REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE *(DD-MM-YYYY)*
1-20-2009

2. REPORT TYPE
Technical

3. DATES COVERED *(From - To)*
Oct 2008 – Jan 2009

4. TITLE AND SUBTITLE
Scalable Emergency Response System for Oceangoing Assets
Final Summary Report

5a. CONTRACT NUMBER
N00014-06-C-0599

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Dougherty, Edmond J.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ablaze Development Corp
771 E. Lancaster Ave, 2nd fl
Villanova, PA 19085-1519

8. PERFORMING ORGANIZATION REPORT NUMBER
Report C0007-010

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
875 N. Randolph Street
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
A002

12. DISTRIBUTION / AVAILABILITY STATEMENT
DTIC Distribution Statement A: Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The scalable emergency system is intended to cover the full scale of possible at-sea incidents from the routine to the rare; from the detection and decontamination of a single piece of equipment before it is loaded on a vessel, to the response, rescue, containment and rehabilitation of a vessel in open waters. The system will be able to safely and quickly decontaminate cargo and personnel, as well as entire vessels at sea and in port. This report concludes the study of concepts developed under the project. Topics include: Scalable Emergency Response System, Chemical Warfare Agent Remediation, Microarray Identification of Pathogens, Enhanced Resolution Nuclear Radiation Detector, Flexbot, Cable Driven Monitoring and Decontamination Robotic System, Compliant Stingray Robot.

15. SUBJECT TERMS
Chemical, Biological, Radiological, Nuclear, and high yield Explosive (CBRNE); At Sea; Sea Basing; Emergency Responders; Terrorism; Scalable Emergency Response System

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Edmond J. Dougherty
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
U	U	U		331	484-557-6590

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Ablaze DEVELOPMENT CORP.

The Radnor Building 771 E. Lancaster Ave Second Floor
Villanova, PA 19085

Program Officer
Attn: Katherine Mangum, Code 333
Office of Naval Research
875 N. Randolph Street
Arlington, VA 22203-1995

January 20, 2009

Subject: Final Summary Report, Contract N00014-06-C-0599

Dear Ms. Mangum,

In fulfillment of Contract Line Item No. 0001, Data Item No. A002, *Final Summary Report,* of Contract N00014-06-C-0599, *Feasibility and Top Level Design of a Scalable Emergency Response System of Oceangoing Assets*, attached please find a copy of the report.

If you have any questions or comment, please contact me at 484-557-6590 or edougherty@ablazedevelopment.com.

Very respectfully,

Edmond J. Dougherty
President

Ablaze Development Corporation
The Radnor Building
771 East Lancaster Ave
Second Floor
Villanova, PA 19085

Final Summary Report

In support of:

Feasibility and Top Level Design of a Scalable Emergency Response System for Oceangoing Assets

Office of Naval Research Contract No. N00014-06-C-0599
Contract Line Item No. 0001, Data Item No. A002

Submitted to:
Program Officer
Attn: Katherine Mangum, Code 333
Office of Naval Research
875 N. Randolph Street
Arlington, VA 22203-1995

Submitted by:
Ablaze Development Corp.
January 20, 2009

Acknowledgement of Support and Disclaimer: This report is based upon work supported by the Office of Naval Research under Contract No. N00014-06-C-0599. Any opinions, findings and conclusions or recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of the Office of Naval Research.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.
a. This statement may be used only on unclassified technical documents that have been cleared for public release by competent authority in accordance with DoD Directive 5230.9. Technical documents resulting from contracted fundamental research efforts will normally be assigned Distribution Statement A, except for those rare and exceptional circumstances where there is a high likelihood of disclosing performance characteristics of military systems, or of manufacturing technologies that are unique and critical to Defense, and agreement on this situation has been recorded in the contract or grant.
b. Technical documents with this statement may be made available or sold to the public and foreign nationals, companies, and governments, including adversary governments, and may be exported.
c. This statement may not be used on technical documents that formerly were classified unless such documents are cleared for public release in accordance with DoD Directive 5230.9.
d. This statement shall not be used on classified technical documents or documents containing export-controlled technical data as provided in DoD Directive 5230.25.

UNCLASSIFIED

Table of Contents

Introduction ... 1
Chapter 1 – Scalable Emergency Response System ... 2
Introduction ... 9
SECTION I. Phased Response System ... 10
Phase I: Local Response ... 10
Overview ... 10
Pre-Event Preparations ... 11
CBRN Personnel Training ... 11
Damage Control Personnel ... 12
Damage Control Training ... 12
Recommended Training for Damage Control Personnel ... 14
Current Navy Training Recommended for Continuation ... 14
Armed Services Training Courses or Programs Recommended for Inclusion ... 16
Damage Control Training Conclusion and Recommendations ... 19
Vessel Design and Purchasing Procedures ... 19
On-Vessel Incident Response ... 20
Integration ... 23
Phase II: Emergency and Expert Response ... 24
Overview ... 24
Delivery Response ... 25
Phase II Personnel ... 27
CBIRF Elements ... 28
Integration ... 29
Phase III: Thorough Decontamination Response ... 29
Overview ... 29
Delivery Options ... 32
Standards of Cleanliness ... 33
Levels of Decontamination ... 33
Delivery Vessels ... 34
Potential Vessel Delivery Options ... 34
CBIRF Team ... 36
SECTION II. TEUs and Modular Response ... 38
Overview ... 38
TEU Personnel ... 38
Benefits of TEUs and Modular Response ... 40
Flexible and Customized Response ... 40
Safety ... 41
Cost Effective ... 42
Ease of Communication ... 43
Equipment ... 43
Environmental Considerations ... 44
TEU Design, Production and Maintenance ... 44
Load-out Scenarios ... 47

Conclusion of Operations 49
Command, Control, Communications and Computers Intelligence/Information Office (C^4I/IO) 49
Operations Center 50
Overview 50
Products 50
Functions 51
Enlisted Personnel 52
Officers 53
Existing Operation Centers 55
Pre-Positioning Phased Roll-Out 55
Pre-Positioning 55
Maritime Prepositioning Force 55
Project Targeted Pre-Positioning Locations 56
Roll-Out 58
Schedule 58
Advantages of a Philadelphia Metropolitan Area Location in Response to Research and Manufacturing Needs 59
Location Options in the Philadelphia Metropolitan Area 62
Philadelphia Naval Ship Yard 62
SECTION III. Reach-back Needs and Philadelphia 66
Research and Development 67
Conclusion 68
Appendix 1: List of Figures 69
Appendix 2: List of Tables 70
Appendix 3: List of Acronyms 71
Appendix 4: TEU Specifications 75
Laboratory Modules 75
Interdepartmental Modules 75
Office/Habitation Modules 76
Support Modules 76
Specifications for General Laboratory Module - Chemical 77
Specifications for General Laboratory Module: Biological 80
Specifications for Nuclear/Radiological Module 81
Specifications for Property Decontamination Module 84
Specifications for Decontamination Module 87
Specifications for Personal Protective Gear Module 90
Specifications for Toxic Diving Module 93
Specifications for the Sensitive Equipment Decontamination Module 95
Specifications for Robotics Module 98
Specifications for CDC Module 101
Specifications for Coast Guard Module 103
Specifications for EPA Module 105
Specifications for FDA Module 107
Specifications for FBI Module 109
Specifications for Datacenter Module 111

Specifications for Media Module 114
Specifications for General Office Module 116
Specifications for Mess Hall Module 118
Specifications for Housing Module 120
Specifications for First Aid Module 122
Specifications for Airlock Module 125
Specifications for Corridor Module 127
Specifications for Power Generator TEU 128
Specifications for Sewage Treatment Module 130
Specifications for Waste Removal Module 132
Specifications for Water Purification Module 136
Specifications for Storage Module - Uncontaminated 139
Specifications for Storage Module - Contaminated 140
Appendix 5: Economic Development Document 141
Appendix 6: Current PNSY Activities 147
Appendix 7: Profiles of Relevant Companies 152
Appendix 8: Environmental Remediation Business Cluster Case Study 157
Appendix 9: Emergency Response Decontamination System Implementation Plan 161
Appendix 10: Emergency Response System Case Study 165
Appendix 11: Clusters, Development and the Power of Agglomeration 171
Software Technology Route 128 – Boston, Massachusetts 173
Research Triangle Park – Raleigh-Durham, North Carolina 176
Connecticut Maritime Cluster 179
Energy Cluster – Houston, Texas 181
Pittsburgh Life Science Greenhouse – Pittsburgh, Pennsylvania 184
Chapter 2 – Chemical Warfare Agent Remediation 187
Executive Summary 187
Background 187
Objectives 190
Findings 190
m-Dinitrobenzene (DNB) 190
Dimethyl methylphosphonate (DMMP) 194
Thiodiglycol (TDG) 197
Conclusions 197
Recommendations 197
Summary 198
References 198
Appendix A: List of Figures 201
Chapter 3 – Microarray Identification of Pathogens 202
Executive Summary 202
Background 202
Objectives 203
Findings 203
Feasibility of PCR-based pathogen detection 203
Feasibility of microarray-based pathogen identification 209
Conclusions 215

Recommendations ... 215
Summary ... 215
References ... 216
Appendix A – Primer characteristics ... 217
Appendix B: List of Figures ... 218
Chapter 4 – Enhanced Resolution Nuclear Radiation Detector ... 219
Executive Summary ... 219
Background ... 220
Objectives ... 221
Completed Tasks ... 223
Future tasks ... 223
Findings ... 224
Filling MOF ... 224
Raman Amplification ... 226
Conclusions ... 227
Recommendations ... 227
Recommended Enhanced Scintillation Scheme ... 229
Summary ... 230
References ... 231
Appendix A – List of Figures ... 233
Chapter 5 – Flexbot ... 234
Executive Summary ... 234
Background ... 234
Objectives ... 235
Findings ... 235
General Configuration ... 236
Hyneman Super Joint (HSJ) ... 237
Electronics ... 239
Conclusions ... 243
Recommendations ... 243
Summary ... 243
Appendix A – A Catalog of Rescue Robots ... 245
Appendix B – List of Figures ... 258
Chapter 6 - Cable Driven Monitoring and Decontamination Robotic System ... 259
Executive Summary ... 259
Background ... 259
Objectives ... 259
Findings ... 259
System Model and Control Law ... 262
Kinematic Representation ... 262
Dynamic Model ... 264
Sliding Mode Control Law ... 264
Simulations ... 265
Disturbance Isolation ... 265
Motion Control ... 265
Conclusions ... 266

Referenced Figures 267
Recommendations 278
Summary 278
References 278
Appendix A – List of Figures 283
Chapter 7 - Aquatic Mobile Robots: A Compliant Stingray Robot 284
Executive Summary 284
Background 284
Motivation 284
Background 284
Technical Issues 286
Dynamics & Hydromechanics 287
Control 289
Scalability 289
Objectives 290
Findings 290
The Real Stingray 290
Concept Robot 293
Actuation 294
Analysis 295
Conclusions 297
Recommendations 298
Relevance to the Navy 298
Anticipated Deliverables 298
Summary 299
References 299
Appendix A – List of Figures 302
Appendix B – List of Tables 302
Chapter 8 – Technical Concepts in Support of an At Sea Emergency Response 303
Introduction 303
Personal Cable Climber 304
Hull Band-Aids 305
Hull Crawler 306
Personal Jet Pack 307
Magnetic Climbing System 308
Bee Stinger 309
Chapter 9 – Observations and Recommendations for Program Development 310
Strategic Context 311
Stakeholder Equities 313
Department of Homeland Security (FEMA, USCG, TSA) 313
Department of Transportation (MARAD, PHMSA) 314
USNORTHCOM 314
Department of Justice (FBI, Bureau of Alcohol, Tobacco, Firearms and Explosives) 314
Central Intelligence Agency 314

Department of State 314
Department of Health and Human Services (Center for Disease Control, Food and Drug Administration) 314
Department of Agriculture 315
Department of Commerce (Bureau of Industry and Security, National Oceanic and Atmospheric Administration) 315
Congress 315
National Defense Transportation Association (NDTA) 315
Commercial maritime companies 315
Recommendation 315
Rationale for a Scalable Emergency Response System for Maritime Assets JCTD 316
Sponsorship, Need, Nomination, and Socialization 316
Sponsorship 317
Need, Nomination, and Socialization 317
Recommended way ahead 318
Other considerations for global agility 319
Final Thoughts 320

Introduction

This is the final report which summarizes the four (4) primary concepts selected for the project, *Feasibility and Top Level Design of a Scalable Emergency Response System for Oceangoing Assets.* The concepts included in the report and organizations performing the work are as follows:

1. *Scalable Emergency Response System,* Ship Recycling Research Institute.
2. *Chemical Warfare Agent Remediation*, Villanova University.
3. *Microarray Identification of Pathogens*, Villanova University.
4. *Optical Fibers for Detection of Radionuclide Contamination*, Villanova University.

This report also outlines the additional concepts selected for the project, and the organizations performing the work are as follows:

5. *Flexbot*, Ablaze Development Corp.
6. *Cable Driven Monitoring Decontamination Robotic System*, Villanova University.
7. *Aquatic Mobile Robots: A Compliant Stingray Robot,* Villanova University
8. *Technical Concepts in Support of an At Sea Emergency Response*
9. *Observations and Recommendations for Program Development,* Logistics Management Institute

Chapter 1 – Scalable Emergency Response System

Ship Recycling Research Institute

Executive Summary

According to the National Research Council, the Navy has largely focused on contamination prevention at the expense of decontamination[1]. At the same time, the U.S. Department of Transportation has documented more than 221 maritime incidents involving hazardous materials within the last 10 years.[2] This situation, coupled with astute and dynamic adversaries who will exploit gaps in U.S. capabilities, underscores the need for a robust, rapidly deployable consequence management and mitigation capability for CBRN accidents and CBRN attacks on U.S. warships, cruise ships, other commercial vessels, offshore energy production infrastructure, sea bases, isolated Pre-positioning sites and other offshore infrastructure that is vital to U.S. interests or national security.

The Emergency Response Decontamination System research is presented in three sections. Section 1 presents the concept of a three-phased scalable emergency response to an at-sea Chemical, Biological, Radiological, Nuclear (CBRN) event. The main text of the report provides detailed descriptions of equipment, personnel, configurations and timelines for all three phases. Section 2 introduces the Twenty-Foot Equivalent Unit (TEU) concept describing the decontamination response using a shipping container supply system. Section 3 is the project reach-back and the research and engineering components proposed for the Philadelphia Navy Yard.

Phase I of the Emergency Response begins with proactive, pre-event preparations:

- Require periodic basic chemical, biological, and radiological defense training for all Navy personnel.
- Enroll all Navy DC personnel in Damage Control "A" School
- Develop and implement a modified version of the U.S. Army's Chemical School training, designed specifically to address the particular working environments and potential situations aboard a Navy vessel during a CBRN event, and require all Navy DC personnel to complete that training.

When a CBRN event occurs, Phase I begins on the vessel and on-board personnel will act within the first 12 hours to perform the existing standard operating procedures established for response to an event and begin basic on-site cleanup.

In Phase II, the 'Alpha' Airborne and 'Bravo' Fast Response elements transport emergency personnel and support experts and the facilities, equipment and tools required to initiate decontamination. Arriving within 12 - 48 hours of the incident, the Airborne evaluation team will provide additional emergency medical care and contribute

[1] NRC-Naval Studies Board 2004
[2] Hazardous Materials Information System, U.S. Department of Transportation Table: Incidents By Mode and Incident Year http://hazmat.dot.gov/pubs/inc/data/tenyr.pdf (as of 3/2/2007)

specialized expertise in CBRN detection, decontamination and protection. The Fast Response team will deploy within 48 hours of the event from various pre-positioned locations around the world aboard a pre-stocked vessel, such as a Landing Craft, Air Cushion (LCAC) or the future Joint High Speed Vessel (JHSV). The Bravo team will establish the Command and Control Office, secure the vessel, establish an operational chain of command and begin in-depth decontamination operations.

Phase III goes into effect if the Commanding Officer determines that further decontamination is necessary. It begins no later than 3 weeks after the CBRN event. There are five options for Phase III implementation to provide maximum flexibility in response. The option selected will depend upon the severity of risk, site accessibility and the requirement of the vessel at port or at sea.

The basic premise of the TEU concept, presented in Section 2, is that every component of the response mission, from living quarters to laboratories to waste collection, will be packaged in individual TEUs that can be arranged on the deck of either the affected ship or a support vessel. Within the TEU network, a series of corridor modules will provide infrastructure connections. Easy to transport and arrange, the 20-foot long metal shipping containers can be customized to serve any role of the emergency response system. Using a mix of new and existing capabilities, qualified personnel will conduct operations and respond to the event, using only the assets available in a TEU network. The main text of the report describes load-out scenarios, and TEU specifications are presented in Appendix 4.

Implementation of the phased response system and the TEU concept will require a series of reach-back capabilities that are either missing entirely or interspersed across geographic, departmental and agency boundaries as well as the private and educational sectors. The report identifies three actions that fulfill the need to unify and centralize reach-back capabilities:

1. Establish a design, fabrication, and maintenance facility for the modular TEU units that this project will use extensively
2. Develop a dedicated research and innovation cluster that draws together DOD personnel, university and other researchers, and the private sector.
3. Integrate and streamline the assets of multiple agencies and researchers and procedures for handling immediate response needs

Section 3 outlines how to move forward from the design phase, which will require a port with ship access and a TEU storage facility nearby. The report's port facility analysis shows that only five American port regions have the ideal combination of industry and labor force for project success. Based upon comparative analysis and data (See Appendices 5-8), Philadelphia is the recommended port for project implementation. This section proposes using a business cluster framework to identify and connect the disparate industries needed to implement the project and to promote industrial and workforce development in the host community. Profiles of successful clusters illustrate the ways in which businesses, government agencies and academic institutions can cooperate, leverage resources and network to increase the productivity of cluster companies, drive research and development, and stimulate new efficiencies and approaches.

Recommendations

The Emergency Response Decontamination System research resulted in 68 specific recommendations to the U.S. Navy in the areas of:

- Readiness Procedures
- Education and Training
- New CBRN Protocols
- Sustainability
- Decision Making
- TEUs and Vessel Layouts
- Personnel
- Operations Center
- Cluster Development.

The specific recommendations are presented below.

Category	Research Recommendations
Education and Training	Increase CBRN training for Navy Damage Control personnel by extending length of training time and focus specifically on responding to onboard CBRN events ***Obstacle***: Currently only minimal CBRN-event response training for Navy personnel ***Proposed Solution***: Modify CBRN training courses from other branches to focus on different vessel types, sizes and overall classification systems to identify constraints on different vessels during a potential CBRN event. ***Obstacle***: Existing first-response SOPs are not sufficient for a response to CBRN threats (SUPSALV method does not specifically address contamination). ***Proposed Solution***: Modify CBRN training courses from other branches to focus on different vessel types, sizes, and overall classification systems to identify constraints on different vessels during a potential CBRN event ***Obstacle***: CBRN training courses in other military branches are not specific to Naval situations and constraints (CBRN events onboard Navy vessels) ***Proposed Solution***: Modify CBRN training courses from other branches to focus on different vessel types, sizes, and overall classification systems to identify constraints on different vessels during a potential CBRN event ***Obstacle***: Navy is the only branch with no specific rating for personnel who can respond to CBRN contamination ***Proposed Solution***: Navy should adopt Air Force's policy of designating more CBRN training for those in higher ranks
Education and Training	Navy DC CBRN training should continue to use training courses currently offered (basic CBRN and survival courses for all Navy personnel, DC "A" School for DC personnel, and periodic ship-wide CBRN Unit Defense exercises) ***Obstacle***: Time intensive; expensive

Category	Research Recommendations
	Proposed Solution: Gradually incorporate changes; prioritize vessels going to high threat areas; Integrate CBRN scenarios into regular fire suppression training exercises
Education and Training	Vessel wide DC training should include a section on CBRN readiness training. ***Obstacle***: Current DC training focuses mainly on firefighting
Education and Training	CBRN training for Navy DC personnel should incorporate training courses used by other branches ***Obstacle***: CBRN training in other branches does not specifically address response to CBRN contamination onboard a Navy vessel ***Proposed Solution***: Modify Army CBRN Specialist training at Army's Chemical School to specifically address challenges that Navy's DC personnel would face in response to CBRN events, in particular working environments and situations onboard a Navy vessel.
Education and Training	Chemical Officer Basic Course should be modified to conduct training onboard various Navy vessels ***Obstacle***: Time intensive; expensive
Education and Training	Components from the Army's Biological Integrated Detections Systems (BIDS) Courses, Chemical Reconnaissance (Recon) Course, Radiological Safety (RADSAFE), Operational Radiation Safety (OPRAD), and Depleted Uranium (DU) awareness courses, Joint Senior Leader (JSL) Course, CBRN Mass Casualty Decontamination Course, and Civil Support Skills Course (CSSC) should be adopted to provide training for Navy DC personnel
Education and Training	The Navy should utilize the Air Force deployment threat area system to prioritize training to vessels that are deployed to higher threat areas
Education and Training	The Navy should create refresher courses in CBRN defense and require DC personnel to take the refresher courses periodically
Education and Training	The Navy should create a system to define which personnel will be most closely working on CBRN events and provide training accordingly
Education and Training	U.S. Coast Guard National Strike Force Weapons of Mass Destruction Technician Course should be modified to emphasize CBRN onboard oceangoing vessels and be offered to Navy DC personnel
Readiness Procedures	New vessel design should integrate technology to more thoroughly sense contaminants, protect the vessel and enable rapid response to CBRN events, based on research of Capabilities Development Documents (CDD) and Capability Production Documents (CPD)
Readiness Procedures	As part of the vessel design integration process, CBRN processes should also be included within existing Navy systems such as the Joint Warning and Reporting Network (JWARN), the Hazardous Material Information Resource System in conjunction with Ship Class Database (HMIRS), and the Joint Acquisition CBRN Knowledge System (JACKS)

Category	Research Recommendations
Readiness Procedures	Purchasing procedures should be designed to protect the vessel, by ensuring that locally acquired equipment and materials are not introduced to afloat vessels. ***Obstacle****:* Risks economic and security benefits of buying locally ***Proposed Solution***: Use Air Force threat area system and similar matrices to create an appropriate balance between economic interdependence and security of USN personnel
Readiness Procedures	All vessels should include standard equipment for preliminary decontamination (including PPE), rated for use in NBC-contaminated conditions, and all personnel be trained to use this equipment ***Obstacle***: May be space/cost prohibitive. ***Proposed Solution***: Prioritize vessels going to high threat areas and utilize space available
Readiness Procedures	DC personnel should monitor and record the general state of the vessel, and address any safety concerns that arise
Readiness Procedures	Equipment for a CBRN response should be pre-positioned in Philadelphia, Diego Garcia, San Diego, Mediterranean Sea, and Guam/Saipan
Readiness Procedures	The roll-out schedule for the Pre-Po nodes should be staggered so that from C-year + 5.5 there will always be three active nodes on alert
New CBRN protocol	Evidence should be preserved, as well as the results of any early hazard identification tests.
New CBRN protocol	Incoming response forces should be notified of whether the contaminated vessel has the structural integrity to accommodate rotary wing assets and decontamination modules that would be lifted aboard the vessel's deck as part of the airborne element
New CBRN protocol	After the Fleet has isolated the contaminated portions of the vessel and given detailed reports to the Operations Center, a formal evaluation team including shipbuilding engineers and a scientific advisory group should be dispatched to begin testing for CBRN contaminants
New CBRN protocol	Further containment of the CBRN material and the beginning of recovery and restoration should be conducted by the USMC CBIRF, consisting of Recon Element, Decon Element, Medical, limited security, Service Support, and a Command and Control Element depending on the complexity and duration of the deployment
New CBRN protocol	The airborne element of the CBRN response should be triggered by the initial contingency, and deploy within 12 hours of the event
New CBRN protocol	The airborne element of the CBRN response should fly directly to the affected vessel and unload if possible
New CBRN protocol	The Recon Element of CBIRF should fly in the lead aircraft with the operation Commander, and should coordinate arrival, locate the HQ Element, and detect, collect, and identify the contaminant. ***Obstacle***: Recon Element may be unable to identify the contaminant. ***Proposed Solution***: If Recon cannot identify the contaminant, members should collect samples for available agencies to identify
New CBRN protocol	The Decon Element of CBIRF should provide decontamination of the vessel and any equipment exposed to CBRN agents ***Obstacle***: Products may not be available that could decontaminate the entire vessel
New CBRN protocol	Support Element personnel should be assigned to one of four sections within the Element: the Headquarters Section should provide all command functions and act as a coordinating agency for the Element.

Category	Research Recommendations
New CBRN protocol	The Embarkation Section of the Support Element should provide embark/debark support to all Elements from its permanent location to the incident site and should be capable of arranging airlift and sealift to the site
New CBRN protocol	Security Element personnel should provide security for the other elements, maintaining lines of cordon, assisting with the evacuation of casualties, assisting fire control and detaining personnel as necessary
New CBRN protocol	A fast response vessel should deploy within 48 hours of the contingency from various forward locations around the world aboard a prepared vessel, such as an LCAC, JHSV, etc., according to the mission requirements
New CBRN protocol	The fast response vessel should tie-off to the affected vessel, and should contain the core components necessary to begin operations on a full scale
New CBRN protocol	Both the airborne element and fast response element should operate under a unified scene commander to coordinate decontamination
New CBRN protocol	A vessel for a large-scale decontamination should load out 2-14 days (on average though incident dependant) after the initial incident and arrive on scene no more than three weeks after the initial incident ***Obstacle***: System development and procurement will be costly ***Proposed Solution***: Pre-Po roll-out schedule will be staggered to spread the costs over a period of 8-10 years and capitalize on lessons learned between now and deployment.
New CBRN protocol	Upon arriving at the contaminated vessel, the decontamination vessel should use sensors and robotics to conduct a scan of the affected areas, both internal and external
New CBRN protocol	Once the mission commander declares the decontaminated vessel to be clean and operational, the specialized equipment used for the decontamination mission should be reloaded aboard the delivery vessel and returned to port
New CBRN protocol	Upon demobilization, the decontamination equipment should be cleansed, repaired, resupplied and prepared again for deployment
Sustainability	The Support Element should be able to self-sustain the CBIRF for 10-14 days and arrange further logistical support to sustain operations, utilizing commercial-off-the-shelf (COTS) equipment whenever possible, as well as commonly available military systems that require little to no customization and are readily available within DOD
Sustainability	The Supply Section of the Support element should provide supply and warehousing support to the CBIRF, ammunition support to the Security element and assist in fiscal/contractor support services from aboard the affected vessel
Sustainability	The Engineer Section of the Support Element should provide water, utilities and heavy equipment support at the incident site.
Decision Making	After the vessel is secured, the Commanding Officer should determine the best of a continuum of options for full-scale decontamination, based on the size and condition of the vessel, and the necessity of returning it to direct action
Decision Making	Option A occurs in-transit and consists of an airlift of necessary equipment to the site of a wet vessel, resulting in a return to port after basic decontamination
Decision Making	Option B, also in-transit, airlifts materials to a dry vessel, performing a mid-to-high level decontamination, resulting in a return to port
Decision Making	Option C is to sealift via decontamination vessel contingent, and perform a high level decontamination so the affected vessel is fully capable of supporting direct action
Decision Making	Option D accesses the site via sealift, and may occur when there is a restriction of decontamination capabilities, so the affected vessel can support direct action only if required; otherwise the vessel is returned to port for refit

Category	Research Recommendations
Decision Making	Option E, used during war-time emergency only, sealifts equipment plus additional assets as needed and leaves the vessel as clean as possible within current strategic constraints so the vessel is returned to fleet use at reduced capability for limited action.
Decision Making	The decontamination vessel should meet a baseline of specifications, including a speed of 15+ knots, sustainable in Sea State 3-4, displacement of 15,000 to 20,000 tons, range exceeding 3,000 nm, secure tie down points, helicopter deployable and external utility access
Decision Making	Choice of a decontamination vessel should depend on the decontamination option implemented by the Commanding Officer. ***Obstacle***: There are some constraints with all three options of retrofitting an existing vessel, constructing a specialized DOD vessel, and using an existing vessel without retrofit
TEUs and Vessel Layout	The platform/transport vessel should carry a series of designated TEU modules, to be configured based upon the specifics of the situation to which the vessel is responding
TEUs and Vessel Layout	Baseline TEUs for a decontamination vessel should include a C4I/IO Cluster (3-6 TEUs), a Datacenter, 4 Housing modules, Waste/HAZMAT, First Aid/BLS, Office, 2 TEUs for Crane, and additional connector TEUs as needed
TEUs and Vessel Layout	Anterooms should be stationed at every entrance to the deck of the vessel allowing personnel to safely remove HAZMAT suits and to decontaminate before entering the larger network of TEUs.
TEUs and Vessel Layout	There should also be portable detection devices customized to the mission at every entrance to ensure that personnel remain uncontaminated
TEUs and Vessel Layout	The delivery vessel should also carry lab equipment for decontaminating sensitive shipboard electronics, as well as an isolation chamber for storing contaminated materials and clean-up related debris for transport to a safe-disposal facility
TEUs and Vessel Layout	A dedicated clean area onboard the vessel should be allocated to handle personnel and equipment as the platform/transport vessel operations move back and forth
TEUs and Vessel Layout	While the vessel is being decontaminated, the platform/transport vessel should also be able to provide housing for affected personnel via TEU-based units as well as basic utilities to augment those affected aboard the contaminated vessel
TEUs and Vessel Layout	Post operations, all TEUs should be decontaminated on-vessel with pre-existing methods and materials used for similar decontamination situations
Personnel	In addition to physical modules, the platform/transport vessel should leverage capabilities of specially trained and equipped teams from various agencies, including but not limited to personnel from the FBI, CIA, EPA, CDC and FDA
Personnel	Recovery in final phase of decontamination should be handled primarily by private decontamination and cleanup contractors, but a CBIRF team should remain to direct and oversee contractor recovery effort
Operations Center	Create a 24/7 one-stop Operations Center to respond to and coordinate response to a CBRN event anywhere that the Navy operates
Operations Center	The Operations Center should direct the mission, act as a communications line between the affected vessel and various government and civilian entities, and leverage resources available to increase the success of the decontamination operation
Operations Center	Standing personnel at the Operations Center should include Navy officers and enlisted personnel with ratings in a variety of support and communication positions, personnel from non-Navy participating entities acting as liaisons between the decontamination efforts and their agencies, and consultants

Category	Research Recommendations
Operations Center	A close working relationship should be established between the Operations Center and the Philadelphia Center, with regular staff rotations, close consultation, and conferences.
Cluster Development	Develop a dedicated research and innovation cluster in the Philadelphia Navy Yard that draws together DOD personnel, university and other researchers, and the private sector
Cluster Development	Establish a design, fabrication, and maintenance facility in the Philadelphia Navy Yard for the modular TEU units that will be used in CBRN response
Cluster Development	The Navy Yard facility should create a TEU prototype, manufacture a small quantity of TEUs as needed, and post-operations will repair, restock, and complete any additional maintenance as necessary
Cluster Development	During manufacturing, each TEU should be tagged with a unique RFID code to aid in later maintenance

"We will continue to work to improve understanding and harmonize best practices amongst interagency partners. This must happen at every level from Washington, DC-based headquarters to the field. DOD, in partnership with DHS, also will continue to develop habitual relationships with state and local authorities to ensure we are positioned to respond when necessary and support civil authorities in times of emergency, where allowable by law. Through these efforts we will significantly increase our collective abilities to defend the homeland."
– National Defense Strategy, 2008, p. 18

Introduction

The goal of this report is to develop a conceptual design for emergency at-sea response and decontamination of a Chemical, Biological, Radiological (CBRN) event. This report has three sections:

- Section I presents a phasing concept detailing a three-phased scalable emergency response to an at-sea CBRN event;
- Section II outlines a Twenty-foot Equivalent Unit (TEU) concept and describes the decontamination response using a shipping container supply system.
- Section III details a project reach-back and research component.

