fragments of the broken down DMMP molecule were present in the gas phase. The technology is being further refined to develop a product that will not only decontaminate surfaces but will also sense when decontamination is complete.	Nonequilibrium corona plasma.	Aluminum surfaces.	NA	Google Scholar		chemical or biological agents, destruction
Q	High	35	2001	N	Atmospheric-Pressure Plasma Decontamination/Sterilization Chamber	An atmospheric-pressure plasma decontamination/sterilization chamber is described. The apparatus is useful for decontaminating sensitive equipment and materials, such as electronics, optics and national treasures, which have been contaminated with chemical and/or biological warfare agents, such as anthrax, mustard blistering agent, VX nerve gas, and the like. There is currently no acceptable procedure for decontaminating such equipment. The apparatus may also be used for sterilization in the medical and food industries. Items to be decontaminated or sterilized are supported inside the chamber. Reactive gases containing atomic and metastable oxygen species are generated by an atmospheric-pressure plasma discharge in a He/O ₂ mixture and directed into the region of these items resulting in chemical reaction between the reactive species and organic substances. This reaction typically kills and/or neutralizes the contamination without damaging most equipment and materials. The plasma gases are recirculated through a closed-loop system to minimize the loss of helium and the possibility of escape of aerosolized harmful substances.	An atmospheric-pressure plasma decontamination/sterilization chamber.	The apparatus is useful for decontaminating sensitive equipment and materials, such as electronics, optics and national treasures, which have been contaminated with chemical and/or biological warfare agents, such as anthrax, mustard blistering agent, VX nerve gas, and the like.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	High	35	2001	N	Wood Made Decontaminable of Chemical Warfare Agents after Sunlight Weathering or Abrasion	Methods of making wood decontaminable of major chemical warfare agents were investigated using phenol-formaldehyde and polyurethane resins. Selected phenol-formaldehyde resins impregnated in southern yellow pine gave enhanced dimensional stability and fire resistance properties without decreasing strength properties, but the decontaminability for one major chemical warfare agent was inadequate. Selected polyurethane resins impregnated in southern yellow pine gave enhanced dimensional stability and strength properties with only a minor deterioration in fire properties, and southern yellow pine, red oak, and aspen impregnated with these polyurethane resins were adequately decontaminated of all three major chemical warfare agents. A polyurethane resin that performs adequately as a coating material for this purpose was also identified.	Phenol-formaldehyde and polyurethane resins.	Southern yellow pine, red oak, and aspen.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	High	35	1984	N	Reaction of CW Agents Simulants on Surfaces in the Presence of O ₂ , UV and O ₃ + UV.	Simulants for the chemical warfare (CW) agents HD, GB and VX, deposited as thin films on stainless steel surfaces, were exposed to UV (254 and 365 nm), O ₃ (0-2 w/v in air) and O ₃ + UV at 0 and 100% relative humidity. The extent of the simulants decomposition was determined. The simulation for HD was found to be most reactive and its half life under easily achievable experiment conditions was estimated at approx. = 7 seconds.	Ultraviolet light and ozone.	Stainless steel surfaces.	NA	Google Scholar		chemical or biological agents, destruction
B	Medium	34	2010	Y	Systems Analysis of Decontamination Options for Civilian Vehicles	The objective of this project, which was supported by the Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Chemical and Biological Division (CBD), was to investigate options for the decontamination of the exteriors and interiors of vehicles in the civilian setting in order to restore those vehicles to normal use following the release of a highly toxic chemical. The decontamination of vehicles is especially challenging because they often contain sensitive electronic equipment, multiple materials some of which strongly adsorb chemical agents, and in the case of aircraft, have very rigid material compatibility requirements (i.e., they cannot be exposed to reagents that may cause even minor corrosion). A systems analysis approach was taken examine existing and future civilian vehicle decontamination capabilities. First, an assessment was performed to determine the chemical threat to vehicles in terms of types of chemicals likely to be released, contamination levels, and extent of contamination (i.e., contamination locations). Next, the state-of-the-art or expected practices that would be employed currently to decontaminate both the exterior and interior of vehicles were identified. A gaps analysis was then conducted to identify technology, capability, and data gaps for potential decontamination approaches. Finally, a roadmap to fill the identified gaps was developed including an assessment of related resources and near-term or emerging technologies that could be used to decontaminate vehicles focusing on efficacy and material compatibility.	Chemical and physical decontamination methods.	Civilian vehicles.	Systems Analysis of Decontamination Options for Civilian Vehicles	Google Scholar		chemical or biological agents, thermal destruction
B	Medium	34	2009	Y	RHELP (Regenerative High Efficiency Low Pressure) Air Purification System	This project aims to develop a RHELP (Regenerative-High Efficiency-Low Pressure) air purification system using a novel ceramic nanofiber on silicon carbide in a microwave oxidizer that can effectively decontaminate air containing aerosolized chemical and biological (CB) agents. Nanofibers of several materials were designed and fabricated using electrospinning process. Physical filtration testing showed performance (filter quality) exceeding military HEPA requirement. Multiple layers were found to have better filter quality than single layer of the same thickness. Biological agent testing showed effectiveness of microwave irradiation to deactivate a wide range of biological agents. System performance can be further enhanced by lowering face velocity during periodic microwave irradiation to minimize heat loss. Chemical agent testing showed excellent regeneration but destruction of the agent needs further improvement.	Regenerative-High Efficiency-Low Pressure (RHELP) air purification system using a novel ceramic nanofiber on silicon carbide in a microwave oxidizer.	Air containing aerosolized chemical and biological (CB) agents.	RHELP (Regenerative High Efficiency Low Pressure) Air Purification System	Google Scholar		chemical or biological agents, thermal destruction

Literature Search Results

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A	Medium	34	2008	N	Development of New Decon Green™: A How-To Guide for the Rapid Decontamination of CARC Paint	This study presents the further refinement of the original Decon Green™ "Classic" to the New Decon Green™ formula. Four main problems were identified with the "Classic": 1) limited capacity for non-traditional agents; 2) long-term stability; 3) homogeneity; and 4) material compatibility, especially with paints, M40 Mask lenses, and HMMWV light housings. These problems have been solved, but at the expense of decon efficacy of Chem Agents (not Bio agents) for soft/sorbent materials such as Chemical Agent Resistant Coating (CARC) paint. The Bio efficacy of New Decon Green™ remains comparable to Decon Green™ Classic as Bio agents do not penetrate/soften materials. Moreover, Chem efficacy still remains better than other peroxide-based decontaminants such as DP200, especially for paint-penetrating HD. Finally, a simple model is presented to extrapolate measured contact hazard levels to potential vapor hazard levels. Off-gassing data for HD and GD on CARC paint is also discussed along with the subjective nature of this test, its ambiguous results, and the problem of relating the results to a true, accurate vapor hazard level. Currently, contact hazard and/or total extraction (residual hazard) remain the only unambiguous tests to verify decontamination efficacy on surfaces such as CARC where substantial agent remains following decontamination.	Decon Green™, chemical agents.	CARC painted surfaces.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Medium	34	2000	Y	An Overview of Research Using the One Atmosphere Uniform Glow Discharge Plasma (OAUGDP) for Sterilization of Surfaces and Materials	The medical, food processing, and heating, ventilating, and air conditioning industries are searching for improved pasteurization, disinfection, and sterilization technologies. Candidate techniques must deal with and overcome such problems as thermal sensitivity and destruction by heat, formation of toxic by-products, costs, and inefficiency in performance. We report the results of a plasma source, the One Atmosphere Uniform Glow Discharge Plasma (OAUGDP), which operates at atmospheric pressure in air and produces antimicrobial active species at room temperature. OAUGDP exposures have reduced log numbers of Gram negative and Gram positive bacteria, bacterial endospores, yeast, and bacterial viruses on a variety of surfaces. The nature of the surface influences the degree of lethality, with microorganisms on polypropylene being most sensitive, followed by glass, and cells embedded in agar. Experimental results showed at least a 5 log10 CFU reduction in bacteria within a range of 50–90 s of exposure. After 10–25 s of exposure, macromolecular leakage and bacterial fragmentation were observed. Vulnerability of cell membranes to reactive Oxygen species (ROC) is hypothesized. Results from several novel OAUGDP configurations are presented, including a remote exposure reactor (REF) which uses transported active species to sterilize material located more than 20 cm from the plasma generation site, and a second planar electrode configuration developed for air filter sterilization. Applications of these technologies to the healthcare industry, the food industry, and decontaminating surfaces compromised by biological warfare agents are discussed.	One Atmosphere Uniform Glow Discharge Plasma (OAUGDP).	Microorganisms on polypropylene, glass, and cells embedded in agar.	An Overview of Research Using the One Atmosphere Uniform Glow Discharge Plasma for Sterilization of Surfaces and Materials	Google Scholar		chemical or biological agents, thermal destruction
U	Medium	34	1999	N	Atmospheric Pressure Plasma Jet (APPJ) for Decontamination of Chem/Bio Warfare Agents	The Atmospheric Pressure Plasma Jet (APPJ) is a unique, capacitively-coupled rf, nonthermal, uniform discharge operating at atmospheric pressure with a high flow of He/O ₂ feed gas. The APPJ generates highly reactive atomic and metastable species of oxygen and directs them onto a contaminated surface at high velocity. This may provide a much needed method of decontamination of CBW agents which, unlike traditional decon methods, is dry and nondestructive to sensitive equipment. The reactive effluent of the APPJ at 175 °C has been shown to kill <i>Bacillus globigii</i> spores, a surrogate for Anthrax, with a D value (time to reduce viability by a factor of 10) of 4.5 sec at a standoff distance of 0.5 cm. This is 10 times faster than hot gas at the same temperature and requires 80% less energy input to achieve the same level of this D value. This is also an order of magnitude better than other decontamination plasma discharges, and unlike these other discharges, the APPJ provides a downstream process which can be applied to all accessible surfaces with no need for the contaminated object to fit within a chamber. Through active cooling of the electrodes, the authors have also achieved a D value of 15 sec at an effluent temperature of just 75 °C, making the decontamination of personnel a definite possibility. The APPJ has also been shown to oxidize surrogates of the CW agents, Mustard and VX, and a collaborative effort is now proceeding with the actual agents at the Edgewood Chem/Bio Center (ECBC, formerly EDECC). Efforts are now being directed towards reducing the consumption of He and increasing the working standoff distance.	Atmospheric Pressure Plasma Jet (APPJ).	Surfaces contaminated with Chem/Bio warfare agents.	NA	Google Scholar	Conference: 1999 IEEE International Conference on Plasma Science, Monterey, CA (US), 06/20/1999--06/24/1999.	chemical or biological agents, thermal destruction
B	Medium	34	1998	Y	Direct Chemical Oxidation A Non-Thermal Technology for the Destruction of Organic Wastes	Direct Chemical Oxidation (DCO) is a non-thermal, ambient pressure, aqueous-based technology for the oxidative destruction of the organic components of hazardous or mixed waste streams. The process has been developed for applications in waste treatment and chemical demilitarization and decontamination at LLNL since 1992, and is applicable to the destruction of virtually all solid or liquid organics, including: chlorosolvents, oils and greases, detergents, organic-contaminated soils or sludges, explosives, chemical and biological warfare agents, and PCB's. The process normally operates at 80-100 °C, a heating requirement which increases the difficulty of surface decontamination of large objects or, for example, treatment of a wide area contaminated soil site. The driver for DCO work in FY98 was thus to investigate the use of catalysts to demonstrate the effectiveness of the technology for organics destruction at temperatures closer to ambient. In addition, DCO is at a sufficiently mature stage of development that technology transfer to a commercial entity was a logical next step, and was thus included in FY98 tasks.	Direct Chemical Oxidation (DCO) is a non-thermal, ambient pressure, aqueous-based technology for the oxidative destruction of the organic components of hazardous or mixed waste streams.	The process has been developed for applications in waste treatment and chemical demilitarization and decontamination at LLNL since 1992.	Direct Chemical Oxidation A Non-Thermal Technology for the Destruction of Organic Wastes	Google Scholar		chemical or biological agents, thermal destruction
U	Medium	34	1996	N	RCRA Compliance Test Destruction of VX in Ton Containers in the Metal Parts Furnace (MPF) at the Chemical Agent Munitions Disposal System (CAMDS), Tooele, Utah	A test series was conducted at the Chemical Agent Munitions Disposal System (CAMDS) using the metal parts furnace (MPF) system to demonstrate thermal detoxification of steel ton containers containing a residual heel of chemical warfare agent, VX. This was done under Congressional mandate by the Department of the Army as part of an on-going program to dispose of existing stocks of obsolete chemical warfare agent munitions. Particulate matter, HCl, trace metals, VX, and CO emissions were all well within State of Utah permit limits established for the MPF. Particulate emissions were <45 mg/dscm at 70% O ₂ (average was <10 mg/dscm [-0.004 grain/dscf] at 7% O ₂). Agent VX (the Principal Organic Hazardous Constituent) destruction and removal efficiency (DRE) exceeded the Resource Conservation and Recovery Act (RCRA) min. of 99% with a >99.99999% DRE. No VX was detected in flue gases at any time during the test program. HCl emissions were well below the RCRA limit of 4 lbs/h with an average <6.75 ± 10.4 lbs/h. Results were reviewed and accepted by the Utah Department of Environmental Quality and were verified by material and energy balance calcs.	Metal parts furnace (MPF).	Steel ton containers containing a residual heel of chemical warfare agent, VX.	NA	CAPUS	Conference paper.	chemical or biological agents, thermal destruction
U	Medium	33	2010	N	Microwave Chemical Remediation of Chemical Warfare (CW) Agents and Structurally Related Compounds (Pesticides, Herbicides) Using Rapid Microwave Hydrolysis in Acidic and Basic Medium	Residues and waste materials from ongoing cleanup of the US's vast CW agent stockpiles, required under current treaty obligations by 2012, present a major problem. These typically comprise contaminated decon components that cannot be incinerated. Additionally, many CW agents are structurally similar to widely used biocides, such as organophosphates malathion, chlorpyrifos and phosmet, which frequently contaminate man-made materials. A rapid, environmentally friendly remediation method for such materials is thus of importance. This contribution describes a very rapid remediation method using ambient pressure microwave hydrolysis of contaminated materials in benign acidic and basic media. CW agents targeted were GB, VX, H, HD, HN-x. Elegant spectroscopic and other analyses (31P, 13C NMR, GC-MS, GLC/MS) demonstrated complete (99.9999%) destruction of agent simulants on a 50 g scale within 20 minutes. Comparative thermal reflux studies showed that equivalent acid-medium destruction required 30 h @ 140 °C, and basic-medium destruction was not achievable at all.	Ambient pressure microwave hydrolysis of contaminated materials in benign acidic and basic media.	CW agents targeted were GB, VX, H, HD, HN-x.	NA	BIOSIS	Conference paper.	chemical or biological agents, thermal destruction
U	Medium	33	2008	N	Plasma Decontamination of Chemical & Biological Warfare Agents by a Cold Arc Plasma Jet at Atmospheric Pressure	The cold arc plasma jet was introduced to decontaminate chemical and biological warfare (CBW) agents for the application of a portable CBW decontamination system. The cold arc plasma jet is a low temperature, high density plasma that produces highly reactive species such as oxygen atoms and ozone. Moreover, it is possible to maintain stable plasma without He or Ar. The discharge operated on N ₂ -O ₂ mixture of 30 l/min, and the high voltage pulse (23 kHz, 30% duty ratio) power was applied to the inner electrode. In the decontamination experiments, <i>Bacillus subtilis</i> and <i>Escherichia Coli</i> were chosen as simulants for biological agents and DMMP (Dimethylmethylphosphonate) was chosen as a simulant for chemical agents. The experimental results showed that <i>B. subtilis</i> and <i>E. coli</i> were efficiently decontaminated. Also, DMMP absorbed on the metal substrate and the glass substrate was removed after plasma treatment. Finally, we identified that DMMP was decomposed very well in the plasma effluent.	Cold arc plasma jet, a portable CBW decontamination system.	Metal and glass substrates.	NA	Google Scholar	Conference Paper, IEEE International Conference on Plasma Science - ICOPS.	chemical or biological agents, thermal destruction
U	Medium	33	2005	N	Decontamination of Bacterial Spores by a Microwave Plasma Torch	Air plasma in a highly energized state, contains radicals such as atomic oxygen, excited oxygen molecules and ozone that are highly reactive. These reactive oxygen species (ROS) can destroy just about all kinds of organic contaminants more effectively than the thermal method. This non-thermal destruction mechanism primarily involves the chemical reactions of ROS with nucleic acids, lipids, proteins and sugars. These chemical modifications result in protein cleavage, aggregation and loss of catalytic and structural function by distorting secondary and tertiary protein structures. These oxidative proteins are irreversibly modified and cannot be repaired. This occurrence is known as protein degradation. Through these chemical reactions, most contaminants are converted by ROS to carbon dioxide and water. The emission spectroscopy of an arc-seed microwave plasma torch (MPT) was examined and the spectral line of O I (777.194 nm) indicating relatively high atomic oxygen content in the torch was detected. This torch was applied to demonstrate this oxidation process for the decontamination of biological warfare agents. In the decontamination experiments, <i>Bacillus cereus</i> was chosen as a simulant of <i>Bacillus anthracis</i> spores for biological agent and the airflow rate was fixed at 0.393 l/s that leads to the maximum concentration of atomic oxygen produced by the torch as well as a good torch size. The results of experiments using dry samples showed that all spores were killed in less than 8 seconds at 3 cm distance, 12 seconds at 4 cm distance, and 16 seconds at 5 cm distance away from the nozzle of the torch. We now extend the experimental effort to decontaminate wet samples. The results will be presented and discussed.	Arc-seed microwave plasma torch (MPT).	In the decontamination experiments, <i>Bacillus cereus</i> was chosen as a simulant of <i>Bacillus anthracis</i> spores for biological agent.	NA	Google Scholar	Conference Paper.	chemical or biological agents, incineration
U	Medium	33	2004	N	Development of a Low-Temperature Catalytic Oxidation System for Destruction of Chemical Warfare Agents	This project is to develop a low-temperature microwave catalytic oxidation system that will effectively decontaminate air containing aerosolized or gaseous chemical agents (CWAs). To protect personnel in shelters catalytic oxidation systems should (1) destroy CWAs in air at low temperatures to avoid NO _x formation, (2) remove sulfur dioxide produced from the oxidation of CWAs containing sulfur atoms, (3) operate for an indefinite period of time and (4) destroy biological agents at low temperatures. This system will be used to supply clean breathing air to a bunker or other facility war zone that has been contaminated with chemical weapons. This work will be performed in two phases Phase I of the experimental effort is to obtain the data needed to design and fabricate a prototype CWA catalytic oxidation system. During Phase II work the prototype microwave air decontamination system will be constructed and tested both at CHA Corporation and at a selected location to demonstrate the effectiveness of the microwave air decontamination system. Experimental results obtained to date indicate that microwave catalytic oxidation will be capable of destroying more than 99.5% of	Low-temperature microwave catalytic oxidation system.	Air containing aerosolized or gaseous chemical agents (CWAs).	NA	Google Scholar	Conference technical report.	chemical or biological agents, thermal destruction