Section I. Phased Response System describes the phasing concept beginning with Phase I, detailing the current on-vessel and local response that could be expected if a CBRN event happened today. Phase I also recommends augmented training and roles for damage control personnel in order to create a better storehouse of local knowledge of the distinct elements of a CBRN event.

Phase II systemizes and codifies action using a two part response in which an evaluation team and then the Marine Corps Chemical, Biological Incident Response Force (CBIRF) lay the groundwork for thorough decontamination. If damage to the vessel is minor, Phase II may result in a return of the vessel to the Fleet.

In the event that additional decontamination is necessary, a supplemental Phase III provides a continuum of options for the completion of thorough decontamination, based on the condition of the vessel and the necessity for returning it to direct action. This capability is a significant departure from the current practice of cleaning up the event as best as possible and then towing the vessel to port for further action or if unsuccessful, sinking it.

Section II. TEUs and Modular Response explains the TEU concept and the way modified shipping containers will be used as modular capability platforms to decontaminate and recover the affected vessel. This section also includes a description of the Command, Control, Communications, Computers, and Intelligence / Information Office (C^4I/IO) TEU. This unit and its accompanying data center module provide the physical and technological interfaces that connect the various working parts of the response, which include other TEUs and agencies on scene, the Operations and Remote Command centers involved in the operation and other parts of the Federal government involved in the operation.

Section III. Reach-back Needs and Philadelphia describes the reach-back, operations, research and development, and maintenance functions that this project requires and outlines the analysis that underpins the compelling advantages of basing these structural aspects at the Philadelphia Naval Yard.

SECTION I. Phased Response System

Phase I: Local Response

Overview

Phase I will consist of pre-event preparations for and first-response actions to a contamination event. Ideally, Phase I will begin before an event, with increased training for the Damage Control ratings and research into ship design as it concerns CBRN contamination. Currently, Damage Control personnel receive limited training in CBRN event response. Additional training is needed to improve response to contamination events. Also, potential contamination incidents should be taken into account when ships are designed or purchased. These acquisitions require consideration of systems and materials that can stop the spread of CBRN contaminants and simplify decontamination efforts.

In addition to pre-contamination planning, Phase I is in effect from the time of the contamination event, H-Hour, to H-Hour +12 (or the arrival of Phase II personnel). Phase I will cover first response assistance to contaminated crewmembers and preliminary decontamination operations. Crewmembers will seal contaminated portions of the ship and put on Personal Protective Equipment (PPE). Any decontamination that can be done on the ship at this time should take place, including use of the wash down system and Collective Protection System (CPS), if it is present. Standard Operating Procedure (SOP) should be followed at all times to ensure the protection of the crew, as outlined in the Multi-Services Tactics, Techniques and Procedures for Nuclear Biological and Chemical

(NBC) Protection document.[3] Phase I duties will conclude with reports of ship stability and a general Situation Report, and preparations for Phase II. Triage and evacuation should be completed based on established Navy response procedures.

Pre-Event Preparations

By planning ahead and training personnel on the specific procedures in response to CBRN events, the Fleet will be able to improve their ability to address the event itself as well as all the issues and actions related to an incident on a ship. Personnel who are familiar with first response SOPs and comfortable with the equipment and procedures are better able to prepare the ship for continuing decontamination while maintaining their own health and avoiding further contamination.

Existing first response SOPs are not sufficient for a response to CBRN threats. In the procedure outlined in the Navy Salvage Handbook[4], the Surplus and Salvage (SUPSALV) method provides an adequate generalized response to hazardous materials spills. SUPSALV procedures direct the Navy On-Scene Coordinators (NOSC) and Navy On-Scene Commanders (NOSCDR) to stop pollution in their area of specialty fight fires and restore the watertight envelope. SUPSALV provides guidance to ensure the vessel's continued seaworthiness and prevent environmental pollution. However, it also illustrates the Navy's lack of a sustained effort to address the consequences of an incident that requires external aid[5]. A weakness of the SUPSALV method is that it does not specifically address CBRN contamination. While it provides guidance for small spills and low-level contamination responses, the Navy Salvage Handbook requires additional instruction or protocols to address more intensive contamination events.

CBRN Personnel Training

The Navy's training personnel training system will also require modifications in order to strengthen the response to CBRN events. Currently, the Navy is the only division of the armed forces that does not have a specific rating for personnel who can respond to a CBRN contamination. There is no Navy Enlisted Classification (NEC) that specifically addresses NBC responses. Instead, squadron maintenance personnel and Seabees receive some training in emergency response.[6] The Navy does use the Navy Occupation Safety and Health (NAVOSH) manual, which details the responses to particular accidents that may occur on a ship.[7] The Navy Safety Center provides NAVOSH procedure training in a variety of locations, generally for one day, or over the course of several days for more intensive courses. However, NAVOSH does not explicitly cover CBRN events, and

[3] *Multiservice Tactics, Techniques, and Procedures for Nuclear, Biological, and Chemical (NBC) Protection.* FM 3-11.4 (FM 3-4). U.S. Army. June 2003.
[4] *U.S. Navy Salvor's Handbook*. S0300-A7-HBK-010, 0910-LP-016-7750. U.S. Navy. January 1, 2004.
[5] Naval Forces' Defense Capabilities Against Chemical and Biological Warfare Threats Naval Studies Board: National Research Council of National Academies 2004
[6] *Seabee Combat Handbook 2*, NAVEDTRA-14235. Naval Education and Training Professional Development and Technology Center. July 2003.
[7] *Course Catalog (FY08).* Naval Safety Center. Accessed on December 17, 2007 via <http://www.safetycenter.navy.mil/training/tableofcontents.cfm.>

instead concentrates on asbestos, fire, spills, hazardous material and industrial hygiene issues. Although crewmembers are taught generally how to respond to hazardous accidents through this training, it does not provide the specific knowledge that CBRN decontamination requires.

In contrast, the Joint Service Family of Decontamination Systems (JSFDS) does have a Damage Control rating[8], specifically tasked with an "all hands evolution to protect and preserve war fighting capabilities[9]" and with training personnel in all aspects of damage control.[10]

Each member performing decontamination operations should be NBC-qualified by the U.S. Marine Corps Forces-Atlantic NBC School or a comparable institution. The responding Element's medical officer and corpsmen should be trained in the Medical Management of CBRN Casualties by the U.S. Army Medical Research Institute of Chemical Defense. Any member of the decontamination team not directly performing decontamination should be trained as an NBC Defense Specialist, for which there is a nine-week school at Fort McClellan.

Damage Control Personnel

Navy personnel, who handle shipboard emergencies such as fire, equipment malfunctions and other emergency repairs to the ship, including CBRN attacks, are known as Damage Control (DC) personnel. DC personnel also provide basic training to the remainder of those onboard to react to, handle and carry out responsibilities during all of these types of emergencies.

Damage Control Training

Upon joining the Navy, all personnel receive basic chemical, biological, and radiological defense (CBR-D) training as outlined in the United States Navy (USN) Basic Military Requirements Naval Education and Training (NAVEDTRA) 14325 Training Course, Chapter 13.[11] Training includes basic recognition of CBR attacks, the need for CBR defense and how best to respond to these attacks including the use of PPE, MOPP, CPS, and basic decontamination of the ship and its personnel. This training is meant to allow the ship to continue on as a combat capable force and properly use its protective systems, equipment, measuring devices and continued training procedures against CBRN attacks. CBR-D training allows Navy units to survive CBR attacks and to continue to fight and defend their ship or unit under CBR-contaminated conditions.

---

[8] *Damage Control Skills and Tricks of the Trade.* NAVSEA. Naval Sea Systems Command. Accessed on August 6, 2007 via http://www.dcfp.navy.mil/library/dctricks/DCTrick021.htm.

[9] *Navy Training System Plan for the Joint Service Family of Decontamination Systems Blocks I, II, III, IV.* N78-NTSP-A-50-0116/I. April 2002. 1-5.

[10] *Damage Controlman Rating.* NAVEDTRA 14057-PPR. 1-5. Accessed on December 17, 2007 via http://www.globalsecurity.org/military/library/policy/navy/nrtc/14057_ppr_ch1.pdf.

[11] *Basic Military Requirements NAVEDTRA 14325*. U.S. Navy. Feb 2002. Chap. 13. Accessed on October 29, 2007 via http://compass.seacadets.org/pdf/nrtc/bmr/14325.pdf

Those who become Damage Control personnel attend Damage Control "A" School, a course "covering everything from shoring to decontamination training to firefighting."[12] Available NAVEDTRA Damage Control Publication Manuals include such courses as Basic Military Requirements, Damage Controlman, Electrician, Engineman, Fireman, Personnel Qualification Standard (PQS) for Damage Control (DC), and First Aid courses.[13]

After going through "A" School, DC personnel are typically trained on the job with further formal training available as their careers progress.[14] Further education takes place in the various rank-specific developmental education courses, as well as courses required of selected specialties. For example, a Navy course at Fort Leonard Wood is titled "Shipboard Chemical, Biological, Radiological Defense Operations and Training Specialist," which provides basic to advanced CBR-D training for Enlisted Personnel (E5-E9), Officers and foreign nationals. Graduates of the course will be prepared to conduct CBR-D training at training commands and aboard ship for functions necessary to prepare for, defend against and recover from CBR-D involvement.[15]

Preparing for and addressing CBRN attacks is just one portion of DC preparedness training. DC personnel are also responsible for the other emergencies that take place on a ship. Firefighting is highlighted during the DC "A" School.

Since DC personnel are required to be able to respond appropriately to chemical, biological, nuclear or radiological threats, the Navy needs to train them more extensively, implementing rigorous training over an extended period of time and focus specifically on responding to onboard CBRN events.

As highlighted in the 2004 *Naval Forces' Defense Capabilities Against Chemical and Biological Warfare Threats* report, "Navy readiness for chemical and biological defense needs improvement. Sustained improvements toward remedying these deficiencies require establishing standards for readiness, training and exercising to those standards, and developing a reporting system attuned to this area. …In fact, if the Navy chooses to

---

[12] Barnes, B. *Casualty Control.* U.S. Navy. Accessed on October 29, 2007 via http://www.mediacen.navy.mil/pubs/allhands/jun99/pg16.htm

[13] *Damage Control Publications: Naval Education and Training (NAVEDTRA) Command Manuals.* NAVSEA. U.S. Navy. Accessed on October 31, 2007 via http://www.dcfp.navy.mil/library/dcpubs/netm.htm

[14] Powers, Rod. Navy Enlisted Rating (Job) Descriptions and Qualification Factors, Damage Controlman (DC). 2007. Accessed on October 31, 2007 via

http://usmilitary.about.com/od/enlistedjob1/a/dc.htm

[15] Shipboard Chemical, Biological, Radiological Defense Operations and Training Specialist. June 8, 2007. Accessed on November 2, 2007 via http://www.wood.army.mil/navy/cbrd.htm

implement only one recommendation from this report, it should be to commit to dramatically *improve readiness*."[16]

Recommended Training for Damage Control Personnel

To improve readiness for CBRN events preparation, the Navy should continue to use several training courses currently offered and incorporate several training courses that other services require. These recommended changes will create a rigorous and prescribed program that brings the Navy's CBRN training up to the advanced level needed for sufficient CBRN response preparation onboard oceangoing vessels.

Current Navy Training Recommended for Continuation

Table 1 lists individual Navy courses and unit Navy training programs, currently offered, that are recommended for continuation.

[16] Naval Forces' Defense Capabilities Against Chemical and Biological Warfare Threats. 2004: 8-9. Accessed on October 31, 2007 via http://www.nap.edu/catalog.php?record_id=11034.

Table 1: Navy Courses and Trainings Recommended for Continuation

INDIVIDUAL Navy Courses Recommended for Continuation	
Course	**Navy Personnel to take course**
Entry level CBR-D training that includes basic chemical, biological, and radiological defense CBR-D training as outlined in the USN Basic Military Requirements[17]	All Navy personnel
Entry level PPE and survival skills training[18]	All Navy personnel
Requirement to attend DC "A" School including the CBR-D element[19]	All DC personnel
Disaster Preparedness Specialist (20 day) and CBR-D Shipboard Operations and Training (10 day) courses[20]	Required for those assigned to ship and shore billets that require specialized CBR-D expertise. These trainees then act as CBR-D trainers for their command. These should be taken by all DC personnel
UNIT Navy Trainings Recommended for Continuation	
Training	**Navy Personnel to take training**
Periodic CBRN Unit Defense training[21]	All Navy personnel
Pre-deployment CBRN Unit training exercises	All deployable units
Basic and advanced CBR-D PQS training to take place after personnel report to units	Navy Units
Participate in ship-wide DC readiness training onboard Navy vessels; however, make sure a portion of the time is devoted to CBRN readiness training and not firefighting[22]	Navy Vessel

[17] *Basic Military Requirements NAVEDTRA 14325*. U.S. Navy. Feb 2002: Chap. 13. Accessed on October 29, 2007 via http://compass.seacadets.org/pdf/nrtc/bmr/14325.pdf
[18] *Department of Defense Chemical and Biological Defense Program. Annual Report to Congress.* April 2007: 111. Accessed on November 1, 2007 via http://www.acq.osd.mil/cp/cbdreports/cbdpreporttocongress2007.pdf.
[19] Barnes, B. *Casualty Control.* U.S. Navy. Accessed on October 29, 2007 via http://www.mediacen.navy.mil/pubs/allhands/jun99/pg16.htm
[20] Ibid.
[21] *Department of Defense Chemical and Biological Defense Program. Annual Report to Congress.* April 2007: 113. Accessed on November 1, 2007 via http://www.acq.osd.mil/cp/cbdreports/cbdpreporttocongress2007.pdf
[22] *Damage Control Skills and Tricks of the Trade.* U.S. Navy. NAVSEA. Accessed on November 2, 2007 via http://www.dcfp.navy.mil/library/dctricks/DCTrick006.htm.

Armed Services Training Courses or Programs Recommended for Inclusion

The Army, Air Force, Marine Corps and Navy maintain CBRN training elements at the United States Army Chemical School (USACMLS) in Fort Leonard Wood, Missouri. Currently, all CBRN defense specialist professional training, except for medical CBRN courses, are co-located at the Army's Chemical School for all services in accordance with Congressional statute (P.L. 103-160, Section 1702).[23] Despite this formal participation very few Navy personnel rotate through Ft. Leonard Wood and few of the trainings have been conceptualized with the limits and special considerations of Navy vessels in mind. The summation below describes best practices of the services active in the collaboration and elements that the Navy might profitably benefit from participating in and/or adopting.

Army

The Army's CBRN Specialists are the centerpiece of the Army's CBRN defense systems and formations. CBRN Specialists are embedded in every Army unit and receive 10 weeks of intensive CBRN training at the Army's Chemical School in Fort Leonard Wood, Missouri.[24]

The Army CBRN Specialist training at the Army's Chemical School is the best option currently available to military personnel. The Navy's DC personnel should receive this training with modifications that *specifically address the Navy's DC personnel in response to CBRN events in particular working environments and situations onboard a Navy vessel.*

---

[23] *Department of Defense Chemical and Biological Defense Program. Annual Report to Congress.* April 2007: 99. Accessed on November 1, 2007 via http://www.acq.osd.mil/cp/cbdreports/cbdpreporttocongress2007.pdf.

[24] *Department of Defense Chemical and Biological Defense Program. Annual Report to Congress.* April 2007: 99-104. Accessed on November 1, 2007 via http://www.acq.osd.mil/cp/cbdreports/cbdpreporttocongress2007.pdf

Table 2: Recommended Ways In Which The Army's Chemical School Courses Can Meet the Navy's CBRN Training Needs

Army Chemical School Course	Course Description	Recommendation
Chemical Officer Basic Course (COBC)	Provides knowledge of radiation fundamentals, CBRN reconnaissance and decontamination operations, etc.	Conduct training onboard various Navy vessels.
Biological Integrated Detections Systems (BIDS) Courses	Training in biological identification and detection principles and required procedures.	Provide training to key Navy personnel to qualify them to perform biological identification and detection operations onboard Navy vessels.
Chemical Reconnaissance (Recon) Course	Training in CBRN identification and detection principles.	Provide training to Navy DC personnel. **Note**: Navy DC personnel do not need training on the M93A1 Fox CBRN Reconnaissance vehicle system because it will probably not be used on the vessel.
Radiological Safety (RADSAFE), Operational Radiation Safety (OPRAD), and Depleted Uranium (DU) awareness courses	Provides DC personnel the opportunity to learn decontamination procedures onboard various vessels. Acquire knowledge of fundamental radiological safety principles onboard a vessel	Provide training to Navy DC personnel
Joint Senior Leader (JSL) Course	DC Leaders further develop and reinforce skills and knowledge in the area of Chemical, Biological Warfare Defense, etc. Emphasis is placed on Joint CB Defense Fundamentals and doctrine (26 week course)	Provide training to Navy DC leaders
CBRN Mass Casualty Decontamination Course*****	Provide DC personnel with casualty decontamination training onboard various vessels	Provide training to Navy DC personnel
Civil Support Skills Course (CSSC)*****	Training for DC personnel in overall issues of a Weapons of Mass Destruction (WMD) incidents	Provide training for Navy DC personnel

*****The CBRN Mass Casualty Decontamination Course and the Civil Support Skills Course are designed to train military personnel to assist local and state response assets by providing casualty decontamination to the civilian populace, and/or to assist an Incident Commander at a Weapons of Mass Destruction (WMD) incident. These courses could also train Navy DC personnel to respond to a CBRN event onboard a vessel. Again, the Navy would need to alter these courses so that they address the specific needs of Navy DC personnel when they respond to CBRN events onboard a Navy vessel.

Air Force

The Air Force does not have any particular training courses that would enhance preparation of the CBRN response capability of the Navy's DC personnel. However, the Air Force does have several training mechanisms or situational factors that prioritize candidates for training.

Personnel deployment locations are ranked at High, Medium and Low threat risk of CBRN attack. Those deployed to high risk areas are given additional training.[25]

Recommendation: All Navy personnel should receive the training outlined in Table 2 under Navy and Army CBRN training options. In addition, the Navy could use the Air Force deployment threat area system to give first priority to ships that are deployed to higher threat areas.

The Air Force requires recurring training every 20 months after the initial training to keep skills current and to introduce new or changed procedures.

Recommendation: The Navy should adopt this approach, create refresher courses for the Navy and Army courses listed in Table 2 and require DC Personnel to take the refresher courses.

The Air Force designates more CBRN training for those in higher ranks and based on command.

Recommendation: The Navy should use this concept to define who would be most closely and thoroughly working on given CBRN events and to train them accordingly. For example, since the DCA has a hand in all CBRN issues, they should receive a higher level of training.

Marine Corps

The Marine Corps has its own 12-week CBRN Defense Specialist Basic Course and 7-week CBRN Defense Officer Basic Course. The Marines utilize the Army's Chemical School for the majority of its additional CBRN training.

Recommendation: Because the Army is the lead military branch for CBRN training, Navy personnel should use the Army's courses rather than the Marine's CBRN Defense Courses as the basis for their training regimen.

Coast Guard

In 1973, the Coast Guard established the National Strike Force (NSF), a cutting-edge force of personnel and equipment that facilitates preparedness and response to oil and hazardous pollution incidents in order to protect public health and the environment.[26]

---

[25] *Department of Defense Chemical and Biological Defense Program. Annual Report to Congress.* April 2007: 93, 105. Accessed on November 1, 2007 via http://www.acq.osd.mil/cp/cbdreports/cbdpreporttocongress2007.pdf.

They too are concerned with and are designated as respondents to WMD/CBRN issues. The Coast Guard also utilizes the Army's Chemical School CBRN training. A Coast Guard officer is assigned to the U.S. Army Chemical School to build a bond between the NSF and the Chemical School.[27] The Chemical School offers a *U.S. Coast Guard National Strike Force Weapons of Mass Destruction Technician Course*[28] that covers chemical, biological and radiological issues, as well as decontamination with field training exercises.

Recommendation: This course may be applicable to Navy DC personnel if it emphasizes CBRN issues onboard oceangoing vessels.

Damage Control Training Conclusion and Recommendations

An efficient and effective training regimen for the Navy's Damage Control personnel would combine courses and training programs from the Navy, Army, Air Force, Marines and the Coast Guard.

Specific Recommendations

- Continue the Navy's current required Damage Control-related training
- Require additional Army courses for select Damage Control Navy personnel as outlined in Table 2. These courses would be offered through the Army's Chemical School and CBRN Specialist training.
- Modify the Army's courses so they specifically address the Navy DC personnel response to CBRN events, in particular working environments and situations onboard a Navy vessel.
- Incorporate the Air Force system that provides additional training for personnel going to high-, medium-, and low-level deployment threat areas. In addition, Navy personnel going into higher risk areas should be trained first and receive a more thorough training with refresher courses recur every 20 months.
- Modify the Coast Guard's National Strike Force Weapons of Mass Destruction Technician Course to focus on CBRN issues onboard oceangoing vessels and offer it to Navy DC personnel.

Vessel Design and Purchasing Procedures

These preparations need to consider and integrate vessel design as well as account for materials and accessibility. Technology to sense contaminants, protect the ship and

[26] *U.S. Coast Guard National Strike Force.* U.S. Department of Homeland Security. Federal Emergency Management Agency. Accessed on November 2, 2007 via http://www.nimsonline.com/resource_typing/U_S_%20Coast%20Guard%20National%20Strike%20Force.htm.

[27] Branson, Dennis E. and Jaime Bigelow. *The Chemical Corps and the Coast Guard – Interoperability in Action.* Accessed on November 1, 2007 via http://www.wood.army.mil/chmdsd/pdfs/2003%20Jan/Branson-Bigelow-03-1.pdf.

[28] Stratman, Guadalupe. *Guardsman Train for Bio-terrorism at Leonard Wood.* TRADOC News Service and Web Operations. Accessed on November 2, 2007 via http://www.tsap.army.mil/pao/training_closeup/CGtrainFLW.htm.

respond to CBRN contaminations may be integrated into the ship's design, based on research of Capabilities Development Documents (CDD) and Capability Production Documents (CPD).[29] CDDs and CPDs are documents that assess, at the outset, the safety capabilities of new systems and equipment. These documents outline how various systems should be acquired, employed and maintained to reduce hazards and Occupational Safety and Health (OSH) risk.

Purchasing procedures may also protect the ship, by ensuring that locally acquired equipment and materials are not introduced to afloat vessels.[30] Set forth in an existing SOP, this purchasing procedure illustrates a direction that CBRN preparation may take: building upon pre-existing equipment, procedures and training. For example, fleet ships already have fully developed contingency plans required for oil spills. Contingency plans for CBRN emergencies can be developed by adjusting existing plans in ways that address the specific issues and needs surrounding a CBRN emergency.

As part of the ship design integration process, CBRN processes should also be included within existing Navy systems such as the Joint Warning and Reporting Network (JWARN),[31] in conjunction with the Hazardous Material Information Resource System (HMIRS)[32] and in conjunction with Ship Class Database and the Joint Acquisition CBRN Knowledge System (JACKS).[33]

On-Vessel Incident Response

Onboard the affected vessels, Damage Controlmen are primarily responsible for responding to CBRN incidents.[34] They are trained to detect, confine and remove contaminants, but they also have the capability and charge to provide additional on-the-job training to other ratings. They maintain material readiness in damage control central and battle dressing stations to prepare for more advanced decontamination maneuvers. Because there are no enlisted personnel with a CBRN-ready rating, DCs will continue to fulfill this aspect of decontamination operations. However, the recommended training, as described in Table 2, should be implemented to increase their training in response to CBRN attacks.

Acting as Safety Officers, DCs will monitor and record the general state of the vessel, and address any safety concerns that either they themselves or personnel locate. They

---

[29] *OPNAV Instruction 5100.24B*. Department of the Navy. Accessed on January 4, 2008 via http://www.safetycenter.navy.mil/instructions/OSH/5100_24B/5100.24B.pdf

[30] *Occupation Safety & Health*. OPNAVINST 5100.19D CH-1. Chap A4 Hazard Control & Deficiency Abatement. August 30, 2001.

[31] *Joint Warning and Reporting Network (JWARN)*. NAVSEA. Naval Sea Systems Command. Accessed on April 30, 2007 via http://www.dcfp.navy.mil/cbrd/ca/jwarn.htm.

[32] *Hazardous Materials Information Resource System*. Defense Logistics Information Service. Accessed on August 6, 2007 via http://www.dlis.dla.mil/hmirs/default.asp.

[33] *Joint Acquisition CBRN Knowledge System*. Joint Program Executive Office. Accessed on May 8, 2007 via https://jacks.jpeocbd.osd.mil/.

[34] *Navy Training System Plan for the Joint Service Family of Decontamination Systems Blocks I, II, III, IV*. N78-NTSP-A-50-0116/I: i. April 2002.

will also participate in hazard control. When an event occurs involving a hazardous material, they may isolate, ventilate and gain administrative control over that area, as appropriate. DCs will also have been trained in the use of PPE, a skill that will also be needed in these first-response decontamination events.

Standard equipment will be included on all vessels for preliminary decontamination operations, and should be rated for use in NBC-contaminated environments. This includes PPE, as well as the attendant training for personnel to become comfortable wearing the equipment, and to get into and out of it safely. Other portable equipment should be trained for and available, such as portable decontamination showers, tents, backpacks with decontamination supplies, and other aspects of personnel decontamination. Because decontamination will often occur in high-stress situations, all personnel should be fully trained and comfortable using all possible equipment, including first-aid and first-responder techniques and materials.

Primary personnel decontamination consists of showering and application of M291 SDK. Decontamination stations should follow established procedure; gross decontamination before re-entering clean spaces, followed by the removal of outer clothing. Inner clothing should be removed as well, followed by showering and redressing in clean clothing.

HAZMAT Shower[35]

Along with personnel response, ship's systems should be adjusted as needed to respond to contamination events. The ship's CPS, if installed, should be used to seal off areas necessary to the operation of the ship such as the bridge, engineering, and other vital areas that are uncontaminated. If the ship does not have a CPS, alternate methods should

[35] ICS of Florida, Inc. Retrieved from http://www.ics-sips-fl.com/HazmatUnit.htm on Sept. 5, 2008; & FoxNews.com article "Satellite Debris Recovery Team Ready for Action. Retrieved from http://www.foxnews.com/story/0,2933,331855,00.html on Sept. 5, 2008

be utilized to continue the operation of the ship, if enough infrastructure and stability allows this possibility.

The Countermeasures Washdown System (CMWDS) should also be used at this time. The system is an efficient way to wash down some sections of the ship because it is easily activated and requires very little manpower. Due to ship design, however, the CMWDS should not be viewed as a thorough, systemic cleansing system. The system is unable to reach approximately 40 percent of the ship. In addition, water would damage parts of the ship such as the control tower and any sensitive equipment. Finally, the design of the superstructure of the ship makes complete cleaning impossible. The CMWDS is a good way to begin decontamination operations. However, to complete ship decontamination, more stringent measures will need to be implemented in later phases.

Decontamination of Ship Deck[36]

Procedures may be broken down into small- and large-scale hazard response. The DC is responsible for the initial response. In a small-scale hazard situation, the DC will assign a Risk Assessment Code (RAC) and may fix the situation if possible. If not, the DC will record it[37] and initiate the chain of command to remediate the situation. Larger-scale hazards require the Hazard Abatement Project Development and interim measures to be put into motion during Phase I.[38]

Once the contamination event has been identified, general and chemical alarms will be sounded by the officer of the deck, proposed decontamination sites will be designated, the CBRN threat assessed, and the defense plans developed per unit should be implemented (dispersing Individual Protective Equipment (IPE) and available

[36] China Military Online. Retrieved from http://english.chinamil.com.cn/site2/news-channels/2008-06/30/content_1340925.htm on Sept. 11, 2008

[37] Incident should be documented per 5100.23G. *Navy Safety and Occupational Health Program Manual.* OPNAVINST 5100.23G. U.S. Navy. 30 December 2005.

[38] Ibid.

detectors).[39] Mission Oriented Protection Posture (MOPP) will be determined and implemented and CBRN detectors activated. Personnel should monitor status of NBC supplies and after preliminary stabilization is complete, crew should respond in the established manner for the type of CBRN decontamination, if it is known.

The Army, Marine Corps, Navy, and Air Force "Multiservice Tactics, Techniques, and Procedures for Nuclear, Biological, and Chemical (NBC) Protection"[40] is a reference manual for addressing CBN attacks and "Multiservice Tactics, Techniques, and Procedures for Chemical, Biological, Radiological, and Nuclear Decontamination"[41] can be referenced for decontamination principles and practices.[42]

After initial post attack operations, reports will need to be gathered, to document the procedures taken so far and to inform the members of Phase II. Evidence should be preserved per SOP, as well as the results of any early hazard identification tests. If any crewmembers were exposed, the report should describe any effects they suffered. Any decontamination processes already done should be listed as well (e.g., a CMWDS wash down). A report on the security situation will need to be prepared for incoming forces, including the continued security level of the ship.

Integration

Once preliminary decontamination is complete, the crew and officers should prepare for integration with Phase II, a two part response, which includes an airborne element and a fast response element that facilitates the arrival of supplementary decontamination personnel and materials. It is estimated that there will be 12 to 48 hours between the time of the incident and the arrival of Deuce Alpha, the airborne element. The estimated arrival time of Deuce Bravo, the fast response element, is 48 hours to two weeks after the incident. Specific information will need to be communicated to these personnel, much of it similar to the reports made during preliminary decontamination and triage. In addition to these early reports of tests, reactions and the decontamination already begun, incoming forces will need to know if the contaminated ship has sufficient structural integrity to handle the rotary wing assets used in the airborne element, in addition to possible decontamination modules that could be dropped on the ship's deck. If the ship's deck is not stable enough to hold foreign objects, the airborne element will be deployed to adjoining assets in the battle space. No preparations are envisioned to be necessary to handle the LCAC or JHSV that will come with the fast response element. Incoming forces will need a complete situation report.

---

[39] *Multiservice Tactics, Techniques, and Procedures for Nuclear, Biological, and Chemical (NBC) Protection.* FM 3-11.4 (FM 3-4). U.S. Army: 29-59. June 2003.

[40] Ibid.

[41] *Multiservice Tactics, Techniques, and Procedures for Chemical, Biological, Radiological, and Nuclear Decontamination.* FM 3-11.5. U.S. Army. 4 April 2006.

[42] This information is not meant to supersede other guidance contained in service-specific TTP or technical Publications.

Existing SOP for changing the chain of command will hold with the arrival of Deuce Alpha and the reordering of command. Likewise, no particular changes will need to be made to accommodate the extra personnel who will arrive with Phase II, because they will bring subsistence supplies with them. Casualty triage will have been completed before Phase II goes into effect.

Phase II: Emergency and Expert Response

Overview

After the Fleet has isolated the contaminated portions of the vessel and given detailed reports to the operations center, a formal evaluation team will be dispatched. The evaluation team, comprised of shipbuilding engineers and a scientific advisory group, will be dispatched with sophisticated equipment to begin the testing process for CBRN contaminants.

Further containment of the CBRN material in the second part (or Bravo element) of Phase II and the beginning of recovery and restoration will be conducted by the United States Marine Corps (USMC) CBIRF. Established at Camp Lejeune in 1996 and now housed within the National Capitol Region, CBIRF's mission is to assist Combatant Commanders (COCOMs) in consequence management operations by providing capabilities for agent detection and identification, Search and Rescue (SAR), personnel decontamination and emergency medical care and stabilization of contaminated personnel.[43]

A standard CBIRF deployment consists of five elements.

(1) Reconnaissance (Recon) detects the location, range and scope of an incident site, and coordinates the arrival of this phase's assets on scene.

(2) Decontamination (Decon) decontaminates personnel to begin life support operations and cordons and isolates equipment exposed to contaminants.

(3) Medical conducts casualty triage during and after decontamination and arranges for their medical evacuation (MEDEVAC).

(4) Security (limited) ensures lines of cordon with additional external security provided first by the contaminated vessel and Fleet escorts and then by the fast response element's fire control systems, whether organic or containerized.

(5) Service Support provides shelter, food and water to sustain the CBIRF on a contaminated vessel.

---

[43] *Chemical/Biological Incident Response Force (CBIRF).* www.Global Security.org. Page last modified: 26-04-2005. Accessed on December 21, 2007 via http://www.globalsecurity.org/military/agency/usmc/cbirf.htm.

A sixth Command and Control Element[44] is added, depending upon the complexity, size and duration of the deployment. The Command and Control Element, is "CBIRF's central nervous system," consisting of operations, intelligence, administration and communication systems that coordinate all of the elements.[45]

The particular strengths of the National Response System (NRS) model which carries over to Phase III, include a superior integration of authority and agencies. Within the model, a clear chain of command exists with the Operations Commander able to request assistance from the Fleet Commander in Chief, who then gains control of the operations for the duration of the salvage procedure. Command reverts to the ship Commander at the end of salvage operations, or if resources are not available to the Fleet Commander, they can be requested from, or authority may be handed over to, the Commander, Naval Sea Systems Command (COMNAVSEASYSCOM)[46].

Delivery Response

Phase II will mobilize the initial response, beginning with the airborne element (Deuce Alpha) that will gauge the situation. The initial airborne response will be followed by a fast-response vessel containing expanded capabilities including the C^4I/IO (Command, Control, Communications, Computers, and Intelligence/Information Office) and the ability to provide interim life support, if necessary, pending medical evacuation (Deuce Bravo).

The two elements will have the ability to work together to quickly obtain information about the situation, and then use that knowledge to begin the decontamination operation. This phase, particularly Deuce Bravo, will focus on the decontamination operations moving from an emergency contingency to an organized operation, with the arrival of a new Commanding Officer specifically tasked with overseeing ship decontamination. With the early response capabilities of the Phase II twin elements, contamination will be more quickly contained.

DEUCE ALPHA / IIA (Phase II – Airborne 'Alpha' Element)
The 'Alpha' element will be the first external response unit on scene. The crew onboard and Fleet escorts will have performed those tasks possible to secure the vessel and its watertight envelope and will provide primary intelligence on the vessel and its contaminants. The airborne element will provide specialized expertise in CBRN detection, decontamination and protection. The airborne element will be able to deploy within 12 hours of a contingency with H-Hour shortly thereafter.

The Deuce Alpha component will deploy via air. Preferably, the airborne element will fly directly to the affected ship and unload, dependent upon the contaminated vessel

---

[44] Counterprofliferation Program Review Committee CPRC Annual Report to Congress 1997. Accessed on January 2, 2008 via http://www.fas.org/spp/starwars/program/cprc97/cprc9708.htm.
[45] Ibid.
[46] *Salvage and Recovery Program.* OPNAVINST 4740.2F. Department of the Navy. July 10, 1997. Accessed on December 21, 2007 via http://www.combatindex.com/mil_docs/pdf/opnav/4700/4740-2F.pdf.

class. The aircraft outlined in Table 3 are examples of those that could be used for Deuce Alpha based on cargo size, range, speed and load needs.

Phase II Airborne Response[47]

Table 3: Airborne Lift Comparisons

Aircraft	Cargo	Range	Speed	Load
C.5 Galaxy (To theater)	143'9"x19'x13'6"	6320nm unlimited w/refueling	450 knots	270,000 lbs palletized cargo, 291,000 lbs max wartime load
C.17 Globemaster III (To Theater)	88'x18'x12'4"	2400 nm unlimited w/refueling	489 knots at 28000'	164,900 lbs palletized cargo, 170,900 lbs max wartime load
MV.22 Osprey	N/A	2289 nm on Self-Deployment 99.4 nm on assault missions unlimited w/refueling	257 knots	20,000 lbs internal OR 15,000 lbs external
CH.53E Super Stallion MH.53E Sea Dragon	N/A	CH:480 nm MH:700 nm unlimited w/refueling	150 knots	36,000 lbs external

DEUCE BRAVO / IIB (Phase II – Fast Response 'Bravo' Element)
The 'Bravo' element will also be triggered by the initial contingency. Aboard the fast response vessel, a standardized set of core response capabilities will provide a command and control structure and the tools necessary to commence decontamination operations. The fast response element will bridge the gap between the initial airborne element and a larger, tailored modular response, Phase III, which will arrive sometime after H-Hour +14 if the Commanding Officer determines that decontamination beyond Phase II capabilities is necessary.

The Deuce Bravo will deploy within 48 hours of the contingency from various forward locations around the world aboard a prepared LCAC.[48] A high-speed, over-

[47] One Marine's View. Retrieved from http://www.onemarinesview.com/one_marines_view/2006/09/index.html on Sept. 12, 2008

the-beach fully amphibious craft capable of carrying a 60-75 ton payload, the LCAC will be assigned to transport equipment and personnel for the Bravo element. It is used to transport weapons systems, equipment, cargo and personnel. The LCAC can transport large quantities of food, supplies and medicine and can conduct evacuations in areas previously accessible only by helicopter.

The LCAC's drawbacks are its limited size, which increases the likelihood of 'cubing-out' (i.e., it cannot be loaded to full weight capacity), the difficulty of transferring cargo and its limited rough sea capabilities. A well deck ship, or one equipped with material handling equipment or an intermediate platform, would not have these drawbacks. However, at this time, the LCAC's speed and amphibious aspects make it the preferred craft for this phase of operations.

The rapid response load-out will contain the core components necessary to begin operations on a full scale in anticipation of any Phase III components. This vessel will tie off to the contaminated vessel.[49]

Phase II Personnel

The personnel accompaniment will be drawn primarily from various components across the Navy and Marine Corps after appropriate additional education and training. It will include primarily corpsman and enlisted personnel, but also Medical Officers and Surface Warfare Officers (SWOs). Deuce Alpha will mobilize to begin conducting operations and managing the various components of this response. The core CBIRF personnel will largely comprise the Deuce Bravo element.

CBIRF typically deploys a 100 to 120 member response team, which maintains a 24-hour readiness posture, to a terrorist incident. CBIRF has the capability to add an additional follow-on force (FOF) of personnel if necessary. The purpose of Deuce Bravo is to deploy a small survey group from CBIRF to conduct the initial stabilization work and prepare reports on the severity of the incident. To fulfill these purposes, Deuce Bravo will mobilize a 25-member team across the CBIRF disciplines to extend the footprint and capabilities of the airborne team and prepare for Phase III operations if necessary. The five CBIRF disciplines will consist of the following personnel:

- Recon – 8 Enlisted; 2 Corpsmen; 1 Medical Officer
- Decon – 2 Enlisted
- Medical – 3 Corpsmen; 1 Physician; 1 Environmental Health Specialist; 1 Nurse
- Security – 2 Infantry Marines
- Support – 1 Enlisted (HQ); 1 Enlisted (Engineering); 1 Enlisted (Embark); 1 Enlisted (Supply)

---

[48] *Landing Craft, Air Cushion (LCAC).* Federation of American Scientists (FAS) Military Analysis Network. Updated February 14, 2000. Accessed on December 21, 2007 via http://www.fas.org/man/dod-101/sys/ship/lcac.htm.

[49] Future plans may utilize the JHSV dependent upon the final vessel design chosen. These recommendations based primarily on LCAC also take that possibility into consideration.

The following C^4I/IO personnel will operate the systems contained within that cluster to support the CBIRF HQ component that will provide the command and control leadership upon arrival of the rapid response vessel:

- AECF – Advanced Electronics Computer Field
    - ET – Electronics Technician
    - FC – Fire Controlman
- IC – Interior Communications man (Advanced Technical Field)
- IS – Intel Specialist
- IT – Information System Technician

Aircrew personnel will also be necessary to operate and maintain the aircraft necessary for mobilization. Each aircrew will consist of 2 pilots and a loadmaster and maintenance personnel as determined. The rapid response vessel will similarly require a crew befitting its usual accompaniment.

CBIRF Elements

The Recon Element will fly in the lead aircraft with the operation Commander. Recon will coordinate arrival, locate the HQ element detect, classify and identify the contaminant. If they are unable to identify an agent with their equipment, members will collect samples for available agencies to identify. In addition to detecting, collecting and identifying, Recon also determines which level of protective gear is necessary for follow-on teams.

The Decon Element is typically responsible for the decontamination of personnel and casualties. For the purposes of this report, Decon will be used to decontaminate the vessel and any equipment exposed to CBRN

The Medical Element is tasked with any arising medical issues. The staff can administer antibiotics and antidotes, and treat chemical burns and conventional injuries. Members of the Medical element will go into an affected area to provide on-scene, life-saving medical attention. Once they stabilize casualties, the element will evacuate them to available land-based medical facilities or hospital ships.

Support Element personnel are assigned to one of four sections within the Element (Typical CBIRF units also have a Motor Transportation Element[50]).

1. The Headquarters Section provides all command functions and acts as a coordinating agency for the Element.
2. The Engineer Section provides water, utilities and heavy equipment support at the incident site. Its inventory includes Reverse Osmosis Water Purification Units (ROWPUs)[51], a variety of generators and heavy equipment.

---

[50] Ibid.
[51] Ibid.

3. The Embarkation Section provides embark/debark support to all Elements from its permanent location to the incident site. Since the CBIRF deploys to a site in the most expeditious means available, the Embarkation Section has to be capable of arranging airlift and sealift for the site.
4. The Supply Section provides supply and warehousing support to the CBIRF, ammunition support to the security element and assists in fiscal/contractor support services from aboard the affected vessel. In Supply, a contracting specialist has the ability to procure logistical support from other vessels within the Fleet as well as land-based distributors and contractors as necessary.

With these respective sections, the Support Element is able to provide housekeeping support for the CBIRF as well as limited support to the affected vessel. In a deployed status, the Support Element can self-sustain the CBIRF for 10-14 days and arrange further logistical support to sustain operations. The CBIRF utilizes COTS equipment whenever possible due to ease of acquisition and lower relative costs. They also will utilize commonly available military systems that require little to no customization and are readily available within DOD.

Security Element personnel will be tasked with providing security for the other elements, maintaining lines of cordon, assisting with the evacuation of casualties, assisting fire control and detaining personnel as necessary.

Integration

Upon the arrival of Deuce Bravo between H-Hour +48 and +2 weeks, the personnel from both detachments will begin to operate under a unified scene command to coordinate decontamination and determine the necessity of implementing Phase III. Phase II will secure the ship, establish an operations chain of command, and evaluate the extent of the damage to the vessel, allowing any Phase III personnel to focus on further decontamination of the ship and equipment.

Once the Commanding Officer decides to implement the supplemental Phase III, all operations will move to the Phase III vessel and full-scale operations will commence. Primarily, Phase II will have prepared the ship for complete physical decontamination and returning the ship to the Fleet or commercial owning entity.

Phase III: Thorough Decontamination Response

Overview

If the CO determines that further decontamination is necessary, a Phase III component will follow Phase II activities. The Phase III delivery vessel must be prepared to swiftly access the site, sustain itself and the crew of the affected vessel, and perform its mission at any location around the world. For this mission set, the delivery vessel must meet a baseline of performance specifications that will best facilitate the completion of the mission including speed, range, stability, power, capacity, etc. Additional details are presented in the “Delivery Options” section. Phase III is a continuum of options that depend on the size of the vessel, the level of cleanliness and decontamination required, and the necessity of returning to direct action. Each option fulfills four objectives: accessibility, sustainability, performance and results.

The Phase III vessel will load-out at as soon as two days and no later than 1 week following the incident. It will depart shortly thereafter, arriving on scene at most three weeks after the incident, at which point all Phase II operations will move to the Phase III vessel and full-scale operations will commence. All units will operate under the guidance provided under each TEU module description and answer to the scene commander.

Phase III-A occurs as the affected vessel transits back to port after basic decontamination and consists of an airlift of necessary equipment to the site. Phase III-B, also an in-transit option, airlifts materials to the vessel and commences a mid-to-high level decontamination. The outcome is a dry variant return to port. Phase III-C will sealift via decontamination vessel contingent, and perform a high level decontamination so the affected vessel is fully capable of supporting direct action. Phase III-D accesses the site via sealift as well, and may occur in areas or situations where the ability to decontaminate is constrained in some way, so the affected vessel can support direct action only if required; otherwise the ship is returned to port for refit. Phase III-E, used during emergency war-time only, sealifts equipment plus additional assets as needed and performs as thorough a containment and decontamination as feasible within strategic constraints to expedite the vessels return to fleet operations.

The platform/transport vessel departs from port with relevant modules onboard based on Situation Reports received from the Phase II quick-response team. The platform/transport vessel is envisioned as a “floating HAZMAT truck,” carrying a series of designated TEU modules. These standard-sized modules are designed for easy transport and activation at the site of the incident. They offer a range of options, to be configured based upon the specifics of the situation to which the vessel is responding.

The following TEU modules are the recommended baseline for a decontamination of a vessel:

C^4I/IO Cluster	(3-6 TEUs)
Datacenter	(1 TEU)
Housing	(4 TEUs)
Waste/HAZMAT	(1 TEU)
First Aid/Basic Life Support (BLS)	(1 TEU)
Office	(1 TEU)
Crane	(2 TEUs)
Additional ‘connector’ TEUs	As Needed

The delivery vessel will carry an accompaniment of laboratory equipment for decontaminating sensitive shipboard electronics, as well as an isolation chamber for storing contaminated materials and clean-up related debris for transport to a safe-disposal facility. Other TEU-based space, such as habitability modules, provides additional life supporting space and will also be a part of the complement.

Within the TEU network, a series of corridor modules would provide infrastructure connections. Power, breathable air, potable water and secure communications will all have identical ruggedized input/output (I/O) points in the TEUs (with a handful of exceptions for safety reasons, e.g., in the decontamination module), allowing a common design to be used, for all of the modules, in delivery and physical arrangement of the modules.

Upon arriving at the contaminated vessel, the platform/transport vessel uses sensors and robotics to conduct a scan of the affected areas. A testing unit confirms the prior evaluations of the incident and the TEU-based modules. A dedicated clean area onboard the vessel is allocated to handle personnel and equipment as the operations of the platform/transport vessel move back and forth. While the vessel is being decontaminated, the platform/transport vessel is also able to provide housing for affected personnel via TEU-based units as well as basic utilities to augment those affected aboard the contaminated vessel.

Once the mission commander declares the decontaminated ship to be as clean and combat capable as determined necessary, the specialized equipment used for the decontamination mission is reloaded aboard the delivery vessel and returned to port. Upon demobilization, the equipment will be cleansed, repaired, resupplied and prepared again for deployment.

Phase III Response with Transfer of TEUs to Contaminated Vessel

Delivery Options

If the Command Center determines that Phase III-A is most appropriate, necessary equipment will be airlifted to the contaminated vessel and the decontamination will occur in-transit. The decontamination vehicle will be sustained by the pre-positioning vessel and security comport with Navy Tactics, Techniques and Procedures (TTPs). Solutions range from basic containment to mid-level decontamination en route to port. The outcome of this option is a return to port clean enough that the ship will be accepted for entry.

If the contaminated vessel is able to float or move independently, Phase III-B may be employed. Phase III-B is also an in-transit variant in which the decon vehicle will be sustained by the affected vessel. The decontamination effort will be high-level and possibly completed en route to port.

Phase III-C may be used if full scale decontamination is required. Phase III-C involves a sealift via the decontamination vessel contingent. The decontamination vessel will be organically sustained with a 21-day supply of food, equipment, decontamination and waste containment gear. A high-level decontamination will be performed at-sea so the contaminated vessel is at minimal safety risk and fully capable of supporting direct action.

Phase III-D consists of large scale decontamination, also by sealift via decontamination vessel contingent. This vessel is organically sustained as well. This option may be prohibitive due to the complexity of the decontamination or the size of the vessel. If possible, decontamination efforts should be completed at-sea so the vessel can return to direct action if required. The affected vessel may be returned to port if unable to support direct action.

Phase III-E occurs during war-time emergency situations when the vessel is required to return to fleet at a reduced capability for limited action. Decontamination equipment will be delivered via sealift and additional assets may be transported as needed. The decontamination vehicle will be externally supplied and sustained with pre-po stocks, plus any additional supplies. The ship will be returned to action as clean as possible, but may pose a severe safety risk for personnel.

The delivery option determined by the Command Center will be dependent on the level of decontamination needed to fit the standards of cleanliness required for the outcome action. If the contaminated vessel is required to return to direct action and a severe risk to personnel is allowable, a low level of decontamination is necessary. If the vessel must return to port and there must be minimal risk to humans for permission to enter, a high level of decontamination is essential.

Standards of Cleanliness[52]

Minimal Risk: Maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing more than:

- Mild transient adverse health effects
- Discomfort, irritation, or certain asymptomatic, nonsensory effects
- Perceiving a clearly defined objectionable odor

Moderate Risk: Moderate risk is an acceptable concentration for unpredicted, single, short-term exposure of the general public in emergency situations. The risk includes maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing more than:

- Possibility of irreversible or other serious, long-lasting, adverse health effects
- Impaired ability to escape

Severe Risk: Maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing more than:

- Notable discomfort
- Impaired ability to escape
- Irreversible or other serious, life threatening effects or death

Levels of Decontamination

Low-Level Decontamination: Basic Containment

- Elimination of threat to human life
- Managed exposure
- Special equipment may be required
- Long term health effects unknown but assumed negative

Mid-Level Decontamination: Large Scale

- All contaminants contained and human exposure at "acceptable risk"
- Special categories of population may see deleterious effects with long term exposure

High-Level Decontamination: Complex

- Longitudinal studies would show no discernable difference between long term exposed group and control population

[52] Definition of PACs. Accessed on February 21, 2008 via http://www.atlintl.com/DOE/teels/teel/teeldef.html

Table 4. Phase III Decontamination Options

	Accessibility	Sustainability	Decon Performance	Cleanliness Level After Action	Results
Phase III-A. In-Transit Variant Wet	Airlift to site	Existing Pre-Po vessel and security comport with USN TTPs	Solutions ranging from basic containment to large scale decon en route to port	Moderate Risk	Return to port "clean enough" so that port will accept vessel; comport with nuclear incident TTPs
Phase III-B. In-Transit Variant Dry	Airlift to site	Existing Pre-Po vessel and security comport with USN TTPs	Approaching complex decon Job may be possibly completed prior to return to port Result possible in transit	Minimal to Moderate Risk	Return to port "clean enough" so that port will accept vessel; comport with nuclear incident TTPs
Phase III-C. At sea Full Scale Decon Variant	Sealift via decon vessel contingent Fast vessel	Organically sustained with 21 day supply decon solutions: food, equipment, decon gear, repair gear, waste containment	Complex decon at sea	Minimal Risk	Fully capable of supporting direct action
Phase III-D. At Sea Large Scale Decon Variant	Sealift via decon vessel contingent	Organically sustained with 21 day supply decon solutions: food, equipment, decon gear, repair gear, waste containment	Scale may be prohibitive If possible/required, complex decon at sea (CVNs and SuperMax)	Moderate Risk	Fully capable of supporting direct action only if required, otherwise returned to port for refit
Phase III-E. Rapid Release Variant	Sealift plus additional assets as needed	Externally supplied and sustained with Pre-Po stocks plus any additional availables (all hands)	As clean as possible within current tactical/strategic constraints	Severe Risk	Returnable to fleet at a reduced capability for limited action (war-time emergency only)

Delivery Vessels

Flexibility is the hallmark of the Phase III response. Multiple TEUs provide collective protection and decontamination and four potential delivery scenarios provide ample options to transport the best systems and personnel to decontaminate a vessel and return it to the fight.

The Phase III delivery vessel must be prepared to rapidly deploy, sustain itself and the crew of the affected vessel, perform its mission and redeploy, in operational scenarios across the spectrum of conflict. For this mission set, the delivery vessel should meet a baseline of specifications that will best facilitate this capability.

- Speed of 15+ knots
- Sustainable in Sea State 3-4
- Displacement of 15,000 to 20,000 tons
- Range exceeding 3,000 nautical miles (nm)
- Secure tie down points
- External utility access
- Capable of Helo Ops

Potential Vessel Delivery Options

The vessels selected in Phase III have a tremendous impact on the ability to access the contamination site and the success of the decontamination effort. This section outlines the vessel options available and the convenience and constraints of each. Vessel preference may vary, depending on whether Phase III-C, -D or -E is implemented. Retrofitting an existing vessel may be the most practical for Phase III-C and -D, while using an existing vessel without retrofitting is likely to be the fastest response for option -E.

Option 1. Retrofit existing Commercial or Navy Vessel (Individual or Ongoing Usage)
This option uses existing DOD contracts or vessels with large-scale transport capabilities to deliver the Phase III manpower and materials.

Conveniences: There are a host of vessels that have the range, lift ability, deck area, carrying capacity and space for wash down. TEUs would be prepositioned in warehouses for deployment after the vessel is placed under contract for timely and inexpensive response.

Constraints: By virtue of different demands, commercial vessels inherently lack organic CBRN air handling and containment systems among other needs and could possibly become contaminated during the mission, which could be hazardous for ship and crew. Making alterations to the vessel for the mission, after agreeing to lease terms, would also be costly, time intensive and involve significant engineering challenges.

Option 2. Construct a Specialized DOD Vessel
This option ensures that the vessel meets necessary requirements and commanders are not constrained by payload, speed or stealth. This vessel will have the ability to enter the area, carry the needed payload and depart.

Conveniences: It will be a next generation vessel with premier, state-of-the-art systems for navigation, firepower and stability, specifically constructed to operate in a contaminated environment. The ship can support and protect the crew, as well as handle incoming contaminated personnel.

Constraints: Designing and building this vessel will be extremely expensive and time consuming; redesigns of existing hulls alone are estimated to be between US$500M and US$1000M.

Option 3. Use Existing Commercial or Navy Vessel Without Retrofit
Utilization of an existing vessel on an as-needed basis permits inexpensive delivery of needed equipment and personnel to the contaminated vessel.

Conveniences: This option provides a range of available ships for use at various locations, allowing for quicker arrival.

Constraints: This vessel may not contain all the ideal components that a specialized vessel offers, and may be costly to adapt or adjust the ship so it fits the delivery needs of Phase III. Loading and setup of TEUs and other materials may require extra time and manpower, however proximity of the vessel can compensate for these needs.