Literature Search Results

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G	Medium	33	2003	Y	Effects of Dimethyl Methylphosphonate on Premixed Methane Flames	The impact of dimethyl methylphosphonate (DMMP) was studied in a premixed methane/oxygen/N ₂ -Ar flame in a flat flame burner slightly under atmospheric pressure at two different equivalence ratios: rich and slightly lean. CH ₄ , CO, CO ₂ , CH ₂ O, CH ₃ OH, C ₂ H ₆ , C ₂ H ₄ , and C ₂ H ₂ profiles were obtained with a Fourier Transform Infrared (FTIR) spectrometer. Gas samples, analyzed in the FTIR, were extracted from the reaction zone using a quartz microprobe with choked flow at its orifice. Temperature profiles were obtained by measuring the probe flow rate through the choked orifice. Flame calculations were performed with two existing detailed chemical kinetic mechanisms for organic hydrocarbon combustion. DMMP addition caused all profiles except that of CH ₃ OH to move further away from the burner surface, which can be interpreted as a consequence of a reduction in the adiabatic flame speed. Experimentally, the magnitude of the shift was 50% greater for the near-stoichiometric flame than for the rich flame. Experimental CH ₃ OH profiles were four to seven times higher in the doped flames than in the undoped ones. The magnitude of this effect is not predicted in the calculations, suggesting a need for further mechanism development. Otherwise, the two mechanisms are reasonably successful in predicting the effects of DMMP on the flame.	Methane/oxygen/N ₂ -Ar flame in a flat flame burner slightly under atmospheric pressure.	Simulants of nerve agents, dimethyl methylphosphonate (DMMP).	Effects of Dimethyl-Methylphosphonate-on-Premixed-Methane-Flames	Google Scholar		chemical or biological agents, thermal destruction
U	Medium	33	2001	N	Biological Weapons Agent Defeat Using Directed Microwave Energy	A synergistic, molecularly targeted microwave approach has demonstrated unprecedented kill of a broad range of biological weapons agents (BWA) using directed microwave energy in conjunction with a specially designed chemical compound called a TPAC. The BWAs are first treated with the TPAC compound, a process that only takes a few moments, and then exposed to the microwaves. Using this synergistic approach, significant kill of the BWAs is achieved using standard microwave equipment at moderate powers (< 1 MW peak and only a few hundred watts average) and exposure levels (100 sim/ few joules). This method is so effective and broad ranged that total kill is achieved on vegetative bacilli and spores and vegetative growth anthrax and an unprecedented 2.5 out of a total of 6 logs of kill is achieved on anthrax type spores, the hardest BWA to defeat. To put the anthrax kill rate in perspective, of the approximately one million spores exposed to the microwaves in a given sample only three survived, even though the spores were given every opportunity to grow after RF irradiation. The TPAC compound consists of two components, a transduction-polymer (TP) and an acceptor-chromophore (AC), that work in conjunction to produce BWA defeat. The AC molecule is designed so that it easily penetrates the wall of the BWA and binds to surface matrix targets. Upon microwave exposure, the TP emits a blue photon that activates the AC producing saturated levels of chemical radicals that are irreversibly bound to the target spore wall, resulting in lethal failure of the spore upon germination. The TP molecule is resonant and thus responds to a given microwave frequency better than others. Its effectiveness also depends upon the rise-time and width of the RF pulse. With optimization of the RF pulse and frequency, total kill of even anthrax spores is expected.	Directed microwave energy in conjunction with a specially designed chemical compound called a TPAC.	Biological weapons agents (BWA).	NA	Google Scholar	Conference paper.	chemical or biological agents, incineration
G	Medium	33	2000	N	Bacterial Decontamination Using Ambient Pressure Nonthermal Discharges	Atmospheric pressure nonthermal plasmas can efficiently deactivate bacteria in gases, liquids, and on surfaces, as well as can decompose hazardous chemicals. This paper focuses on the changes to bacterial spores and toxic biochemical compounds, such as mycotoxins, after their treatment in ambient pressure discharges. The ability of nonthermal plasmas to decompose toxic chemicals and deactivate hazardous biological materials has been applied to sterilizing medical instruments, ozonating water, and purifying air. In addition, the fast lysis of bacterial spores and other cells has led us to include plasma devices within pathogen detection instruments, where nucleic acids must be accessed. Decontaminating chemical and biological warfare materials from large, high value targets such as building surfaces, after a terrorist attack, are especially challenging. A large area plasma decontamination technology is described.	Atmospheric pressure nonthermal plasmas.	A large area plasma decontamination technology is described for decontaminating chemical and biological warfare materials from large, high value targets such as building surfaces, after a terrorist	Google Scholar		chemical or biological agents, incineration	
G	Medium	33	1998	Y	On Modeling of the Evaporation of Chemical Warfare Agents on the Ground	A model for evaporation of chemical warfare agents on the ground has been developed. The process of evaporation is described in three steps: 1. the immediate drop enlargement due to impact momentum is modeled using an empirical correlation from technical literature; 2. further enlargement caused by capillary spreading upon the surface and the simultaneous sorption into the substrate, modeled in three dimensions; 3. subsequent drying and redistribution of the sorbed material is described as a one-dimensional vertical process. The formulation of the flux in the soil takes into account vapour, liquid, solute, and adsorbed phases. The evaporation from the surface is determined by the vapour concentration at the surface and the conditions in the atmospheric viscous sub-layer close to the droplet spots on the surface. Model results agree with the limited experimental data found in the literature. The model shows a very rapid sorption and redistribution of chemical warfare droplets on sand. This effect gives a rapid decrease of the evaporation, except for a shorter initial period. However, a small residual evaporation exists for a rather long time from liquid, which has penetrated down into the soil.	Development of a model for the evaporation of chemical warfare agents on the ground.	Soils contaminated with Soman and Mustard agents.	On modeling of the evaporation of chemical warfare agents on the ground	Google Scholar		chemical or biological agents, thermal destruction
U	Medium	33	1998	N	Utilizing a One-Atmosphere Uniform Glow Discharge Plasma for Chemical/Biological Warfare Agent Decontamination	An innovative approach to the decontamination of chemical and/or biological warfare agents is described. This recently developed technology involves utilizing a one atmosphere uniform glow discharge plasma (OAUGDP) as the decontaminant/sterilant. The plasma provides a very powerful but environmentally safe oxidizing and disinfecting technique without the use of strong chemicals (chlorine bleach) or high temperatures (autoclaving). Initial laboratory results indicate a greater than six log kill of bacteria in under one minute, significantly faster than autoclaving. In addition, the highly ionizing nature of the plasma discharge is expected to quickly degrade chemical agents through energetic bond breaking mechanisms. The active species of the air plasma are nonpersistent and are expected to revert to the components of atmospheric air. Selected simulants for the highly toxic agents were exposed to the OAUGDP and the sterilizing/decontamination effect quantified.	One atmosphere uniform glow discharge plasma (OAUGDP).	Selected simulants for the highly toxic agents were exposed to the OAUGDP and the sterilizing/decontamination effect quantified.	NA	Google Scholar	Conference paper.	Destruction or Decomposition or Incineration; Thermal or Heating or (Hot (w) (Temperature or Air)); Chemical or Biological Agent; Anthracis or Stearotherophilus ; HD or Mustard; Building or Soil or Carpet or (Ceiling (w) Tile); Concrete or Asphalt
T	Medium	32	NA	Y	Radiological, Chemical, and Biological Decontamination Using Atmospheric-Pressure Plasmas	NA	Atmospheric-pressure plasma jet (APPJ).	Stainless steel coupons (disks).	Radiological, Chemical, and Biological Decontamination Using Atmospheric-Pressure Plasmas	Google Scholar	The temperature of this gas discharge typically ranges from 50°C to 300°C, which allows for plasma processing of sensitive materials and equipment at low temperatures and accelerated processing of more robust surfaces at higher	chemical or biological agents, thermal destruction
G	Medium	32	2007	Y	A Decontamination Study of Simulated Chemical and Biological Agents	A comprehensive decontamination scheme of the chemical and biological agents, including airborne agents and surface contaminating agents, is presented. When a chemical and biological attack occurs, it is critical to decontaminate facilities or equipments to an acceptable level in a very short time. The plasma flame presented here may provide a rapid and effective elimination of toxic substances in the interior air in isolated spaces. As an example, a reaction chamber, with the dimensions of a 22 cm diameter and 30 cm length, purifies air with an airflow rate of 5,000 l/min contaminated with toluene, the simulated chemical agent, and soot from a diesel engine, the simulated aerosol for biological agents. Although the airborne agents in an isolated space are eliminated to an acceptable level by the plasma flame, the decontamination of the chemical and biological agents cannot be completed without cleaning surfaces of the facilities. A simulated sterilization study of micro-organisms was carried out using the electrolyzed ozone water. The electrolyzed ozone water very effectively kills endospores of <i>Bacillus atrophaeus</i> ATCC 9372 within 3 min. The electrolyzed ozone water also kills the vegetative micro-organisms, fungi, and virus. The electrolyzed ozone water, after the decontamination process, deionerates into on-line water. This study determines the effectiveness of pulsed streamer discharges (PSD), a type of advanced oxidation technology (AOT) to clean water contaminated with chemical agents. For the purpose of this study, experiments were conducted with G and H agent simulants to determine the degradation kinetics and to determine the effects of various electrical and chemical parameters in the degradation of these contaminants. The energy efficiency of contaminant degradation shows that pulsed streamer discharges can be an efficient technology in treating water contaminated with chemical agents. The maximum energy yields of degradation of H and G agent simulants by the pulsed corona discharges are 0.029 and 0.008 molecules/100 eV, respectively, in the series configuration with ferrous sulfate salt	Plasma flame and electrolyzed ozone water.	The plasma flame presented here may provide a rapid and effective elimination of toxic substances in the interior air in isolated spaces and electrolyzed ozone water for surfaces.	A decontamination study of simulated chemical and biological agents	Google Scholar		chemical or biological agents, destruction
G	Medium	32	2006	Y	Degradation of Chemical Warfare Agent Simulants Using Gas-Liquid Pulsed Streamer Discharges	Incorporation is being used or is planned as destruction for stockpiles of chemical warfare agents in the U.S. This paper presents the development of models for analyzing a Liquid Incinerator Chamber (LIC) for destroying liquid chemical weapon agent (GB, HD, or VX) drained from munitions containing in the US Army chemical warfare stockpile. The models predict complete destruction of the chemical agent when the incinerators and afterburners are operated as per standard operating conditions. Under normal operating conditions	Pulsed streamer discharges (PSD).	Water contaminated with chemical agents.	Degradation of chemical warfare agent simulants using gas liquid pulsed streamer discharges	Google Scholar		chemical or biological agents, thermal destruction
U	Medium	32	2004	Y	Computational Modeling of a Chemical Liquid Incinerator Chamber	Incorporation is being used or is planned as destruction for stockpiles of chemical warfare agents in the U.S. This paper presents the development of models for analyzing a Liquid Incinerator Chamber (LIC) for destroying liquid chemical weapon agent (GB, HD, or VX) drained from munitions containing in the US Army chemical warfare stockpile. The models predict complete destruction of the chemical agent when the incinerators and afterburners are operated as per standard operating conditions. Under normal operating conditions	Liquid Incinerator Chamber (LIC).	Liquid chemical weapon agent (GB, HD, or VX) from munitions.	Computational Modeling of a Chemical Liquid Incinerator Chamber	Google Scholar	Conference paper.	chemical or biological agents, incineration

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
G	Medium	32	2002	Y	Critical Evaluation of Proven Chemical Weapon Destruction Technologies	A critical evaluation is made of the chemical weapon destruction technologies demonstrated for 1 kg or more of agent in order to provide information about the technologies proven to destroy chemical weapons to policy-makers and others concerned with reaching decisions about the destruction of chemical weapons and agents. As all chemical agents are simply highly toxic chemicals, it is logical to consider the destruction of chemical agents as being no different from the consideration of the destruction of other chemicals that can be as highly toxic—their destruction, as that of any chemicals, requires the taking of appropriate precautions to safeguard worker safety, public health, and the environment. The Chemical Weapons Convention that entered into force in 1997 obliges all States Parties to destroy any stockpiles of chemical weapons within 10 years from the entry into force of the Convention—by 2007—with the possibility of an extension for up to 5 years to 2012. There is consequently a tight timeline under the treaty for the destruction of stockpiled chemical weapons and agents—primarily held in Russia and the United States. Abandoned or old chemical weapons—notably in Europe primarily from World War I, in China from World War II as well as in the United States—also have to be destroyed. During the past 40 years, more than 2000 tonnes of agent have been destroyed in a number of countries and over 80 % of this has been destroyed by incineration. Although incineration is well proven and will be used in the United States to destroy over 80 % of the U.S. stockpile of 25,800 tonnes of agent, considerable attention has been paid particularly in the United States to alternative technologies to incineration because of several constraints that are specific to the United States. Much of the information in this report is based on U.S. experience—as the United States had, along with the Russian Federation, by far the largest stockpiles of chemical weapons and agents anywhere in the world. The United States has made much progress in destroying its stockpile of chemical weapons and agents and has also done more work than any other country to examine alternative technologies for the destruction of chemical weapons and agents. However, the national decisions to be taken by countries faced with the destruction of chemical weapons and agents need to be made in the light of their particular national conditions and standards—and thus may well result in a decision to use different approaches from those adopted by the United States. This report provides information to enable countries to make their own informed and appropriate decisions.	Incineration, plasma pyrolysis, molten metal technology, hydrogenolysis, and destruction of arsenicals.	Chemical agents, munitions, gas, liquid, and solid effluents.	Critical Evaluation of Proven Chemical Weapon Destruction Technologies	Google Scholar		chemical or biological agents, incineration
N	Medium	32	2001	N	A Modified Baseline Incineration Process for Mustard Projectiles at Pueblo Chemical Depot	The United States has maintained a stockpile of chemical warfare agents and munitions since World War I. The Army leadership has sought outside, unbiased advice on how best to dispose of the stockpile. In 1987, at the request of the Under Secretary of the Army, the National Research Council (NRC) established the Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee) to provide scientific and technical advice and counsel on the CSDP. This report is concerned with the technology selection for the Pueblo site, where only munitions containing mustard agent are stored. The report assesses a modified baseline process, a slightly simplified version of the baseline incineration system that was used to dispose of mustard munitions on Johnston Island. A second NRC committee is reviewing neutralization-based technologies for possible use at Pueblo. The evaluation in this report is intended to assist authorities making the selection. It should also help the public and other non-Army stakeholders understand the modified baseline process and make sound judgments about it.	Modified incineration process.	Munitions containing mustard agent.	NA	Google Scholar		chemical or biological agents, destruction
B	Medium	31	2012	N	Decontamination Efficacy of Three Commercial Off-the-Shelf Sporicidal Agents on Medium-Sized Panels Contaminated with Surrogates of <i>Bacillus anthracis</i>	A significant gap in technology preparedness exists in the U.S. Federal response to wide-area contamination resulting from the release of biological agents such as <i>Bacillus anthracis</i> spores. In 2001, release of just a few letters containing anthrax spores resulted in the contamination of several building interiors, including the U.S. Postal and Distribution Centers (Brentwood, Washington, DC; Trenton and Jersey City, NJ) and American Media Inc. (Boca Raton, FL). Despite heavy contamination levels of several building interiors, remediation of building interiors was achieved successfully by fumigation with chlorine dioxide (CD) or vapor hydrogen peroxide (VHP). A wide-area release and contamination of building exteriors and the outdoors would likely exhaust the national remediation capacity. Cleanup could take years and lead to incalculable financial drain because of a delay in effective response. Additionally, agencies responsible for the mitigation of contaminated sites are exploring alternative methods for decontamination including combinations for the disposal of contaminated items, source reduction by vacuuming, mechanical scrubbing, and pH-adjusted bleach pressure wash. If proven effective, a pressure wash-based removal of anthrax spores from building surfaces with readily available equipment will significantly increase the readiness of federal agencies to meet the daunting challenge of restoration and cleanup efforts following a wide-area biological release.	Fumigation with chlorine dioxide (CD) or vapor hydrogen peroxide (VHP).	Remediation of building interiors.	NA	Google Scholar		chemical or biological agents, incineration
Q	Medium	31	2010	N	Large-Volume Elimination of Airborne Chemical and Biological Warfare Agents by Making Use of a Microwave Plasma Burner	The invention is related to an apparatus made of microwave plasma burner for a large-volume elimination of toxic airborne chemical and biological warfare agents. The apparatus can purify the interior air of large volume in an isolated space such as buildings, public transportation systems, and military vehicles contaminated with chemical and biological warfare agents. The apparatus consists of a microwave plasma torch connected in series to a fuel injector and a reaction chamber for elimination and burnout of toxic airborne warfare agents in large quantities. Hydrocarbon fuel in gaseous or liquid state injected into the microwave plasma torch evaporates instantaneously, generating a large volume of plasma flame in the reaction chamber where the oxidation mechanism eliminates the chemical and biological warfare agents that pass through the reaction chamber. The apparatus can also purify air contaminated with volatile organic compounds and eliminate soot from diesel engines.	Microwave plasma burner.	A large-volume elimination of toxic airborne chemical and biological warfare agents.	NA	Google Scholar		chemical or biological agents, thermal destruction
C	Medium	31	2007	Y	Present State of CBRN Decontamination Methodologies	Decontamination is defined as the removal and/or neutralization of chemical, biological, radiological and/or nuclear (CBRN) contamination. In this report, the present state of the art of decontamination technologies is discussed. Advantages and disadvantages of the available methods are given, as well as the applicability towards CBRN agents and toxic industrial chemicals (TICs) and the commercial availability of decontaminants. Decontamination methods are divided into four basic processes: physical, chemical, enzymatic and energetic decontamination. Physical methods aim at removing the contaminants from surfaces and include weathering, rinsing with water and solvents, accelerated evaporation by heating, and the use of solid adsorbents and strippable coatings. In principle, RN decontamination can only be obtained through physical removal and containment. Chemical, enzymatic and energetic methods aim at modifying the structure of contaminants in order to reduce or eliminate the toxicity of the compounds. The following chemical decontamination methods are discussed: oxidation (chlorine, peroxides and reactive gasses), nucleophilic substitution (alkaline hydrolysis and oximes) and alternative chemical approaches. Some chemical decontaminants are effective but highly toxic and environmentally unsafe. An example is DS-2, that is currently being replaced by safer decontaminants such as, in The Netherlands, GDS2000. An environmentally friendly alternative for aggressive chemical decontaminants was found in the use of enzymes. Some enzymatic decontaminants are commercially available. Most enzymes are only effective against GB and GD, however, some enzymatic approaches towards destruction of VX, HD and BWAs have been reported. Finally, directed energy methods, such as photochemical, ultra violet radiation, plasma, and microwave radiation have all been demonstrated to disinfect surfaces. However, these methods are not generally applicable. Unfortunately, there is no single decontamination technology that is effective against all CBRN agents. Therefore, there are still sufficient challenges for further innovative developments in the future.	The present state of the art of decontamination technologies is discussed (physical, chemical, enzymatic, and energetic decontamination).	Decontamination of chemical, biological, radiological and/or nuclear (CBRN) material waste.	Present State of CBRN Decontamination Methodologies	Google Scholar		chemical or biological agents, thermal destruction
U	Medium	31	2005	Y	Advanced Modeling of Incineration of Building Decontamination Residue	In this paper we present recent development of the component models for a pilot scale rotary kiln simulator for the incineration of building materials. A transient zonal model approach for use with a computational fluid dynamics (CFD) model is presented. Comparisons are made between the model and experimental data. The models predict complete destruction of the biological agent that remains in the building material matrix when the incinerators and afterburners are operated as per standard operating.	Component models for a pilot scale rotary kiln simulator for the incineration of building materials.	Building materials.	ADVANCED_MODELING_OF_INCINERATION_OF_BUILDING_DECONTAMINATION_RESIDUE	Google Scholar	Conference paper.	chemical or biological agents, destruction
U	Medium	31	2004	N	Inactivation of Airborne Bacterial Endospores with OAUAGDP	Atmospheric Glow Technologies (AGT) has developed an innovative means of safeguarding indoor environments using One Atmosphere Uniform Glow Discharge Plasma (OAUAGDP/Up TM). AGT has placed an atmospheric plasma device within HVAC duct work and is using reactive chemical species present in the exhaust from this device to neutralize biological agents captured on filter media. This plasma device, using air only, requires no additives. Importantly, since our design does not impede airflow, those flow rates typical for HVAC systems can be maintained. The biological inactivation achieved by this system is broad-spectrum and includes bacterial endospores. AGT routinely achieves neutralization of 6 kg of <i>Bacillus anthracis</i> (formerly <i>B. subtilis</i> var. <i>niger</i> , ATCC 9372) endospore within 5-20 minutes up to 2 feet downstream depending upon airflow parameters. Data correlating biological inactivation with electrical and airflow parameters will be presented. Ongoing research indicates singlet delta oxygen plays a significant role in OAUAGDP-based biological neutralization. Liability of microorganisms was assessed using standard plate counts from filter media. All plates were incubated for a minimum of 96 h at 37/psl deg/C in order to accurately quantify any surviving organisms. The ability to provide broad-spectrum reduction of air-borne biological agents indicates that the use of a duct-mounted OAUAGDP atmospheric plasma device can provide a reliable, unobtrusive means of protecting high-risk buildings.	One Atmosphere Uniform Glow Discharge Plasma (OAUAGDP).	An atmospheric plasma device within HVAC duct work a to neutralize biological agents captured on filter media.	NA	Google Scholar	Conference paper.	chemical or biological agents, thermal destruction
U	Medium	31	2002	Y	Advanced Computational Modeling of Military Incinerators	Atmospheric Glow Technologies (AGT) has developed an innovative means of safeguarding indoor environments using One Atmosphere Uniform Glow Discharge Plasma (OAUAGDP/Up TM). AGT has placed an atmospheric plasma device within HVAC duct work and is using reactive chemical species present in the exhaust from this device to neutralize biological agents captured on filter media. This plasma device, using air only, requires no additives. Importantly, since our design does not impede airflow, those flow rates typical for HVAC systems can be maintained. The biological inactivation achieved by this system is broad-spectrum and includes bacterial endospores. AGT routinely achieves neutralization of 6 kg of <i>Bacillus anthracis</i> (formerly <i>B. subtilis</i> var. <i>niger</i> , ATCC 9372) endospore within 5-20 minutes up to 2 feet downstream depending upon airflow parameters. Data correlating biological inactivation with electrical and airflow parameters will be presented. Ongoing research indicates singlet delta oxygen plays a significant role in OAUAGDP-based biological neutralization. Liability of microorganisms was assessed using standard plate counts from filter media. All plates were incubated for a minimum of 96 h at 37/psl deg/C in order to accurately quantify any surviving organisms. The ability to provide broad-spectrum reduction of air-borne biological agents indicates that the use of a duct-mounted OAUAGDP atmospheric plasma device can provide a reliable, unobtrusive means of protecting high-risk buildings.	In this paper we present recent development of the component models for the Metal Parts Furnace for the incineration of mustard. Both a transient zonal model and CFD models are presented.	Mustard stockpiles.	ADVANCED COMPUTATIONAL MODELING OF MILITARY INCINERATORS	Google Scholar	Conference paper.	chemical or biological agents, destruction
G	Medium	31	2000	N	Biological Decontamination by Nonthermal Plasmas	Incineration is being used or is planned as a primary destruction technology of stockpiles of chemical warfare agents (CWA) in the United States. Computer modeling tools may play an important role in reducing the time, cost and technical risk of using incineration. A simulation workbench is being developed to assist the chemical demilitarization community. The workbench will consist of models for a Liquid Incinerator (LI), Metal Parts Furnace (MPF), a De-Activation Furnace System (DFS), and the afterburners and Pollution Abatement Systems (PAS) for these incinerators. In this paper we present recent development of the component models for the MPF for the incineration of mustard. Both a transient zonal model and CFD models are presented. Results of several practical cases are presented including comparison with experimental data. The models predict complete destruction of the chemical agent when the Nonthermal gaseous discharges have been found to be effective agents for biological decontamination/sterilization. The ability to generate these discharges at atmospheric pressure makes the decontamination process practical and inexpensive. In addition, the fact that the plasmas generated by such discharges are cold makes their use suitable for applications where medium preservation is desired. To fully understand the biophysical and biochemical processes induced by the interaction of living cells with gaseous discharges, a multidisciplinary approach is required. In this paper, we present two studies on bacteria killing obtained by two different discharges: a glow discharge at atmospheric pressure and an enhanced corona discharge at atmospheric pressure.	Glow discharge at atmospheric pressure and an enhanced corona discharge at atmospheric pressure.	Biological decontamination/sterilization.	NA	Google Scholar		chemical or biological agents, incineration

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
N	Medium	31	1997	N	Incineration and Thermal Treatment of Chemical Agents and Chemical Weapons	The U. S. Army has been directed by Congress to dispose of its approximately 24,800 ton stockpile of chemical weapons and chemical warfare agents (CWAs) by December 31, 2004 and has chosen to use incineration for this purpose[1]. This stockpile contains the mustard gas, blister agents H, HD, and HT, and the organophosphorus nerve agents VX and GB. On Johnston Atoll a prototype disposal facility, consisting of four separate process streams each containing a furnace, afterburner and air pollution control section, has been constructed, tested and is now operational. In spite of the fact that this facility has met all major performance goals, there is considerable opposition to the use of incineration for disposal of that portion of the stockpile stored at eight sites in the continental U.S. In this paper we review what is known concerning the relevant chemical mechanisms for the high temperature reactions of CWAs, simulants and related compounds. Focus is placed on the reactions associated with the heteroatoms present in the agents—Cl, F, N, O, P and S. While there have been few kinetics studies using either agents or their simulants, the relevant combustion literature on waste incineration (Cl ₂), fire suppression (Cl ₂) and fossil fuel combustion (S ₂ N ₂) contains significant information and is reviewed. In addition, conjectures are offered as to what might be important elementary reaction pathways, for both the mustard and nerve agents. It is concluded that the mustard agents, which are straight chain molecules, should react quickly in lean mixtures at high temperature giving HCl, oxides of sulfur and normal combustion products. Because of their structural complexity and the presence of P and, in the case of the nerve agent GB, of the strong P-F bond a similar conclusion for the nerve agents is not as well founded.	Incineration. In this paper we review what is known concerning the relevant chemical mechanisms for the high temperature reactions of CWAs, simulants and related compounds.	This stockpile of mustard gas, blister agents H, HD, and HT, and the organophosphorus nerve agents VX and GB.	NA	Google Scholar	This stockpile of mustard gas, blister agents H, HD, and HT, and the organophosphorus nerve agents VX and GB.	chemical or biological agents, thermal destruction
B	Medium	30	2011	Y	Testing Nonthermal Plasma for Decantamination of Sensitive Weapon Platforms and Systems	Efficient decantamination of military platforms and systems represents the first line of defense and protection for U.S. warfighters. Using solvents, wet decantamination approach generates secondary pollution and requires extra care of the contaminated solutions afterwards. The wet approach could also degrade material integrity of the treated platforms and systems. Alternative decantamination technique that does not erode the integrity and not produce secondary contamination is required. Nonthermal plasma was tested as a decantamination alternative for a number of pollutants in this project. A radiofrequency-powered nonthermal plasma technique was applied to biological aerosols, oil and grease, and paint-stained airframe structural material. Raman spectroscopy, scanning electron microscopy, and aerosol monitoring techniques were used to assess the effectiveness of the plasma decantamination technique. The nonthermal plasma technique was found to be useful in the cleanup of the stained surface, reduce the potency of the biological agents, and maintain the surface structure intact. Time-resolved Raman analysis on biological aerosols indicates the antigens were either vaporized or decomposed during the treatment. Optical emission spectroscopy, aerosol electrometer, and scanning mobility particle sizer were used to monitor the nanoparticles and charges emissions during the treatment of oil and CWA-contaminated surface. ELISA assay shows the reduction and or elimination of the antigens, although scanning electron microscopy indicates the morphology of the biological agents remain unchanged by the plasma treatment. The technique does not produce secondary pollutants, is fairly safe to material and reasonably easy to operate. The technique is not a line-of-sight technique therefore it can be used to remove effectively organic contaminants and bioaerosols on a range of complex surfaces.	Nonthermal plasma.	A radiofrequency-powered nonthermal plasma technique was applied to biological aerosols, oil and grease, and paint-stained airframe structural material.	TESTING NONTHERMAL PLASMA FOR DECONTAMINATION OF SENSITIVE WEAPON PLATFORMS AND SYSTEMS	Google Scholar	Operated at 200 W power, the temperature was about 160 °C at the source, and 110 °C at about 15mm distance from the source.	chemical or biological agents, thermal destruction
G	Medium	30	2010	N	Antimicrobial Agents: Synthesis, Spectral, Thermal, and Biological Aspects of a Polymeric Schiff Base and its Polymer Metal(II) Complexes	Some new coordination polymers of Mn(II), Co(II), Ni(II), Cu(II), and Zn(II) obtained by the interaction of metal acetates with polymeric Schiff base containing formaldehyde and piperazine have been investigated. Structural and spectroscopic properties have been studied by elemental, spectral (FT-IR, ¹ H-NMR, and UV-Vis), and thermogravimetric analysis. UV-Vis spectra and magnetic moments indicate that Mn(II), Co(II), and Ni(II) polymer metal complexes are octahedral, while Cu(II) and Zn(II) polymer metal complexes are square planar and tetrahedral, respectively. All compounds were screened for their antimicrobial activities against <i>Escherichia coli</i> , <i>Bacillus subtilis</i> , <i>Staphylococcus aureus</i> , <i>Pseudomonas aeruginosa</i> , <i>Salmonella typhi</i> , <i>Candida albicans</i> , <i>Agelastes niger</i> , and <i>Microsporum canis</i> using the Agar well diffusion method with 100 mg/ml of each compound.	Antimicrobial properties of polymers of Mn(II), Co(II), Ni(II), Cu(II), and Zn(II) obtained by the interaction of metal acetates.	<i>Escherichia coli</i> , <i>Bacillus subtilis</i> , <i>Staphylococcus aureus</i> , <i>Pseudomonas aeruginosa</i> , <i>Salmonella typhi</i> , <i>Candida albicans</i> , <i>Agelastes niger</i> , and <i>Microsporum canis</i> .	NA	SCISEARCH	chemical or biological agents, thermal destruction	
G	Medium	30	2009	N	Decantamination of Chemical Warfare Agents by Photocatalysis	Photocatalysis has been widely applied to solar-energy conversion and environmental purification. Photocatalytic, typically titanium dioxide (TiO ₂), produces active oxygen species under irradiation of ultraviolet light, and can decompose not only conventional pollutants but also different types of hazardous substances at mild conditions. We have recently started the study of photocatalytic decantamination of chemical warfare agents (CWAs) under collaboration with the National Research Institute of Police Science. This article reviews environmental applications of semiconductor photocatalysis, decantamination methods for CWAs, and previous photocatalytic studies applied to CWA degradation, together with some of our results obtained with CWAs and their simulant compounds. The data indicate that photocatalysis, which may not always give a striking power, certainly helps detoxification of such hazardous compounds. Unfortunately, there are not enough data obtained with real CWAs due to the difficulty in handling. We will add more scientific data using CWAs in the near future to develop useful decantamination systems that can reduce the damage caused by possible terrorism.	Semiconductor photocatalysis, decantamination methods for CWAs.	Chemical warfare agents.	NA	Google Scholar	chemical or biological agents, thermal destruction	
G	Medium	30	2009	N	Decantamination of the Chemical Warfare Agent Simulant Dimethyl Methylphosphonate by Means of Large-Area Low-Temperature Atmospheric Pressure Plasma	Dimethyl methylphosphonate (DMMP), a chemical simulant of the nerve gas GB, was decantaminated with a nonthermal atmospheric pressure plasma. The decantamination efficiency was measured qualitatively by means of Fourier transform spectroscopy and quantitatively by means of gas chromatography. With helium gas only, 10 g/m ² of DMMP on an aluminum surface was 99.9% decantaminated in 2 min, furthermore, with the addition of 5% of oxygen gas, it was 99.99% decantaminated in 10 min. Given the low input power (<100 W) and temperature (<75 °C), this plasma is eligible for nondestructive decantamination of almost all material surfaces.	A nonthermal atmospheric pressure plasma (input power: <100 W) and temperature (<75 °C).	Aluminum surfaces.	NA	Google Scholar	chemical or biological agents, thermal destruction	
Q	Medium	30	2007	N	Process for Non-Incineration Decantamination of Hazardous Agents	A process for the low temperature, non-incineration decantamination of contaminated materials, such as chemical weapon components containing residual quantities of chemical warfare agents. The process includes the steps of (a) contacting the contaminated materials with steam at substantially ambient pressure in a substantially dry first heated vessel for a period of at least about 15 minutes, the steam being at a temperature of at least about 560° C, (b) removing condensable and non-condensable gases from the first heated vessel and heating them in a second vessel at substantially ambient pressures to temperatures of at least about 500° C, for a period of at least about one second in an atmosphere containing steam, and (c) catalytically treating non-condensable gases from the second vessel in the presence of oxygen so as to reduce the concentration of chemical warfare agents to less than about 1.0 mg/m ³ at standard temperature and pressure.	Multi-stage steam treatment up to 560 °C.	Contaminated materials, such as chemical weapon components containing residual quantities of chemical warfare agents.	NA	Google Scholar	chemical or biological agents, thermal destruction	
G	Medium	30	1999	N	Decantamination of Chemical and Biological Warfare (CBW) Agents Using an Atmospheric Pressure Plasma Jet (APPJ)	The atmospheric pressure plasma jet (APPJ) is a nonthermal, high pressure, uniform glow plasma discharge that produces a high velocity effluent stream of highly reactive chemical species. The discharge operates on a feedstock gas (e.g., He/O ₂ /H ₂ O), which flows between an outer, grounded, cylindrical electrode and an inner, coaxial electrode powered at 13.56 MHz rf. While passing through the plasma, the feed gas becomes excited, dissociated or ionized by electron impact. Once the gas exits the discharge volume, ions and electrons are rapidly lost by recombination, but the fast-flowing effluent still contains neutral metastable species (e.g., O ² , He [*]) and radicals (e.g., O, OH). This reactive effluent has been shown to be an effective neutralizer of surrogates for anthrax spores and mustard blister agent. Unlike conventional wet decantamination methods, the plasma effluent does not cause corrosion and it does not destroy wiring, electronics, or most plastics, making it highly suitable for decantamination of sensitive equipment and interior spaces. Furthermore, the reactive species in the effluent rapidly degrade into harmless products leaving no lingering residue or harmful by-products.	The atmospheric pressure plasma jet (APPJ).	The plasma effluent does not cause corrosion and it does not destroy wiring, electronics, or most plastics, making it highly suitable for decantamination of sensitive equipment and interior spaces.	NA	Google Scholar	chemical or biological agents, autoclave	
G	Medium	30	1998	N	A High-Level Computational Study on the Thermochemistry and Thermal Decomposition of Sulfur Mustard (2,2'-Dichlorodiethyl Sulfide): A Chemical Warfare Agent	The calcs. of enthalpies and free energies for various monomol. decomps. of sulfur mustard using G2(MP2) theory have shown that noncatalytic thermal destruction of this chemical warfare agent apparently is not feasible at temps. up to 1,800 K at least. Environmentally robust decomposition/destruction demands operating conditions in excess of 2,000 K to insure intrinsic safety in the absence of a catalyst. The preferable decomposition pathways involve C-C and C-S bond cleavages. The G2(MP2)-calculated enthalpy of formation of sulfur mustard is -36.86 kcal/mol for the lowest energy C2 configuration.	Noncatalytic thermal destruction.	Sulfur mustard.	NA	TOXCENTER	chemical or biological agents, destruction	
U	Medium	30	1998	N	Corona Discharge Plasma Reactor for Decantamination	The feasibility of using a gas phase corona plasma to sterilize objects from toxic battlefield, medical, and industrial environments was assessed. Plasma chemical processes can be highly effective in promoting oxidation, enhancing molecular dissociation, or producing free radicals to enhance chemical reaction. Until recently, plasma processes were applied in either the high temperature environment of arc plasmas, or at pressures low enough to give large active volumes with higher electron energies and lower gas temperatures. The evolution of the corona reactor has allowed atmospheric pressure applications of plasma processing at reduced power and low bulk gas temperature. We developed and demonstrated the use of a prototype low temperature, ambient pressure, corona discharge plasma reactor (CDPR), which generates photons, ionized molecules and other active species, to decompose toxic chemical and biological materials. The reactor was used to treat several different types of materials that were contaminated with chemical and biological agent simulants. The system's capacity for destroying these contaminants rapidly, effectively, and at a substantial energy savings was evaluated.	Gas phase corona plasma.	Objects from toxic battlefield, medical, and industrial environments.	NA	Google Scholar	chemical or biological agents, incineration	