Table 5: Maritime Lift Comparisons

Maritime Vessel	Speed	Capacity	Length	Beam	Displacement	Notes
LCAC – Landing Craft, Air Cushion	40+ knots w/ payload	60 tons; 75 tons at Overload	88’	47’	200 tons at full load	
JHSV - Joint High Speed Vessel	35-48 knots	none given	313’ – 410’	n/a	8,000 tons	Currently being leased; however, scheduled for delivery in the near-term
Rapid Strategic Lift Ship	36-39 knots	3000 Tons of Cargo in 250 Containers	Not Specified	Not Specified	5,000 tons; 3,000 tons in 250 Containers	None Yet Acquired
Wasp Class LHD	20+ knots	none given	844’	106’	40,500 tons at full load	
LHA (Replacement)	20+ knots	1,687 troops (plus 184 surge).	921’	116’	44,970 tons	Scheduled for Delivery in 2013
San Antonio Class LPD	22+ knots	personnel and vehicles only	684’	105’	25,000 tons	
ACS – Auxiliary Crane Ship	T-ACS 4-6 : 20 knots	none given	669’	76’	31,500 tons	
Marlin-class Heavy Lift Vessel	13.3 knots max (Blue Marlin) 14.5 (Black Marlin)	none given	736’ 6”	137’	76,061 tons	
T-AKR LMSR	24 Knots	380,000 sq. ft. (Bob Hope class); 393,000 sq. ft. (Watson Class)	951’	106’	62,000 – 63,000 tons	
T-AK 3015/3016/3017 MPF(E)	17 – 24 Knots	3015:751 containers	3015: 754’ // 3016: 864’ // 3017: 885’	3015: 106’ // 3016: 98’ // 3017: 106’	48,000 – 54,000 tons	
Typical Ocean-Going Barge	N/A	varies with type of barge	310’	76’	9,000 tons	

CBIRF Team

In addition to physical modules based on TEUs, the platform/transport vessel will leverage capabilities of specially trained and equipped teams from a variety of agencies. These teams could be called up to staff the mission depending on the situation and the TEU modules being employed.

Because the U.S. Marines Corps’ Chemical Biological Incident Response Force (CBIRF) is “trained to go into contaminated areas to rescue and stabilize victims exposed to dangerous airborne agents,”[53] they will be used specifically for the fast vessel response portion of Phase II. CBIRF has been used and/or they have exercised in many important cleanups in the past few years. For example, they collected anthrax bacteria samples at

[53] Dalke, Kate. *Life Inside a Hazardous Materials Suit.* Medill News Service. Accessed on December 21, 2007 via http://www.medillnewsdc.com/hazmatsuit.shtml.

the Senate Offices during the October 2001 anthrax event on Capitol Hill.[54] They also worked alongside fire and hazardous materials teams during an exercise following the 1996 Summer Olympics pipe bomb explosion in the Olympic Village in Atlanta.[55]

CBIRF is an organized, self-contained and self-sufficient unit that trains extensively for biological and chemical terrorist attacks. They are flexible, and are known for their quick, prepared, and precise response during events and are capable of rapid response deployment anywhere in the world. These traits not only make them ideal to handle the second portion of Phase II, but also to be the main entity to oversee the thorough decontamination during Phase III of the response.

Normally CBIRF members are first responders, thus recovery in Phase III should be handled primarily by private decontamination and cleanup contractors. However, given the sensitive location of the attack on a U.S. vessel, a CBIRF team should remain after Phase II to direct and oversee the contractor recovery effort in Phase III. It will be important not to tie up the entire CBIRF unit, and only use those necessary to oversee, manage, and coordinate the cleanup during Phase III. Private contractors could be especially beneficial during a long-term recovery effort, for example those lasting a month or more. The use of contractors will allow a CBIRF team to oversee, manage, and coordinate a large-scale cleanup during Phase III.

CBIRF Team Responding to Contamination[56]

During the Capitol Hill anthrax event, the Environmental Protection Agency (EPA) oversaw 27 contractors and three government agencies who conducted the clean up.

---

[54] Ibid.

[55] *Chemical/Biological Incident Response Force (CBIRF).* Global Security.org. Page last modified: April 26, 2005. Accessed on December 21, 2007 via http://www.globalsecurity.org/military/agency/usmc/cbirf.htm.

[56] A.C.T. Ambulance Service. Retrieved from http://www.esa.act.gov.au/ESAWebsite/content_actas/photo_gallery_page/photo_gallery.html on Sept. 5, 2008.

These contractors were either removal, technical, supplies, or laboratory contractors and were utilized under EPA's existing competitive Superfund contracts or additional non-competitive contracts that were designed during and for the additional help needed during the anthrax event.[57] In a similar fashion, CBIRF could use these types of contractors to assist with a large scale cleanup event onboard an oceangoing vessel at sea.

SECTION II. TEUs and Modular Response

"To address more effectively many security challenges, the Department is continuing to shift its emphasis from Department-centric approaches toward interagency solutions. Cooperation across the Federal Government begins in the field with the development of shared perspectives and a better understanding of each agency's role, missions and capabilities. This will complement better understanding and closer cooperation in Washington, and will extend to execution of complex operations."

- Quadrennial Defense Review, 2006, pp. 84-85.

Overview

These containerized units are specifically designed to meet any contingency. Through a mix of new and existing capabilities, qualified personnel from DOD and myriad agencies can conduct operations rapidly and effectively using only the assets available in these units.

A set of laboratory equipment can be used to decontaminate personnel, sensitive shipboard electronics, general equipment and ship surfaces and internal systems. Isolation chambers will store contaminants and wastewater for safe transport and disposal. Habitability and Advanced Life Support (ALS) modules add additional life supporting space that could also be a part of this complement. Basic Life Support spaces augment organic first aid capabilities. Office modules provide the meeting spaces for DOD, Department of Justice (DOJ), DHHS, Department of Homeland Security (DHS), Center for Disease Control and Prevention (CDC), EPA staff, etc., to work together effectively.

Within the TEU network, a series of corridor modules provide infrastructure connections. Ruggedized external I/O points ensure that utility assets can connect. Additional details on specific TEU load-outs can be found in "Load-out Scenarios" and also in Appendix 4.

TEU Personnel

In addition to physical modules based on TEUs, the platform/transport vessel will leverage capabilities of specially trained and equipped teams from a variety of agencies. The personnel accompaniment will include various Navy and Marine Corps components as well as civilian personnel from a variety of governmental agencies, including the Federal Bureau of Investigation (FBI), Central Intelligence Agency (CIA), CDC, EPA

[57] *Capitol Hill Anthrax Incident, EPA's Cleanup Was Successful; Opportunities Exist to Enhance Contract Oversight.* GAO-03-686. GAO. June 2003: 13-19.

and the Food and Drug Administration (FDA). These agencies will contribute their particular expertise, research, and unique abilities to the operation in order to accelerate cleanup and increase understanding of the situation. Civilian participation will necessitate using the already-existing Navy SOP to collapse personnel into the chain of command. The Phase III forces will join other officers and enlisted personnel on scene at the end of Phase II.

Benefits of TEUs and Modular Response

Flexible and Customized Response

The components of a full decontamination platform/transport vessel will be modularized in order to maximize the project's flexibility and reach. The modular approach gives the CBRN team the ability to quickly assemble a completely customized response. On the resulting decontamination platform, everything is interconnected and each piece is essential. The platform's footprint and resource use will be kept to a minimum. Another advantage of this model is that it does not require new deliverable technology. It is based entirely on preexisting technology and materials. TEUs are relatively inexpensive and easy to obtain and they require only minor adjustments to make them livable. The end result, therefore, is a completely mission-customizable, interchangeable system of laboratories, living quarters, and other necessities for any possible decontamination operations.

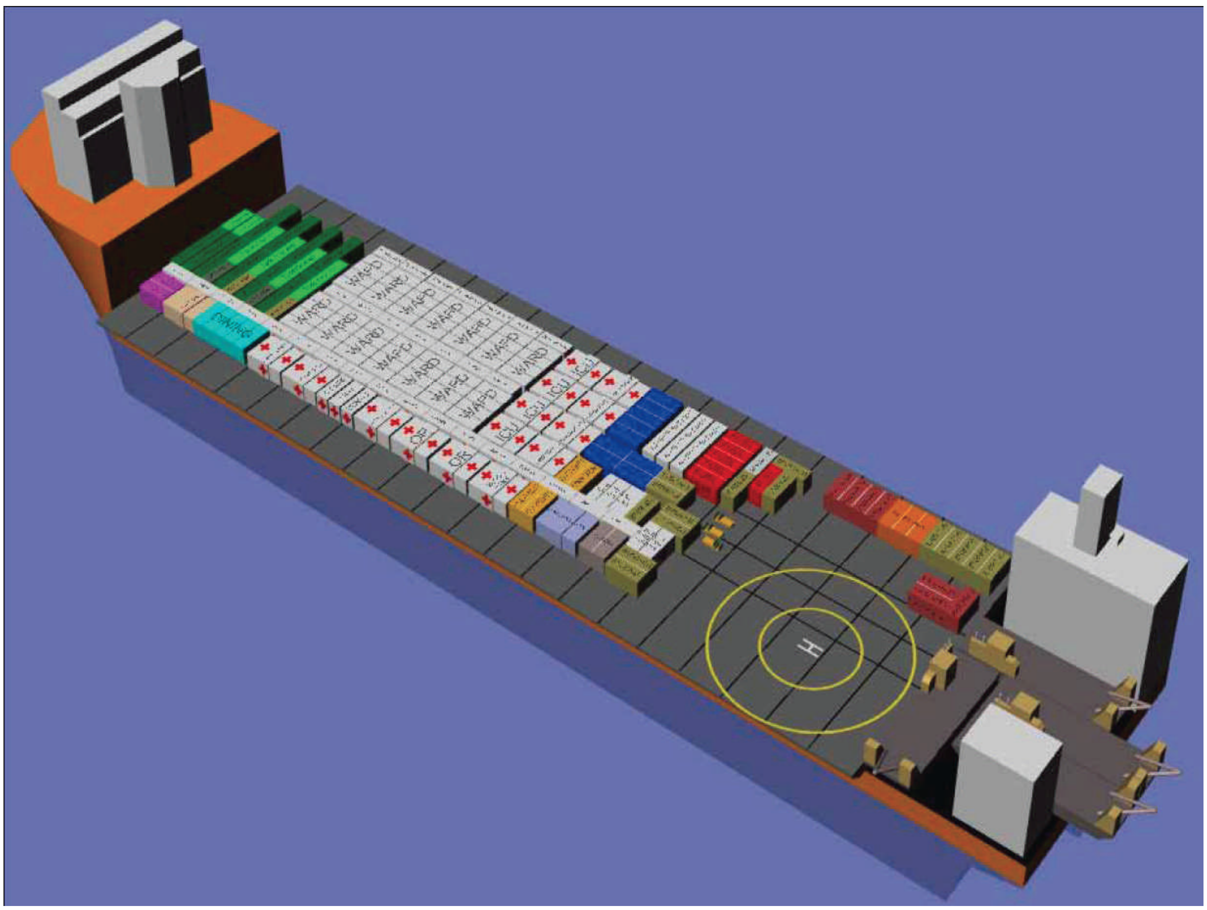


Figure 1: TEU arrangement for a mobile hospital onboard a HLS. This shows the potential for flexibility and customization of a system. [58]

[58] Illustration is used with permission from Naval Surface Warfare Center Carderock Division/ Center for Innovation in Ship Design (NSWCCD CISD).

Safety

The basic premise is that every component of the response mission, from living quarters to laboratories to waste collection, will be packaged in an individual TEU that can be arranged on the deck of the ship. Corridor TEUs will connect all of these ‘rooms’. The specially-designed TEU corridors will link laboratories, offices, storage space and living quarters, resulting in a completely self-contained living space that requires no input or connection with the transport ship. With the TEU corridor design, at no point should any personnel be on the deck of the ship unless they are wearing HAZMAT gear. There will be anterooms stationed at every entrance to the deck of the ship, allowing personnel to safely remove HAZMAT suits and to decontaminate before entering the larger network of TEUs. At every entrance, there will also be portable detection devices, customized to the mission, to ensure that personnel remain uncontaminated. Additionally the connected TEU modules will be sealed and over pressurized to further limit the possibility of contamination.

Within each TEU, spec papers will cover all aspects with a reasonable level of detail, while allowing the contents of each module to be adjusted as needed on a mission-by-mission basis. The most technical aspects, such as the exact lab equipment used, can be stated with rough parameters now and more rigorously researched as the project moves forward.

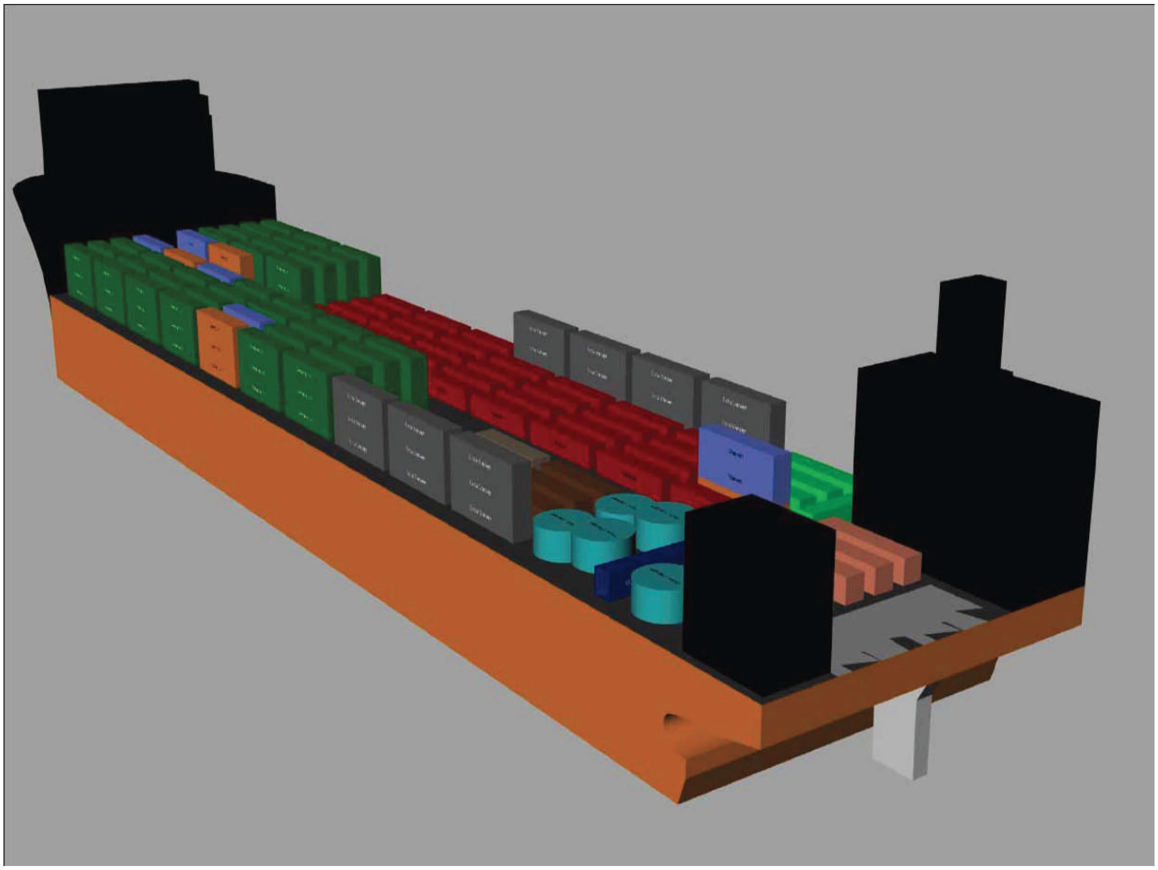


Figure 2: This image demonstrates a layout with stacked TEUs, a possibility for decreasing the footprint and increasing the potential range of ship sizes for the transport vessel. [59]

Cost Effective

Price is an additional factor in planning the TEU village. Shipping containers are readily available at prices below US$6,000 per unit, and would require only additional sealing and environmental controls to transform them into a module for the decontamination platform. In this 'plug-n-play' model, longshoremen can quickly arrange the TEUs to fit pre-designed maps customized to the type of CBRN event to which the ship is responding. It will take minimal time and manpower to prepare one of the TEU 'villages' for deployment, and no new deliverable technology is required for the project.

The small, self-contained network can facilitate coordination of different laboratories and offices, as well as the various agencies that may be represented on the ship. There will be

[59] Illustration is used with permission from Naval Surface Warfare Center Carderock Division/ Center for Innovation in Ship Design (NSWCCD CISD).

a clear path to disseminate and share information among the onshore Operations Center, the bridge of the ship, and the various departments and modules making up the mission.

Ease of Communication

The on-ship intranet will also facilitate communication of findings and updates on the decontamination process, and every member of the ship will have reach-back capabilities through easy contact with onshore personnel, either through the Operations Center, if they are Navy personnel, or through their departments, if they are non-Navy Personnel.

With its easy networking capabilities and its inexpensive creation and maintenance, a modular TEU-based system facilitates a well-orchestrated decontamination operation, allowing personnel at all levels to stay in contact, around the clock, with one another as well as with the operations center, which has reach-back capabilities. Because the system is built around standard-sized, existing technology, any shipyard can store TEUs, transfer them to the ship and, using pre-designed maps, assemble a decontamination village. Because the network is completely self- sufficient, with TEUs handling wastewater, electricity and potable water, space only becomes a factor when choosing the platform/transport vessel to move the decontamination ops to the CBRN event location.

Equipment

The equipment space will act as the connector. The four nodes will contain all the systems necessary to operate any individual Navy vessel, and these systems complement each other with minimal overlap. These systems will connect and interoperate with other TEUs through networked systems architecture as well as through internal communications.

Each TEU within this system will be powered off of the vessels main power source with redundancy systems contained within the cluster. Because of the sensitive equipment and specialized environment necessary to operate the systems contained within this cluster, no water access will be required or installed. The baseline container will be a 20’ heavy test TEU. Further customization to the container will include:

- Insulated floor, walls and ceiling to prevent interference from outside sources;
- Raised floors consistent with those typically used in Top Secret (TS) environs;
- Specialized lighting necessary for optimal performance of personnel and equipment;
- Equipment bracing to prevent shifting during maneuvers and in high sea states;
- Container airlocks preventing contamination by outside variables;
- Anterooms outside of sensitive areas to prevent contamination, enhance security and maintain integrity of sensitive areas;
- Keycard access;
- Tracking beacons in the event that a container is lost at sea.

Environmental Considerations

These TEUs will be especially sensitive to external contaminants. A number of environmental considerations will be built into the structure of these TEUs including passive protection from external electromagnetics through insulation and anterooms that will limit the introduction of external contamination from environmental variables (sea water, dust, etc). Airlocks for these containers will also allow for their recovery should adverse conditions affect the vessel (catastrophic loss of vessel, container tie down failure, etc) enabling these containers to remain buoyant, even when fully loaded, until recovery.

Post-ops, the TEUs will need to be decontaminated. This can be accomplished on-ship with preexisting methods and materials used for tank decontamination.

In addition to the TEUs themselves, the waste products from the decontamination process will have to be safely disposed of. All ports in the United States allow properly-stored hazardous waste, with a permit from the US Coast Guard (USCG). Once returned to port, the inert waste can be disposed of properly. There are a large number of waste disposal companies in the Philadelphia area. The major companies are:

- Environmental Control Systems Inc. - Broomall, PA
- Envirosource Inc. - Horsham, PA
- Solid Waste Services Inc. - Audubon, PA
- Mxi Inc. - Langhorne, PA
- Jack Robinson Waste Disposal Service - Bellmawr, NJ

TEU Design, Production and Maintenance

The fabrication of the TEUs used on the platform/transport vessel will take place over three major phases. The initial concepts for each TEU, which are laid out in the completed specification documents included in Appendix 4, will be combined with any additional research and planning necessary before a physical prototype is constructed. From this prototype, testing and adjustments will be made to result in the final designated TEUs, which will then be manufactured in the relatively small required quantities (Because some designs will need more reproductions than others, such as living quarters and corridors, the manufacturing process should be scalable). Finally, post-mission, the TEUs will need to be restocked, repaired and have any additional maintenance completed before their return to storage.

Although the TEUs have gone through a top level conceptual design, major research will still be required to complete the design of some of the containers, specifically those tasked as laboratories. Additional research and planning may be needed to quantify the specific methods to cover and seal the TEUs against potential environmental contaminants while maintaining a hospitable environment within them. Engineering and pharmaceutical/HAZMAT knowledge will be required to complete this portion of the design process.

Once the prototypes are completed and approved, the manufacturing phase will begin. A warehouse will be needed, with attached offices for a pool of engineers. These personnel will produce blueprints based on the prototypes already created, and from that basis the actual TEUs will be fabricated and/or modified. Access to various transport methods will likely be required, with the TEUs moving via air, rail and road at different points of their fabrication and use.

This is not envisioned as a large-scale manufacturing project, although the manufacture of even limited numbers of TEUs will create short-term jobs requiring a trained workforce at a manufacturing base. Multiples of most of the planned TEU prototypes will need to be made, to account for the maximum flexibility of the mission. During manufacture, each TEU should be tagged with a unique Radio Frequency Identification (RFID) tag to aid in later maintenance.

After a completed mission, TEUs should be decontaminated while still on the transport vessel, and then returned to the manufacturing base on an as-needed basis. There, based on the data linked to the RFID tag, any necessary repair may take place, as well as any design changes that are required. Finally, the container can be restocked and returned to its storage warehouse in preparation for the next decontamination ops.

There will be some specific needs in the manufacturing and maintenance location. Experience with maritime issues is necessary, as well as the equipment to manufacture and move the specialized TEUs. A pool of engineers to produce blueprints and test the TEU prototypes will be needed for the duration of the design and production parts of this project, and a trained workforce will be needed to produce them as well as maintain TEUs after their return from completed missions.

Stacking TEUs for Transport

Table 6: TEU Action Timeline

	TIMELINE ACTION	RESPONSIBILITY
1	Develop concept for each TEU type (laboratory, hospital, wastes/hazmat, office, housing, etc.) designed through research and planning including covering & sealing TEUs against potential environmental contaminants	Research Cluster/TEU Facility
	↓	
2	Construct physical prototype	TEU Facility
	↓	
3	Test and make adjustments to prototype	Research Cluster/TEU Facility
	↓	
4	Design final TEU per TEU type	TEU Facility
	↓	
5	Manufacture designed TEUs in necessary quantities	TEU Facility
	↓	
6	Perform maintenance on all TEUs twice yearly in storage	TEU Facility
	↓	
7	Design specific TEUs based on the strategic environment and potential threats/adversary capabilities and/or if an attack occurs	Research Cluster
	↓	
8	If utilized, decontaminate TEUs while on transport vessel prior to being returned to Port	CBIRF and/or contractors
	↓	
9	If utilized, post mission TEUs restocked, repaired and maintenance completed before their return to storage	TEU Facility

Load-out Scenarios

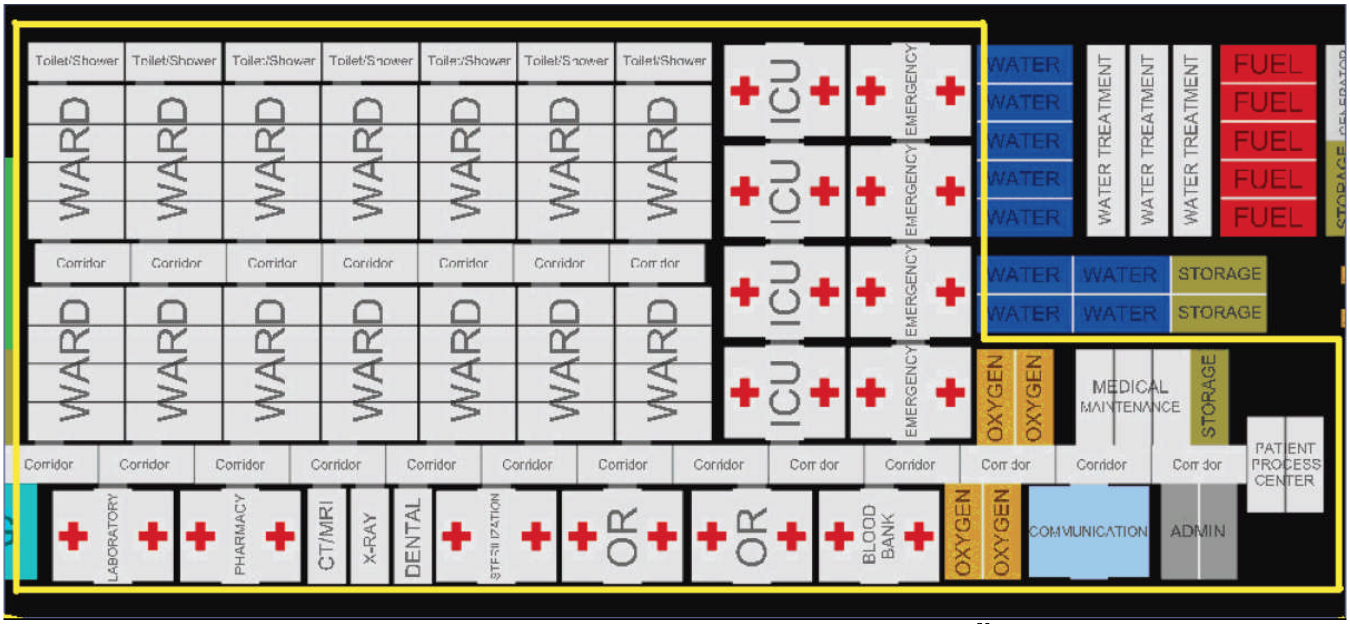


Figure 3: Example load-out scenario for a mobile, TEU-based hospital. [60]

Due to the vast variety of crew accompaniments fleet-wide, as well as the vast range of commercial vessels that the Navy may be called on to assist, it is impossible to estimate the number of TEU units needed for a 'typical' response. There are, however, some reasonable assumptions and each Phase III response personnel accompaniment will likely have as a baseline:

- CDC/FBI (8)
- ChemBio Equip Decon, if necessary (10)
- Waste/HAZMAT (50)
- General Office (4)
- Sensitive Equipment Decon (5)
- Toxic Diving (1)
- Robotics (1)
- FBI, if necessary (1)

[60] Illustration is used with permission from Naval Surface Warfare Center Carderock Division/ Center for Innovation in Ship Design (NSWCCD CISD).

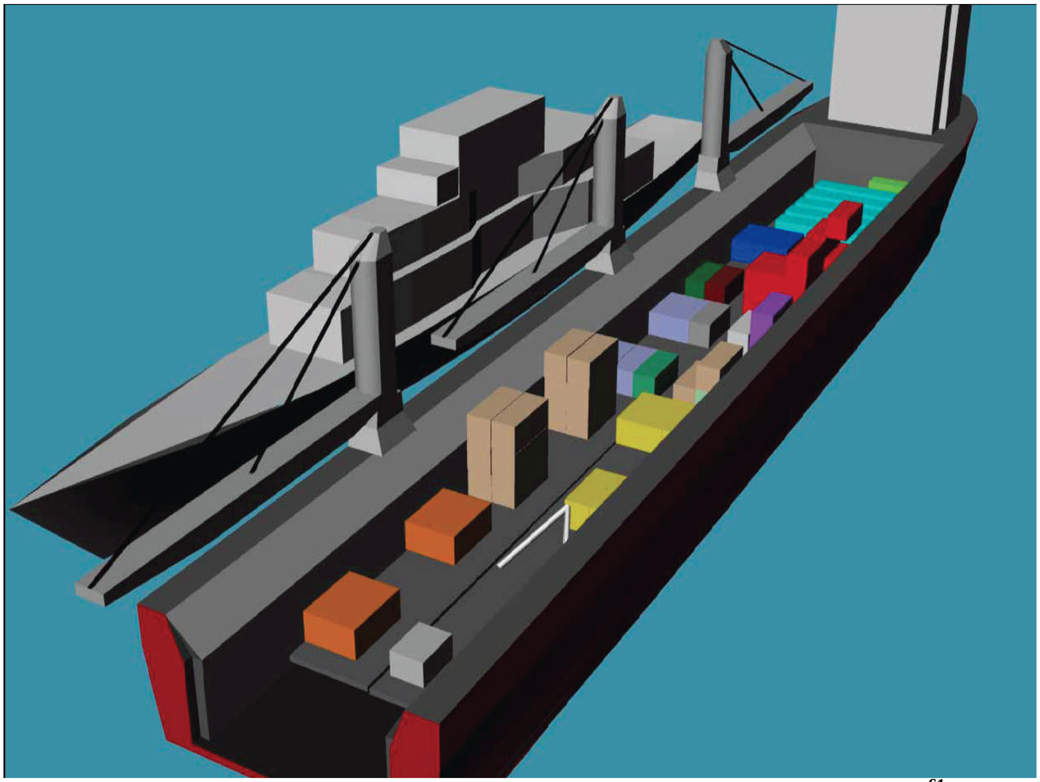


Figure 4: Ship layout that may closely approach a decontaminated vessel. [61]

Smooth coordination of interagency operations will be particularly important during these contingencies. This will only be achievable through a robust training and exercise program that drills this capability on a regular basis. The chain of command must be maintained in this type of complex situation, i.e., a CBRN event. All those aboard will fall under the Commanding Officer (CO) as this will, at all times, be a Navy operation. Ultimately, the CO will have the final say about the conclusion of operations and the parameters of safe operation. The CO will directly oversee the site and is in charge of ensuring the safety of all members of the team regardless of their agency affiliation.