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
G	Medium	29	2014	Y	Understanding Evaporation Characteristics of a Drop of Distilled Sulfur Mustard (HD) Chemical Agent from Stainless Steel and Aluminum Substrates	We report herein the evaporation rates and mechanism of a drop of distilled sulfur mustard (HD) agent from stainless steel and aluminum substrates. For systematic analysis, we used a laboratory-sized wind tunnel, thermal desorption (TD) connected to gas chromatograph/mass spectrometry (GC/MS) and drop shape analysis (DSA). We found that the evaporation rates of HD from stainless steel and aluminum increased with temperature. The rates were also linearly proportional to drop size. The time-dependent contact angle measurement showed that the evaporation of the drop of HD proceeded only by constant contact area mechanism from stainless steel surface. On the other hand, the evaporation of HD from aluminum proceeded by a combined mechanism of constant contact area mode and constant contact angle mode. Our experimental data sets and analysis could be used to predict vapor and contact hazard persistence of chemical warfare agents (CWAs) in the air and on exterior surfaces with chemical releases, which assists the military decision influencing personnel safety and decontamination of the site upon a chemical attack event.	Determined evaporation rates and mechanism of a drop of distilled sulfur mustard (HD) agent from metal substrates.	Stainless steel and aluminum substrates.	Understanding evaporation characteristics of a drop of distilled sulfur mustard (HD) chemical agent from stainless steel and aluminum substrates.	Google Scholar		Destruction or Decomposition or Incineration; Thermal or Heating or (Hot (w) (Temperature or Air)); Chemical or Biological Agent; Anthrax or Anthrax or Stearotherophilus ; HD or Mustard; Building or Soil or Carpet or (Ceiling (w) Tie); Concrete or Asphalt
G	Medium	29	2009	N	Escherichia Coli Deactivation Study Controlling the Atmospheric Pressure Plasma Discharge Conditions	Bio-applications of plasma have been widely studied in recent years. However, considering the high interests, the inactivation mechanisms of micro-organisms by plasma have not been clearly explained. The goal of this study was to find the sterilization mechanisms and define the major sterilization factors with the atmospheric pressure radio-frequency helium glow discharge. For the sterilization target the <i>Escherichia coli</i> was used. To begin with the sterilization study, the plasma characteristics were investigated by means of electrical and optical diagnostics. Especially, the gas temperature was controlled under 50 °C by keeping the input power less than 70 W to eliminate the thermal effects. Contribution of the UV irradiation from the plasma was studied and it turned out to be negligible. On the other hand, it was found that the sterilization was more effective up to 40% with only 0.15% oxygen addition to the helium supply gas. It indicates that the inactivation process was dominantly controlled by oxygen radicals, rather than heat or UV	Atmospheric pressure plasma radio-frequency helium glow discharge.	Sterilization of <i>Escherichia coli</i> .	NA	Google Scholar		chemical or biological agents, thermal destruction
R	Medium	29	1997	N	Destruction for Disposal of Chemical Warfare Agent VX by Blending with Lignin, Styrene and Azobisisobutyronitrile and Heating	Toxin of VX type is mixed with lignin, styrene and 2,2'-azobisisobutyronitrile, their mass ratio being 1: 0.5-0.7:3.1-3.0:0.04-0.06 respectively. This prepared reaction mass is heated to 135-145 °C and is allowed to stand by mixing at said temperature within 1.5-2.1 h. Then excess of styrene is removed, reaction mass is allowed to stand at 200-230 °C within 0.4-0.6 h and cooled. Hardened mass is affected by burying.	Destruction of chemical agents by blending with lignin, styrene and azobisisobutyronitrile and heating.	Chemical warfare agents.	NA	TOXCENTER	Russian patent.	chemical or biological agents, thermal destruction
G	Medium	28	1994	N	Clean-up of Chemical Warfare Agents on Soils Using Simple Washing or Chemical Treatment Processes	Several simple processes have been studied for the destruction of chemical agents, Soman and Mustard, on soils. A double wash or an extended single wash with water was effective in removing Mustard and Soman from soil; addition of either anionic or cationic surfactant did not improve removal efficiency. Soils with higher organic carbon content were more difficult to decontaminate. The most effective chemical process for the removal of Mustard was treatment with hypochlorite; treatment with Na2CO3 or NaOH were almost as effective as hypochlorite in cleaning Mustard contaminated soil. Soman was removed most effectively by treatment with Na2CO3. Overall the most efficient process for the destruction of both Mustard and Soman was treatment with Na2CO3 solution.	Washing or chemical processes.	Soils contaminated with Soman and Mustard agents.	NA	Google Scholar		chemical or biological agents, incineration
U	Medium	27	2011	N	Review of the MDF-LSA 100 Spray Decontamination System	DSTO were given a sample of the Modex Decontamination Foam (MDF)-LSA 100 Spray Decontamination System and two Force 1 Decon products (surfactant and sodium hypochlorite) to evaluate and determine their effectiveness against chemical warfare agents (CWAs). However a laboratory-based evaluation was not undertaken due to the age of the MDF-LSA 100 sample and therefore the sample's integrity. As a result this report was prepared to provide a general overview of the history of the MDF-LSA 100 Spray Decontamination System as well as information regarding the decontamination systems which have since superseded it. This report also aims to provide brief information on the two Force 1 Decon products. MDF-LSA 100, also referred to as DF-100 (Decontamination Foam -100), was the original decontamination formulation developed by Sandia National Laboratories (SNL) during the late 1990s, to provide the armed forces with a single decontaminant that would work effectively against all potential chemical and biological threats. However after testing, it became apparent that the original formulation was less than ideal as it required the pH to be adjusted for optimal decontamination of each specific chemical and biological agent and the formulation was found to degrade sulfur mustard at a relatively slow rate. In late 2000, an enhanced version of the DF-100 was developed, called DF-200 or MDF-LSA 200, which took into account the aforementioned problems.	Chemical decontamination foams (surfactant and sodium hypochlorite).	NA	NA	Google Scholar	Technical report.	chemical or biological agents, thermal destruction
P	Medium	27	2004	N	Development of Novel Alternative Technologies for Decontamination of Warfare Agents: Electric Heating with Intrinsically Conductive Polymers	So far, all the systems developed for detoxification and decontamination of chemical and biological weapons have been based on the use of chemical or biological agents. Here, we have demonstrated a novel, simple, non-chemical/biological, multipurpose, re-usable, low-cost, alternative technology for decontamination based on electric heating with conducting polymers. The basic concept is that electrically conducting polymers, such as polyaniline, can be used as coatings or fabrics on military equipment (e.g., tanks, personnel carriers, artillery pieces, etc.) and installations (e.g., buildings and other structures), and that the conducting polymers function as heating elements to convert applied electric energy to thermal energy, which would raise the surface temperature of the coatings and fabrics high enough to thermally decompose the chemical or biological warfare agents on the equipment or installations. This concept has been established by the fact that applying household alternating current to the polyaniline-coated panels resulted in a rapid increase in the surface temperature to 120-180 degrees Celsius in a few minutes. The system is very easy to fabricate and re-usable and can undergo several heating-cooling cycles without significant damage.	Electric heating with intrinsically conductive polymers (120-180 degrees Celsius in a few minutes).	Polyaniline, can be used as coatings or fabrics on military equipment (e.g., tanks, personnel carriers, artillery pieces, etc.) and installations (e.g., buildings and other structures); and that the conducting polymers function as heating elements to convert applied electric energy to thermal energy to thermally decompose the chemical or biological warfare agents on the equipment or installations.	NA	Google Scholar		chemical or biological agents, thermal destruction
Q	Medium	27	2003	N	Reactive Decontamination Formulation	The present invention provides a universal decontamination formulation and method for detoxifying chemical warfare agents (CWA's) and biological warfare agents (BWA's) without producing any toxic by-products, as well as, decontaminating surfaces that have come into contact with these agents. The formulation includes a sorbent material or gel, a peroxide source, a peroxide activator, and a compound containing a mixture of KH505, KH504 and K2504. The formulation is self-decontaminating and once dried can easily be wiped from the surface being decontaminated. A method for decontaminating a surface exposed to chemical or biological agents is also provided.	Chemical decontamination process.	Surfaces that have come into contact with chemical and biological warfare agents.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Medium	27	2002	N	Routes of Photocatalytic Destruction of Chemical Warfare Agent Simulants	Selected imitants of chemical warfare agents such as dimethyl methylphosphonate (DMMP), diethyl phosphoramidate (DEPA), pinacolyl methylphosphonate (PMP), butylmethylsulfonate (BAET) were subjected to photocatalytic and sonophotocatalytic treatment in aqueous suspensions of TiO2. Complete conversion of the same mass of imitants to inorganic products was obtained within 600 min for DMMP, DEPA, PMP, but required a longer time for BAET. Sonolysis accelerated photodegradation of DMMP. No degradation was observed without ultraviolet illumination. Final products of degradation were PO43-, CO2 for DMMP and PMP; PO43-, NO3- (25%), NH4+ (75%), CO2 for DEPA, and SO42-, NH4+, CO2 for BAET. The number of main detected intermediate products increases in the order DMMP (7), DEPA (8), PMP (21), and exceeds 34 for BAET. Degradation of DMMP mainly proceeds through consecutive oxidation of methoxy groups and then the methyl group. Dimethyl hydroxymethylphosphonate and dimethylphosphonate testify to the parallel oxidation of the methyl group. Destruction of DEPA mainly starts with cleavage of the P-NH2 bond to form diethyl phosphate, which transforms further into ethyl phosphate. Oxidation of α and β carbons of ethoxy groups to form ethylphosphonoamide, hydroxyethyl ethylphosphonoamide and other products also contributes to the destruction. Photocatalytic degradation of PMP mainly starts with oxidation of the pinacolyl fragment, methylphosphonic acid and acetone being the major products. Oxidation of BAET begins with dark dimerization to disulfide, which undergoes oxidation of sulfur forming sulfonic and sulfonic acids as well as oxidation of carbons to form butanal, aminobutane, etc., and cyclic products such as 2-propylthiazole. A scheme of degradation was proposed for DMMP and DEPA, and starting routes for PMP and BAET. Quantum efficiencies of complete mineralization calculated as reaction rate to photon flux ratio	Photocatalytic and sonophotocatalytic treatment in aqueous suspensions of TiO2.	Aqueous suspensions of chemical warfare simulants,	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Medium	27	1999	Y	Plasma Jet Takes Off	NA	Atmospheric Pressure Plasma Jet (APPJ).	The APPJ has been tested against <i>Bacillus globigii</i> as a surrogate for <i>Bacillus anthracis</i> (the organism that causes anthrax), resulting in the destruction of 1.0 million bacterial spores in 30	Plasma Jet Takes Off	Google Scholar		chemical or biological agents, thermal destruction

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R	Medium	27	1997	N	Thermal Decomposition of Chemical Warfare Agents Contained in a Shell and Means for Pyrolysis of the Entire Shell	The shell, from which the explosives have been removed, is autoclaved at a temperature and for a time suitable to pyrolyze the contents. The method is especially suitable for pyrolysis of VX, soman, and similar materials.	Autoclave.	Munition shells containing VX, soman, and similar materials.	NA	TOXCENTER	French patent.	Destruction or Decomposition or Incineration; Thermal or Heating or (Hot (w) (Temperature or Air)); Chemical or Biological Agent; Anthracis or Anthrax or Stearotherophilus ; HD or Mustard; Building or Soil or Carpet or (Ceiling (w) Tile); Concrete or Asphalt
G	Medium	26	2012	N	Sterilization and Decontamination of Surfaces by Plasma Discharges	This chapter discusses the possible application of non-equilibrium plasma discharges for the sterilization and decontamination of surfaces. First, the basic properties of electrical discharges are reviewed and a survey of different methods of plasma generation both at atmospheric pressure and reduced pressures is provided. The chapter subsequently discusses the interactions of plasma with diverse biological systems such as bacteria and bacterial spores, endotoxins and proteins.	Non-equilibrium plasma discharges.	Sterilization and decontamination of surfaces.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Medium	26	2004	N	Thermal Conversion of Chemical Weapon	There is offered the method of chemical weapon conversion consisting in two-stage destruction. On the first stage, destruction occurs under no-oxygen conditions. Further destruction (second stage) takes place in plasmatron with formation of orthophosphoric acid. Schematic circuit of the unit is presented.	On the first stage, destruction occurs under no-oxygen conditions. Further destruction (second stage) takes place in plasmatron with formation of orthophosphoric acid.	Chemical weapons.	NA	CAPLUS		Destruction or Decomposition or Incineration; Thermal or Heating or (Hot (w) (Temperature or Air)); Chemical or Biological Agent; Anthracis or Anthrax or Stearotherophilus ; HD or Mustard; Building or Soil or Carpet or (Ceiling (w) Tile); Concrete or Asphalt
U	Medium	26	1999	N	Using Thermal Decomposition for the Destruction of Chemical Weapons	The purpose of this study is to show that low-pressure pyrolysis can be a suitable industrial technique to destroy the chems. which are contained in unexploded ammunition produced during the First World War. For this, an exptl. study has been performed at the laboratory scale. This paper presents the results obtained for chloropicrin, diphogene, and phosgene at temps. ranging between 100 and 530 °C, at an initial pressure of 25 Torr (3.29 kPa), and for reaction times ranging from 10 to 120 min. Under these conditions, chloropicrin and diphogene are completely decomposed to form phosgene as the main carbon-containing product. Simulations show that a quasi-total destruction of phosgene should be obtained above 700 °C. The possible industrial use of the process and the related hydrodynamic and thermal problems are discussed.	Low-pressure pyrolysis.	Chloropicrin, diphogene, and phosgene.	NA	CAPLUS	Conference paper.	Destruction or Decomposition or Incineration; Thermal or Heating or (Hot (w) (Temperature or Air)); Chemical or Biological Agent; Anthracis or Anthrax or Stearotherophilus ; HD or Mustard; Building or Soil or Carpet or (Ceiling (w) Tile); Concrete or Asphalt
U	Medium	26	1995	N	Chemistry of Destroying Chemical Warfare Agents in Flame. Technical Project Report, April 1994 May 1995.	The goal of the research is to increase our understanding of flame chemistry of organophosphorus compounds (OPC). This class of chemicals includes chemical warfare agents. (CWAs) such as the nerve agents GB GD and VX, stockpiles of which in the United States and Former Soviet Union are scheduled for destruction by incineration or other technologies. Although high CWA destruction efficiency has been demonstrated in incinerator tests in the U.S. it is necessary to improve technology for achievement higher efficiency and lower level of pollutants. The knowledge of detailed destruction chemistry of the CWA and simulants can be obtained by studying the structure of flames, doped with simulants and CWA and by the development of the combustion model which will include the chemical mechanism of destroying CWA in flame. Alkyl phosphates and alkyl phosphonates are typical organophosphorus compounds, that are simulants of sarin.	Incineration and development of a combustion model for CWA.	Studying the structure of flames, doped with simulants and CWA.	NA	Google Scholar	Technical project report.	chemical or biological agents, incineration
S	Medium	26	1975	Y	Effects of Ultra-High Temperatures on <i>Bacillus Subtilis</i> var. <i>Niger</i> Spore Aerosols as a Function of Relative Humidity	NA	Thermal sterilization of <i>BACILLUS SUBTILIS</i> VAR. <i>NIGER</i> SPORE aerosols.	Bacterial spores.	Effects of Ultra-High Temperatures on <i>Bacillus Subtilis</i> Var. <i>Niger</i> Spore Aerosols as a Function of Relative Humidity	Google Scholar	The objective of this investigation were to determine: (1) the mathematical relationship between the exposure time required to give a 90% reduction in a know gas-borne microbial population (D value) and the temperature over a range of 300-1,100°F(149-533°C); (2) the effect of variations in the moisture content of the carrier gas on this time/temperature relationship; and (3) the role, if any, that sub-lethal heat injury plays in the apparent population reductions observed at various temperatures.	chemical or biological agents, thermal destruction
G	Medium	25	2012	N	Photocatalytic Decontamination of Sulfur Mustard Using Titania Nanomaterials	Photocatalytic decontamination of sulfur mustard (HD) was studied on titania nanomaterials, and data obtained with irradiation of sunlight and UV-A light was compared with that obtained without irradiation. Role of particle size on photocatalytic decontamination of HD was also investigated. Decontamination efficiency was found to decrease when particle size was increased from 11 nm to 1000 nm. TiO2 nanoparticles of ~11 nm size of anatase phase exhibited superior decontamination properties relative to larger ones. 100% of HD was decontaminated on their surface within 6 h with irradiation of light. Without irradiation only 24.7% of HD was found to be decontaminated. GC-MS data indicated decontamination of HD to acetaldehyde, carbon dioxide, sulfur mustard sulfoxide, thiodiglycol, acetic acid, etc. due to photocatalysis. Without irradiation only hydrolysis products of HD like thiodiglycol were observed to be formed.	Photocatalytic decontamination of sulfur mustard (HD).	Sulfur mustard (HD) on titania nanomaterials.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Medium	25	2010	N	Test Method and Simple Analysis Model for Off-Gassing Studies of Military-Relevant Surfaces Contaminated with Chemical Warfare Agent Simulants	This study was conducted to develop methods for testing off-gassing from select military-relevant surfaces and to establish a model for predicting off-gassing from a broad range of such surfaces. Vapor contaminated surfaces were investigated by exposing representative field materials to chemical warfare agent (CWA) simulants, and then monitoring the off-gassing concentration as a function of time. Concrete, plastic, wood, steel and latex paint surfaces were contaminated with triethyl phosphate, 4-chlorobutyl acetate, 3-hepten-2-one, trimethyl phosphate, and 2-isobutyl-3-methoxyprazine. The testing process and simple analysis model provide test and analysis methods that will be used to test agent off-gassing and can serve as a standard for vapor hazard testing following vapor exposure. Use of the simple model was justified, based on analyses of the measured off-gassing trends and the predicted trends of interaction between each compound and each surface.	Simple model was employed, based on analyses of the measured off-gassing trends and the predicted trends of interaction between each compound and each surface.	Concrete, plastic, wood, steel and latex paint surfaces were contaminated with triethyl phosphate, 4-chlorobutyl acetate, 3-hepten-2-one, trimethyl phosphate, and 2-isobutyl-3-methoxyprazine.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Medium	25	2009	N	Thermal Effects on Bacterial Bioaerosols in Continuous Air Flow	Exposure to bacterial bioaerosols can have adverse effects on health, such as infectious diseases, acute toxic effects, and allergies. The search for ways of preventing and curing the harmful effects of bacterial bioaerosols has created a strong demand for the study and development of an efficient method of controlling bioaerosols. We investigated the thermal effects on bacterial bioaerosols of <i>Escherichia coli</i> and <i>Bacillus subtilis</i> by using a thermal electric heating system in continuous air flow. The bacterial bioaerosols were exposed to a surrounding temperature that ranged from 20 °C to 700 °C for about 0.3 s. Both <i>E. coli</i> and <i>B. subtilis</i> vegetative cells were rendered more than 99.9% inactive at 160 °C and 350 °C of wall temperature of the quartz tube, respectively. Although the data on bacterial injury showed that the bacteria tended to sustain greater damage as the surrounding temperature increased, Gram-negative <i>E. coli</i> was highly sensitive to structural injury but Gram-positive <i>B. subtilis</i> was slightly more sensitive to metabolic injury. In addition, the inactivation of <i>E. coli</i> endotoxins was found to range from 9.2% (at 200 °C) to 82.0% (at 700 °C). However, the particle size distribution and morphology of both bacterial bioaerosols were maintained, despite exposure to a surrounding temperature of 700 °C. Our results show that thermal heating in a continuous air flow can be used with short exposure time to control bacterial bioaerosols by rendering the bacteria and endotoxins to a large extent inactive. This result could also be useful for developing more effective thermal treatment strategies for use in air purification or sterilization systems to control bioaerosols.	Thermal electric heating system in continuous air flow.	Air sterilization of bacteria.	NA	Google Scholar		Destruction or Decomposition or Incineration; Thermal or Heating or (Hot (w) (Temperature or Air)); Chemical or Biological Agent; Anthracis or Anthrax or Stearotherophilus ; HD or Mustard; Building or Soil or Carpet or (Ceiling (w) Tile); Concrete or Asphalt