In terms of the chain of command, all members of decontamination teams (Center for Disease Control (CDC) and Environmental Protection Agency (EPA) elements) should be treated as enlisted personnel and will coordinate with the NCOs and officers of the decontamination element. Any Field Agents involved will report directly to the CO because the evidence they collect and conclusions they draw will likely require immediate action and be pertinent to the decision making process.

Daily SitReps will require a coordinated and cooperative effort among the lead officers of each specialty area, the Executive Officer (XO) and the CO to ensure the most appropriate conclusion of operations. Daily SitReps between the scene and the Pentagon will also ensure continuity between the operation and the DOD. Interagency cooperation

[61] Illustration is used with permission from Naval Surface Warfare Center Carderock Division/ Center for Innovation in Ship Design (NSWCCD CISD).

at the higher levels has traditionally been difficult, and it is likely that this will continue to be an issue. Therefore, on-site intra-agency cooperation is essential.

Conclusion of Operations

The CO will determine when to conclude operations. The only external minimum requirement is a determination that the vessel is either combat-ready or that it cannot be decontaminated at sea. The CO will evaluate and establish decontamination standards during Phase Deuce Alpha.

Command, Control, Communications and Computers Intelligence/Information Office (C^4I/IO)

The complexities of decontamination operations at sea are innumerable – a multitude of agencies, personnel and materials in constant motion all while under threat. Maintaining command over such a complex operating environment is difficult, but necessary, and will be performed through a complement of TEUs that will combine to create the Command, Control, Communications and Computers Intelligence/Information Office (C^4I/IO).

This cluster will collapse the multiple layers of the decontamination process – detection, protection, treatment, clean-up, investigation, etc – into a single integrated picture for the Commander, enabling him to coordinate responses, protect the Fleet and operate efficiently. In the C^4I/IO, all information available through all other TEUs will be integrated with additional information from throughout the Fleet, creating a seamless view of the battle space. This cluster will be extremely adaptable and allow for a multitude of delivery vessels, from civilian freighters to naval warships.

The C^4I/IO is the lead Phase III component. Accompanied only by equipment necessary to sustain the Command team, this cluster is the first sea-bound, rapid deployable component of the response to be preceded by the airborne response and assessment team and followed by the full-up decontamination capability. The C^4I/IO cluster allows the Fleet to shift Command and Control from the Carrier Battle Group Commander to a dedicated Situation Commander who will oversee the remainder of the response before turning the ship back over to the Combatant Command.

The C^4I/IO is the nerve center for operations and logistics and is comprised of 5 modular nodes: (1) NetCentrics and Comm's; (2) On-Vessel Tracking Data; (3) Fleetwide Intelligence, Surveillance and Reconnaissance (ISR); (4) Fire Control Center: (5) Logistics.

Upon arrival, the C^4I/IO Commander will assume command over the scene. He will first be briefed on the incident. As the nerve center for the operation, the C^4I/IO will control and monitor operations during the decontamination, determining which assets are appropriate for a given task and the priority in which those tasks will be performed. The Commander will control all assets and personnel regardless of agency or affiliation unless otherwise dictated by the SecDef or Combatant Command. Outside investigative agencies (FBI et al.) are responsible to the Commander as well as through their usual chains of command with final say over safety matters going to the CO.

Aboard host vessels not organically equipped with the fleetwide ISR and Fire Control systems, the C^4I/IO will also integrate fleetwide intelligence on movements of friendly and enemy vessels, aircraft and personnel and maintain control over defensive systems. Due to the high level of automation with the Phalanx, RAM or Sea Launched Rolling Airframe Missile (SeaRAM) system, fire control is marginally intensive but remains vitally important.

The final and most important capability contained within the C^4I/IO cluster is the secure communication system that allows the various TEUs a direct reach-back link to stateside support assets.

The C^4I/IO will fuse data from all other TEUs into a single reporting architecture that gives the Commander a single picture of the battle space as the information becomes available. From these reports, the Commander can determine the length of operations and coordinate the movement of any additional assets to the scene, casualty evacuation, contaminated vessel transit, and vessel and operational support vessels based upon intelligence gathered aboard the contaminated vessel and upon the analysis and recommendations of subordinate and support personnel. The CO also has final authority concerning the conclusion of operations.

The C^4I/IO gives the Commander all the assets he will need to prosecute operations and complete his mission.

Operations Center

Overview

The Operations Center will provide a 24/7/365 center to act as a contact point for the platform/transport vessel. At the same time, the Operations Center will direct the mission, acting as a communications line among the various phases and relevant government, military and civilian entities, and leveraging resources available to increase the success of the decontamination operation. Ideally, the Center should be the only entity a CO needs to contact in order to initiate the decontamination process. This efficient movement of information and personnel will increase the likelihood of a quick response to CBRN events. It will also establish a chain of command and set of procedures that may be used as needed, instead of the largely ad hoc nature of current responses.

Products

- Output of information – the Operations Center will gather and disseminate collected data from both the platform/transport vessel and related research efforts.
- Situational awareness, on ship and land, of all involved assets

- Define and articulate situation, steps needed for amelioration, and current status of contaminated ship

The Operations Center will primarily produce and communicate information about the state of the CBRN event and contaminated ship. The Center will have the staff and capability to gather data from the platform/transport vessel as well as relevant research and data from on-land resources, thus planning and executing a more efficient, informed decontamination process.

The Center will also act as the lynchpin of the decontamination process, maintaining situational awareness both on ship and on land, leveraging its unique position as the entity in constant contact with personnel from all involved entities. Finally, the Center can also use its unique position to articulate the general situation, the specifics of the decontamination mission and the status of the contaminated ship.

Functions

- Act as an intermediary between Navy, vessel and other participants
- Link on-scene responders, Federal agencies, educational institutions and private sector research

The Center will have the capability to facilitate contact among the affected vessel and relevant expert entities. Participants will include:

- Navy
- Other DOD branches
- Other Governmental departments and agencies judged appropriate
- Watchstanders

Operations Center personnel may belong to one of three groups, depending upon their position: staff, watchstanders and consultants. Staff will consist primarily of Navy Officers and ratings in a variety of support and communication positions. They will maintain situational awareness at all levels, and monitor the joint efforts of decontamination, clarifying and articulating the desired outcome in order to best use the specific strengths of the cross-section of civilian, government, and military participants.

Watchstanders will consist of personnel from non-Navy participating entities acting as liaisons between the decontamination efforts and their agencies. They will primarily come from DHS and HHS agencies, but other entities may become involved as well. Watchstanders are often present in multiple DHS operations centers, although historically their role has not been so well-defined. Within the decontamination Operations Center, watchstanders will specifically maintain situational awareness, thus increasing their ability to respond quickly when their agency needs knowledge and/or manpower.

The Operations Center will be completely integrated with the entire decontamination process. They will be an information hub, reachable through the on-ship intranet to quickly access knowledge and analysis of findings. Lines of communication with the platform/transport vessel will remain open at all times, allowing a quick transfer of information between the Operations Center and the bridge of the ship. Communication will occur solely among Navy personnel, with necessary information being disseminated to non-Navy personnel on a need-to-know basis. Adaptations of this model will be accommodated when necessary.

<u>OPERATIONS CENTER (Washington D.C. area based) FUNCTIONS</u>

- ✓ Onshore Center to Filter & Exchange Information with contaminated ship simultaneously directing the mission, acting as a communications line between phases and government, military, and civilian entities
- ✓ Gives ship ability to communicate with onshore expertise (staff, watchstanders, contractors)
  - Staff – 1st responders (Navy), CBRN personnel
  - Watchstanders – Non-navy liaisons between decontamination efforts and their agencies (DHS, HHS)
- ✓ Gathers and disseminates collected data from contaminated ship and related research effort
- ✓ Produces and communicates information on the state of the CBRN event and the contaminated ship and plans a more efficient, informed decontamination
- ✓ Provides link between responders on the scene, federal agencies, educational institutes and private research sector (pharmaceutical, chemical, and engineering centers)

Figure 5: Operations Center Functions

Enlisted Personnel

<u>ET - Electronics Technician</u> (Advanced Electronics Computer Field).
ETs maintain and repair electronics equipment such as radar, communication and navigation equipment.

<u>IC - Interior Communicationman</u> (Advanced Technical Field).
IC duties include: maintaining and repairing interior communications systems; preparing and interpreting blueprints, wiring diagrams and sketches; installing and inspecting dry cell and storage batteries; recharging wet cell batteries; testing interior communications and gyrocompass equipment; installing telephone and other communications circuits, boxes, switchboards and bell buzzer systems; maintaining and operating TV systems; maintaining and repairing shipboard navigation equipment.

IS - Intel Specialist.
IS duties include: analyzing intelligence information; identifying and producing intelligence from raw information; assembling and analyzing multisource operational intelligence; preparing and presenting intelligence briefings; plotting imagery data using maps and charts; providing input to and receive data from computerized intelligence systems ashore and afloat; maintaining intelligence libraries and files.

IT - Information System Technician.
IT duties include: designing, installing, operating and maintaining state-of-the-art information systems technology including local and wide area networks, mainframe, mini and microcomputer systems and associated peripheral devices; writing programs to handle the collection, manipulation and distribution of data for a wide variety of applications and requirements; performing the functions of a computer system analyst; operating and coordinating telecommunications systems including automated networks and the full spectrum of data links and circuits; transmitting, receiving, operating, monitoring, controlling and processing all forms of telecommunications through various transmission media including global networks; applying diagnostic, corrective and recovery techniques to all facets of the integrated information systems; maintaining all necessary logs, files and publications at the communications center.

Officers

IO - Intel Officer.
SWO - Surface Warfare Officer.

Netcentrics and Comms
AN/USQ-119E(V) - GCCS-M Afloat Node
The Global Command and Control System - Maritime (GCCS-M) provides all Maritime Commanders with a single, integrated, scalable command, control, communication, computers, and intelligence (C^4I) system that processes, correlates, and displays geographic track information on friendly, hostile and neutral land, sea and air forces, integrated with available intelligence and environmental information, to support command decision making.

GCCS-M fields a baseline system consisting of core functionalities and a set of mission-specific subsystems. Additional subsystems, as well as core upgrades and new functionality, will be fielded in future releases allowing GCCS-M to evolve as warfighter requirements change with incremental implementation of hardware and software releases.

GCCS-M will utilize super-high frequency (SHF), ultrahigh frequency (UHF), and extremely high frequency (EHF) satellite communications (SATCOM) for secure communications and the Navy Multi-band Terminal SECRET Internet Protocol Router Network (SIPRNET), Non-Secure Internet Protocol Router Network (NIPRNET), and JWICS (Joint Worldwide Intelligence Communication System).

International Maritime Satellite (INMARSAT) access will serve as back-up non-essential bandwidth.

On-Vessel Tracking Data

Active RFID

Radio Frequency Identification has been employed by DOD since the early-1990s. RFID tags will provide information and track equipment and inventory. Active RFID tags utilize an onboard power supply to transmit at higher power levels than passive tags, allowing them to be more effective in "RF challenged" environments like shipping containers. Active tags typically have a 1500' range and a battery life of up to 10 years. They also experience fewer failures and errors than other tags or human tracking. Active tags are also beneficial to monitor a number of additional dynamics including temperature, humidity, atmospherics, radiation, etc. The central reporting and control center would be housed within this tracking center.

FBCB2 – Force XXI Battle Command Brigade and Below

FBCB2, commonly known as *Blue Force Tracking*, gives the Command and Control center an integrated picture of the battlespace. For this contingency it provides for accountability of all members of the decontamination team. Blue Force will tell the C^4I/IO where every member of the team is at all times.

JTIDS/TADIL J/LINK 16, TADIL A/LINK 11, TADIL C/LINK 4A, TADIL/LINK 14/LINK 22

These data links provide real-time or near real-time ISR data to be passed from other vessels, aircraft and systems utilized in the battlespace, enabling the commander to make choices on ship survivability and maintain situational awareness.

TAC-4 Datalink Processing Systems

Pieces of the TAC-4 system will process signals and bring down data off the network to be processed by analysts or consumed by commanding officers, providing a complete picture of the battle space.

MK-15 Mod 31 SeaRAM Fire Control System

The SeaRAM system provides the latest in survivability armament by combining the sensor and tracking systems of the MK-15 Phalanx Close-In Weapon System (CIWS) with the Rolling Airframe Missile (RAM) system. SeaRAM is capable of countering a broad array of threats including anti-ship cruise missiles, surface craft, helicopters, unmanned aerial vehicles (UAVs) and fixed wing aircraft using a self-contained 11-missile kinetic weapon assembly. The Ku-band search-and-track radar and a new Forward-Looking Infrared (FLIR) imaging system are borrowed from the Phalanx. The RAM battery can put each 9' round downrange above Mach-1 with a 20lb blast fragmentation warhead. This system is also unique to the Fleet because of its indigenous Fire Control system. The Fire Control officers, a SWO element, would be housed in this node.

Existing Operation Centers

A review of current Operations Centers managed by DHS and DOD suggests that these new activities may be rolled into one of the existing centers. To facilitate contact, DHS and DOD stakeholders would select the most appropriate Operations Center, preferably located in the National Capital region. The expanded Operations Center and the Philadelphia Center would establish a close working relationship, with regular staff rotations, close consultation and conferences.

Pre-Positioning Phased Roll-Out

The biggest challenge is to ensure that the system will get to the contingency as quickly as possible in order to carry out its mission. We remedy what would be a long supply chain by extending the capability through co-location at Pre-Positioned stocks around the world. The deployment of our equipment to Pre-Positionings, however, will likely not be immediate. This section outlines the Pre-Positioning system and establish a phased roll-out to key Pre-Positionings globally allowing for the establishment of a global response capability over an 8 to 10 year spiral beginning with the first unit in Philadelphia.

Pre-Positioning

The U.S. military stockpiles or prepositions reserve military equipment and supplies near potential conflict areas to ensure that the materiel is quickly available to forces in the event of a contingency. During a contingency, Pre-Positioned stocks accelerate response times so that only the response forces and a relatively small amount of materiel need to be transported to the contingency area. As a result, DOD can field heavily-equipped, combat-ready forces in hours and days rather than weeks and months.

The Army and Marine Corps rely heavily on Pre-Positioning. The Air Force and Navy have relatively small programs, because they tend to deploy with most required equipment. USN/USMC programs include:

1) The 16-ship Maritime Prepositioning Force;
2) A brigade of equipment in Norway, and;
3) Other items, including hospitals, ordnance and a small amount of other material.

Maritime Prepositioning Force

The top priority in the Marine Corps and the Navy Pre-Positioning programs is the Maritime Prepositioning Force. This force consists of 16 Military Sealift Command (MSC) Prepositioning ships especially configured to transport supplies for the USMC. The ships were built or modified beginning in the mid-1980s and are forward-deployed in three squadrons to regions around the world. The ships contain nearly everything the Marines need for initial military operations including tanks, personnel carriers, ammunition, food, fuel, spare parts, etc. The force also contains Navy equipment, including construction equipment and crafts used for off-loading and ferrying equipment and supplies ashore.

The three squadrons – MPS Squadron One, located in the Mediterranean Sea and eastern Atlantic, MPS Squadron Two, located at Diego Garcia, and MPS Squadron Three, located in the Guam/Saipan area – each carry sufficient equipment and supplies to sustain about 15,000 marine air-ground task force (MAGTF) personnel for up to 30 days. Any of the 16 ships is designed to discharge cargo either pier-side or while anchored offshore using an assortment of lighterage (small craft designed to transport cargo or personnel from ship to shore) carried aboard.[62]

Project Targeted Pre-Positioning Locations

There will be four planned pre-positioned locations for this system throughout the world. Each unit will be identical in every way, enabling the specialized force to rapidly respond to any contingency in any Area of Responsibility (AOR). The chosen locations will provide the best access for stateside reach-back and re-supply while also being forward deployed to hotspots where this function will be most useful. All targeted locations other than Philadelphia house land-based and afloat PREPO stocks and are the largest within the DOD PREPO system.

Philadelphia – As the project base point and home to the Manufacturing Maintenance and Research and Development (R&D) Center, Philadelphia will provide the best test bed for the first deployable unit. Philadelphia is ideally suited for security, transportation access, available land, skilled and unskilled labor, room for growth and is a center of excellence for technology, pharmaceuticals and medical research developments. From a Defense standpoint, the first unit should be housed away from the main Fleet in Norfolk to prevent having a single point of failure, but it should be within short range of that Fleet in the event of a contingency. The Philadelphia Naval Ship Yard (PNSY) is also ideal because it is isolated from collateral targets. Finally given the proximity to the system's proposed manufacturing base will expedite rapid replacement of parts and materials.

Diego Garcia - Diego Garcia is an essential PREPO point for missions stretching from Africa through the Philippines and beyond. It is a primary waypoint between the Pacific and Atlantic and it has a direct support mission for Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). Remote and isolated, Diego Garcia has enough runway space to accommodate any aircraft carrying any load and has substantial offset for afloat PREPO stocks. Because this site is so remote, security is somewhat less of a challenge. A main advantage of the location is the ability to rapidly mobilize from Diego Garcia to any point within the Indian Ocean in hours.

Mediterranean Sea - The Mediterranean region is the centerpiece of our strike portfolio. From this region, it is possible to monitor activities on three continents. Our PREPO in the Mediterranean are required to extend our reach into the Middle East and North Africa as well as to support of operations in the Balkans. The Med PREPO could respond both to the immediate threats in the eastern Mediterranean and to contingencies along the Atlantic seaboards of Europe and Africa. It also has the capacity, together with the Diego

[62] Information culled from two primary sources:
(1) United States Navy Military Sealift Command – Maritime Prepositioning Force, *http://www.msc.navy.mil/pm3/mpf.asp, and;*
(2) General Accounting Office, *Military Prepositioning: Army and Air Force Programs Need to be Reassessed*; GAO/NSIAD-99-6 (Washington, DC: U.S. GAO, 16 November 1998), Appendix I - Page 60.

Garcia PREPO, to provide a robust response capability to multiple simultaneous contingencies in-theater.

Guam/Saipan - This node will be the main support provider for PACOM. As discussed in the prior San Diego section, this node will probably be relocated to the Guam/Saipan PREPO after a brief stint on the West Coast of the Continental United States (CONUS). Guam/Saipan will be able to respond easily to contingencies revolving around United States Forces Korea (USFK), China, as an SSN response force for Pearl Harbor, and in conjunction with the Diego Garcia PREPO in the Philippines, Indonesia, etc.

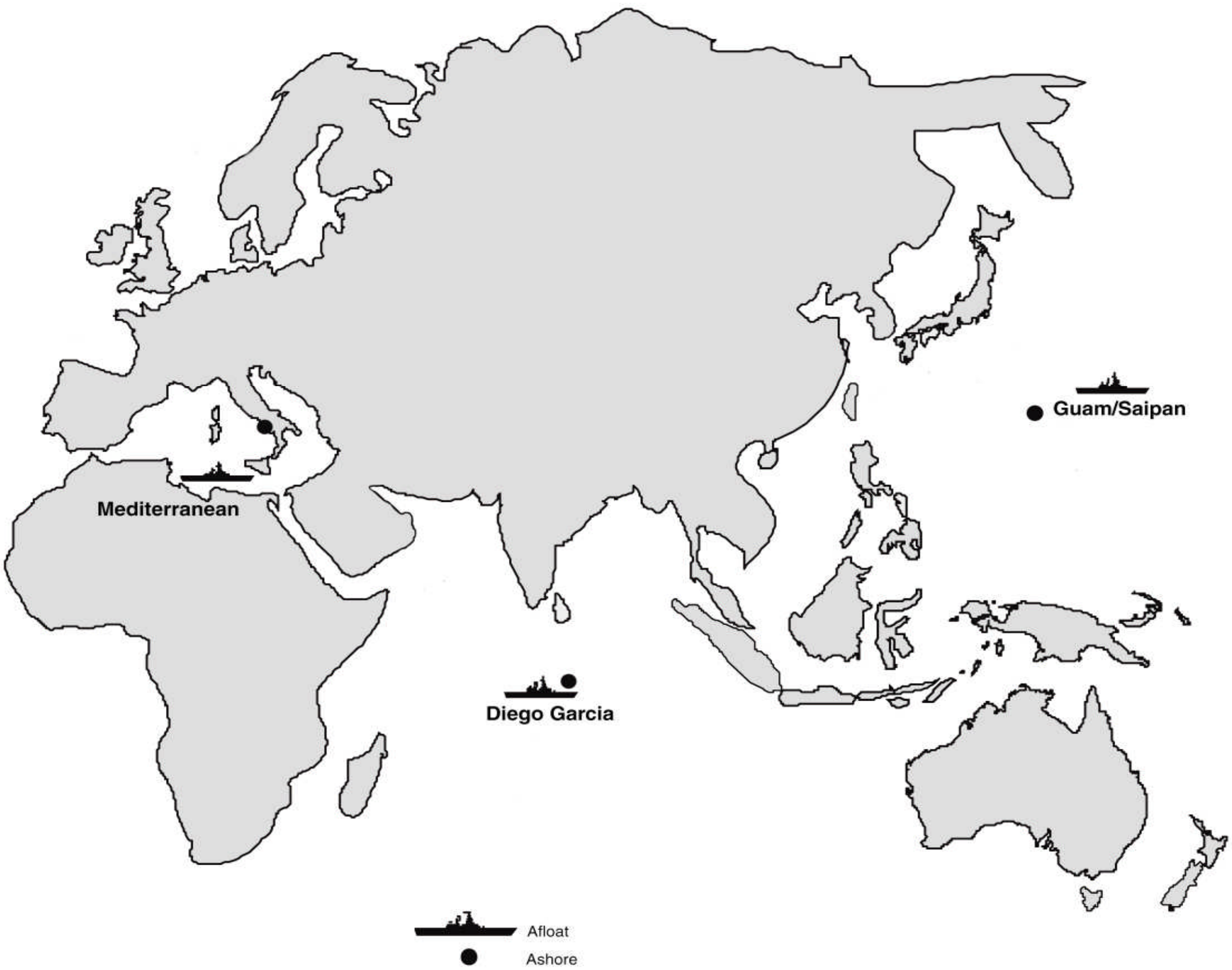


Figure 6: This chart shows the non-CONUS Pre-Po's.[63]

[63] Developed from Figure 1, Page 9 in GAO/NSIAD-99-6 (Washington, DC: U.S. GAO, 16 November 1998)

Roll-Out

The roll-out schedule, which is prescribed more specifically in later sections, will permit the Navy to spread the costs of system development and procurement over several years and capitalize on lessons learned between now and deployment.

Schedule

The roll-out of the Philadelphia node will be the longest and most involved. The total build-out period will likely take several years due, in part, to the large amount of infrastructure involved within the PNSY footprint. The follow-on PREPO nodes, however, should follow rather rapidly with the longest delays being for year-to-year procurement. Total build-out should take between 8 and 10 years with the funding continuum remaining constant every other year with funds being expended over the course of 1.5 years.

Each TEU should proceed from the factory location, which, as proposed, is a Philadelphia-area manufacturer, by ground transit to their secondary mode of transit upon completion of that secondary mode's load-out requirements. For example, if nodes are to be deployed by PREPO vessel, all TEUs should ship from the final assembly within a single window whereas if the nodes were being deployed by strategic airlift assets, the convoy of fully assembled assets would be considerably smaller and would require multiple additional convoys to fully stock the PREPO. This chart shows the projected roll-out schedule beginning from 'zero-year' which is the year from which funding begins for the procurement of TEU systems for the PNSY node. Under this projected roll-out, capability is transferred from San Diego to the Guam-Saipan PREPO at Z-Year +8.

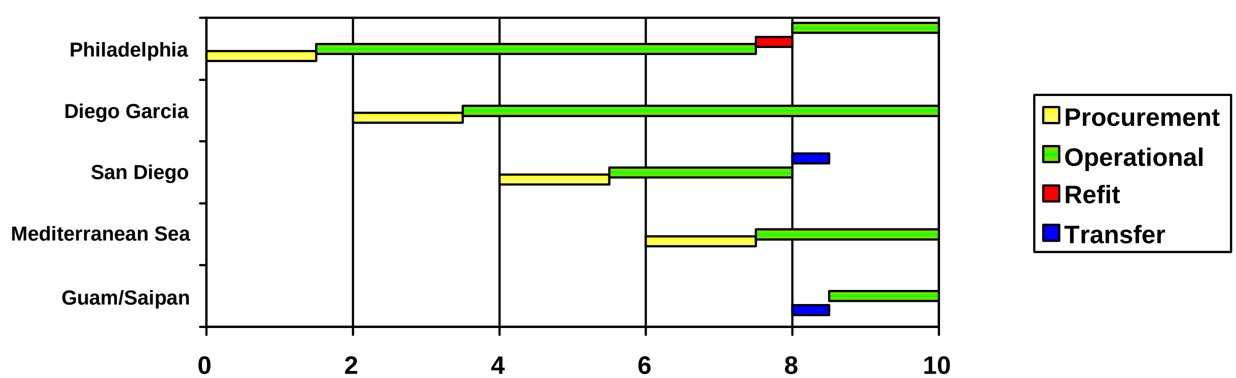


Figure 7: Projected TEU System Roll-Out Schedule

NOTE: All times are projected and rounded to the nearest half-year, therefore, the estimated length of time for transfer of the San Diego node to Saipan is estimated at six months. Obviously a number of variables can affect schedule. This chart takes into account some but not all of those factors and should be used as a rough guide rather than a scripted schedule.

The PNSY node, being the most intellectually rigorous and technically complex, will undoubtedly present significant challenges. For this reason, there is a six-month refit period structured into the build-out schedule to allow for updates of equipment and incorporation of lessons learned from later spiraled nodes. One final detail of the roll-out schedule is that from Z-Year +5.5 there are always three active nodes on alert and available for rapid deployment.

Advantages of a Philadelphia Metropolitan Area Location in Response to Research and Manufacturing Needs

This project has geographical requirements from the design phase forward. It requires a port with ship access and a warehouse storage facility for the TEUs, preferably nearby. After the initial construction period, each shipping container will need to be stored, when not in use, and often repaired, overhauled and restocked upon its return from a mission. A port-side warehouse (or one within easy reach via air, train or road), will house the TEUs during construction and when not needed for a decontamination operation.

The strengths and weaknesses of various large ports around the United States should be evaluated when deciding where to base the research center and the TEU design, production, and maintenance facility. The port facility analysis, conducted by SRRI, evaluated the various port options based on their access to research, cost structure and threat potential. Table 7 shows that only five American port regions have the right combination of industries and labor forces for project success. These ports are New York City, Los Angeles, Philadelphia, Boston and San Francisco.

Table 7: Port Regions Cluster Analysis[64]

Metro Area[65]	Bio & Pharma	Chemical Products	Transport & Logistics	Med. Devices	Education & Knowledge Creation	Analytic Inst.	Combined Cluster Ranking (lower numbers signify better rankings)*	Best Cluster Value (lower numbers signify higher value)
New York City, N. NJ LI	1	2	1	3	1	4	2.00	27.92
Los Angeles	3	7	2	1	3	1	2.83	41.11
Philadelphia	**4**	**4**	**9**	**8**	**5**	**8**	**6.33**	**24.23**
Boston	6	10	16	4	2	2	6.67	45.57
San Francisco	5	30	7	7	7	9	10.83	167.20
Miami	7	30	6	9	15	30	16.17	
Houston	30	1	8	30	16	30	19.17	
Baltimore	16	19	30	30	12	12	19.83	
Seattle	30	30	10	20	19	11	20.00	
Atlanta – Savannah	30	12	4	30	14	30	20.00	
DC & N. Virginia	30	30	15	30	4	15	20.67	
San Diego	30	30	30	11	10	13	20.67	
New Orleans	30	16	18	30	30	30	25.67	
Tampa	20	30	30	30	30	19	26.50	

There are several serious considerations that must be factored into these ratings of the potential port cities. The New York and Los Angeles/Long Beach port are both considered high value targets for terrorism by DHS. New York has been the site of two major terrorist actions in the last 15 years. In addition, both New York City and Los Angeles have maximized their cargo handling capacity and suffer space constraints in highly valued real estate markets. San Francisco's affordability index rating shows that the area has a very high cost of living. As an example, Google employees find it an expensive place to live, and many commute over 2 hours each way to work[66]. Boston

[64] Internal analysis of cluster mapping project data, Harvard Business School Institute for Strategy and Competitiveness.

[65] Only top 20 rankings were given. When an area was not ranked we have assumed a 30 for the calculation. In many cases this is a higher ranking than its actually would be.