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G	Medium	25	2005	N	Photoassisted Reaction of Chemical Warfare Agent VX Droplets Under UV Light Irradiation	A photoassisted reaction of O-ethyl S-[2-(diisopropylamino) ethyl] methylphosphonothioate (VX) droplets in air was carried out. The experimental results indicated that VX droplets could be easily and chemically transformed into other compounds under irradiation of a germicidal lamp over sufficient time. Quantum chemical calculation results demonstrated that UV light less than 278 nm wavelength could possibly initiate photoreaction of VX and that both P-S and P-O bonds in the VX molecule were lengthened. The identification of reaction products by gas and liquid chromatography mass spectroscopy and NMR revealed that the VX molecule in air under UV light irradiation could undergo isomerization of S-esters to O-esters, cleavage of P-S, S-C, and C-H bonds, and ozonation of tertiary amines.	Irradiation with a germicidal lamp at a wavelength of less than 278 nm.	O-ethyl S-[2-(diisopropylamino) ethyl] methylphosphonothioate (VX) droplets in air.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Medium	25	2005	N	Photoassisted Reaction of Sulfur Mustard Under UV Light Irradiation	The photoassisted reaction of sulfur mustard (HD) in both the vapor and droplet states under UV light irradiation was investigated. It was found that HD molecules in either the gas or the condensed phase could be easily converted into other chemicals under the irradiation of a germicidal lamp. The products detected under reaction suggested that the photoassisted reaction of HD molecules in the gas phase produced a kind of nontoxic heavy polymer, and this method seemed to be applicable for decontamination of air. Nevertheless, the photoassisted reaction of HD droplets would produce a series of products containing -SCH ₂ CH ₂ Cl or -OCH ₂ CH ₂ Cl groups, some of which were proven to be even more toxic than HD. Therefore, it was not an effective method for the decontamination of HD droplets. The obtained experimental results would indicate that two possible pathways might be involved in the destruction of HD molecules: (1) HD molecules may undergo a photochemical reaction upon absorbing photons of sufficient energy, which leads to cleavage of the C-S bond in HD molecules at the primary step, or (2) HD molecules could be oxidized by the photogenerated ozone.	UV light irradiation.	Sulfur mustard (HD) in both the vapor and droplet form.	NA	Google Scholar		chemical or biological agents, thermal destruction
Q	Medium	25	2002	N	Oxidizer Gels for Detoxification of Chemical and Biological Agents	A gel composition containing oxidizing agents and thickening or gelling agents is used to detoxify chemical and biological agents by application directly to a contaminated area. The gelling agent is a colloidal material, such as silica, alumina, or aluminosilicate clays, which forms a viscous gel that does not flow when applied to tilted or contoured surfaces. Aqueous or organic solutions of oxidizing agents can be readily gelled with less than about 30% colloidal material. Gel preparation is simple and suitable for field implementation, as the gels can be prepared at the site of decontamination and applied quickly and uniformly over an area by a sprayer. After decontamination, the residue can be washed away or vacuumed up for disposal.	A gel composition containing oxidizing agents and thickening or gelling agents.	Field implementation, applied with a sprayer.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Low	24	2011	N	Application of a Flow-Through Catalytic Membrane Reactor (FTCMR) for the Destruction of a Chemical Warfare Simulant	In this study the flow-through catalytic membrane reactor (FTCMR) concept is applied in the thermal oxidation of a chemical warfare simulant, namely dimethyl methylphosphonate (DMMP), in air. Preliminary experiments under different DMMP feed concentrations and reactor temperatures (373–573 K) have demonstrated the potential advantages of the FTCMR concept in the catalytic oxidation of DMMP. Complete destruction of various concentrations of DMMP in air was achieved at lower temperatures, with the FTCMR showing superior performance when compared to a wall-coated, plug-flow reactor (monolith) containing the same amount of catalytic metal. A mathematical model has also been developed in order to provide a better understanding of the fundamental transport phenomena underpinning the FTCMR operation. The model makes use of the Dusty-Gas formulation of transport, and incorporates continuum and Knudsen diffusion, as well as viscous flow as the mechanisms for gas transport through the porous membrane. The model is used for identifying the advantages of the FTCMR concept in comparison with the wall-coated catalytic monolith, and also for investigating some of the limitations, which may exist in applying this concept for the complete oxidation of chemical warfare simulants. The results of the model support the superiority of the FTCMR concept over the more conventional plug-flow monolith reactor.	Flow-through catalytic membrane reactor (FTCMR).	Thermal oxidation (373–573 K) of a chemical warfare simulant, dimethyl methylphosphonate (DMMP), in air.	NA	Google Scholar		chemical or biological agents, thermal destruction
G	Low	24	2010	Y	Chemical, Biological, Radiological, and Nuclear Decontamination: Recent Trends and Future Perspective	Chemical, biological, radiological, and nuclear (CBRN) decontamination is the removal of CBRN material from equipment or humans. The objective of the decontamination is to reduce radiation burden, salvage equipment, and materials, remove loose CBRN contaminants, and fix the remaining in place in preparation for protective storage or permanent disposal work activities. Decontamination may be carried out using chemical, electrochemical, and mechanical means. Like materials, humans may also be contaminated with CBRN contamination. Changes in cellular function can occur at lower radiation doses and exposure to chemicals. At high dose, cell death may take place. Therefore, decontamination of humans at the time of emergency while generating bare minimum waste is an enormous task requiring dedication of large number of personnel and large amount of time. General principles of CBRN decontamination are discussed in this review with emphasis on radiodecontamination.	General principles of CBRN decontamination are discussed (chemical, electrochemical, and mechanical).	Chemical, biological, radiological, and nuclear decontamination of materials.	NA	Google Scholar		chemical or biological agents, destruction
G	Low	24	2010	Y	Microwave Assisted Nanofibrous Airfiltration for Disinfection of Bioaerosols	Airborne biological agents, albeit intentionally released or naturally occurring, pose one of the biggest threats to public health and security. In this study, a microwave assisted nanofibrous air filtration system was developed to disinfect air containing airborne pathogens. Aerosolized <i>E. coli</i> vegetative cells and <i>B. subtilis</i> endospores, as benign surrogates of pathogens, were collected on nanofibrous filters and treated by microwave irradiation. Both static on-filter and dynamic in-flight tests were carried out. Results showed that <i>E. coli</i> cells were efficiently disinfected in both static and in-flight tests, whereas <i>B. subtilis</i> endospores were more resistant to this treatment. Microwave power level was found to be the major factor determining the effectiveness of disinfection. Both thermal and non-thermal effects of microwave irradiation contributed to the disinfection. Reducing flow velocity to decrease heat loss yielded	A microwave assisted nanofibrous airfiltration.	Disinfected air containing airborne pathogens. Aerosolized <i>E. coli</i> vegetative cells and <i>B. subtilis</i> endospores, as benign surrogates of pathogens.		Google Scholar		chemical or biological agents, thermal destruction
G	Low	24	2007	N	Chemical Warfare Agent Degradation and Decontamination	The decontamination of chemical warfare agents (CWA) from structures, environmental media, and even personnel has become an area of particular interest in recent years due to increased homeland security concerns. In addition to terrorist attacks, scenarios such as accidental releases of CWA from U.S. stockpile sites or from historic, buried munitions are also subjects for response planning. To facilitate rapid identification of practical and effective decontamination approaches, this paper reviews pathways of CWA degradation by natural means as well as those resulting from deliberately applied solutions and technologies; these pathways and technologies are compared and contrasted. We then review various technologies, both traditional and recent, with some emphasis on decontamination materials used for surfaces that are difficult to clean. Discussion is limited to the major threat CWA, namely sulfur mustard (HD, bis(2-chloroethyl)sulfide), VX (O-ethyl S-[2-(diisopropylamino)ethyl] methylphosphonothioate), and the G-series nerve agents. The principal G-agents are GA (tabun, ethyl N,N-dimethylphosphoramidate), GB (sarin, isopropyl methylphosphonofluoridate), and GD (soman, pinacolyl methylphosphonofluoridate). The chemical degradation pathways of each agent are outlined, with some discussion of intermediate and final degradation product toxicity. In all cases, and regardless of the CWA degradation pathway chosen for decontamination, it will be necessary to collect and analyze pertinent environmental samples during the treatment phase to confirm attainment of clearance levels.	This paper reviews pathways of CWA degradation by natural means as well as those resulting from deliberately applied solutions and technologies; these pathways and technologies are compared and contrasted.	Discussion is limited to the major threat CWA on surfaces, namely sulfur mustard (HD, bis(2-chloroethyl)sulfide), VX (O-ethyl S-[2-(diisopropylamino)ethyl] methylphosphonothioate), and the G-series nerve agents.	NA	Google Scholar		chemical or biological agents, destruction
G	Low	24	2004	N	Comparative Study on Photocatalytic Oxidation of Four Organophosphorus Simulants of Chemical Warfare Agents in Aqueous Suspension of Titanium Dioxide	Photocatalytic oxidation by oxygen of air was carried out for dimethyl methyl phosphonate (DMMP), trimethyl phosphate (TMP), triethyl phosphate (TEP), and diethyl phosphonate (DEPA) in different concentration. The initial rate of organophosphorus compounds consumption increases with the initial concentration at relatively low concentrations but decreases at higher initial concentrations. If the concentration is higher than the concentration in maximum, the rate decreases because of the lack of adsorbed oxygen. These summit-like dependences are well approximated by one site Langmuir-Hinshelwood equation with competitive adsorption of oxygen and organophosphorus compound. Parameters of the Langmuir-Hinshelwood equation are reported. Complete mineralization of the organophosphorus compounds at the end of reaction was evidenced by the total organic carbon concentration profiles. These profiles have sigmoidal shape. GC-MS technique was used to identify intermediates of TEP and TMP oxidation. The main intermediates are dimethyl phosphate and methyl phosphate in the case of TMP and diethyl phosphate and ethyl phosphate in the case of TEP. The set of intermediates shows that photocatalytic oxidation proceeds primarily at a carbon atoms of TEP. The distribution of intermediates corroborates that photocatalytic oxidation is initiated by reaction with hydroxyl radicals.	Photocatalytic oxidation by oxygen of air.	Dimethyl methyl phosphonate (DMMP), trimethyl phosphate (TMP), triethyl phosphate (TEP), and diethyl phosphonate (DEPA) at different concentrations.	NA	Google Scholar		chemical or biological agents, destruction
G	Low	24	2004	N	Solubility of Chemical Warfare Agent Simulants in Supercritical Carbon Dioxide: Experiments and Modeling	Solubility data are reported for ethyl phenyl sulfide (EPS) and 2-chloroethyl ethyl sulfide (CEES) in CO ₂ at temperatures from 25 to 100°C. These two sulfide-based compounds are homomorphous chemical warfare agents (CWAs). Both sulfide-CO ₂ mixtures exhibit type I phase behavior. The maximum in the 100°C isotherm is approximately 2,600 psia for the CEES-CO ₂ system and approximately 3,400 psia for the EPS-CO ₂ system. The Peng-Robinson equation of state (PREOS) is used to model both sulfide-CO ₂ mixtures as well as the phase behavior of the 2-chloroethyl methyl sulfide (CEMS)-CO ₂ system previously reported in the literature. The Joback-Lydersen group contribution method is used to estimate the critical temperature, critical pressure, and acentric factor for the sulfides. Semi-quantitative estimates of the phase behavior are obtained for the CEES-CO ₂ and EPS-CO ₂ systems with a constant value of k _{ij} , the binary interaction parameter. It is the 75°C isotherm. However, very poor fits are obtained for the 2-chloroethyl methyl sulfide-CO ₂ system regardless of the value of k _{ij} . On the basis of the high solubility of EPS and CEES in CO ₂ , supercritical fluid (SCF)-based technology could be used to recycle or recover chemical warfare materials.	Solubility data are reported for ethyl phenyl sulfide (EPS) and 2-chloroethyl ethyl sulfide (CEES) in CO ₂ at temperatures from 25 to 100°C.	The maximum solubility in the 100°C isotherm is approximately 2,600 psia for the CEES-CO ₂ system and approximately 3,400 psia for the EPS-CO ₂ system.	NA	Google Scholar		chemical or biological agents, thermal destruction
N	Low	24	1993	N	Alternative Technologies for the Destruction of Chemical Agents and Munitions	The U.S. Army Chemical Stockpile Disposal Program was established with the goal of destroying the nation's stockpile of lethal unitary chemical weapons. Since 1990 the U.S. Army has been testing a baseline incineration technology on Johnston Island in the southern Pacific Ocean. Under the planned disposal program, this baseline technology will be imported in the mid to late 1990s to continental United States disposal facilities; construction will include eight stockpile storage sites. In early 1992 the Committee on Alternative Chemical Demilitarization Technologies was formed by the National Research Council to investigate potential alternatives to the baseline technology. This book, the result of its investigation, addresses the use of alternative destruction technologies to replace, partly or wholly, or to be used in addition to the baseline technology. The book considers principal technologies that might be applied to the disposal program, strategies that might be used to manage the stockpile, and combinations of technologies that might be employed.	Incineration technology is the baseline technology on Johnston Island in the southern Pacific Ocean. This book addresses the use of alternative destruction technologies to replace, partly or wholly, or to be used in addition to the baseline technology.	Lethal unitary chemical weapons.	NA	Google Scholar		chemical or biological agents, destruction

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
U	Low	23	2006	N	Application of Atmospheric-Pressure Nonequilibrium Plasma in Air Decontamination	In atmospheric-pressure gas discharge system, silt discharge (SD), has been developed for the removing of biological and chemical contaminants from the ambient air. The system consists of multiple plasma grids stacked perpendicularly to the air flow. The performance of the system has been tested using the surrogates of biological and chemical warfare agents. The results of the biological testing will be presented. The experiments have been done using the "in-room" and "in-duct" scenarios, simulating the stand alone room air cleaner and the HVAC system. The efficacy of the system in removal of bacterial spores will be presented as a function of flow rate, discharge power, number of plasma grids, and concentration of the spores in the air. Sampling methods and associated challenges will be discussed. Silt discharge (SD) is a promising technology in air-cleaning. Its performance is comparable with and often exceeds that of the convective methods, such as dilution ventilation, filtration and ultraviolet germicidal irradiation. SD is an energy efficient, high performance, and low cost technology for air decontamination with potential uses in industry, health care and household applications	Atmospheric-pressure gas discharge system.	Biological and chemical contaminants from the ambient air.	NA	Google Scholar	Conference paper.	chemical or biological agents, destruction
G	Low	23	2001	N	Thermal Decomposition of Dimethyl Methylphosphonate over Manganese Oxide Catalysts	The thermal oxidative decomposition of dimethyl methylphosphonate (DMMP) has been studied over amorphous manganese oxide (AMO) and Al ₂ O ₃ -supported manganese oxide catalysts. The reaction was carried out using air as the oxidant at temperatures between 200 and 400°C. The highest reaction rates occurred with temperatures of 400°C. Gas chromatography (GC) was used to examine the reactant DMMP and other gas phase products. DMMP was found to oxidatively decompose over AMO and Al ₂ O ₃ -supported manganese oxide catalysts. The highest activity was observed using a catalyst prepared by precipitation of AMO on Al ₂ O ₃ . During the initial stages of reaction, DMMP was completely removed from the gas phase. During this period DMMP was oxidized to CO ₂ , with no other gas phase products being observed. After a certain period of time (5 min–8 h), DMMP reappeared in the gas phase. The CO ₂ concentration then decreased and MeOH began to form, indicative of hydrolysis of DMMP. These results indicate that deactivation of catalysts occurs due to adsorbed P-species. Fourier transform infrared (FTIR) spectroscopy and ion chromatography (IC) were used to examine adsorbed products on the surface of the catalysts. The IC analyses indicated that several products accumulate on the surface of the catalysts, including methyl methylphosphonate, methylphosphonic acid, and phosphoric acid. FTIR analyses showed that DMMP bonds strongly to Mn Lewis acid sites on the manganese oxide surface via phosphoryl oxygen. The bare Al ₂ O ₃ support was also examined in DMMP decomposition reactions and showed high activity, with 100% DMMP removal from the gas stream for over 15 h. The major products observed over Al ₂ O ₃ were dimethyl ether and MeOH. No CO ₂ was observed, indicating that DMMP is not oxidized over Al ₂ O ₃ . The GC, IC, and FTIR results suggest that DMMP is dissociatively adsorbed over Al ₂ O ₃ . Finally, the results for the thermal oxidation of DMMP over AMO are compared to results previously obtained using photo-assisted oxidative methods.	Thermal oxidative decomposition of dimethyl methylphosphonate (DMMP) has been studied over amorphous manganese oxide (AMO) and Al ₂ O ₃ -supported manganese oxide catalysts. The reaction was carried out using air as the oxidant at temperatures between 200 and 400°C.	A gas stream of dimethyl methylphosphonate (DMMP).	NA	Google Scholar		Destruction or Decomposition or Incineration; Thermal or Heating or (Hot (w) (Temperature or Air)); Chemical or Biological Agent; Anthrax or Stearotherophilus ; HD or Mustard; Building or Soil or Carpet or (Ceiling (w) Tile); Concrete or Asphalt
U	Low	20	2002	N	Destruction of Bacteria Using an Atmospheric-Pressure Dielectric Capillary Electrode Discharge Plasma	The interaction of plasmas with chemical and biological agents, in particular in the context of sterilization and decontamination has received much attention in recent years. Particular emphasis has been on the utilization of atmospheric-pressure plasmas as they do not require operation in costly vacuum enclosures and thus facilitate the convenient and low-cost treatment of large surface areas. However, atmospheric-pressure discharge plasmas are highly susceptible to instabilities and the generation and reliable maintenance of uniform, large-volume discharge plasmas at or near atmospheric pressure remain formidable challenges. A new concept to generate and maintain atmospheric-pressure plasmas over a wide range of operating conditions was developed at Stevens Institute of Technology and subsequently licensed to Plasma50 for development in various areas of applications. The atmospheric-pressure plasma is produced using a patented capillary dielectric electrode discharge concept that employs dielectric capillaries that cover one or both electrodes of the discharge reactor. The capillaries serve as plasma sources, which produce jets of high-intensity plasma at atmospheric pressure in a variety of carrier gases under the right operating conditions. Spore-forming bacteria, in particular bacteria of the genera <i>Bacillus</i> , among the most resistant microorganisms. The species <i>Bacillus subtilis</i> has received particular attention, as these bacteria are easy to grow in a reproducible fashion under chemically well-defined conditions. As a result, <i>Bacillus subtilis</i> has been the species of choice in many sterilization experiments in the past. In this paper, we report the first experiments aimed at the quantitative determination of the destruction of spore-forming bacteria, which are believed to be among the most resistant micro-organisms, using a novel atmospheric-pressure plasma shower reactor whose design utilizes a patented atmospheric-pressure dielectric capillary electrode discharge plasma. We established a straight forward protocol to prepare and characterize various bacteria including <i>Bacillus subtilis</i> on either glass or aluminum surface supports and analyze the samples after treatment by atmospheric-pressure plasma jets emanating from the plasma reactor using either in He or air (N/sub 2/O/sub 2/ mixture) as a carrier gas at varying power levels and exposure times. We used several <i>Bacillus subtilis</i> strains such as <i>Bacillus subtilis</i> var. niger ATCC 9372 in its three different colonial morphologies, <i>Bacillus subtilis</i> var. niger W 0235, and <i>Bacillus subtilis</i> W 0228 as prototypical examples of spore-forming bacteria. In some cases, we also used non-spore-forming bacteria (<i>Pseudomonas fluorescens</i> ATCC 1474) for selected experiments for reasons of comparison. We found significant reductions in colony-forming units ranging from 10 ¹⁰ /sub 4/ (He plasma) to 10 ¹⁰ /sub 8/ (air plasma) for plasma exposure times of less than 10 minutes. We also measured the UV/Vis absorption spectrum of the spore suspension before and after several minutes of plasma treatment. The UV absorption spectrum of a suspension of <i>Bacillus subtilis</i> showed a marked increase in the absorption of the plasma-treated sample below 300 nm with a local maximum around 260 nm. This is attributed to the presence of extracellular compounds that are released during the plasma treatment, most likely DNA, RNA, and proteins and thus verifies the destruction of the cell by the plasma. The utilization of our plasma device in other sterilization and decontamination applications is currently also being studied.	Atmospheric-pressure plasmas produced using a patented capillary dielectric electrode discharge.	Various bacteria including <i>Bacillus subtilis</i> on either glass or aluminum surface supports.	NA	Google Scholar	Conference paper.	chemical or biological agents, thermal destruction
Q	Low	18	2012	Y	Thermobaric Materials and Devices for Chemical/Biological Agent Defeat	A thermobaric self-sustaining reactive composition, method and device for defeating chemical or biological agents includes a first material including at least one of a Group IV or Group V metal; a second material reactive with the first material in an exothermic intermetallic reaction to generate heat sufficient to vaporize a third material; and the third material that when vaporized combusts with air producing an elevated temperature sufficient to destroy the chemical and biological agents. The device includes a container having a center core explosive driver with the self-sustaining reactive composition surrounding the center core explosive driver.	Exothermic intermetallic reaction to generate heat sufficient to destroy chemical and biological agents.	Materials contaminated with chemical and biological agents.	THERMOBARIC MATERIALS AND DEVICES FOR CHEMICAL BIOLOGICAL AGENT DEFEAT	Google Scholar		Destruction or Decomposition or Incineration; Thermal or Heating or (Hot (w) (Temperature or Air)); Chemical or Biological Agent; Anthrax or Anthrax or Stearotherophilus ; HD or Mustard; Building or Soil or Carpet or (Ceiling (w) Tile); Concrete or Asphalt
U	Low	14	2002	Y	Benefits of Dry Heat to Clean Structures of Biological Contamination and Improve Indoor Air Quality (IAQ)	Structures once compromised by biological contamination, e.g. toxic mold, can show significantly improved indoor air quality (IAQ) following heat treatment. Dry heat of 150 °C for 10 minutes effectively sterilizes most items of active biological agents, e.g., bacteria, fungi, etc. At 63 °C most insects, protozoa, bacteria, and fungi cease to function. Heat also neutralizes and oxidizes harmful chemicals produced by biological organisms. While 150 °C may be difficult to achieve when heating an entire structure, at least not without adversely affecting some architectural elements, heating a structure and its contents to 80 °C has its merits and is possible with today's technology. Moreover, holding a structure at 80 °C for 60 minutes not only kills most active biological agents, it accelerates the neutralization of many	Heat can be generated using thermal solar radiation, a building's heating ventilation and air conditioning (HVAC) system, portable electric-inductive heaters, lamps, etc. Portable fuel-fired heaters (burning natural gas, propane, or kerosene) can also generate	Building structures.	Benefits of Dry Heat to Clean Structures of Biological Contamination and Improve Indoor Air Quality	Google Scholar		chemical or biological agents, destruction
U	Low	9	2009	N	Aerosol Decontamination of Biological Warfare Agents for Complex Platform Interiors	NA	NA	Biological warfare agents on platform interiors.	NA	Google Scholar	Conference Paper.	chemical or biological agents, destruction
S	Low	24		Y	Laser ablation decontamination in liquid (LADIL)	Research Objective: The objective of this project is to develop a novel laser ablation in liquid technology for surface decontamination. It aims to achieve more efficient surface decontamination without secondary contamination. The major goals are as follows: 1. To develop novel Laser Ablation Decontamination in Liquid (LADIL) technology for safe removal of radioactive and/or toxic contaminants from a surface without producing dangerous secondary pollutants. 2. To obtain a data base for the basic physical processes of laser ablation on a solid-liquid interface and use the results of this basic study to improve the cleaning efficiency of surface-contaminated materials. 3. To optimize the cleaning process for efficient recycling of contaminated materials. 4. To evaluate the feasibility of LADIL for large	laser ablation decontamination in liquid	contaminated liquids - no mention of chemical or biological agents	Laser Ablation Decontamination in Liquid (LADIL).pdf	Google Scholar		chemical or biological agents, destruction
G	Medium	31	2001	N	Atmospheric-pressure plasma decontamination/sterilization chamber	An atmospheric-pressure plasma decontamination/sterilization chamber is described. The apparatus is useful for decontaminating sensitive equipment and materials, such as electronics, optics and national treasures, which have been contaminated with chemical and/or biological warfare agents, such as anthrax, mustard blistering agent, VX nerve gas, and the like. There is currently no acceptable procedure for decontaminating such equipment. The apparatus may also be used for sterilization in the medical and food industries. Items to be decontaminated or sterilized are supported inside the chamber. Reactive gases containing atomic and metastable oxygen species are generated by an atmospheric-pressure plasma discharge in a He/O ₂ mixture and directed into the region of these items resulting in chemical reaction between the reactive species and organic substances. This reaction typically kills and/or neutralizes the contamination without damaging most equipment and materials. The plasma gases are recirculated through a closed-loop system to minimize the loss of helium and the possibility of escape of aerosolized harmful substances.	atmospheric pressure plasma	electronics, optics, national treasures	Atmospheric-pressure plasma decontamination-sterilization chamber .url	Microsoft academic search		chemical or biological agents, destruction

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
U	Medium	33		Y	Destruction of bacteria using an atmospheric pressure dielectric capillary electrode discharge plasma	The interaction of plasmas with chemical and biological agents, in particular in the context of sterilization and decontamination has received much attention in recent years. Particular emphasis has been on the utilization of atmospheric-pressure plasmas as they do not require operation in costly vacuum enclosures and thus facilitate the convenient and low-cost treatment of large surface areas. However, atmospheric-pressure discharge plasmas are highly susceptible to instabilities and the generation and reliable maintenance of uniform, large-volume discharge plasmas at or near atmospheric pressure remain formidable challenges. A new concept to generate and maintain atmospheric-pressure plasmas over a wide range of operating conditions was developed at Stevens Institute of Technology and subsequently licensed to Plasmasol for development in various areas of application.	atmospheric pressure plasma	NA	Destruction of Bacteria Using an Atmospheric-Pressure Dielectric Capillary Electrode Discharge Plasma.pdf	Google Scholar		chemical or biological agents, destruction
G	Medium	33	1998	Y	Kinetic Model for the decomposition of DMMP in a Hydrogen-Oxygen Flame	A kinetic model of the combustion chemistry of a hydrogen/oxygen base flame, doped with dimethyl methylphosphonate, a useful simulant for chemical warfare agents (CWAs), has been developed to assist in the controlled thermal destruction of CWA stockpiles. Laser-ionization mass spectrometry is employed to record concentration profiles of radical intermediates in a low-pressure premixed laminar flame. These measurements, combined with ab initio estimates of thermochemical properties of organophosphorus compounds, lead to a kinetic model incorporating several key reaction intermediates, which include methyl metaphosphate CH3OP2, methyl diophosphonate CH3PO2, and monomethyl methylphosphonate PQ(OH)(CH3)(OCH3).	incineration	DMMP	Kinetic Model for the decomposition of DMMP in a Hydrogen Oxygen Flame.pdf	Google Scholar		chemical or biological agents, destruction
B	High	41	2004	Y	ADVANCED COMPUTER SIMULATIONS OF MILITARY INCINERATORS	Incineration is one of the technologies being used by the US Army to destroy the highly toxic chemical agents and munitions contained within the Chemical Weapons Stockpile. In this paper we describe a suite of models for conducting detailed simulations of chemical demilitarization incinerator operation. The models contain 3D furnace and canister geometries and all of the relevant physics and chemistry. The destruction of chemical agent is predicted using non equilibrium chemistry models. Models have been developed for a Liquid Incinerator, Metal Parts Furnace, and a Deactivation Furnace System. Using computational chemistry methods, chemical kinetics have been developed that describe the incineration of organo-phosphorus nerve agent (GB, VX) and sulfur mustard (H, HD, HT). The models have been used to study a variety of scenarios to develop a deeper understanding of furnace operation and agent destruction when processing munitions or equipment containing or contaminated by chemical agent. Model results demonstrate the incinerators to be robust systems that destroy chemical agent in a safe and efficient manner.	Development of a suite of models for simulating incineration of chemical weapons.	The simulation uses information on chemistry methods and kinetics for GB, VX, and sulfur mustard.	Advanced Computer Simulations of Military Incinerators.pdf	Source provided by EPA during conference call on 10/16/14.		chemical or biological agents, destruction
B	High	43	2008	Y	IMPROVED KINETIC MODELS FOR HIGH-SPEED COMBUSTION SIMULATION	Report developed under an STR contract. The overall goal of this STR project has been to improve the realism of chemical kinetics in computational fluid dynamics modeling of hydrocarbon-fueled scramjet combustors. A new, pressure-dependent detailed chemical kinetic model for a JP-8 surrogate has been created. Extinction strain rate measurements have been performed with an opposed jet burner at subatmospheric conditions for a variety of fuels, namely, methane, ethylene, n-heptane, Jet A, n-decane, trimethylbenzene, and blends of n-decane and trimethylbenzene. Skeletal and quasi-steady-state (QSS) reduced mechanisms have been created based on the new mechanism and mechanisms from the literature for ethylene, JP-8, and n-decane. Parallel strategies for the in situ adaptive tabulation (ISAT) algorithm have been implemented and tested. Reduced mechanisms and ISAT have been demonstrated in the	Study conducted to improve the chemical kinetics in CFD modeling.	hydrocarbon fuel.	IMPROVED KINETIC MODELS FOR HIGH_SPEED COMBUSTION SIMULATION.pdf	Source provided by EPA during conference call on 10/16/14.		chemical or biological agents, destruction
B	High	41	2008	Y	Destruction Chemistry of Mustard Simulants	This study investigates the destruction chemistry of organosulfur compounds under both pyrolytic and oxidative conditions. We focus on the destruction of alkyl sulfides that are surrogates for chemical warfare agents H, HD, and HT. We report our work on developing thermochemistry, reaction pathways and kinetic parameters for multiple chemical subsystems, using computational chemistry methods. We also report our experimental results from flow reactor experiments for pyrolysis and oxidation of two alkyl sulfides: diethyl sulfide and ethyl methyl sulfide. A detailed, elementary reaction, mechanism has been developed to describe the pyrolysis and oxidation chemistry relevant to these compounds.	Development of thermochemistry, reaction pathways and kinetic parameters for multiple chemical subsystems, using computational chemistry	Focus on the destruction of alkyl sulfides that are surrogates for chemical warfare agents H, HD, and HT.	Destruction Chemistry of Mustard Simulants.pdf	Source provided by EPA during conference call on 10/16/14.		chemical or biological agents, destruction
A	Medium	33	2001	Y	Guidelines for Mass Fatality Management During Terrorist Incidents Involving Chemical Agents	NA	Cremation of contaminated remains.	Mass fatalities from chemical weapon incident.	Guidelines for mass fatality management during terrorist incidents involving chemical agents	Google Scholar	This report assists emergency managers, medical examiners, and coroners to better prepare for and determine the best course of action for responding to a mass fatality situation following a chemical weapon of mass destruction (WMD)	Cremation, warfare agents, remains
U	Medium	26	2004	Y	Guidance on Dealing with Fatalities in Emergencies	NA	Cremation of contaminated remains.	Mass fatalities from emergencies.	Guidance on dealing with fatalities in emergencies	Google Scholar	British government document on procedures for dealing with mass fatalities.	Cremation, warfare agents, remains
S	Medium	31	2006	Y	Medical strategies to handle mass casualties from the use of biological weapons	This article reviews the definitions of biological weapons and mass casualties. In addition, it discusses the main operational and logistical issues of impact in the medical management of mass casualties from the use of biological weapons. Strategies for medical management of specific biologic agents also are highlighted.	Cremate contaminated remains.	Human remains.	Medical strategies to handle mass casualties from the use of biological weapons	Google Scholar		Cremation, warfare agents, remains
A	Medium	28	2004	Y	Mortuary Affairs - Is USNORTHCOM and the Department of Homeland Security Positioned for Contaminated Mass Fatality Management?	The Global War on Terrorism has emphasized homeland defense and security as a priority for the Nation. The United States Northern command (USNORTHCOM) recently attained its initial operational capability as the Department of Defense executive agent for Homeland Defense. Terrorists have demonstrated the ability and willingness to obtain and use Weapons of Mass Destruction to further their goals. An unfortunate reality of the use of such weapons is the creation of contaminated remains. The recovery, identification, and disposition of such remains, including their decontamination, falls within the scope of Mortuary Affairs. This is a hugely sensitive issue. As USNORTHCOM and the Department of Homeland Security grapple with their transition to lead Homeland Defense and Homeland Security agencies, a seam in policy and capabilities may exist. USNORTHCOM's ability to provide support to meet surge requirements for decontaminating and processing human remains is not articulated or properly sourced. This paper looks at the threat posed within the Nation's borders that requires a synchronized response by USNORTHCOM and the Department of Homeland Security. Policies, directives, and programs that highlight current government capability to handle domestic contaminated mortuary affairs incidents and potential seams are identified, and recommendations for potential policy, training requirements, and force structure are discussed.	Policies, directives, and programs that highlight current government capability to handle domestic contaminated mortuary affairs incidents and potential seams are identified, and recommendations for potential policy, training requirements, and force structure are discussed.	Contaminated remains.	NA	Google Scholar		Cremation, warfare agents, remains
A	Low	24	2003	Y	Emerging Concepts of Mortuary Affairs Doctrine for the 21ST Century War Fighter	NA	This is a review of the Department of Defense's (DoD) Mortuary Affairs program to determine if existing doctrine and planning is sufficient in the event the United States (US) is required to execute a wartime mortuary operation.	Contaminated remains.	Emerging Concepts of Mortuary Affairs Doctrine for the 21st Century War Fighter	Google Scholar		Cremation, warfare agents, remains
G	High	36	2009	Y	Safe Management of Mass Fatalities Following Chemical, Biological, and Radiological Incidents	Contaminated mass fatalities following the release of chemical, biological, or radiological agents pose a potential major health hazard. A United Kingdom government investigation has identified a number of areas of risk. This paper presents an outline of the findings of the study and describes specific pathways for the management of contaminated and non-contaminated fatalities. Factors determining the choice between cremation and burial are discussed. Effective decontamination remains a neglected area of study for both fatalities	Factors determining the choice between cremation and burial are discussed.	Describes specific pathways for the management of contaminated and non-contaminated fatalities.	Safe Management of Mass Fatalities Following Chemical, Biological, and Radiological Incidents	Google Scholar		Cremation, warfare agents, remains
G	Medium	26	2005	N	In-hospital Management of Victims of Chemical Weapons of Mass Destruction	Emergency situations caused by chemical weapons of mass destruction add a new dimension of risk to those handling and treating casualties. The fundamental difference between a hazardous materials incident and conventional emergencies is the potential for risk from contamination to health care professionals, patients, equipment and facilities of the Emergency Department. Accurate and specific guidance is needed to describe the procedures to be followed by emergency medical personnel to safely care for a patient, as well as to protect equipment and people. This review is designed to familiarize readers with the concepts, terminology and key operational considerations that affect the in-hospital management of incidents by chemical weapons.	This review is designed to familiarize readers with the concepts, terminology and key operational considerations that affect the in-hospital management of incidents by chemical weapons	Casualties of emergency situations caused by chemical weapons.	NA	Google Scholar		Cremation, warfare agents, remains
N	Low	18	2008	N	Handbook of Chemical and Biological Warfare Agents, Second Edition	NA	The book contains a chapter on fatality management from chemical and biological agents including cremation.	Fatalities from chemical and biological agents.	NA	Google Scholar		Cremation, warfare agents, remains

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
G	Medium	26	2004	Y	Infectious disease risks from dead bodies following natural disasters	Objective. To review existing literature to assess the risks of infection from dead bodies after a natural disaster occurs, including who is most at risk, what precautions should be taken, and how to safely dispose of the bodies. Methods. Disease transmission requires the presence of an infectious agent, exposure to that agent, and a susceptible host. These elements were considered to characterize the infectious disease risk from dead bodies. Using the PubMed on-line databases of the National Library of Medicine of the United States of America, searching was done for relevant literature on the infection risks for public safety workers and funeral workers as well as for guidelines for the management of the dead and prevention of infection. A small but significant literature was also reviewed regarding the disposal of the dead and the contamination of groundwater by cemeteries. Results. Victims of natural disasters usually die from trauma and are unlikely to have acute or "epidemic-causing" infections. This indicates that the risk that dead bodies pose for the public is extremely small. However, persons who are involved in close contact with the dead—such	A review of existing literature to assess the risks of infection from dead bodies after a natural disaster occurs, including who is most at risk, what precautions should be taken, and how to safely dispose of the bodies.	Victims of natural disasters.	Infectious disease risks from dead bodies following natural disasters	Google Scholar		Cremation, warfare agents, remains
G	Medium	33	2013	Y	BIOLOGICAL RESPONSE AND RECOVERY SCIENCE AND TECHNOLOGY ROADMAP	NA	This report categorizes key scientific knowledge gaps, identifies technology solutions to these gaps, and prioritizes research areas that will enable government at all levels to make decisions more effectively during the response to, and recovery from, biological incidents. Fatality management cremation and burial options discussed.	Contaminated bodies.	Biological Response and Recovery	Google Scholar		Cremation, warfare agents, remains
U	Low	20	2006	N	Ecological Risks Associated with the Destruction of Chemical Weapons	The Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and their Destruction provides for the elimination of chemical weapons arsenals amassed during the Cold War. The easier-said-than-done task of removing these deadly weapons, however, poses huge environmental problems. This book is the compendium of the workshop on the "Ecological Risks Associated with the Destruction of Chemical Weapons", hosted by the University of Lindeburg in October 2003, which brought the former enemies NATO and Russia together to discuss, reflect on, and exchange their experiences in the laudable mission of environmentally friendly disposal of chemical weapons. This four-day workshop received contributions from 57 experts from North America, Russia, and European countries. Most of them are recognized authorities in the field of chemical weapons disposal as well as in related fields. The speeches by those who share the burden of this terrible undertaking concentrated on cleaning up contaminated sites, the ethics, political and international law aspects of the destruction of chemical weapons, and on issues related to human health, pathogenesis, toxicity, and exposure to the polluted environment. Contributions were also made on Lewisite detection, risk prevention, insurance safety, monitoring of old chemical weapons destruction as well as public awareness for this problem	Safe and environment-friendly disposal of chemical weapons and cleaning up of contaminated sites all around the world, but not least in the ex-Soviet-led countries.	Chemical weapons.	NA	Google Scholar	Proceedings of the NATO ARW on Ecological Risks Associated with the Destruction of Chemical Weapons, Lindeburg, Germany, from 22-26 October 2003	Environmental impact, risk, warfare agents, destruction
G	Low	21	2010	Y	Biosafety and Biosecurity as Essential Pillars of International Health Security and Cross-cutting Elements of Biological Nonproliferation	The critical aspects of biosafety, biosecurity, and biocontainment have been in the spotlight in recent years. There have also been increased international efforts to improve awareness of modern practices and concerns with regard to the safe pursuit of life sciences research, and to optimize current oversight frameworks, thereby resulting in increased risk of terrorist/malevolent acquisition of deadly pathogens or accidental release of a biological agent, and increased safety of laboratory workers. Our purpose is to highlight how the World Health Organization's (WHO) revised International Health Regulations (IHR[2005]), the Biological Weapons Convention (BWC), and the United Nations Security Council Resolution (UNSCR) 1540 overlap in their requirements with regard to biosafety and biosecurity in order to improve the understanding of practitioners and policymakers and maximize the use of national resources employed to comply with internationally-mandated requirements. The broad range of goals of these international instruments, which are linked by the common thread of biosafety and biosecurity, highlight their significance as essential pillars of international health security and cross-cutting elements of biological nonproliferation. The current efforts of the Republic of Georgia to enhance biosafety and biosecurity in accordance with these international instruments are summarized.	International requirements of biosafety and biosecurity.	Biological hazards.	Biosafety and Biosecurity as essential pillars of international health security and cross-cutting elements of biological nonproliferation	Google Scholar		Biosafety, warfare agents, destruction
G	Low	21	2004	Y	State-of-the-Art in Biosafety and Biosecurity in European Countries	The terms biosafety and biosecurity are widely used in different concepts and refer not only to protection of human beings and their surrounding environment against hazardous biological agent, but also to global disarmament of weapons of mass destruction. As a result, the biosafety and biosecurity issues should be considered interdisciplinary based on multilateral agreements against proliferation of biological weapons, public health and environmental protection. This publication presents information on both, international and national biosafety and biosecurity legislation. Status of national implementation of the Biological and Toxin Weapons Convention, penalization issues and measures to account for and secure production, use, storage of particularly dangerous pathogens or activities involving humans, plants and animals where infection may pose a risk have been analyzed. Safety and security measures in laboratories have been studied. Moreover, dual-use technology and measures of secure transport of biohazard materials have been also taken into account. In addition, genetic engineering regulations, biosecurity activities in laboratories and code of conducts have been investigated, as well.	International and national biosafety and biosecurity. Issues and measures to account for and secure production, use, storage of particularly dangerous pathogens or activities involving humans, plants and animals where infection may pose a risk have been analyzed.	Biological agents.	State-of-the-Art in Biosafety and Biosecurity in European Countries	Google Scholar		Biosafety, warfare agents,
G	Low	15	2013	N	Reducing health risk assigned to organic emissions from a chemical weapons incinerator	Organic emissions from a chemical weapons incinerator have been characterized with an improved set of analytical methods to reduce the human health risk assigned to operations of the facility. A gas chromatography/mass selective detection method with substantially reduced detection limits has been used in conjunction with scanning electron microscopy/energy dispersive X-ray spectrometry and Fourier transform infrared microscopy to improve the specification of semi-volatile and non-volatile organics emitted from the incinerator. The reduced detection limits have allowed a significant reduction in the assumed polycyclic aromatic hydrocarbon (PAH) and aminobiphenyl (ABP) emission rates used as inputs to the human health risk assessment for the incinerator. A mean factor of 17 decrease in assigned human health risk is realized for six common local exposure scenarios as a result of the reduced PAH and ABP	Investigation of emissions from chemical weapons incinerator.	Chemical weapons.	NA	Google Scholar		Incinerator, emissions, warfare agents
G	Medium	25	2013	Y	Challenges and Practices in Building and Implementing Biosafety and Biosecurity Programs to Enable Basic and Translational Research with Select Agents	Select agent research in the United States must meet federal-mandated biological surety guidelines and rules which are comprised of two main components: biosafety and biosecurity. Biosafety is the process employed for ensuring biological agents are properly safeguarded against theft, loss, diversion, unauthorized access or use/release. Biosafety is those processes that ensure that operations with such agents are conducted in a safe, secure and reliable manner. As such, a biological surety program is generally concerned with biological agents that present high risk for adverse medical and/or agricultural consequences upon release outside of proper containment. The U.S. Regional and National Biocontainment Laboratories (RBL, NBL) represent expertise in this type of research, and are actively engaged in the development of programs to address these critical needs and federal requirements. While this comprises an ongoing activity for	A simplified yet comprehensive review of the U.S. Regional and National Biocontainment Laboratories requirements on biosafety and biosecurity.	Biological agents.	Challenges and Practices in Building and Implementing Biosafety and Biosecurity Programs to Enable Basic and Translational Research with Select Agents	Google Scholar		Biosafety, warfare agents,
G	Low	15	2000	N	Preliminary assessment of health impacts for the Newport Chemical Agent Disposal Facility	A Preliminary Assessment of Health Impacts (PAHI) study was conducted to look at potential human and environmental health impacts due to the air and water emissions generated from the proposed Newport Chemical Agent Disposal Facility (NECDF) in Newport, Indiana. As an alternative to incineration, the NECDF will use a neutralization-based treatment process followed by supercritical water oxidation to destroy the VX nerve agent stored in ton containers at the Newport Chemical Depot. There is no regulatory guidance on conducting an assessment of health impacts for this type of facility. Therefore, The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) designed a PAHI study based on bench-scale data and best engineering estimates that conservatively evaluate possible health effects from the projected air and water emissions. The air portion of the PAHI focused primarily on estimating carcinogenic risks and noncarcinogenic hazards from direct and indirect exposures to the subsistence farmer, subsistence fisher, adult resident, and child resident. The water portion of the PAHI evaluated potential human and environmental impacts using two different procedures individual	A Preliminary Assessment of Health Impacts (PAHI) study was conducted to look at potential human and environmental health impacts due to the air and water emissions generated from the proposed Newport Chemical Agent Disposal Facility (NECDF) in Newport, Indiana.	VX nerve agent stored in ton containers at the Newport Chemical Depot.	NA	Google Scholar		Incinerator, emissions, warfare agents
G	Low	14	2003	Y	Public Health, Law, and Local Control: Destruction of the US Chemical Weapons Stockpile	Destruction of US chemical weapons has begun at one of the 8 sites in the continental United States, was completed on Johnston Island in the Pacific Ocean, and is scheduled to begin in at least 3 other locations during the upcoming year. About 25% of the stockpile and 38% of the munitions had been destroyed as of December 31, 2002. However, the program has become controversial with regard to choice of technology, emergency management, and cost. This controversy is in large part due to efforts by some state and local governments and activist groups to play a more central role in a decision making process that was once fully controlled by the US Army.	Discussion on the decision making process on technology, emergency planning, and cost for chemical weapon destruction.	Chemical warfare agents.	Public Health, Law, and Local Control: Destruction of the US Chemical Weapons Stockpile	Google Scholar		Incinerator, emissions, warfare agents
N	High	36	1999	N	Carbon Filtration for Reducing Emissions from Chemical Agent Incineration	NA	Installation of carbon filtration systems on incinerators to reduce/eliminate substances of potential concern in emissions.	Chemical weapons.	NA	Google Scholar	The Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program (Stockpile Committee) of the National Research Council has endorsed incineration (with comprehensive air pollution control systems) as a safe and effective procedure for destroying	Incinerator, emissions, warfare agents