[66] Helft, Miguel. *Google's Buses Help Its Workers Beat the Rush.* New York Times. March 10, 2007. Accessed on April 30, 2007 via http://www.nytimes.com/2007/03/10/technology/10google.html.

ranks lower in the combined cluster ranking, but the expense of working in the area and its distance from U.S. ports in the South and Gulf Coast make Boston a suboptimal location for acutely time sensitive cargo and manufacturing operations. Below, in Table 8 is the results of an analysis of the costs associated with developing and maintaining a human capital based research and engineering cluster.

Table 8: Affordability Index - select regions[67]

	Cost of Living	Median Income	Median Home Price	Housing Affordability	Affordability rating (lower number signify more affordable)
New York MSA	212.1	71,300	469,300	6.58	13.96
Los Angeles MSA	153.1	61,700	584,800	9.48	14.51
Philadelphia MSA	**119**	**71,600**	**230,200**	**3.22**	**3.83**
Boston MSA	136.8	80,500	402,200	5.00	6.83
San Francisco MSA	177	84,500	736,800	8.72	15.43

The tri-state (Pennsylvania, New Jersey, Delaware) Philadelphia metro region has a stable cluster of the needed industries and significantly lower costs of doing business, living and staying in the area. The greater Philadelphia region has the workforce, research funding and institutions to support the project. In addition, the local governments have a strong desire to support and grow knowledge-based industries with a skilled manufacturing component. Below are some highlights of the area's labor and research resources and infrastructure.

- Availability of qualified workforce: 42,000 in bioscience[68].
- Public research infrastructure: University of Pennsylvania (second in the nation for National Institutes of Health (NIH) funding), Thomas Jefferson University, Children's Hospital of Philadelphia, Temple University Hospital, the Wistar Institute, Fox Chase Cancer Center, Hahnemann Hospital / Drexel University. In 2005, these institutions collectively received more than US $2.5 billion in NIH funding for research. In addition, more than 20 universities and non-profit institutions were engaged in related research[69].
- Proximity to research institutions: Four general medical schools, fifteen engineering schools (including Villanova University, one of the participants in

[67] Cost of living data from ACCRA, median income from HUD AMI data, median home price data from National Association of Realtors.
[68] DeVol,Ross, Koepp, Rob Wallace, Lorna et Al. *The Greater Philadelphia Life Sciences Cluster: An Economic and Comparative Assessment.* Milken Institute. June 2005.
[69] *The Biosciences in Greater Philadelphia.* Pennsylvania Bio. Accessed on August 6, 2007 via http://www.pennsylvaniabio.org/index.php?option=com_content&task=view&id=18&Itemid=20.

this project), a school of osteopathic medicine, two schools of dentistry, two schools of pharmacy, a school of veterinary medicine, a school of podiatry, and a school of optometry.

- Cost of living is comparatively lower than other locations with similar advantage profiles. (See Table 8: Affordability Index of Select Regions)

Location Options in the Philadelphia Metropolitan Area

Philadelphia Naval Ship Yard

Basing the research cluster and the TEU design, manufacturing storage and maintenance facilities in Philadelphia would optimize project requirement fulfillment and cost effectiveness. Specifically, the Navy Yard facility, with its research and manufacturing mandate, would appear to be the ideal base for activity. In order to accelerate research and design innovation into field operations, it would be preferable to establish the operations center near to the research and TEU projects. This location strategy would create a tight network of formal and informal linkages among stakeholders. The operations center will and should rely heavily on a cohort of other Federal agencies based in the national capital region. Further study is necessary to determine the best way to construct relationship bridges and communication links among the project components, the Navy and other Federal agencies.

The Philadelphia Naval Complex includes the Philadelphia Naval Shipyard, the Philadelphia Naval Station, and the Philadelphia Naval Hospital and is slightly less than 1,500 acres. The Complex is located approximately 4 miles south of Philadelphia's Center City[70], with the shipyard occupying approximately 350 acres. As the nation's first government-owned shipyard, it began operating in Philadelphia's Southwark district in 1801. After Congressional approval in 1867, the land was made available and the Navy officially moved its operations to the Philadelphia Naval Complex.

During its long history, the Philadelphia Naval Complex built 50 new warships, and repaired or renovated 1,218 ships. The main buildings on site were built for industrial use. The complex contained 1,000 buildings, 52 miles of streets and 4.2 miles of waterfront.[71] The shipyard included buildings like a power plant, foundry, paint shop and an electroplating plant.

Environmentally hazardous organic and inorganic chemicals were stored and used for these operations. From the historic use of this site "prominent site types include landfills and oil spill sites that have released petroleum/oil/lubricants (POLs) and heavy metals to groundwater and soil." Operations produced environmental contaminants including

[70] *Philadelphia Naval Complex Current Site Information*. U.S. Environmental Protection Agency. Accessed on October 15, 2007 via http://www.epa.gov/reg3hscd/npl/PA4170022418.htm.

[71] Ibid.

substances such as asbestos, POLs, heavy metals, polychlorinated biphenyls (PCBs), solvents and volatile organic compounds (VOCs).[72]

After more than a century of service, the military's Base Realignment and Closure (BRAC) process, which is used to close surplus military bases, recommended the Naval Hospital for closure in 1988[73] and both the Naval Shipyard and Naval Station for closure in 1991. [74]

Environmental implications of the BRAC closure by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the EPA's National Contingency Plan (NCP) required the Navy to clean up the property for transfer and to disclose the environmental condition of the property. In 1991, after BRAC listed the shipyard and base for closure, preparations for the environmental cleanup began and included "asbestos abatement in buildings, PCB transformer site remediation, removal of underground storage tanks and resulting contaminated soil, and removal and off-site disposal of construction debris and blasting grit".[75] Most of the cleanup was concluded by 1996, when naval operations at the complex ceased, with a few cleanup areas that were officially completed by 2000.

The PNSY environmental cleanup was the largest cost for the Naval Facilities Engineering Command (NAVFAC), during the closure and transfer process. It cost approximately $75 million and breaks down to the following figures per fiscal year from 1996 to 1999:

Table 9: Environmental Cleanup Costs for the Naval Shipyard (in thousands of $)[76]

FY 1996	FY 1997	FY 1998	FY 19991	**Total**
43,799	17,864	7,266	5,768	**74,697**

**A detailed breakout of these costs follows.[77]

[72] *Philadelphia Naval Complex*. Accessed on 15 October 15, 2007 via https://www.denix.osd.mil/denix/Public/Library/Cleanup/CleanupOfc/arc/Reports/FY1994/phillync.html.
[73] *Base Realignment and Closure.* www.GlobalSecurity.org. Last modified November 9, 2005. Accessed on October 15, 2007 via http://www.globalsecurity.org/military/facility/brac.htm.
[74] For the purposes of this report, we will refer to the Philadelphia Naval Complex as only the Philadelphia Naval Shipyard and the Philadelphia Naval Station. The hospital was closed under the 1998 BRAC process and is located approximately three quarters of a mile north of the Naval Shipyard and Station.

[75] *Philadelphia Naval Complex Current Site Information*. U.S. Environmental Protection Agency. Last updated 3 April 2007. Accessed on October 15, 2007 via http://www.epa.gov/reg3hscd/npl/PA4170022418.htm.

[76] Hess et al. *The Closing and Reuse of the Philadelphia Naval Shipyard*. 2001. Information from Table 5.4, p. 46. Accessed on October 15, 2007 via http://192.5.14.110/pubs/monograph_reports/2007/MR1364.pdf.
[77] Hess et al. *The Closing and Reuse of the Philadelphia Naval Shipyard*. 2001. Table 5.5, Pg 46. Accessed on October 15, 2007 via http://192.5.14.110/pubs/monograph_reports/2007/MR1364.pdf.

Environmental Cleanup Costs at the PNSY
(thousands of dollars)

Environmental Project	Cost
Polychlorinated Biphenyl (PCB) Remediation	203
Asbestos Abatement	26,831
Basewide BRAC Cleanup	448
Surveys, Leases, Transfers	2,247
Fuel Farm Contamination Remediation	31,549
Building 694 Underground Storage Tank Contamination Remediation	364
Lead-Based Paint Remediation	805
One-Time Compliance Projects	12,250
Total	74,697

Figure 8: Environmental Cleanup Costs Breakout

The Navy also conducted an Environmental Impact Statement (EIS) under the National Environmental Policy Act (NEPA), which describes the impacts on the environment of a proposed action. For NEPA, the Navy analyzed the potential environmental impacts of the reuse alternative for its "effects on land use compatibility, socioeconomics, public services, transportation, air quality, noise, cultural resources, natural resources, and generation of hazardous materials."[78]

As a result of the NEPA process, the Navy's Record of Decision for the disposal and reuse of the Naval Complex was published in the Federal Register on July 9, 1997. It called for the community to reuse the facility, which was the City of Philadelphia's preferred alternative. Reuse was slated for a "mix of industrial, commercial, educational, research and development, residential, warehousing, intermodal transportation and open space uses".[79]

In August 1998, a Finding of Suitability to Transfer (FOST) from the Navy to the City of Philadelphia was signed for the naval base, and a FOST was signed for the Naval Shipyard in December, 1998.[80] The land was then transferred to the City of Philadelphia and is managed by the Philadelphia Industrial Development Corporation (PIDC**),** a

[78] *Record of Decision for the Disposal and Reuse of Naval Base Philadelphia, Pennsylvania*. U.S. Environmental Protection Agency. Accessed on October 15, 2007 via

http://www.epa.gov/EPA-IMPACT/1997/July/Day-09/i17901.htm.
[79] Ibid.
[80] *Philadelphia Naval Complex Current Site Information*. U.S. Environmental Protection Agency. Accessed on October 15 2007 via http://www.epa.gov/reg3hscd/npl/PA4170022418.htm.

private, not-for-profit organization tasked with creating economic development throughout the city.[81]

The Philadelphia Naval Business Center is now listed as a Brownfields Site by the Pennsylvania Department of Environmental Protection's (DEP) Brownfields Action Team (BAT).[82] The EPA defines a brownfield site as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant."[83] The Naval Complex's Brownfields Site classification enabled the Federal, state and local government to contribute $400 million, while Kvaerner, a European company that is now leasing a portion of the shipyard, contributed $45 million to redevelop and lease a portion of the Complex.[84]

In March 1999, EPA gave PIDC written assurance that the Navy would "continue to be responsible for any environmental contamination on the Philadelphia Navy Yard property when the site is redeveloped. This responsibility would still apply if the property were leased, subleased or re-sold."[85] Kvaerner/Aker received the same assurance.

---

[81] *Philadelphia Industrial Development Corporation*. 2007. Accessed on October 15, 2007 via http://www.pidc-pa.org/.

[82] *Brownfields Action Team*. Pennsylvania Department of Environmental Protection (DEP). Accessed on October 15, 2007 via http://www.depweb.state.pa.us/landrecwaste/cwp/view.asp?a=1243&Q=462059&landrecwasteNav=|30958|.

[83] Brownfield Definition. U.S. Environmental Protection Agency. Accessed on October 15, 2007 via http://www.epa.gov/brownfields/glossary.htm.

[84] Hallenbeck, Bob. *Bypassing brownfields: a success story; a "comfort letter" allows a private shipbuilding company to start fresh without the legacy of pre-existing conditions - Special Report: Environmental*. Risk & Insurance. July 2003. Accessed on October 15, 2007 via

http://findarticles.com/p/articles/mi_m0BJK/is_9_14/ai_105477040/.

[85] *EPA Helps Smooth the Way for Navy Yard Redevelopment - Agency Assures Redeveloper that Contamination is Navy's Responsibility*. U.S. Environmental Protection Agency. 15 March 1999. Accessed on October 15, 2007 via http://yosemite.epa.gov/opa/admpress.nsf/89745a330d4ef8b9852572a000651fe1/a12cafdcba8cd513852570d60070f9cb!OpenDocument.

"The United States must improve its ability to deploy civilian expertise rapidly, and continue to increase effectiveness by joining with organizations and people outside of government – untapped resources with enormous potential. We can make better use of the expertise of our universities and of industry…"
– National Defense Strategy, 2008, p. 17

SECTION III. Reach-back Needs and Philadelphia

The creation of a phased response system requires a series of reach-back capabilities that are currently either missing entirely or spread widely across geographic, departmental and agency boundaries as well as the private and educational sectors. These requirements include:

- On-shore Operations Center to filter and exchange information to and from the decontamination site.
- Integrated research component to expand capability in the field.
- The ability to leverage the commercial sector to expand capability.
- A warehouse to store, repair and restock the TEUs.
- A working port with sea access.
- Design, fabrication, and manufacturing facilities and skills base.

We have identified three primary actions that fulfill these needs:

1. Create a one-stop Operations Center to respond to and coordinate response to a CBRN event anywhere that the Navy operates at sea
2. Establish a design, fabrication, and maintenance facility for the modular TEU units that this project will use extensively
3. Develop a dedicated research and innovation cluster that draws together DOD personnel, university and other researchers, and the private sector

The Operations Center will supply reach-back and research capabilities to those onboard the platform/transport vessel. This Center will be modeled after the existing 24/7/365 DHS operations centers, keeping staff, contractors and watchstanders in constant contact with the bridge of the decontamination vessel.[86] Additionally, the Center will enable vessel personnel to communicate with onshore individuals with appropriate expertise during CBRN situations that may occur.

The TEU design and production facility will translate the conceptual work presented here into prototype units with input from the various participating agencies and special work forces. Once approved, production will be highly technical, will probably generate small batches of units, and will require a great deal of collaboration between the research and production facility. Additionally, the facility will be able to produce, on very short turn around, specialized equipment and other single use items that a decontamination response team requires.

---

[86] GAO Report 4/5/2007 Department of Homeland Security Coordination of Operations Centers Briefing for House and Senate Appropriation Committees.

The cluster for research and innovation in decontamination technology will be an ongoing activity and will require the creation of a technology and pharmaceutical center to best leverage companies, universities and related institutions. It is envisioned that this cluster will create and nurture the cross-industrial cooperation needed to promote the development of decontamination methods, research and related capabilities. For example, the research and innovation cluster would nurture synergy between pharmaceutical innovations and technical advances that results in more capable decontamination methods.

Research and Development

The Research and Development Center will leverage the partnerships with the tech sector to find new ways to protect Armed Forces personnel and the public from chemical and biological warfare (CBW). Developing partnerships with area colleges, universities and teaching hospitals will connect specialized programs of study[87] – e.g., parasitology, virology, molecular biology, microbiology, biochemistry, bioengineering, biomedical neurology, pharmaceutical sciences – to the research and development tools that will produce advances in primary and secondary prophylaxis.

The basing region will require a strong engineering base, a large skilled labor force and a concentration of engineering education to enable students, graduates, professors and researchers to examine the effects of CBRN events on personnel and material and facilitate the creation of a research cluster. Below in Figure 9 is a depiction of the roles and functions that are proposed for the PNSY or similar location.

[87] Gibbons, Michael T. *Engineering by the Numbers.* American Society for Engineering and Education. Accessed on December 21, 2007 via http://www.asee.org/publications/profiles/upload/2006ProfileEng.pdf.

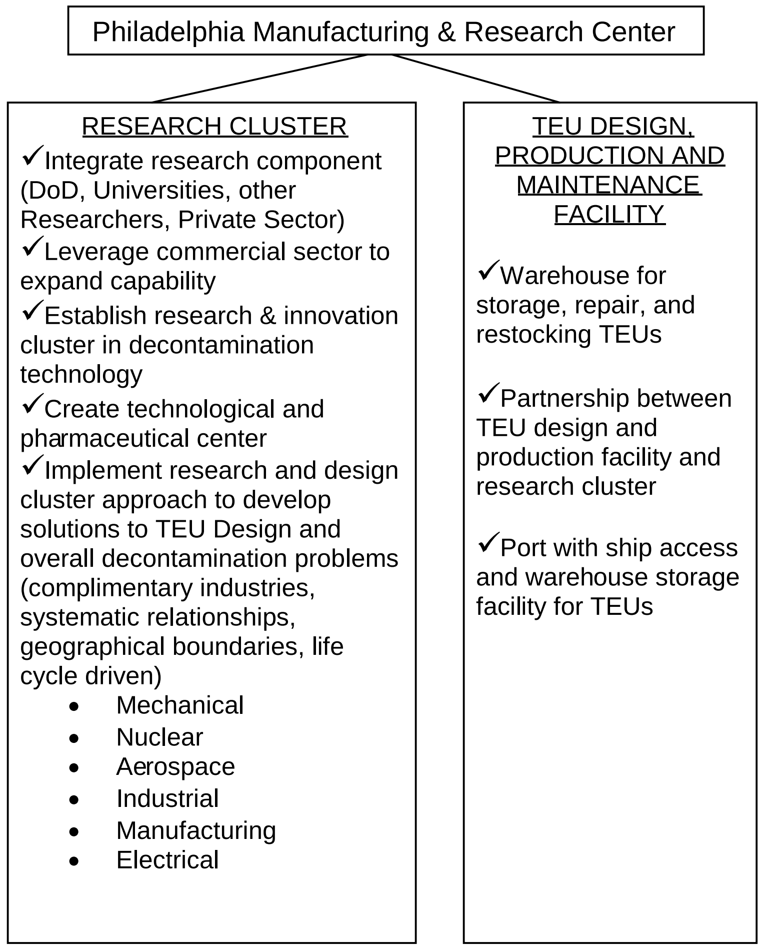


Figure 9: Reach-back Needs: Research and TEU Production

Conclusion

This report has started from a different point than the vast majority of US Navy CBRN documents, i.e., from the moment after the incident. At some level this differentiated starting point is among its most valuable contributions. The Navy has invested a lot of time and effort into developing ways to detect and defend against a CBRN event. Some of those efforts have paid impressive dividends. However, the Navy still needs to develop a method of consequence management and property recovery for its increasingly expensive fleet. In addition, mitigating the effects of a CBRN event on strategic capabilities lessens the efficacy of such attacks. The Global War on Terror has demonstrated the need for quick and flexible responses. This report presents a three-phased emergency response system that would allow the Navy a way forward as it thinks about how to recover and resume operations after a worst case scenario CBRN event. If this response system can change the discourse from “Sink the ship!” to “How quickly can we safely bring it back into operations and what will be the opportunity and financial costs?” it will be ringing success. Given additional funding and attention, the three-phased emergency response system can go several steps beyond changing the discourse.

Appendix 1: List of Figures

Figure 1: TEU arrangement for a mobile hospital onboard a HLS. This shows the potential for flexibility and customization of a system.. 40
Figure 2: This image demonstrates a layout with stacked TEUs, a possibility for decreasing the footprint and increasing the potential range of ship sizes for the transport vessel.. 42
Figure 3: Example load-out scenario for a mobile, TEU-based hospital.......................... 47
Figure 4: Ship layout that may closely approach a decontaminated vessel...................... 48
Figure 5: Operations Center Functions.. 52
Figure 6: This chart shows the non-CONUS Pre-Po's. 57
Figure 7: Projected TEU System Roll-Out Schedule 58
Figure 8: Environmental Cleanup Costs Breakout 64
Figure 9: Reach-back Needs: Research and TEU Production 68

Appendix 2: List of Tables

Table 1: Navy Courses and Trainings Recommended for Continuation 15
Table 2: Recommended Ways In Which The Army's Chemical School Courses Can Meet the Navy's CBRN Training Needs 17
Table 3: Airborne Lift Comparisons 26
Table 4. Phase III Decontamination Options 34
Table 5: Maritime Lift Comparisons 36
Table 6: TEU Action Timeline 46
Table 7: Port Regions Cluster Analysis 60
Table 8: Affordability Index - select regions 61
Table 9: Environmental Cleanup Costs for the Naval Shipyard (in thousands of $)........ 63

Appendix 3: List of Acronyms

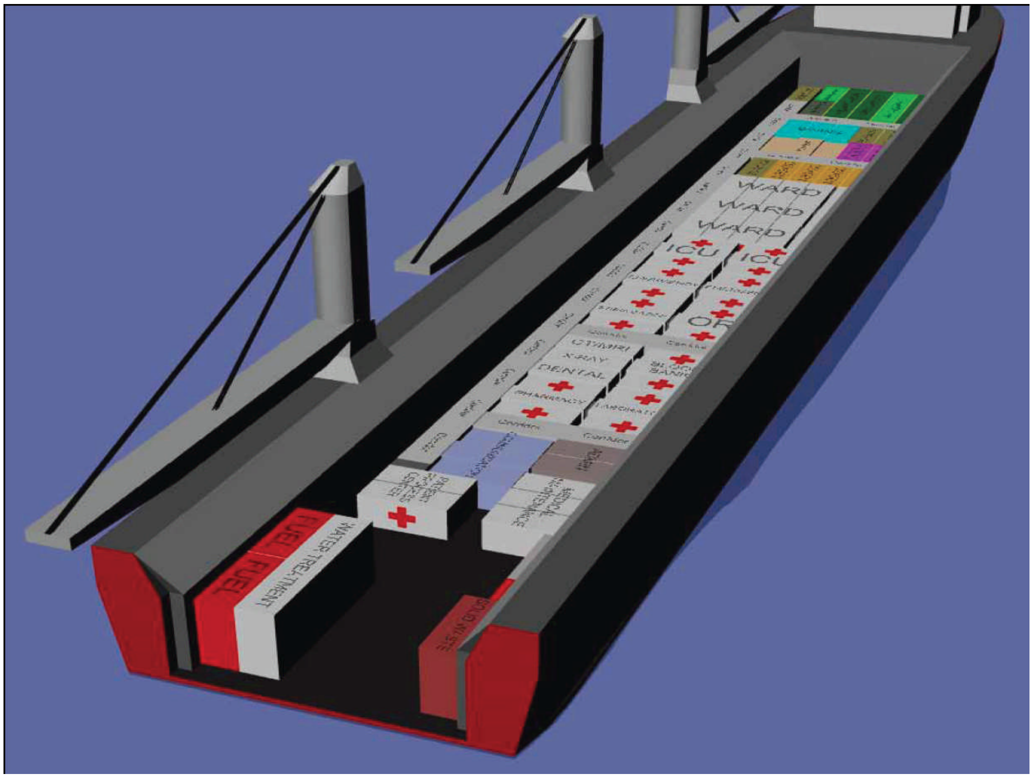
ACS	Auxiliary Crane Ship
ALS	Advanced Life Support
AOR	Area of Responsibility
APU	Auxiliary Power Unit
BIDS	Biological Integrated Detections Systems
BLS	Basic Life Support
BRAC	Base Realignment and Closure
CBIRF	Chemical, Biological Incident Response Force
CBR-D	chemical, biological, and radiological defense
CBRN	Chemical, Biological, Radiological, Nuclear
CBW	Chemical and Biological Warfare
CDC	Center for Disease Control
CDD	Capabilities Development Documents
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
C4I/IO	Command, Control, Communications and Computers Intelligence/Information Office
CIA	Central Intelligence Agency
CIWS	Close-In Weapon System
CMWDS	Countermeasures Washdown System
CNBC	Center for the Neural Basis of Cognition
CO	Commanding Officer
COBC	Chemical Officer Basic Course
COCOM	Combatant Commanders
COMNAVSEASYSCOM	Commander, Naval Sea Systems Command
CONNDOT	Connecticut Department of Transportation
CONUS	Continental United States
COTS	Commercial-off-the-shelf
CPD	Capability Production Documents
CPS	Collective Protection System
CSSC	Civil Support Skills Course
CTMC	Connecticut Maritime Commission
CVBG	Carrier Battle Group
CVN	Aircraft Carrier, Nuclear
DARPA	Defense Advanced Research Project Agency
DC	Damage Control
DECD	Department of Economic and Community Development
DHS	Department of Homeland Security
DHHS	Department of Health and Human Services
DMAT	Disaster Medical Assistance Team
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice

DRASH	Deployable Rapid Assembly
DU	Depleted Uranium
EHF	Extremely high frequency
EIS	Environmental Impact Statement
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ERRDC	Emergency Response Research and Design Center
ET	Electronics Technician
EWS	Early Warning System
FBI	Federal Bureau of Investigation
FC	Fire Controlman
FDA	Food and Drug Administration
FLIR	Forward-Looking Infrared
FOF	Follow-on Force
FOST	Finding of Suitability to Transfer
FRC	Fast Response Cutter
GCCS-M	Global Command and Control System - Maritime
GNF	Graphite Nanofiber
GQ	general quarantine
HAZMAT	Hazardous Materials
HMIRS	Hazardous Material Information Resource System
IC	Interim Communicationman
IED	Improvised Explosive Device
INMARSAT	International maritime satellite
IO	Intel Officer
I/O	Input/output
IPE	Individual Protective Equipment
IS	Intel Specialist
ISO	International Shipping Organization
ISR	Intelligence, Surveillance and Reconnaissance
IT	Info Systems Technician
IT	Information Technology
JACKS	Joint Acquisition CBRN Knowledge System
JHSV	Joint High Speed Vessel
JSFDS	Joint Service Family of Decontamination Systems
JSL	Joint Senior Leader
JWARN	Joint Warning and Reporting Network
JWICS	Joint Worldwide Intelligence Communication System
KIZ	Keystone Innovation Zone
LCAC	Landing Craft, Air Cushion
LEED	Leadership in Energy and Environmental Design
LHD	Amphibious assault ship
MAGTF	Marine air-ground task force
MEDEVAC	Medical Evacuation
MEP	Mobile electric power
MOPP	Mission-Oriented Protective Posture

MPF	Maritime Pre-Positioning Force
MSA	Metropolitan Statistical Area
MSC	Military Sealift Command
NASA	National Aeronautics and Space Administration
NAVEDTRA	Naval Education and Training
NAVFAC	Naval Facilities Engineering Command
NAVOSH	Navy Occupation Safety and Health
NBC	Nuclear Biological and Chemical
NCP	National Contingency Plan
NEC	Navy Enlisted Classification
NEPA	National Environmental Policy Act
NIH	National Institutes of Health
NIPRNET	Non-Secure Internet Protocol Router Network
Nm	Nautical Mile
NMR	Nuclear Magnetic Resonance
NOSC	Navy On-Scene Coordinators
NOSCDR	Navy On-Scene Commanders
NRS	National Response System
NRT	National Response Team
NSF	National Strike Force
NSF	National Science Foundation
OCONUS	Outside the Continental United States
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
ONR	Office of Naval Research
OPC	Offshore Patrol Cutter
OPRAD	Operational Radiation Safety
OSH	Occupational Safety and Health
PIDC	Philadelphia Industrial Development Corporation
PLSG	Pittsburgh Life Science Greenhouse
PNSY	Philadelphia Naval Shipyard
POLs	Petroleum/Oil/Lubricants
PPE	Personal Protective Equipment
PQS	Personnel Qualification Standard
R&D	Research and Development
RAC	Risk Assessment Code
RADSAFE	Radiological Safety
RAM	Rolling Airframe Missile
RFID	Radio Frequency Identification
ROWPU	Reverse Osmosis Water Purification Unit
RTP	Research Triangle Park
SABT	Static Automatic Bus Transfer
SAR	Search and Rescue
SARS	Severe Acute Respiratory Syndrome
SATCOM	Satellite Communications
SeaRAM	Sea Launched Rolling Airframe Missile

SHF	Super-high frequency
SIPRNET	SECRET Internet Protocol Router Network
SOP	Standard Operating Procedure
SSN	Attack Submarine, Nuclear
SWO	Surface Warfare Officer
SUPSALV	Surplus and Salvage
TAK	Cargo ship
TEU	Twenty-Foot Equivalent Unit
TIC	Toxic Industrial Chemical
TS	Top Secret
TTP	Tactics, Techniques and Procedures
TUCASI	Triangle Universities Center for Advanced Studies, Inc.
UAV	Unmanned Aerial Vehicle
UHF	Ultrahigh frequency
USCG	United States Coast Guard
USACMLS	United States Army Chemical School
USB	Upper Side Band
USFK	United States Forces Korea
USMC	United State Marine Corps
USN	United States Navy
USPACOM	United States Pacific Command
VHP	Vaporized Hydrogen Peroxide
VOC	Volatile Organic Compound
WHEC	USCG High Endurance Cutter
WMEC	USCG Famous-class and Reliance-class Medium Endurance Cutter
WMD	Weapons of Mass Destruction
XO	Executive Officer

Appendix 4: TEU Specifications



Laboratory Modules

The most unique to the operations, many of these modules will need to be specially constructed.

1. General Laboratory Module - Chemical
2. General Laboratory Module - Biological
3. Nuclear/Radiological Module
4. Property Decontamination Module
5. Decontamination Module
6. Personal Protective Gear Module
7. Toxic Diving Module
8. Sensitive Equipment Decontamination Module
9. Robotics Module

Interdepartmental Modules

Connected intimately with the ops, these modules will house interdepartmental personnel.

1. CDC Module
2. Coast Guard Module
3. EPA Module
4. FDA Module

5. FBI Module

Office/Habitation Modules

These modules require less customization, and will be used primarily by crew.

1. Datacenter Module
2. Media Module
3. General Office Module
4. Mess Hall Module
5. Housing Module
6. First Aid Module
7. Airlock Module
8. Corridor Module

Support Modules

These modules do not require personnel, and are solely infrastructural.

1. Power Generator Module
2. Sewage Treatment Module
3. Waste Removal Module
4. Water Purification Module
5. Storage Module - Uncontaminated
6. Storage Module – Contaminated

Specifications for General Laboratory Module - Chemical

Note: In accordance with industry standards, there will be two General Laboratory Modules, following the model of similar projects –one each for Chemical and Biological testing.

A. Overview

The General Laboratory Module is envisioned as a state-of-the-art portable laboratory, easily configured for any situation that might be encountered. A converted TEU will house equipment and personnel able to test a high volume of material in a very short amount of time, thus identifying CBRN decontaminants more precisely than in Phase I or Phase II. This TEU will contain basic laboratory equipment to do a wide range of tests, and above all a flexible design, allowing a response to all possible situations.

B. Personnel

1. Basic Laboratory Technician
   a) Entry-level lab technician, or equivalent, with a bachelor's in Chemistry or related subject.
   b) Experience with common equipment and techniques[88]
      1) Gas Chromatograph (GC)
      2) Gas Chromatograph/ Mass Spectrometer (GC/MS)
      3) ICP instrumentation
      4) USEPA SW-846 and 600 Series Methods for organic and inorganic compounds.
2. There will be access to more experienced personnel stationed on land through the Operations Center.
   a) Similar to the WMD-CST (Weapons of Mass Destruction Civil Support Team), training to NFPA (National Fire Protection Association) 472 Hazardous Materials (HAZMAT) technician level or above is desirable for this position.
      1) The WMD-CST organization is designed to augment local and regional terrorism response capabilities in events known or suspected to involve Weapons of Mass Destruction. WMD events are incidents involving hostile use of chemicals (such as nerve or blister agents, or toxic industrial chemicals (TICs), biological (for example, anthrax or ricin), or radiological source." [89]
      2) 472 hazardous materials technicians have the skills necessary to respond to and mitigate hazardous materials releases. Training to this skill level covers the following:
         - Surveying the Incident
         - Container ID, Condition, and Marking

[88] http://www.newagelandmark.com/emp.php
[89] http://c21.maxwell.af.mil/wmd-cst/cst_factsheet_103rd.pdf

- Monitoring Equipment
- Resource Utilization
- Response Objectives
- Action Option
- Personal Protective Equipment
- Chemical Compatibility
- Developing Action Plans
- Incident Management
- Control Functions
- Evaluation Progress
- Incident Termination
- Field Exercises[90]

Having someone of this skill level available for consultation will allow the laboratory technicians to complete their routine work, but defer to the more experienced personnel if/when something unusual occurs.

3. While there is no equivalent rating, this position will be similar to the Army position Chemical Operations Specialist (74D)[91].
    a) Equivalent civilian jobs can be found at all levels of government and in private agencies.
4. Two technicians will be assigned to this TEU, due to the constraints of space. With the flexibility in changing the working environment, more technicians may be added as needed, when possible.

C. Equipment
1. Environment[92]
    a) Independent climate control and ventilation
    b) Counter space should have the ability to be moved to accommodate personnel and equipment.
2. Sink and sample prep area
3. Separate analysis and extraction areas, to avoid cross-contamination
4. General Laboratory Equipment[93]
    a) Freezer space for samples
    b) Computer system, networked with other modules and onshore personnel
    c) Seawater and compressed air connections
    d) GC and GC/MS units
    e) Glove box
    f) XRF and/or Mercury Analyzer technologies
5. Efficiency

---

[90] http://www.teex.com/teex.cfm?pageid=training&area=TEEX&templateid=14&Division=ESTI&Course=HAZ020
[91] http://www.goarmy.com/JobDetail.do?id=40
[92] http://www.moc.noaa.gov/rb/science/labs.htm
[93] http://www.newagelandmark.com/labs.html, http://c21.maxwell.af.mil/wmd-cst/cst_factsheet_103rd.pdf, http://www.ecbc.army.mil/uf/mobile_labs.htm

a) Ideally, the General Laboratory should have capabilities to process several hundred samples a day, with an average turn-around time of 24 hours[94]. Preliminary decontamination sample collection and identification will have taken place already in Phases I and II, so that the Laboratory will only need to identify the contaminants more precisely so as to facilitate further decontamination.

b) Throughout the design process, flexibility should be given high priority. The equipment and environment of the module should be changeable as much as practically possible, allowing counter space to be configured as needed. The module should be able to accommodate a wide variety of equipment.[95]

D. Environmental Considerations

1. Standard maritime technology, such as the use of waterproof keyboards, tie-down railings around counter space and similar should be implemented.[96]

2. Dedicated environmental controls and venting should be utilized to prevent possible cross-contamination.

E. Agency Partnerships

1. Partner personnel will most likely be stationed at the operations center, or in another TEU, and will fill an advisory role.

a) Center for Disease Control

1) Generally will liaise only with the Biological TEU, but may be needed for other CBRN knowledge.

b) State Agencies, as applicable

1) This will become necessary in littoral areas, where civilian populations may be affected by the CBRN agents detected.

2. Because this module is concerned with testing only, we do not foresee a great need for physical co-location with other agencies personnel.

F. Operation Center

1. This TEU will have the ability to be in constant communication with the onshore Operations Center, through the C^4I/IO, via a variety of technologies.

a) VOIP, online messaging and videoconferencing (using technology in the Datacenter module) will all be available for immediate contact. For exchanging documents, a VPN connection can be used so that two parties have access to the same documents.

b) Exchange of information between cleanup site and shore will be instantaneous.

[94] http://www.ecbc.army.mil/uf/mobile_rtap.htm
[95] http://www.moc.noaa.gov/rb/
[96] http://www.moc.noaa.gov/rb/science/labs.htm#labsurface

Specifications for General Laboratory Module: Biological

A. Special Considerations

1. Technology, personnel and design to be identical to the General Laboratory Module.
    a) Further biological testing-specific technology may be called for.
2. Industry standard calls for a separate area specifically for biological laboratory space, to avoid cross-contamination and the possibility of unintentionally spreading biological contaminants.[97]
    a) An independent climate-control and venting system is absolutely vital to this module.

[97] http://www.moc.noaa.gov/rb, http://www.newagelandmark.com/labs.html

Specifications for Nuclear/Radiological Module

A. Overview

The Nuclear/Radiological Module is a mobile laboratory utilized in response to an array of incidents ranging from shipping accidents to the detonation of radiological dispersal devices. The NR module is outfitted with numerous testing systems to identify radioactive contaminates and determine the potential risk posed to working personnel as well as the vessel itself. The information provided by this module will be used to design an effective decontamination operation tailored to each individual incident.

B. Personnel

1. Damage Controlman Third Class (DC3)[98]
    a) Civilian equivalent of this position is a Certified Health Physicist[99]
2. Prior training with all radiation detection equipment and experience with handling radioactive material are essential.
3. Responsibilities include the following:[100]
    a) Operate radiation detection instruments
    b) Identify radioactive contaminates
    c) Map the location and intensity of contamination based on air samples
    d) Compute radiological stay times
    e) Relay all information to working personnel
    f) Aid executive personnel in determining the ideal decontamination procedure and the protective clothing that will be needed
    g) Maintain the cleanliness of all equipment
4. Personal Protective Gear must be worn by NR Module personnel at all times.
    a) Computers will be used as a means of communication between the NR Module personnel and other personnel on site and on shore.
    b) Two-way radios can also be used to maintain contact with other modules.

C. Equipment

1. Radiation detection instruments will test air samples from multiple sections of the contaminated area.
    a) Survey meters with Geiger-Mueller probes detect and measure contamination.[101]
    b) Spectrometers identify radionuclides and determine dose rates.[102]
2. Personal electronic dosimeters will be clipped to the belts of the NR Module personnel when working near a radiation source or handling contaminated material.[103]

---

[98] http://buperscd.technology.navy.mil/bup_updt/508/OccStandards/CHAPTER%2021.htm#dc1
[99] http://www.hps.org/
[100] http://www.doza.ru/eng/catalog/movable_labs/mobile_laboratory_poisk.shtml
[101] http://www.biodex.com/radio/detection/detection_007.htm
[102] http://www.xrfcorp.com/products/ics-4000.html

a) The dosimeter measures the rate of exposure to and the dose of radiation that the wearer experiences.

b) A mixture of light, sound, and vibration resonating from the dosimeter will warn the wearer when preset dosage thresholds are passed.

c) At a 2.5 R dose the working personnel must retire from the NR Module and undergo examination by a medical physician.

3. Collapsible counter space along the TEU walls will give personnel an area for operating radiation detection instruments and testing air samples.
4. Computers with remote monitoring software will log data and transfer information to C^4I/IO, and via them to the onshore Operations Center.[104]
5. One storage closet will house all radiation detection instruments.
6. A generator will provide power for lighting and electrical equipment.
7. A ventilation system unique to the NR Module will circulate new air into the NR Module while preventing cross-contamination between TEUs.

D. Efficiency

1. The NR Module will have the capacity to test all first-round samples within the first 24 hours of operation.
2. After the first round of testing, all new samples will be tested based on priority.
3. Results will be determined and relayed to executive personnel within one hour of testing.

E. Environmental Considerations

1. All equipment and furnishings inside the TEU will be capable of undergoing decontamination in the event of direct exposure to radiation.
2. All storage containers will be secured and tie-down straps will be installed on the counter space for additional safety during transport and rough seas.

F. Operations Center

1. The Operations Center will be connected to the NR Module's computer software in order to gain up-to-date information from the contamination site.
2. Experts working in the Operations Center will need to have access to the following data:

a) Which radioactive contaminants are involved in the incident

b) The dosage and intensity of contamination

c) The size of the contaminated area

d) What hazards are posed to working personnel

e) Which treatment options are available for decontaminating the vessel and its equipment

G. Agency Partnerships

1. Environmental Protection Agency[105]

---

[103] http://hps.org/hsc/documents/Radiation_detection.pdf
[104] http://www.thermo.com/com/cda/newsevents/news_detail/1,,11761,00.html
[105] http://www.epa.gov/radiation/rert/monitoring.htm#how_monitor

a) The EPA's Radiological Emergency Response Team (RERT) specializes in responding to radiation-related incidents.
b) Members of the RERT are experienced in using two Mobile Environmental Radiation Laboratories during operations to detect and measure radiation.

2. Centers for Disease Control and Prevention[106]
    a) Under the National Response Plan, the CDC is designated to protect the health of everyone on site following a radioactive incident.
    b) The CDC will ensure the safety of the NR Module's personnel and provide information on the specific hazards posed by the radioactive contaminates that are identified.
3. State Agencies, where appropriate
    a) When civilian populations are threatened by an incident near shore, officials from state agencies can be reached through the Operations Center.

H. Similar Projects

1. Bhabha Atomic Research Centre[107]
    a) The compartmentalized Mobile Radiological Laboratory (MRL) designed by this Indian nuclear research facility incorporates a computer laboratory and many radiation measuring devices.
    b) The MRL is designed to run autonomously for up to two weeks.
2. The National Air and Radiation Environmental Laboratory[108]
    a) The NAREL, managed by the U.S. EPA, has designed a mobile radio analysis laboratory for the Republic of Ukraine.
    b) The mobile lab is compact enough to be transported by a standard eighteen wheeler truck.
    c) Numerous testing systems are built into the mobile lab, including some that can be converted into chemical agent analyzers.
3. Lokmis[109]
    a) The compact mobile laboratory produced by this Lithuanian company can test samples from a nuclear or radiological accident using a range of the company's own measuring equipment.
    b) This laboratory provides an ideal model for rapid radiation detection in a contained area of operation.

[106] http://www.bt.cdc.gov/radiation/cdcrole.asp
[107] http://www.dae.gov.in/ni/nimjun03/mobile.htm
[108] http://www.epa.gov/narel/ukraine.html
[109] http://www.lokmis.lt/en/Ionizingradiationregistrationequipment/MobileLaboratories/tabid/783/Default.aspx

Specifications for Property Decontamination Module

A. Overview

This module will focus specifically on testing decontamination procedures on large-scale objects. It will have the ability to decontaminate samples of the ship itself, furniture, etc., while monitoring the effectiveness of procedures on a variety of materials. It is envisioned that this module will work closely with the General Laboratory Module, but will be separate and dedicated to testing CBRN decontamination procedures as opposed to analyzing samples to detect the specific type of decontamination. This module will consist entirely of laboratory space, with office work to be done in a separate general office module, or to be done onshore after the information is transmitted over communication lines (VOIP, VPN, etc.).

B. Personnel

1. Basic Laboratory Technician
    - a) Entry-level lab technician, or equivalent, with a bachelor's in Chemistry or related subject.
    - b) Experience with common equipment and techniques[110]
        - 1) Gas Chromatograph (GC)
        - 2) Gas Chromatograph/ Mass Spectrometer (GC/MS)
        - 3) ICP instrumentation
        - 4) USEPA SW-846 and 600 Series Methods for organic and inorganic compounds.
2. There will be access to more experienced and knowledgeable personnel stationed on land via the Operations Center and C^4I/IO.
    - a) Similar to the WMD-CST (Weapons of Mass Destruction Civil Support Team), training to NFPA (National Fire Protection Association) 472 HAZMAT technician level or above would be valuable.
        - 1) "The WMD-CST organization is designed to augment local and regional terrorism response capabilities in events known or suspected to involve Weapons of Mass Destruction. WMD events are incidents involving hostile use of chemicals (such as nerve or blister agents, or toxic industrial chemicals – (TICs), biological (for example, anthrax or ricin), or radiological source."[111]
        - 2) 472 hazardous materials technicians have the skills necessary to respond to and mitigate hazardous materials releases. Training to this skill level covers the following:
            - Surveying the Incident
            - Container ID, Condition, and Marking
            - Monitoring Equipment
            - Resource Utilization

[110] http://www.newagelandmark.com/emp.php

[111] http://c21.maxwell.af.mil/wmd-cst/cst_factsheet_103rd.pdf

- Response Objectives
- Action Option
- Personal Protective Equipment
- Chemical Compatibility
- Developing Action Plans
- Incident Management
- Control Functions
- Evaluation Progress
- Incident Termination
- Field Exercises[112]

Having someone of this skill level within easy communication will allow the laboratory technicians to complete their routine work, but also have someone to consult if necessary if/when something unusual occurs.

3. While there is no equivalent rating, this position will be similar to the Army position Chemical Operations Specialist (74D)[113].
    a) Equivalent civilian jobs can be found at all levels of government and in private agencies.
4. Two technicians will be assigned to each TEU, due to the constraints of space. With the flexibility in changing the working environment, more technicians may be added as needed, space allowing.

C. Equipment

1. This module will need access to pressurized water and air.
2. Drainage in the testing area will need to be routed to special containment.[114]
3. Personal Protective Gear is essential.
4. The module will need access to all decontamination materials that will be used on the ship in sufficient quantities to test a variety of larger objects.
5. This module will also need the necessary equipment to test the contamination levels of the objects being worked on.
    a) As in the decontamination of the Hart Building, test strips can be used to measure the levels of contamination remaining.[115] Detection tickets and detection tubes will be standard equipment.[116]
    b) The module will be able to determine the following: the performance of the contaminant and decontamination products; the effectiveness of the restoration method; the cost and duration of the decontamination, cleaning, or neutralization material; and the contamination resulting from the cleanup.[117]

[112] http://www.teex.com/teex.cfm?pageid=training&area=TEEX&templateid=14&Division=ESTI&Course=HAZ020
[113] http://www.goarmy.com/JobDetail.do?id=40
[114] Ibid.
[115] http://yosemite.epa.gov/opa/admpress.nsf/a16b318fd6d8e076852572a000650bff/f93e59a8346b3cf985256b1700590dcb!OpenDocument
[116] http://www.gulflink.osd.mil/marine_breaching_ii/marine_breaching_ii_refs/n34en232/detect.htm
[117] http://www.crti.drdc-rddc.gc.ca/en/investments/technology_demonstration/04_0019td.asp

1. Storage capabilities
    a) Storage will not be indefinite.
    b) The storage capabilities will have to be able to handle large samples such as parts of the ship, furniture and other large objects in addition to temporary storage for liquid and solid detritus after the decontamination is complete.[118]
    c) Due to the potentially large objects, storage may require multiple, entirely separate TEUs.

D. Environmental Considerations

1. Standard maritime precautions will be taken to address the effects of water and movement on equipment.

E. Agency Partnerships

1. DOD/Defense Advanced Research Projects Agency (DARPA)
    a) "DARPA's TIGER [Triangulation Identification for Genetic Evaluation of Risk] program has developed a universal sensor that can detect any type of pathogen – even unknown and engineered ones – through an innovative method of measuring and weighing nucleic acid sequences."
    b) DARPA is also working closely with the FDA and DHS to develop and refine techniques for detection, decontamination and remediation of areas that have suffered CBRN attacks.[119]
2. DHS and FDA
    a) See in re: working with DARPA to develop techniques for detection and decontamination of CBRN events.
3. Local authorities
    a) As necessary, the results from the tests conducted in these modules may need to be passed on to local government/DHS/EPA, if the contaminated ship is near civilians.

F. Operations Center

1. The Property Decontamination TEU will have onshore experts at the Operations Center, similarly to the General Laboratory TEU. This way they will be able to consult the necessary personnel if necessary, but also be able to handle the usual work.

G. Similar Projects

1. This style of decontamination is similar to that done at the Hart building during the 2001 anthrax incident.[120] Decontamination methods were tested in a nearby trailer to evaluate the effectiveness and the dosage level needed to properly clean the area and the objects in it.

---

[118] http://www.ukresilience.info/emergencies/cbrn/defra/management.aspx
[119] http://72.14.205.104/search?q=cache:hqHdNaHxe70J:www.arpa.mil/body/news/2005/tethertestim7_21_05.pdf+CBRN+remediation+testing&hl=en&ct=clnk&cd=9&gl=us&client=firefox-a
[120] Reopening Public Facilities After a Biological Attack: A Decision-Making Framework

Specifications for Decontamination Module

A. Overview

The Decontamination Module is a fully-equipped mobile storage facility designed to safely house and transport decontamination equipment to the site of contamination. With the capacity to store and support a wide variety of decontamination systems, this TEU is well-suited to handle a multitude of CBRN incidents. An efficient decontamination operation relies heavily upon the flexibility and preparedness of the Decontamination Module.

B. Personnel

1. Damage Controlman Third Class (DC3) Navy rating[121]
    a) Civilian equivalent of this position is a Facilities Maintenance Specialist.
2. Two ratings will be assigned to each TEU, due to the constraints of equipment space
    b) When available, increased specialization of the equipment can allow for more personnel to work from each TEU.
    c) Additional personnel for instruction or consultation are available on land through the Operations Center.
3. Will operate all decontamination systems housed in the TEU
    a) Personnel should be familiar with handling the different systems onboard and should receive formal training as to their proper use.
4. Personal Protective Gear must be worn at all times

C. Equipment

1. Interior lighting
2. Dry containers to store decontaminants
3. Ample shelving for the decontamination systems
4. General equipment to support decontamination systems
    a) Electric generator to be used as a back-up energy supply and to run decontamination systems that are not self-powered.
    b) Water intake system must be capable of heating and pressurizing water.[122]
    c) Drainage system to safely remove water and waste from the module floor

D. Operation

[121] http://buperscd.technology.navy.mil/bup_updt/508/OccStandards/CHAPTER%2021.htm
[122] http://www.forces.gc.ca/admmat/dglepm/cfnbcds/documents/SOW_Appendix_1_-_Module_1_Specification.DOC

1. Multiple decontamination systems should be included to tailor the decontamination effort to as many potential situations as possible.
    a) Take into consideration the following circumstances:
        1) Size of contaminated area
        2) Type of material contaminated
        3) Type of chemical/biological agent
    b) Systems should be compatible with multiple decontaminates.[123]
        1) Liquid-based topical agents
        2) Foams and gels
        3) Gaseous and vapor technologies
    c) Systems should be capable of running autonomously or with the aid of utilities provided by the module itself.
2. The module should allow for easy roll-on/roll-off loading and unloading of all equipment.
    a) Neither setup nor takedown should require more than 30 minutes.
3. Each TEU should have the capacity to decontaminate 10,000 square meters per hour.[124]
4. All used equipment will be cleaned and verified contamination-free before being repackaged inside the TEU.

E. Environmental Factors
1. The interior of the TEU can be cleaned in the event of direct exposure to contamination.
2. Great care must be taken to secure the module's contents before transportation so as to ensure their safe arrival at the maritime site.
    a) Supply stable containment for bottles of liquid and foam decontaminates.
    b) Bolt shelving to the floor and walls.
    c) Each system will be individually packaged and secured to the module's shelves.

F. Operations Center
1. Personnel working from the Decontamination Module can communicate with onshore experts to determine the best decontamination methods to use for a specific incident.
    a) Experts must be familiar with the decontamination systems onboard the response vessel as well as the environments in which each system should be used.
2. The Operations Center will have access to a chemical/biological agent database such as the EPA's Contaminant Data Dictionary.[125]

G. Agency Partners
1. U.S. National Response Team (NRT)[126]

---

[123] http://www.epa.gov/nhsrc/pubs/reportBuildDecon052705.pdf
[124] http://www.allen-vanguard.com/Catalogue/CB/613/909498.html
[125] http://www.epa.gov/ordnhsrc/news/news120606.html

a) NRT's Regional Response Teams are well-versed in providing technical assistance and coordinating the attainment of additional manpower and equipment during emergency incidents involving hazardous substances.

2. Center for Disease Control[127]

   a) Personnel from Bioterrorism and Chemical Emergencies areas with information on the chemical or biological agent should remain on call until decontamination has been completed and the agent eliminated.

H. Similar Projects

1. Karcher Futuretech Gmbh[128]

   a) Multiple compact and easily transportable decontamination systems are already manufactured by Karcher for an array of NBCR incidents.

2. OWR[129]

   a) A compact, adaptable containerized system developed by this German firm is used for the decontamination of personnel, buildings, clothing, and equipment.

   b) The system, which was designed to be transported via truck, demonstrates consideration to space, mobility, and easy setup.

3. PW Allen & Company and Canadian Vanguard Response Systems[130]

   a) Allen-Vanguard has developed the compact CASCAD Universal Decon Module, a self-contained military decontamination system designed for rapid deployment to an incident site.

   b) Foam-based Allen-Vanguard decontamination equipment is stored inside the module to be used on vehicles, aircraft, and ships.

   c) The CASCAD system can decontaminate roughly 10,000 square meters each hour.

---

[126] http://www.nrt.org/
[127] http://www.bt.cdc.gov/
[128] http://www.karcher-futuretech.com/futuretech/Products/NBC_Protection_Systems/Decon_Systems.htm
[129] http://www.owr.de/go/owr/home/products/multi_purpose_decont/containerised_decontamination_system/1.xhtml
[130] http://www.vanguardresponse.com/products_im_decon.shtml

Specifications for Personal Protective Gear Module

A. Overview

The Personal Protective Gear Module is a portable supply container, stocked with a range of equipment and clothing to protect against chemical and biological agents. In order to reduce direct contact with hazardous material, this module is to be used by multiple shifts of personnel from all vessels until decontamination has been completed.

B. Layout

1. The majority of the inside space of this TEU will be reserved for storing protective equipment.
    a) Shelving and containers should be secured to the walls and floor and labeled as to their contents.
    b) The design of the TEU must provide for quick and easy access to all protective gear.
2. A portion of the TEU will be reserved as a dressing area for personnel.
3. All areas should be well-lit and have open walking spaces for optimum use of the module during emergencies.

C. Supply of Protective Gear

1. Personnel from the response vessels as well as crewmembers of the contaminated vessel will be supplied by this TEU.
2. All protective clothing and equipment must be easy to maneuver in and able to withstand thorough decontamination after use.
3. Each article of protective gear will be operable by itself as well as in conjunction with other personal equipment.
4. Will include the following:
    a) Full-body over suit and hood equipped with respiration system.[131]
        1) Zipper front for easy donning
        2) Double seamed for extra protection
        3) Must ensure prime visibility through face mask
    b) Full-body over suit without head cover.
    c) Standalone respiration mask to be used when no personal protective suit is deemed necessary.
        1) Filters airborne agents while still allowing for verbal communication.[132]
    d) Brightly colored hardhats with adjustable chinstraps
    e) Impermeable steel-toed boots
        1) Stretch-fasteners will allow for easy donning and snug fitting.[133]
    f) Textured gloves resistant to chemical permeation and degradation.[134]

[131] http://nbcprotect.com/products/protective_item109.htm
[132] http://www.allen-vanguard.com/Catalogue/PP/612/909419.html
[133] http://nbcprotect.com/products/nbcaccessories_1000.htm

    g) Personal cooling systems to be used during times of high temperatures.
    h) Waterproof battery-powered radios that clip to the over suit waistband.
5. All equipment will be stocked in multiple standard sizes to accommodate all personnel.
    a) Before deployment, all clothing may be assigned and fitted to response personnel instead of being used in rotation.
6. Each TEU should hold supplies for no less than 20 personnel.

D. Personnel
1. Master-at-arms Second Class (MA2) Navy rating[135]
    a) Civilian equivalent of this position is a Safety, Health and Environmental Coordinator.
2. Space allowing, assign two ratings per TEU to maintain suits and storage.
3. Training and familiarity with all equipment is required.
4. Experience in high-threat level incident response and special protective equipment is recommended.
5. Responsibilities include the following:
    a) Overseeing the allocation of all equipment.
    b) Instructing personnel on the proper usage of the personal gear
    c) Making equipment adjustments when necessary
6. Written instructions complete with diagrams showing proper equipment use should also be posted at eye-level on the TEU walls.

E. Environmental Considerations
1. All contents of the TEU should be secured inside closed containers due to the possibility of inclement weather and rough seas.
2. The simplistic design of the module allows personnel to rapidly retrieve necessary protective equipment even in the worst weather, maritime, or HAZMAT conditions.
3. All personnel entering the TEU during a CBRN incident will first be decontaminated to ensure that no hazardous material enters the container.

F. Agency Partnerships
1. National Institute of Standards and Technology[136]
    a) This institute is developing standards for protective equipment for the Department of Homeland Security.
    b) Information from the NIST will be vital in determining the most appropriate protective gear for all potential situations.
2. PHMSA Office of Hazardous Materials Safety[137]
    a) Trainers well-versed in HAZMAT response can aid in overseeing that all personnel are properly protected and using all protective equipment correctly.

---

[134] http://www.safetyequipment.org/glovestd.htm
[135] http://www.navcops.com/magazine/articles/12/10/History-of-the-Master-At-Arms-%28MA%29-Rating
[136] http://www.nist.gov/public_affairs/factsheet/protective_equipment.htm
[137] http://hazmat.dot.gov/contact/ohhms_fn.htm

G. Operations Center

1. Experts working in the Operations Center will keep all personnel informed as to the extent of protective gear necessary for every task and phase of the response process.
2. Personnel involved in the decontamination process can maintain communication and exchange information with the Operations Center at all times via radio.

Specifications for Toxic Diving Module

A. Overview

This module will store the supplies needed for any diving that may need to take place in waters in and around the CBRN-contaminated ship. It will not have decontaminating apparatus, but may store contaminated diving gear if necessary. There will be a sister module physically separate from this one for general office work and keeping in constant contact with divers.

B. Personnel

Personnel shall consist of a minimum of two divers and one contact person to remain onboard the platform/transport vessel.

1. Divers should have completed the Navy's Fleet Diver Program[138] and received specialized training in working in a contaminated diving atmosphere.
2. Non-diving personnel will keep in constant radio contact with the divers, and relay findings to the Operations center and other module personnel if necessary.
3. Civilian equivalent jobs are less common due to civilians rarely needing to dive in CBRN waters. Similar jobs, though, can be found in government and some police forces. The NYPD SCUBA division, for example, often does harbor diving in TIC/TIM contaminated waters.[139]

C. Equipment

1. This module will store clean diving gear, with the possibility for also storing post-dive contaminated equipment.
2. Thus the module will have two sets of storage bins, one to only be used for clean gear, the other only for contaminated gear until it can be cleaned, either on the ship or once the ship returns to port.
3. Specific Equipment
   a) Dry suits fitted for all potential personnel (assuming that this module will be staffed on a rotating schedule), in addition to a range of sizes that can be used if needed by other personnel.
   b) Breathing apparatuses for the two divers, as well as at least one backup apparatus. These should be specifically constructed for use in CBRN environments and have a completely closed-loop air recycling system.[140]
   c) Two oxygen tanks for use by the divers, and two backups. These should be kept full at all times.

D. Environmental Considerations

1. Storage, especially for potentially-delicate equipment such as SCBA breathing apparatuses will be fastened securely to minimize movement in rough weather conditions.
2. Oxygen tanks will be stored in fireproof containers.