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
A			NA	Y	Chemical Warfare Agent Disposal Public Health Oversight	NA	Disposal options are discussed for chemical weapons and safety considerations.	Chemical weapons.	Chemical Warfare Agent Disposal Public Health Oversight	Google Scholar	Safeguards for chemical weapon disposal include: Procedural, Engineering, and Monitoring. For example, the continuous emissions monitoring is an integral part of the	Incinerator, emissions, warfare agents
G	Medium	34	1989	N	Disposing of the US Chemical Weapons Stockpile An Approaching Reality	A congressional mandate to dispose of the current US stockpile of lethal unitary weapons (Public Law 99-145, Department of Defense Authorization Act of 1986) has international implications and is responsible for a recent major assessment of available disposal alternatives. Eight installations in the continental United States currently host aging stockpiles of chemical warfare agents. The stockpiles are described, the toxicology and physical properties of each agent are characterized, disposal options considered by the US Army are identified, and the role of a programmatic health and environmental assessment in the decision-making process is outlined. Critical findings are that existing community emergency planning and preparedness are inadequate and that communication of risk information requires significant improvement. Measures are under way to address these needs. However, timely disposal of the stockpile entails less of a hazard than continued storage.	The stockpiles are described, the toxicology and physical properties of each agent are characterized, disposal options considered by the US Army are identified, and the role of a programmatic health and environmental assessment in the decision-making process is outlined.	Chemical weapons stockpile.	NA	Google Scholar		Incinerator, emissions, warfare agents
N	Medium	29	2001	N	Occupational Health and Workplace Monitoring at Chemical Agent Disposal Facilities	NA	The book discusses workplace monitoring and occupational health programs at chemical weapon disposal facilities (JACADS and TOCDF).	Chemical weapons stockpile.	NA	Google Scholar	The Army must ensure that the chemical demilitarization workforce is protected from the risks of exposure to hazardous materials during disposal operations and during and after facility closure. Good industrial practices developed in the chemical and nuclear energy industries and other operations that involve the processing of hazardous materials include workplace	Incinerator, emissions, warfare agents
G	Medium	27	2002	N	The Use of Thermal Desorption in Monitoring for the Chemical Weapons Demilitarization Program	Under international treaty, the United States and Russia are disposing of their aging stockpile of chemical weapons. Incineration and chemical neutralization are options for sites in the United States, although Russia prefers the latter. The storage and disposal of bulk and chemical agents and weapons involve unique hazards of handling extremely toxic materials. There are three major areas of concern—the storage stockpile, the disposal area, and the discovery and destruction of “found” material not considered part of the stockpile. Methods have been developed to detect the presence of chemical agents in the air, and these are used to help assure worker protection and the safety of the local population. Exposure limits for all chemical agents are low, sometimes nanograms per cubic meter for worker control limits and picograms per cubic meter for general population limits. There are three types of monitoring used in the USA: alarm, confirmation, and historical. Alarm monitors are required to give relatively immediate real-time responses to agent leaks. They are simple to operate and rugged, and provide an alarm in near real-time (generally a few minutes). Alarm monitors for the demilitarization program are based on sorbent pre-concentration followed by thermal desorption and simple gas chromatography. Alarms may need to be confirmed by another method, such as sample tubes collocated with the alarm monitor and analyzed in a laboratory by more	The types of monitoring, alarm, confirmation, and historical are discussed for incineration of US stockpile.	Stockpile of chemical weapons.	NA	Google Scholar		Incinerator, emissions, warfare agents
G	Low	23	1997	N	Destruction Chemistry of Organophosphorus Compounds in Hydrogen-Oxygen Flames	A review of the results of experimental studies of the destruction chemistry of organophosphorus compounds modeling sarin in hydrogen-oxygen fuelled flames is presented. These studies were performed at the Institute of Chemical Kinetics and Combustion of the Siberian Division of the Russian Academy of Sciences by soft ionization probe molecular beam mass spectrometry. A method is described that allows one to identify almost all starting, intermediate (including atoms and free radicals), and final organophosphorus compounds, and to measure concentration profiles in flames. The destruction products of organophosphorus compounds—dimethyl methylphosphonate and trimethylphosphate—are identified in various zones of an H ₂ /O ₂ /Ar flame. Mass peak intensities proportional to the concentrations of the indicated products are measured. The inhibition and promotion phenomena of the flames are discovered and studied. A chemical mechanism for the destruction of organophosphorus compounds in the flames is proposed. The results obtained are important for understanding the processes involved in the incineration of chemical warfare agents and munitions and other toxic and hazardous substances, for optimization of this technology, and also for understanding the inhibition and promotion mechanisms of flames.	A method is described that allows one to identify almost all starting, intermediate (including atoms and free radicals), and final organophosphorus compounds and to measure concentration profiles in flames. The results obtained are important for understanding the processes involved in the incineration of chemical warfare agents and munitions and other toxic and hazardous substances, for optimization of this technology, and also for	Chemical weapons.	NA	Google Scholar		Incinerator, emissions, warfare agents
G	Medium	28	1995	N	Incinerator Air Emissions Inhalation Exposure Perspectives	Incineration is often proposed as the treatment of choice for processing diverse wastes, particularly hazardous wastes. Where such treatment is proposed, people are often fearful that it will adversely affect their health. Unfortunately, information presented to the public about incinerators often does not include any criteria or benchmarks for evaluating such facilities. This article describes a review of air emission data from regulatory trial burns in a large prototype incinerator, operated at design capacity by the U.S. Army to destroy chemical warfare materials. It uses several sets of criteria to gauge the threat that these emissions pose to public health. Incinerator air emission levels are evaluated with respect to various toxicity screening levels and ambient air levels of the same pollutants. Also, emission levels of chlorinated dioxins and furans are compared with emission levels of two common combustion sources. Such comparisons can add to a community's understanding of health risks associated with an incinerator. This article focuses only on the air exposure/inhalation pathway as related to human health. It does not address other potential human exposure pathways or the possible effects of emissions on the local ecology, both of which should also be examined during a complete analysis of any major new facility.	This article describes a review of air emission data from regulatory trial burns in a large prototype incinerator, operated at design capacity by the U.S. Army to destroy chemical warfare materials.	Chemical warfare agents.	NA	Google Scholar		Incinerator, emissions, warfare agents
U			NA	Y	Proposed Modifications to Support the Destruction of Mustard Agents and Munitions at the Tooele Chemical Agent Disposal Facility (TOCDF) in Utah	NA	Proposed installation of a Pollution Abatement System (PAS) filtration system (PFS) on incinerators to remove mercury from stack gases.	Chemical warfare agents.	Environmental Assessment (EA) and Draft Finding of No Significant Impact for Proposed Modification to Support the Destruction of Mustard Agents and Munitions at the TOCDF	Google Scholar	The CMA proposes to install alternative technologies to augment the baseline incineration process at the TOCDF to provide greater operational flexibility for destroying those mustard agents and munitions which have elevated levels of mercury contamination and/or a large solids content.	Incinerator, emissions, warfare agents
U	Low	24	NA	Y	Incineration and Human Health	NA	Health impact to populations and the environment due to incinerators.	Municipal and industrial waste.	Incineration and Human Health	Google Scholar	This UK report was undertaken to draw together scientific findings on incinerator or releases and their impacts on human health. A broad range of health effects have been associated with living near to incinerators as well as with	Incinerator, emissions, warfare agents
B	Medium	27	1993	Y	DISPOSAL OF CHEMICAL AGENTS AND MUNITIONS STORED AT UMATILLA DEPOT ACTIVITY, HERMISTON, OREGON FINAL PHASE I ENVIRONMENTAL REPORT	The Umatilla Depot Activity (UMDA) near Hermiston, Oregon, is one of eight U.S. Army installations in the continental United States where lethal unitary chemical agents and munitions are stored, and where destruction of agents and munitions is proposed under the Chemical Stockpile Disposal Program (CSDP). The chemical agent inventory at UMDA consists of 11.6%, by weight, of the total U.S. stockpile. The destruction of the stockpile is necessary to eliminate the risk to the public from continued storage and to dispose of obsolete and leaking munitions. In 1988 the U.S. Army issued a Final Programmatic Environmental Impact Statement (FPEIS) for the CSDP that identified on-site disposal of agents and munitions as the environmentally preferred alternative (i.e., the alternative with the least potential to cause significant adverse impacts). The FPEIS identified the environmentally preferred alternative using a method based on five measures of risk for potential human health and ecosystem/environmental effects; the effectiveness and adequacy of emergency preparedness capabilities also played a key role in the FPEIS selection methodology.	This Phase I report contains information that will be used in the development of environmental analyses and assessments to be included in a site-specific environmental impact statement regarding the disposal of the UMDA stockpile.	Chemical weapons stockpile.	DISPOSAL OF CHEMICAL AGENTS AND MUNITIONS STORED AT UMATILLA DEPOT ACTIVITY	Google Scholar		Incinerator, emissions, warfare agents

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
G	Low	21	1995	N	HOW DO WE GET RID OF THESE THINGS?: DISMANTLING EXCESS WEAPONS WHILE PROTECTING THE ENVIRONMENT	NA	This Article examines the potential legal and political conflict posed when a dramatic and crucial new arms control agreement, the 1993 Chemical Weapons Convention (CWC), confronts the equally fundamental and pressing dictates of national environmental protection policy.	Chemical weapons stockpile.	NA	Google Scholar	The startling successes of contemporary international arms control negotiations call to mind the old aphorism that one should be careful about what one wishes for, because the wish just might come true. Today, disarmament diplomacy has wrought unprecedented triumphs across a wide range of global	Incinerator, emissions, warfare agents
N	Low	14	2007	N	The Fate of Chemical Warfare Agents in the Environment	NA	The fate of the degradation products from chemical weapons.	warfare agents	NA	Google Scholar	Emphasis in this review is on these potential degradation products resulting from agent contact with soil, water or the atmosphere after unintended release from historically buried chemical weapons and wastes, or potential spills during munition demilitarization and disposal activities.	Incinerator, emissions, warfare agents
G	High	40	1999	Y	The Sources, Fate, and Toxicity of Chemical Warfare Agent Degradation Products	We include in this review an assessment of the formation, environmental fate, and mammalian and ecotoxicity of CW agent degradation products relevant to environmental and occupational health. These parent CW agents include several vesicants: sulfur mustards [undistilled sulfur mustard (H), sulfur mustard (HD), and an HD/agent T mixture (HT)]; nitrogen mustards [ethylbis[2-chloroethyl]amine (HN1), methylbis[2-chloroethyl]amine (HN2), tris[2-chloroethyl]amine (HN3)], and Lewisite; four nerve agents [Oethyl S [2-(diisopropylamino)ethyl] methylphosphonothioate (VX), tabun (GA), sarin (GB), and soman (GD)]; and the blood agent cyanogen chloride. The degradation processes considered here include hydrolysis, microbial degradation, oxidation, and photolysis. We also briefly address decontamination but not combustion processes. Because CW agents are generally not considered very persistent, certain degradation products of significant persistence, even those that are not particularly toxic, may indicate previous CW agent presence or that degradation has occurred. Of those products for which there are data on both environmental fate and toxicity, only a few are both environmentally persistent and highly toxic. Major degradation products estimated to be of significant persistence (weeks to years) include thiodiglycol for HD; Lewisite oxide for Lewisite; and ethyl methyl phosphonic acid, methyl phosphonic acid, and possibly S [2-(diisopropylamino)ethyl] methylphosphonothioic acid (EA 2192) for VX. Methyl phosphonic acid is also the ultimate hydrolysis product of both GB and GD. The GB product, isopropyl methylophosphonic acid, and a closely related contaminant of GB, diisopropyl methylophosphonate. Combustion aerosols were measured in a 22 MW (thermal energy) municipal waste incinerator. Different types of waste fractions were added to a base-load waste and the effect on aerosol formation was measured. The waste fractions applied were: PVC plastic, pressure-impregnated wood, shoes, salt (NaCl), batteries, and automotive shredder waste. Also, runs with different changes in the operational conditions of the incinerator were made. Mass-based particle size distributions were measured using a cascade impactor and the number-based size distributions were measured using a Scanning Mobility Particle Sizer. The plant is equipped with flue gas cleaning and the penetration through this was determined. The particle morphology was investigated by Transmission Electron Microscopy (TEM) and chemical analysis of the aerosol particles was made by Energy Dispersive X-ray Spectroscopy (EDS). The mass-based particle size distribution was bimodal with a fine mode peak around 0.4 µm and a coarse mode peak around 100 µm. The addition of NaCl, shredder waste, and impregnated wood increased the mass concentration of fine particles (aerodynamic diameter below 2.5 µm). In general the mass concentration was stable and close to the reference PM2.5-value of 252 ± 21 mg/m (std.T,P). The total number concentration deviated during runs and between runs spanning from 43 · 10 to 87 · 10 #/cm(std.T,P). The aerosols formed were mixtures of dense and aggregated particles in all tests. The fine particles are mainly composed by alkali salts, zinc, and lead. The heavy metals Cu, Cd, Hg, and	We include in this review an assessment of the formation, environmental fate, and mammalian and ecotoxicity of CW agent degradation products relevant to environmental and occupational health.	Chemical weapons.	The Sources, Fate, and Toxicity of Chemical Warfare Agent Degradation	Google Scholar	Incinerator, emissions, warfare agents	
G	Medium	29	2007	N	COMBUSTION AEROSOLS FROM MUNICIPAL WASTE INCINERATION—EFFECT OF FUEL FEEDSTOCK AND PLANT OPERATION	Combustion aerosols were measured in a 22 MW (thermal energy) municipal waste incinerator. Different types of waste fractions were added to a base-load waste and the effect on aerosol formation was measured. The waste fractions applied were: PVC plastic, pressure-impregnated wood, shoes, salt (NaCl), batteries, and automotive shredder waste. Also, runs with different changes in the operational conditions of the incinerator were made. Mass-based particle size distributions were measured using a cascade impactor and the number-based size distributions were measured using a Scanning Mobility Particle Sizer. The plant is equipped with flue gas cleaning and the penetration through this was determined. The particle morphology was investigated by Transmission Electron Microscopy (TEM) and chemical analysis of the aerosol particles was made by Energy Dispersive X-ray Spectroscopy (EDS). The mass-based particle size distribution was bimodal with a fine mode peak around 0.4 µm and a coarse mode peak around 100 µm. The addition of NaCl, shredder waste, and impregnated wood increased the mass concentration of fine particles (aerodynamic diameter below 2.5 µm). In general the mass concentration was stable and close to the reference PM2.5-value of 252 ± 21 mg/m (std.T,P). The total number concentration deviated during runs and between runs spanning from 43 · 10 to 87 · 10 #/cm(std.T,P). The aerosols formed were mixtures of dense and aggregated particles in all tests. The fine particles are mainly composed by alkali salts, zinc, and lead. The heavy metals Cu, Cd, Hg, and	Measurement of aerosols from a municipal waste incinerator.	Municipal waste.	NA	Google Scholar	aerosol containment, warfare agents, incineration	
G	High	36	2007	N	Dioxin formation from waste incineration	There has been great concern about dioxins-polychlorinated dibenzo dioxins (PCDDs), polychlorinated dibenzo furans (PCDFs), and polychlorinated biphenyls (PCBs)-causing contamination in the environment because the adverse effects of these chemicals on human health have been known for many years. Possible dioxin-contamination has received much attention recently not only by environmental scientists but also by the public, because dioxins are known to be formed during the combustion of industrial and domestic wastes and to escape into the environment via exhaust gases from incinerators. Consequently, there is a pressing need to investigate the formation mechanisms or reaction pathways of these chlorinated chemicals to be able to devise ways to reduce their environmental contamination. A well-controlled small-scale incinerator was used for the experiments in the core references of this review. These articles report the investigation of dioxin formation from the combustion of various waste-simulated samples, including different kinds of paper, various kinds of wood, fallen leaves, food samples, polyethylene (PE), polystyrene (PS), polyvinyl chloride (PVC), polyvinylidene chloride, polyethylene terephthalate (PET), and various kinds of plastic products. These samples were also incinerated with inorganic chlorides (NaCl, KCl, CuCl ₂ , MgCl ₂ , MnCl ₂ , FeCl ₂ , CoCl ₂ , fly ash, and seawater) or organic chlorides (PVC, chlordane, and pentachlorophenol) to investigate the role of chlorine content and/or the presence of different metals in dioxin formation. Some	A small-scale incinerator was used for the investigation of the formation mechanisms or reaction pathways of chlorinated chemicals to be able to devise ways to reduce their environmental contamination.	The article reports on the investigation of dioxin formation from the combustion of various waste-simulated samples.	NA	Google Scholar	aerosol containment, warfare agents, incineration	
G	Low	24	2005	N	Health risk related to municipal waste incineration	There are exposures to various organic and inorganic xenobiotics related to municipal waste incineration in work places and environment close to incinerators. Among others, these are polychlorinated biphenyls, dioxins, furans, chlorobenzenes, mono- and polycyclic aromatic hydrocarbons, toxic metals and irritation gases. Numerous studies revealed that these chemicals and their metabolites were generally not elevated in worker's blood and urine and in persons living near incinerators. The epidemiological studies indicate increased cancer risk and excess of ischemic heart disease in incinerator workers. In residents living in the vicinity of incinerators, a slightly increased cancer risk, respiratory symptoms, multiple pregnancy, congenital abnormalities, and disturbances in thyroid hormone levels were observed. However, these data do not provide univocal evidence that the cause-effect relationship between exposure and health risk does really exist.	Study on the presence of chemicals in worker's and resident's blood and urine in the vicinity of municipal waste incinerators.	Waste from a municipal waste incinerator.	NA	Google Scholar	aerosol containment, warfare agents, incineration	
B	Low	19	1993	N	Mixed-waste treatment – What about the residuals? A comparative analysis of MSO and incineration	This report examines the issues concerning final waste forms, or residuals, that result from the treatment of mixed waste in molten salt oxidation (MSO) and incinerator systems. MSO is a technology with the potential to treat a certain segment of the waste streams at US Department of Energy (DOE) sites. MSO was compared with incineration because incineration is the best demonstrated available technology (BDAT) for the same waste streams. The Grand Junction Projects Office (GIPO) and Oak Ridge National Laboratory (ORNL) prepared this report for the DOE Office of Environmental Restoration (OER). The goals of this study are to objectively evaluate the anticipated residuals from MSO and incineration, examine regulatory issues for these final waste forms, and determine secondary treatment options. This report, developed to address concerns that MSO residuals present unique disposal difficulties, is part of a larger effort to successfully implement MSO as a treatment technology for mixed and hazardous waste. A Peer Review Panel reviewed the MSO technology in November 1991, and the implementation effort is ongoing under the guidance of the MSO Task Force.	The goals of this study were to objectively evaluate the anticipated residuals from MSO and incineration, examine regulatory issues for these final waste forms, and determine secondary treatment options.	Final waste forms, or residuals, that result from the treatment of mixed waste in molten salt oxidation (MSO) and incinerator systems.	NA	Google Scholar	aerosol containment, warfare agents, incineration	

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
B	Medium	30	2005	N	A sensor management architecture concept for monitoring emissions from open-air demill operations	Sandia National Laboratories, CA proposed a sensor concept to detect emissions from open-burning/open-detonation (OB/OD) events. The system would serve two purposes: (1) Provide data to demilitarization operations about process efficiency, allowing process optimization for cleaner emissions and higher efficiency. (2) Provide data to regulators and neighboring communities about materials dispersing into the environment by OB/OD operations. The proposed sensor system uses instrument control hardware and data visualization software developed at Sandia National Laboratories to link together an array of sensors to monitor emissions from OB/OD events. The suite of sensors would consist of various physical and chemical detectors mounted on stationary or mobile platforms. The individual sensors would be wirelessly linked to one another and controlled through a central command center. Real-time data collection from the sensors, combined with integrated visualization of the data at the command center, would allow for feedback to the sensors to alter operational conditions to adjust for changing needs (i.e., moving plume position, increased spatial resolution, increased sensitivity). This report presents a systems study of the problem of implementing a sensor system for monitoring OB/OD emissions. The goal of this study was to gain a fuller understanding of the political, economic, and technical issues for developing and fielding this technology.	A sensor concept to detect emissions from open-burning/open-detonation (OB/OD) events. The system would serve two purposes: (1) Provide data to demilitarization operations about process efficiency, allowing process optimization for cleaner emissions and higher efficiency. (2) Provide data to regulators and neighboring communities about materials dispersing into the environment by OB/OD operations.	Demilitarization materials.	NA	Google Scholar		aerosol containment, warfare agents, incineration
G	Medium	29	2004	N	An investigation of halogens in Izmit hazardous and clinical waste incinerator	In the combustion facilities, halogens (Cl, F, Br, I) should be considered with regard to the control of the compounds such as polychlorinated dibenzodioxins (PCDD), polychlorinated dibenzofurans (PCDF), halogenated polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) and volatile heavy metals formed as a result of incomplete combustion and caused adverse environmental effects. In this study halogens were observed in Izmit Hazardous and Clinical Waste Incinerator (IZAYDAS). Halogen contents of the combustion menu, flue gas, fly ash, bottom ash and filter cake were measured and their distributions in these exit streams were determined. Results showed that the major part of the halogens was partitioned to solid residues, i.e., bottom ash and filter cake which represents the removal by wet scrubbers. Fly ash and flue gas fractions of halogens were much lower due to the reduced formation of volatile compounds.	In this study halogens were observed in Izmit Hazardous and Clinical Waste Incinerator (IZAYDAS). Halogen contents of the combustion menu, flue gas, fly ash, bottom ash and filter cake were measured and their distributions in these exit streams were determined.	Halogen emissions from a clinical incinerator.	NA	Google Scholar		aerosol containment, warfare agents, incineration
G	Medium	27	2010	N	Surrogate study for dioxins from municipal waste incinerator in startup condition: applicability as a dioxin control indicator and an organohalogen emission warning	Dioxins and their surrogates were continuously monitored during the startup of two municipal waste incinerators (MWIs). The surrogates studied included low-volatility organohalogen compounds (LVOH) sampled by online systems, as well as chlorobenzenes (CBs) and chlorophenols (CPs). The changes in levels of LVOH, CBs, and CPs corresponded well with the trend of the toxicity equivalent quantity (TEQ). The correlation of LVOH with TEQ was fairly good, whereas that of CBs and CPs with TEQ was not consistent. The correlation of LVOH with TEQ involved a memory effect related to the delayed emission of less volatile compounds. The isomer analysis of the dioxins present under startup conditions showed evidence of the memory effect, i.e., highly chlorinated isomers were emitted slowly, whereas low-chlorinated isomers and LVOH decreased rapidly as the temperature rose. LVOH cannot act as a perfect dioxin surrogate, but it can give a versatile, quick, and comprehensive warning of the presence of organohalogen compounds because it is free from the memory effect and covers many kinds of organohalogen compounds, including dioxins.	Dioxins and their surrogates. (CBs) were continuously monitored during the startup of two municipal waste incinerators (MWIs).	Dioxins and their surrogates.	NA	Google Scholar		aerosol containment, warfare agents, incineration
G	High	35	2000	N	Characterization of organic emissions from hazardous waste incineration processes under the new EPA draft Risk Burn Guidance: measurement issues	EPA's recently published draft Risk Burn Guidance recommends that hazardous waste combustion facilities complete a mass balance of the total organics (TOs) that may be emitted from the combustor. TOs, consisting of three distinct fractions (volatile, semivolatile, and nonvolatile organic compounds) are determined using measurement techniques specific to the boiling point (bp) range of each component. Preliminary proof-of-concept tests have been performed to gain further knowledge of the total chromatographable organics (TCO) and gravimetric analysis (GRAV) procedures used to determine the semivolatile and nonvolatile organic fractions. A commercially prepared Method 8270 semivolatile organic standard solution, made up of 112 compounds containing a variety of halogenated, oxygenated, nitrogenated, and sulfonated hydrocarbons, in addition to those hydrocarbons containing only carbon and hydrogen, was used to examine measurement biases of the TCO and GRAV methods. The results indicate that, at least for this particular standard, both methods are accurate, exhibiting biases <10%. However, these TCO results may be deceiving. TCO measurement biases observed for	Preliminary proof-of-concept tests have been performed to gain further knowledge of the total chromatographable organics (TCO) and gravimetric analysis (GRAV) procedures used to determine the semivolatile and nonvolatile organic fractions.	Total organics (TOs), consisting of three distinct fractions (volatile, semivolatile, and nonvolatile organic compounds) that may be emitted from the combustor.	NA	Google Scholar		aerosol containment, warfare agents, incineration
G			2000	Y	Managing the Health Impacts of Waste Incineration	Incineration has emerged over the last century as a viable strategy for (a) reducing the volume of municipal waste, (b) for reducing substantially the volume of chemical and biological hazardous wastes, (c) for destroying medically contaminated hospital waste, and (d) for producing energy. Facing an exponential rise in garbage production, policy-makers in the US selected waste incineration in the 1970s as a waste-management option. By that time European nations had already made a strong commitment to waste incineration. Waste incineration has been employed in some form for centuries. However, in the last several decades, the quantity of material combusted, public concerns about the health and ecological impacts of combustion facilities, the level of environmental control, and the cost of control have all increased. Whether waste incineration poses a health risk has been the subject of continuous scientific debate.	Discussion on public concerns about the health and ecological impacts of combustion facilities, the level of environmental control, and the cost of control.	Chemical, biological, municipal, and medical waste for incineration.	Managing the Health Impacts of Waste Incineration.pdf	Google Scholar		aerosol containment, warfare agents, incineration
A	High	42	2005	N	Human Health Risk Assessment Protocol (HHRAP) for Hazardous Waste Combustion Facilities, Final	NA	Discussion on identification of emission sources and emission rates and air dispersion models of contaminants from incinerators.	Emissions from incinerators.	NA	Google Scholar		aerosol containment, warfare agents, incineration
G	High	34	1992	N	Release of bacterial aerosols during infectious waste compaction: an initial hazard evaluation for healthcare workers	Compaction has been suggested as an interim processing method for infectious waste. Compaction greatly reduces the volume of waste at the site of generation and produces a more stable package for handling, shipment, and treatment. Preliminary studies have also indicated that when partially compacted waste is burned in an incinerator, the performance of the incineration unit is enhanced. Compaction is not currently used in institutions because the process may lead to the release of infectious aerosols, which could pose a significant hazard to healthcare workers. To determine if bacterial releases can be adequately controlled by a compaction device specially designed and constructed for the task, a prototype infectious waste compactor was challenged by compressing waste containing known quantities of indicator bacteria. Samples were collected to monitor bacterial releases and surface contamination. The data collected from this initial evaluation document that indicator bacteria were released from the unit. Modifications to the design and operation of a compactor of this type are proposed as suggestions that may improve system performance with regard to the health and safety of workers. Since the issuance of the Environmental Protection Agency (EPA)'s Guidance for Total Organics (Draft guidance for total organics. 2nd ed. EPA National Exposure Research Laboratory, September, 1996) a great deal of variance has been observed regarding the measured results of unsuspected mass organic determinations. Starting primarily at the end of 1997, the EPA Regions implemented requirements to facilities for conducting stack emissions tests that included unsuspected mass quantifications as part of their demonstration of acceptable risk. After several months of data collection experience, experimental observations have been made that allow refinements in the laboratory methods, and future structuring of the procedures of the methods in a format similar to traditional SW-846 [Test methods for evaluating solid waste, physical/chemical methods (SW-846). 3rd ed. September 1986] methods. Examples of procedural techniques will be presented with attendant data quality objectives (DQOs) that are used to observe the relative control of these measurements. Laboratory techniques will also be discussed that represent one laboratory's good laboratory practices for these	To determine if bacterial releases can be adequately controlled by a compaction device specially designed and constructed for the task, a prototype infectious waste compactor was challenged by compressing waste containing known quantities of indicator bacteria. Samples were collected to monitor bacterial releases and surface contamination. The data collected from this initial evaluation document that indicator bacteria were released from the unit. Modifications to the design and operation of a compactor of this type are proposed as suggestions that may improve system performance with regard to the health and safety of workers. Since the issuance of the Environmental Protection Agency (EPA)'s Guidance for Total Organics (Draft guidance for total organics. 2nd ed. EPA National Exposure Research Laboratory, September, 1996) a great deal of variance has been observed regarding the measured results of unsuspected mass organic determinations. Starting primarily at the end of 1997, the EPA Regions implemented requirements to facilities for conducting stack emissions tests that included unsuspected mass quantifications as part of their demonstration of acceptable risk. After several months of data collection experience, experimental observations have been made that allow refinements in the laboratory methods, and future structuring of the procedures of the methods in a format similar to traditional SW-846 [Test methods for evaluating solid waste, physical/chemical methods (SW-846). 3rd ed. September 1986] methods. Examples of procedural techniques will be presented with attendant data quality objectives (DQOs) that are used to observe the relative control of these measurements. Laboratory techniques will also be discussed that represent one laboratory's good laboratory practices for these	Bacterial aerosols.	NA	Google Scholar		aerosol containment, warfare agents, incineration
G	Medium	32	2000	N	The application of traditional data quality objectives (DQOs) to the measurement of stack gas unsuspected mass: techniques and observations	Since the issuance of the Environmental Protection Agency (EPA)'s Guidance for Total Organics (Draft guidance for total organics. 2nd ed. EPA National Exposure Research Laboratory, September, 1996) a great deal of variance has been observed regarding the measured results of unsuspected mass organic determinations. Starting primarily at the end of 1997, the EPA Regions implemented requirements to facilities for conducting stack emissions tests that included unsuspected mass quantifications as part of their demonstration of acceptable risk. After several months of data collection experience, experimental observations have been made that allow refinements in the laboratory methods, and future structuring of the procedures of the methods in a format similar to traditional SW-846 [Test methods for evaluating solid waste, physical/chemical methods (SW-846). 3rd ed. September 1986] methods. Examples of procedural techniques will be presented with attendant data quality objectives (DQOs) that are used to observe the relative control of these measurements. Laboratory techniques will also be discussed that represent one laboratory's good laboratory practices for these	Experimental observations have been made on incinerator emission data that allow refinements in the laboratory methods, and future structuring of the procedures of the methods in a format similar to traditional SW-846 methods.	Incinerator emissions.	NA	Google Scholar		aerosol containment, warfare agents, incineration
U	Low	11	1977	N	Disposal of WW II mustard gas hydrolysate by burning	NA	Burning of hydrolysate.	Hydrolysate from mustard gas.	NA	Google Scholar	Conference publication. Presentation at the 70th Annual Meeting of the Air Pollution Control Association, Toronto, Ontario, Canada, June 20-June 24, 1977.	Hydrolysate, incineration, warfare

Literature Search Results

Document Type	Relevance	Relevancy Score	Publication Year	Full Text Available?	Article/Report Title	Abstract	Existing Procedures and Methodologies Discussed	Types of Waste	Full Text File Name	Information Source	Notes	Keywords
T	Medium	29	2014	Y	Eliminating Syria's chemical weapons	NA	Incineration of hydrolysis effluent.	Syria's chemical weapon stockpile.	Eliminating Syria's chemical weapons	Google Scholar	The effluent from the Cape Ray hydrolysis operation will also be incinerated. The DF effluent will go to the Finnish incinerator, while the effluent from the mustard hydrolysis will go to a German government run incinerator near Münster. This site is normally used to destroy old chemical weapons discovered abandoned in Germany.	Hydrolytate, incineration, warfare
T	Medium	26	2008	Y	Destroying VX	NA	Incineration of VX hydrolytate.	VX hydrolytate (VXH)	Destroying VX	Google Scholar	Description of transportation of VX hydrolytate from Indiana to Texas for incineration	Hydrolytate, incineration, warfare
G	Medium	31	1998	N	Hydrolysis and Oxidation Process Effluents of Some Chemical Warfare Agents and Possible Secondary Treatments	Traditional chemical decontamination and disposal treatments for chemical warfare (CW) agents rely largely on base hydrolysis or oxidation reactions in aqueous solution. Although often used as methods for decontamination or for disposing of relatively small quantities of agent (often as a partial treatment together with open pit burning), these types of process have also been used in the US, UK and Canada, for example, to dispose of relatively large amounts of CW agent. The use of these chemical neutralisation treatments for large scale disposal was superseded in recent times by the use of incineration. In the 1950's, large quantities of mustard were destroyed by incineration (which is of course an oxidation reaction) in the UK. More recently, the Canadian stockpile was also disposed of by incineration as were the Iraqi stocks of mustard by UNSCOM. The US baseline technology is also, of course, based on incineration and this, together with the existing incinerators in Germany and the UK, uses modern pollution abatement systems and is efficient and effective. Nevertheless, there is considerable public opposition to incineration and alternative technologies are actively being sought in several countries.	Hydrolysis or oxidation of chemical warfare agents and possible secondary treatments.	Chemical warfare agents.	NA	Google Scholar		Hydrolytate, incineration, warfare
U	Medium	27	2012	Y	Biological Treatment of Chemical Agent Hydrolytate by Immobilized Cell Bioreactor Technology	The Pueblo Chemical Agent-Destruction Pilot Plant (PCAPP) is for demilitarization of chemical weapons stored at the Pueblo Chemical Depot (PCD), Pueblo, Colorado. The PCD stockpile consists of projectiles and mortars containing blister agents (93.4% of total stockpile), explosives (4.2%), and propellants (2.4%). Agents are approximately 98% HD (distilled mustard, β , β' -dichloroethylsulfide), and 2% HT, a mixture of HD and T (bis-2,2-chlorethylthioethyl ether). Agent demilitarization involves: collection from munitions; hot water and caustic hydrolysis to produce agent-free hydrolytate; biological treatment of hydrolytate to reduce organic content; and effluent treatment to recover water for reuse. The selected biotreatment process for the hydrolytate is Immobilized Cell Bioreactor (ICB) technology. This paper describes the design of ICBs for PCAPP. The design is based on laboratory and pilot testing results, which defined organic loading rates, hydraulic retention times (HRT), aeration and nutrient requirements, and Laboratory-scale, continuous-flow reactor tests were conducted to confirm the destruction efficiency of methylphosphonic acid (MPA) and the effect of sodium hydroxide on MPA destruction efficiency under supercritical water oxidation (SCWO) conditions. Oxygen was used as the oxidant. The reaction temperatures ranged from 400 to 594 °C; the reactor residence times varied from 3 to 83 s; and the oxygen concentrations varied from 110 to 200% of stoichiometric requirements. Fixed parameters included (1) a nominal pressure of 27.6 MPa (4000 psi), (2) a MPA feed concentration of 1000 mg/L, (3) a feed flow rate of 25 g/min, and (4) a NaOH to MPA molar ratio of 2:1. MPA destruction efficiencies (DE) of greater than 99% were achieved at a temperature of 550 °C, oxygen concentration of 200% stoichiometric requirements, and reactor residence time of less than 20 s. On the basis of data derived from 43 MPA experiments, kinetic correlations for the DE of MPA were developed. The model predictions agreed well with the experimental data. Furthermore, data derived from 22 MPA/NaOH experiments indicated that NaOH did not affect the overall effectiveness of SCWO for the destruction of MPA under the Supercritical water oxidation provides a powerful means to transform toxic organic materials into simple, relatively inert oxides. Over the past decade, our understanding of the fundamental chemistry of this process has increased markedly. Many fascinating research papers are appearing from laboratories around the world, on the use of the technique for the decomposition of a variety of organic wastes. This paper summarizes the important findings of few such studies, which are particularly relevant to the disposal of industrial waste water containing organic pollutants.	Hot water and caustic hydrolysis to produce agent-free hydrolytate; biological treatment of hydrolytate to reduce organic content; and effluent treatment to recover water for reuse.	The PCD stockpile consists of projectiles and mortars containing blister agents (93.4% of total stockpile), explosives (4.2%), and propellants (2.4%). Agents are approximately 98% HD (distilled mustard, β , β' -dichloroethylsulfide), and 2% HT, a mixture of HD and T (bis-2,2-chlorethylthioethyl ether).	Biological_Treatment_of_Chemical_Agent_Hydrolytate_by_Immobilized_Cell_Bioreactor_Technology	Google Scholar	WEFTEC conference proceedings.	Hydrolytate, incineration, warfare
G	Medium	30	1999	Y	Supercritical Water Oxidation of Methylphosphonic Acid	Supercritical water oxidation. Laboratory-scale, continuous-flow reactor tests were conducted to confirm the destruction efficiency of methylphosphonic acid (MPA) and the effect of sodium hydroxide on MPA destruction efficiency under supercritical water oxidation (SCWO) conditions. Oxygen was used as the oxidant. The reaction temperatures ranged from 400 to 594 °C; the reactor residence times varied from 3 to 83 s; and the oxygen concentrations varied from 110 to 200% of stoichiometric requirements. Fixed parameters included (1) a nominal pressure of 27.6 MPa (4000 psi), (2) a MPA feed concentration of 1000 mg/L, (3) a feed flow rate of 25 g/min, and (4) a NaOH to MPA molar ratio of 2:1. MPA destruction efficiencies (DE) of greater than 99% were achieved at a temperature of 550 °C, oxygen concentration of 200% stoichiometric requirements, and reactor residence time of less than 20 s. On the basis of data derived from 43 MPA experiments, kinetic correlations for the DE of MPA were developed. The model predictions agreed well with the experimental data. Furthermore, data derived from 22 MPA/NaOH experiments indicated that NaOH did not affect the overall effectiveness of SCWO for the destruction of MPA under the Supercritical water oxidation provides a powerful means to transform toxic organic materials into simple, relatively inert oxides. Over the past decade, our understanding of the fundamental chemistry of this process has increased markedly. Many fascinating research papers are appearing from laboratories around the world, on the use of the technique for the decomposition of a variety of organic wastes. This paper summarizes the important findings of few such studies, which are particularly relevant to the disposal of industrial waste water containing organic pollutants.	Supercritical water oxidation.	Methylphosphonic acid (MPA).	Supercritical Water Oxidation of Methylphosphonic Acid	Google Scholar		Hydrolytate, incineration, warfare
G	Medium	31	2002	Y	Supercritical water oxidation: An environmentally safe method for the disposal of organic wastes	Supercritical water oxidation: An environmentally safe method for the disposal of organic wastes. This paper summarizes the important findings of few such studies, which are particularly relevant to the disposal of industrial waste water containing organic pollutants.	Destruction of VX hydrolytate with supercritical water oxidation.	The article discusses VX hydrolytate.	Supercritical water oxidation An environmentally safe method for the disposal of organic wastes	Google Scholar	The article describes destruction of VX hydrolytate with supercritical water oxidation. The reaction products are reported to be carbon dioxide and inorganic salts. The liquid effluent contains mainly a 1 : 1 molar mixture of NaH2PO4, Na2HPO4 and Na2SO4.	Hydrolytate, incineration, warfare
N	High	35	2007	N	Review of Chemical Agent Secondary Waste Disposal and Regulatory Requirements	NA	Secondary waste generation at chemical agent disposal facilities. Trial burns of secondary waste, compliance testing, and health risk	Secondary agent disposal facilities.	NA	Google Scholar		Hydrolytate, incineration, warfare
T	Medium	32	2008	Y	Incineration of VX hydrolytate	NA	A letter in response to the article "Destroying VX" discussing environmental concerns with the incineration of VX hydrolytate.	VX hydrolytate	Incineration of VX Hydrolytate	Google Scholar	A letter to C&EN's discussing the article "Destroying VX".	Hydrolytate, incineration, warfare
T	Medium	27	2013	Y	DESTRUCTION ACCORDING TO THE CHEMICAL WEAPONS CONVENTION AND ITS APPLICATION IN SYRIA	This paper analyses the complex process of chemical weapons destruction. It starts with sea dumping, the most simple and used method, now prohibited, continuing with conventional methods like hydrolysis and incineration, which have been used since the fifties. Finally, new technologies with specific applications are reviewed, like the use of explosives, biodegradation and supercritical water oxidation. Also, we discuss issues related to categories and deadlines for chemical weapons destruction in the Chemical Weapons Convention and possible modifications based on the need to complete Syria's chemical's stockpiles destruction before mid-2014.	Discussion of incineration of hydrolytate produced from demilitarization of Syria's chemical weapon stockpile.	Syria's chemical weapon stockpile.	DESTRUCTION ACCORDING TO THE CHEMICAL WEAPONS CONVENTION AND ITS APPLICATION IN	Google Scholar		Hydrolytate, incineration, warfare
A	Medium	29	2001	Y	Chemical Demilitarization-Assembled Chemical Weapons Alternatives (ACWA):	NA	Discussion on chemical agent destruction using various processes including neutralization. Processing of hydrolytate waste.	Chemical weapons and hydrolytate.	Chemical Demilitarization Assembled Chemical weapons Alternative.pdf	Google Scholar		Hydrolytate, incineration, warfare
A	Medium	27	2007	Y	Chemical Demilitarization: Actions Needed to Improve the Reliability of the Army's Cost Comparison Analysis for Treatment and Disposal Options for Newport's VX Hydrolytate	NA	Cost-benefit discussion for 8 disposal options to treat 2 million gallons of VX hydrolytate waste.	VX hydrolytate waste.	Chemical Demilitarization Actions Needed to Improve the Reliability of the Army's Cost Comparison Analysis for Treatment and Disposal Options for Newport's VX Hydrolytate.pdf	Google Scholar		Hydrolytate, incineration, warfare

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