[138] http://usmilitary.about.com/od/enlistedjob1/a/diver.htm
[139] http://www.nyc.gov/html/nypd/html/pct/sodpct.html
[140] http://www.virtualacquisitionshowcase.com/docs/Paragon-Brief.pdf

3. All delicate equipment will have customized storage bins as much as possible, to prevent it from moving while stored.

E. Agency Partnerships

1. Navy Experimental Diving Unit[141]

a) A division of the Navy Diving Unit, this unit (under NAVSEA) researches, tests and evaluates equipment and techniques for use in undersea, hyperbaric, and other life-support situations. In addition to training CBRN-ready divers, they will be invaluable for testing a research of new diving apparatus.

2. CDC

a) The CDC has developed NIOSH testing, certification, and guidelines for CBRN SCBA gear that will fully protect the diver. The divers can work with the CDC to ensure that their equipment will sufficiently protect them, as well as potentially test and develop new equipment.[142]

F. Operations Center

1. The Operations Center may be able to tune into the radio between divers and the ship. In addition they will receive all data related to the divers' findings and be able to disseminate it to both on-land personnel and other personnel aboard the platform/transport vessel.

G. Similar Projects

1. Paragon Space Development Corporation[143]

a) Although primarily tasked with researching and designing equipment for NASA, Paragon has developed a CBRN diving apparatus.

b) Paragon, working off of the evidence that traditional diving equipment protects the diver for only 5 – 15 minutes, developed a breathing system that is completely self-contained, isolating the diver from his or her environment.

2. Current technology

a) Current baseline Navy technology consists of the Kirby Morgan superlite 17b helmet, also known as the MK21 or the MK37/Viking dry suit combination.

b) Although adequate in many ways, the current technology has a lot of weaknesses where CBRN contaminants can enter and come into contact with the diver.

1) For example, the MK21 stops preventing water intrusion when the diver's head moves from the upright position.[144]

---

141 http://www.supsalv.org/NEDU/nedu.htm
142 http://www.cdc.gov/niosh/npptl/pdfs/CBRNSCBAJuly15.pdf
143 http://www.paragonsdc.com/chem_bio_hazard.php
144 http://www.virtualacquisitionshowcase.com/docs/Paragon-Brief.pdf

Specifications for the Sensitive Equipment Decontamination Module

A. Overview

This module will decontaminate sensitive equipment encountered during the whole-ship decontamination after a CBRN event. Sensitive equipment includes avionics, electronics, environmental control systems, life support systems, and other objects which could potentially be harmed by the standard caustic decontaminants.

B. Personnel

1. Space allows for approximately 2-3 persons at any time.
2. Personnel should have training in decontamination procedures, and experience or equivalent training in CBRN decontamination specifically, preferably to a 472 HAZMAT technician level or above.[145]
   a) 472 hazardous materials technicians have the skills necessary to respond to and mitigate hazardous materials releases. Training to this skill level covers the following:
      - Surveying the Incident
      - Container ID, Condition, and Marking
      - Monitoring Equipment
      - Resource Utilization
      - Response Objectives
      - Action Option
      - Personal Protective Equipment
      - Chemical Compatibility
      - Developing Action Plans
      - Incident Management
      - Control Functions
      - Evaluation Progress
      - Incident Termination
      - Field Exercises[146]

3. While there is no equivalent rating, this position will be similar to the Army position Chemical Operations Specialist (74D)[147].
   a) Equivalent civilian jobs can be found at all levels of government and in private agencies.
      1) Although there is not a great call for decontamination personnel in the civilian world, many private agencies are working on developing sensitive equipment decontamination procedures.[148]

[145] http://c21.maxwell.af.mil/wmd-cst/cst_factsheet_103rd.pdf
[146] http://www.teex.com/teex.cfm?pageid=training&area=TEEX&templateid=14&Division=ESTI&Course=HAZ020
[147] http://www.goarmy.com/JobDetail.do?id=40

b) Navy EOD forces also receive similar training, particularly as concerns responding to terrorist threats.[149]

C. Equipment

This module will primarily feature autoclave-like closed-loop decontamination systems to safely decontaminate small objects. It will have the ability to safely decontaminate large areas onboard ship, as well.

1. Small-scale decontamination

a) There will be several small, closed-loop systems approximately the size of a dishwasher that will be able to decontaminate small items, such as laptop computers or night-vision goggles.[150]

b) This system will wash the object with a 'friendly' decontaminant such as ACES, an enzyme-based decontaminant developed by Edgewood.[151] This non-corrosive, non-flammable material will neutralize the decontaminant, and the remaining material can be flushed away and safely disposed of.[152]

D. Environmental Considerations

1. Extreme caution should be taken in securing objects, and particularly in the method in which the equipment being decontaminated is secured within the closed-loop system, due to the sensitivity of everything involved. Aside from that, standard maritime cautions should be taken.

E. Agency Partnerships

1. EPA

a)"The EPA and other agencies will develop standards, protocols, and capabilities to address the risks of contamination following a biological weapons attack and developing strategies, guidelines, and plans for decontamination of persons, equipment, and facilities."[153]

b) This TEU may turn to the EPA to get information about specific decontamination procedures, as there will be different procedures used than for large-scale decontamination.

2. CDC

a) If needed, this TEU will liaise with members of the CDC in order to collect and share information about decontamination procedures. It may also become necessary to consult with the CDC on how to transport and safely handle the byproducts of CBRN decontamination.

---

[148] http://nationalsecurity.battelle.org/clients/inno_related.aspx?id=44, http://www.enviroexperts.net/deconindclean.htm, http://www.smiths-aerospace.com/News/Archive/2002/Decontamination-equipment-decision-offers-Smiths--75-million/index.asp

[149] http://www.eod.navy.mil/whatwedo.htm

[150] http://www.nationaldefensemagazine.org/issues/2003/Jun/Decontamination.htm

[151] http://www.ecbc.army.mil/ip/annual_report/ecbc_2004_annual_report.pdf

[152] http://www.ecbc.army.mil/ip/annual_report/ecbc_2004_annual_report.pdf

[153] http://www.epa.gov/sab/pdf/homeland_security_presidential_directives.pdf.

F. Operations Center

1. This TEU will use the Operations Center for access to experts in the field as necessary.
2. Communications will be open with the Operations Center at all times in order to share data and receive updates as necessary on the identification and decontamination of the ship, as affects this TEU.

G. Similar Projects

1. Edgewood Chemical Biological Center has been working for some time on developing materials and equipment for sensitive decontamination.[154]
2. The JSSED (Joint Services Sensitive Equipment Decontamination) is a program used across the DOD by U.S. Army, U.S. Navy, U.S. Air Force, and U.S. Marine Corps to decontaminate sensitive objects. They have worked closely with Edgewood to develop non-aqueous and non-caustic decontaminants.[155]
3. The Battelle team, at request of the DOD, has also worked on creating a modular decontamination system for sensitive equipment. Their system used modified commercial decontaminants placed in a specialized environment that decontaminates the object and then removes both contaminant and decontaminant.[156]

---

[154] http://www.dps.state.vt.us/cjs/mcl.html
[155] http://www.jpeocbd.osd.mil/page_manager.asp?pg=2&sub=15
[156] http://nationalsecurity.battelle.org/clients/inno_related.aspx?id=44

Specifications for Robotics Module

A. Overview

This TEU will store exploratory robots to be used to safely investigate contaminated spaces and potentially collect samples without placing personnel in danger. The module will also be able to handle the returned robots, storing them safely until they can be decontaminated as well.

B. Personnel

1. Personnel will consist of technicians who have been trained in the maintenance and usage of the robots used. Decontamination of the robots themselves will mostly be handled by the Sensitive Equipment Decontamination TEU, but some experience with CBRN handling and decontamination is necessary, especially when handling samples of the contaminant. As the robots will be field-programmable, personnel should have training in the chosen programming language and debugging techniques.

2. Primary technicians should be an ET rating who has completed at least "A" school training. These individuals will be responsible for maintaining and controlling their robots, guiding them on reconnaissance missions and retrieving the samples, if their robot is equipped to do so.[157]

a) The ET will also be responsible for any field programming necessary.

b) While the ET will not decontaminate the robot, they are responsible for making sure that each robot is fully decontaminated by the end of the mission, and in good working order for the next.

3. ET's will also be able to reach Information Systems Technicians in the event of communications issues between the robot and controller, and advanced technical issues.[158]

4. Equivalent civilian jobs to the ET rating include electronics technicians, electronic equipment repairers, data communications technicians and electronics mechanics.[159] In addition to these in-demand jobs, the technicians assigned to this TEU will gain experience and knowledge in working with robotics.

C. Equipment

1. The TEU will need power access, storage capabilities and environmental controls.

2. The TEU itself will store the robots used on reconnaissance missions.

3. Ideally, one robot would be able to handle all required duties including reconnaissance, sample collection, and planning the navigation of the contaminated ship.

a) Required (or industry-standard) in the design of the robot would be:

[157] http://www.cnrc.navy.mil/factsheets/AECF.pdf
[158] http://usmilitary.about.com/od/enlistedjob1/a/it.htm
[159] http://www.cnrc.navy.mil/factsheets/AECF.pdf

1) Ability to withstand temperatures between 40 and 120 degrees Fahrenheit.
2) Ability to run for 2 to 4.5 hours at a time without recharging.
3) A monthly maintenance time of .5 to 2 hours.
4) An annual maintenance cost of $300-$500 (this is aside from costs of CBRN decontamination)
5) A top speed of 5 kph.
6) Weighing 59 kg or less
7) An LED light with a camera
8) Multiple firing circuits.
9) Waterproof
10) Ability to traverse uneven surfaces, including standard 8-inch commercial stairs.
11) .75 inch cleats to provide traction

b) Ideal additions to the design:
1) USB joystick-controlled, or a similar control device
2) A retractable, multi-jointed arm that allows a mounted camera or a sample container.
3) Field-programmable
4) Modular design with a small footprint.
5) Increase top speed to 10kph
6) Decrease weight to 24 kg
7) Ability to move from floor to walls and traverse vertical surfaces.
8) Autonomous navigation in addition to remote control.

D. Environmental Considerations

1. Robots should be hardy enough to withstand the effects of rough seas.
   a) Similar to Apple's Sudden Motion Sensor, the hard drive head should instantly park if unusually high vibrations, a sudden change in position, or sudden, unexpected acceleration is detected. This will protect the hard drive on the robot, as well as any data that it has stored, while allowing the hard drive to start up again almost instantly.[160]
   b) Another solution, although one that is far more expensive, is to use a solid-state drive that does not have the vulnerable moving parts that a traditional drive does.[161]
2. Only clean robots will be stored in the TEU.
   a) When the mission is complete, the controller should maneuver the robot into a secure container in which it can be transported to the Sensitive Equipment Decontamination TEU, its samples collected and sent off for analysis, and the robot decontaminated for another mission or to be returned to storage. This will eliminate the possibility of this unit's personnel being exposed to contaminants.

[160] http://docs.info.apple.com/article.html?artnum=300781
[161] http://www.sandisk.com/OEM/ProductCatalog(1274)-SanDisk_SSD_Solid_State_Drives.aspx

E. Operations Center

1. This module will need access to the secured network for communication with onshore personnel about the robot's findings.

F. Similar Projects

1. iRobot PackBot EOD
    a) Selected by Edgewood as the premier CBRN detection robot due to its wide array of sensor capabilities.[162]
    b) Notable for being lightweight (less than 24 kg), with a deployment time of less than 2 minutes, all-weather and all-terrain and with a manipulator arm that has multiple articulation points.[163]
    c) Operator interface is an all-weather keyboard with integrated mouse and two multi-degree-of-freedom controllers.[164]
    d) Unit is designed to deal with a wide variety of Improvised Explosive Device (IED), HAZMAT, EOD and conventional ordnance missions.[165]
2. ASENDRO[166]
    a) Developed robots specifically for EOD
    b) Has autonomous controls as well as the ability to be remotely controlled.
    c) Unique in that the cameras are stereo, resulting in a 3-d image.
3. Allen Vanguard
    a) Developed the Vanguard ROV[167]
        1) Ascends and descends stairs.
        2) Unique component is an integrated RS232 port for CBRN sensor devices.
4. Vortex VRAM[168]
    a) Brand-new technology allows the robot to climb walls and move from the floor to the wall and back again.
    b) Hasa single joystick and allows field programmability

[162] http://findarticles.com/p/articles/mi_m0EIN/is_2006_June_26/ai_n16498604
[163] http://www.irobot.com/sp.cfm?pageid=165
[164] http://www.irobot.com/filelibrary/GIspecsheets/iRobot_PackBot_EOD.pdf
[165] http://www.irobot.com/sp.cfm?pageid=138
[166] http://www.asendro.de/index.php?id=110&L=1
[167] http://www.allen-vanguard.com/Catalogue/RO/555/909403.html
[168] http://www.vortexhc.com/vmrp.html

Specifications for CDC Module

A. Overview

This module will be provide office and lab space for CDC personnel. The CDC will help identify contaminants, assess dangers, assist in creating a strategy and action plan, provide information to personnel on safety at the site, train other personnel as needed, and provide technical assistance to decontamination efforts and evaluation processes. If necessary, they will also test personnel for contamination.[169]

B. Personnel

Personnel will be made up of employees of the CDC, to include an emergency response specialist[170] and a health scientist[171] trained in emergency preparedness and response.

C. Equipment

1. Standard office equipment – allow CDC employees to access key databases including Pulsenet, a surveillance system that lets labs exchange information about bacteria using DNA fingerprints.[172] Scanners are key in transmitting results to CDC colleagues and other partners onshore.[173]
2. The Laboratory Response Network for bioterrorism has four levels: A, B, C, and D. The lab on the platform/transport vessel is envisioned to be a Level D laboratory with the "highest level containment and expertise in the diagnosis of rare and dangerous biological agents." Level D laboratories can also have a strain bank of biological agents. They have the capacity to perform advanced diagnostic technologies and tests.[174]
3. In terms of equipment, the lab component will be similar to the General Laboratory Module. Equipment should be durable; breakable materials such as glass should be avoided.[175] Safety features such as biological medical cabinets are important.[176] Features should include climate control, counter space, sink and sample prep areas, freezer space, and seawater and compressed air connections.[177]

D. Environmental Considerations

[169] http://www.bt.cdc.gov/radiation/cdcrole.asp
[170] http://www.cdc.gov/employment/topjobs.htm
[171] http://www.cdc.gov/employment/topjobs.htm
[172] http://www.cdc.gov/about/stateofcdc/cdrom/SOCDC/SOCDC2006.pdf
[173] http://www.cdc.gov/print.do?url=http://www.bt.cdc.gov/agent/anthrax/webcast/110901/anthrax-webcast-transcript110901--3of9.asp
[174] http://www.cdc.gov/print.do?url=http://www.bt.cdc.gov/agent/anthrax/webcast/110901/anthrax-webcast-transcript110901--3of9.asp
[175] http://www.who.int/csr/resources/publications/biosafety/Biosafety7.pdf
[176] http://www.who.int/csr/resources/publications/biosafety/Biosafety7.pdf
[177] From General Lab Module write-up

1. Standard maritime technology and techniques should ameliorate most issues that might arise. Technicians may need training specifically in working in a laboratory environment aboard a ship.[178]
2. It is likely that the platform/transport vessel will arrive well after the events that caused the contamination, minimizing the effect of the wartime or meteorological events on the ship.[179] However, neutralizing the effects of high seas and/or wartime issues will be taken into account in the design of the ship.

E. Agency Partnerships
1. The CDC will work with the USN throughout the investigation.
2. CDC personnel onboard will work with colleagues onshore, who will build on partnerships already established:
a) CDC partners with NIH on developing vaccines[180]
b) CDC partners with the FBI at an organizational level through the Association of Public Health Laboratories (APHL)[181]
c) CDC partners with the EPA, with the Nuclear Regulatory Commission (NRC), with the Department of Homeland Security, and with other agencies within HHS including the FDA.[182]

F. Operations Center
1. The CDC module may partner with the Operations Center to report data findings, but they will work primarily with CDC colleagues.[183]

G. Similar Projects
1. The CDC has "developed an effective way to rapidly test methamphetamine contamination to be used by law enforcement to detect if police officers seizing illegal meth labs have experienced a toxic exposure."[184]
2. The CDC has developed an international team called the Global Disease Detection Program, or GDD. In 2006, the GDD responded to an outbreak of avian influenza in Nigeria. Two GDD lab scientists and one epidemiologist did lab work to assess the situation, and two other GDD staff worked with local authorities to implement surveillance and control activities. The CDC partnered with GDD to train local public health officials on diagnostics, response, and containment.[185]

---

178 From the FBI TEU write-up
179 From the FBI TEU write-up
180 http://www.cdc.gov/about/stateofcdc/cdrom/SOCDC/SOCDC2006.pdf
181 http://www.aphl.org/programs/emergency_preparedness/Pages/default.aspx
182 http://www.bt.cdc.gov/radiation/cdcrole.asp
183 From the FBI TEU write-up
184 http://www.cdc.gov/about/stateofcdc/cdrom/SOCDC/SOCDC2006.pdf
185 http://www.cdc.gov/about/stateofcdc/cdrom/SOCDC/SOCDC2006.pdf

Specifications for Coast Guard Module

A. Overview

This module will allow the USCG to be physically present on the platform/transport vessel, so as to better work with the Navy on decontamination efforts. While the USCG has been involved in CBRN decontamination efforts in the past[186], this module will primarily serve as office space and a communications center allowing Coast Guard personnel to relay information between the ship and the USCG.

B. Personnel

1. This module will have office space for between two and four persons. These should be USCG personnel with training and, ideally, experience in CBRN events.

2. If the CBRN event takes place in littoral areas, or otherwise falls under the USCG's physical jurisdiction, is likely that there will be ships and/or helicopters in the area that will need to be able to work with Navy personnel[187]. The persons assigned to this module may need to act as liaison between the two groups, as well as DHS and local civilians, in order to fulfill their missions of maritime security and national defense[188].

C. Equipment

1. The module will contain desk space for two people, with the option to expand as more personnel are brought onboard. There will also be a setup to retain communication with the USCG, most likely a radio transmitter/receiver. The module will consist of office space, but the basic design should be flexible enough to take on additional personnel and equipment as needed.

D. Environmental Considerations

1. Standard maritime measures will be taken to both fasten the TEU to the ship, and to keep its contents from being jarred in inclement environments.

E. Agency Partnerships

1. Department of Homeland Security (DHS)[189]

a) Since the creation of DHS, the Coast Guard has been placed under their guidance, protecting littoral areas from terrorist threats. As a result of this, the Coast Guard provides a valuable link with DHS personnel and resources.

2. Local civilian government

a) As a part of DHS, the Coast Guard is experienced in working with local government personnel in affected areas.

---

[186] http://proceedings.ndia.org/5460/5460/1_hooper.pdf
[187] Ibid.
[188] http://www.uscg.mil/top/missions/
[189] http://www.cnn.com/2003/ALLPOLITICS/02/25/homeland.security/index.html

3. Joint Program Executive Office for Chemical and Biological Defense (JPEO-CBD)[190]

a) "The Joint Program Executive Office for Chemical and Biological Defense (JPEO-CBD) is the principal advocate and single point of contact for all chemical, biological, nuclear and radiological detection, and vaccine and medical diagnostic acquisition efforts within the scope of the JPEO-CBD charter."

b) Under the Joint Task Force Civil Support (USNORTHCOM), the Coast Guard works with the JPEO-CBD in order to research and implement protection and decontamination of chemical and biological agents.[191] JPEO-CBD is particularly interested in discouraging biological warfare.

F. Operations Center

It is unlikely that the Coast Guard will need to rely heavily on the Operations Center. A connection to the ship/OC intranet should be sufficient, as personnel in this module will primarily report to USCG officers.

G. Similar Projects

1. The USCG and the Navy have worked together since before WWI. Notably, during WWII, several Naval transport vessels (among other sea craft) were staffed by Coast Guard personnel.[192]

2. The Navy and the USCG have joined forces before in issues of Homeland Security, specifically under OPERATION NOBLE EAGLE.[193] Under this mission, Naval ships were employed jointly with Coast Guard forces to monitor the Gulf and East Coast areas.

---

[190] http://www.jpeocbd.osd.mil/
[191] http://www.jtfcs.northcom.mil/pages/news20030425.html
[192] http://www.uscg.mil/history/h_cgnvy.html
[193] http://c21.maxwell.af.mil/maritime/navyuscg.htm

Specifications for EPA Module

A. Overview

This module will provide office and analytic laboratory space to employees of the EPA in order to further their ability to research CBRN contamination prevention. The EPA is primarily concerned with the health of both humans and the environment, and thus has a stake in contaminants that can affect both the population of a ship and the environment around that ship.[194]

B. Personnel

1. Office and laboratory space should allow for two to three employees to use the module.
2. Employees should receive training and have a background in CBRN events and working with contaminants in a safe manner.

C. Equipment

1. This module will be set up as a standard office module with some adjustments as needed.
2. Part of the module should be able to be turned into a laboratory with standard testing equipment, so that the EPA can conduct tests if it becomes necessary.

D. Environmental Considerations

1. Standard precautions should be taken for working in a marine environment. Office equipment should be secured, and any smaller supplies should be safely stored away to prevent any damage.
2. The laboratory will be separated from the office portion by a secure partition and door, and should have its own entrance, to reduce the possibility of introducing contamination to the office. Due to these requirements, the EPA TEU may require a forty-foot container.

E. Agency Partnerships

1. Department of Homeland Security
   a) The EPA has been specifically tasked with monitoring drinking-water and water-treatment systems by DHS. They are also tasked with surveying CBRN laboratories “standards, protocols, & capabilities to address the risks of contamination following a biological weapons attack & developing strategies, guidelines, & plans for decontamination of persons, equipment, & facilities. “[195]
2. Food and Drug Administration
   a) Due to overlap in their duties, the FDA and EPA often overlap, particularly when it comes to environmental effects on human populations,

[194] http://www.epa.gov/epahome/aboutepa.htm#mission
[195] http://www.epa.gov/sab/pdf/homeland_security_presidential_directives.pdf

as with mercury in fish[196]. As explained in the FDA module description, the effects of a CBRN event may require input from both agencies.

3. Center for Disease Control (CDC)

a) As with the FDA, often the EPA's interests overlap with the CDC when disease and environmental factors come together[197]. Notably, they worked together post-Katrina to address contamination concerns in floodwater.[198]

F. Operations Center

The module will have a connection to the Operations Center through the intranet, but will primarily report back to the EPA.

G. Similar Projects

1. EPA guidelines have routinely been used in developing protective equipment to be used in CBRN situations, such as the CBRN Powered Air Purifying Respirator (PAPR) Standard.[199]

2. The EPA has specifically been singled out and applauded by the Chemical and Biological Defense Information Analysis Center (CBIAC) for their work in protecting and maintaining safe drinking water, specifically from CBRN threats.[200]

---

[196] http://www.cfsan.fda.gov/~dms/admehg3.html

[197] http://www.epa.gov/pesticides/health/mosquitoes/mosquitojoint.htm

[198] http://yosemite.epa.gov/opa/admpress.nsf/d035c490ea7b4166852572a000658ee9/43426907350a956a8525707500675088!OpenDocument

[199] http://www.cdc.gov/niosh/npptl/standardsdev/cbrn/papr/concepts/paprcon-020604.html

[200] http://www.cbrniac.apgea.army.mil/products/newsletter_pdfs/vol7_num2.pdf

Specifications for FDA Module

A. Overview

This module will provide office space and connectivity to FDA employees who are assigned to accompany the platform/transport vessel out into the field. Employees will have access the data on the contaminated ship so that they can keep in contact with FDA land offices, and fulfill their mission statement of protecting the public's health[201].

B. Personnel

1. Space in the module will allow for desk space for two or three employees. These employees will share living quarters with Navy personnel, and have access to the intranet, allowing them to communicate with experts on land if necessary.
2. Employees should have received training in proper responses to CBRN events, and have some connection to the National Center for Toxicological Research (NCTR).[202]

C. Equipment

1. This module will be set up as a standard office module with some adjustments as needed.
2. Following the FDA's pattern of developing treatments for bioterrorist agents, part of the module should have the ability to become a laboratory with standard testing equipment, so that the FDA can conduct their own tests if it becomes necessary.[203]

D. Environmental Considerations

1. Standard precautions should be taken for working in a marine environment. Office equipment should be secured, and any smaller supplies should be safely stored away to prevent any damage.
2. If the module will act as a laboratory, additional precautions should be taken to prevent contaminants from spreading. (This may necessitate breaking this module out into two connected TEUs, one dedicated to office space and the other to a research laboratory.)

E. Agency Partnerships

1. Center for Disease Control (CDC)
    - a) The FDA and CDC have historically worked closely on issues of disease prevention and eradication.
        - 1) Response to and prevention of Severe Acute Respiratory Syndrome (SARS) transmission[204]
        - 2) Blood donation purity issues[205]

---

[201] http://www.fda.gov/opacom/morechoices/mission.html
[202] http://www.fda.gov/nctr/
[203] http://www.fda.gov/nctr/initiatives/initiatives.htm#Bioterrorism
[204] http://findarticles.com/p/articles/mi_m3225/is_10_67/ai_102223782

2. Pine Bluff Arsenal
    a) The NCTR is physically located near the Army Pine Bluff Arsenal, and has historically worked closely with the armed forces.[206]

3. Department of Health and Human Services (DHHS)
    a) DHHS has also become concerned with CBRN WMDs and their possible use against civilian populations. They have worked with the FDA to develop and stockpile treatments for these agents.[207]

F. Operations Center

The module will have a connection to the Operations Center through the intranet, but will primarily report back to the FDA.

G. Similar Projects

1. The FDA primarily protects food products, cosmetics, and licenses drugs.
2. Due to this, the only overlap between the FDA and at-sea decontamination ops would likely involve compromised food supplies.
3. On the personnel side, the FDA may also have a role, as they have developed drugs (such as ciprofloxacin[208]) for treatment of bioterrorism agents. Their presence on the ship may lead to increased chances for real-world research and development of treatments.

---

[205] http://www.fda.gov/cber/infosheets/tickborne2.htm
[206] http://www.fda.gov/nctr/initiatives/initiatives.htm#Bioterrorism
[207] http://www.asanltr.com/newsletter/07-2/articles/072c.htm
[208] http://www.fda.gov/fdac/features/2004/104_terror.html

Specifications for FBI Module

A. Overview

1. This module will provide office and crime scene investigation space for FBI personnel.
    a) It is estimated that this module will be necessary for all CBRN events that occur in US waters and many out-of-country as well.
2. At time of writing, only one module is planned. If necessary, this TEU may be broken out into two, one to act as office and the other to act as a CSI lab.

B. Personnel

1. Personnel will be made up of employees of the FBI.
    a) At least one member, if not all employees assigned to this module, will be part of the Hazardous Materials Response Unit[209]. These persons will have received training and have experience in CBRN events.
2. Space will likely allow for 2-3 personnel per TEU.[210]

C. Equipment

1. Standard office equipment (computer, desk, etc.)
    a) This will allow the FBI to fulfill the intelligence-gathering aspects of their job.[211]
    b) Communication will occur over the network with both the operations center and FBI headquarters/Quantico as needed.
2. The CSI compartment of the TEU will be similar to the General Laboratory Module, to be used for storing and analyzing collected materials before decontamination takes place. Some specialized containment may be necessary, but the focus of the laboratory will be less on finding the proper decontamination procedure.[212]

D. Environmental Considerations

1. Standard maritime technology and techniques should ameliorate most issues that might arise. Technicians may need training specifically in working in a laboratory environment aboard a ship.[213]

E. Agency Partnerships

1. It is expected that the FBI will work closely with the Navy throughout the investigation.
2. As with the Navy, the FBI will likely liaise with the EPA and CDC in order to collect information or share findings throughout the investigation and decontamination of the CBRN event. The majority of crime scenes the FBI

[209] http://www.fbi.gov/hq/lab/org/hmru.htm
[210] http://www.newagelandmark.com/labs.html
[211] http://www.fbi.gov/congress/congress07/mueller011107.htm
[212] http://www.fbi.gov/hq/lab/fsc/backissu/april2000/twgcsi.pdf
[213] http://www.moc.noaa.gov/rb/science/labs.htm#labsurface

investigates are not CBRN events, and they will likely need to quickly gather information on these unique scenes, despite the specialized knowledge of the technicians.[214]

F. Operations Center

1. The FBI module may contact the Operations Center to report data found, but it is likely that they will mostly work directly with FBI personnel.

G. Similar Projects

1. This modular laboratory is similar both to the FBI Hazardous Materials Response Unit[215] and to many of the aspects of the FBI Laboratory.[216]
2. Mobile CSI units have been produced before.
   a) In the UK by the Forensic Science Services (an executive agency of the Home Office), a mobile CSI van was debuted in 2005 in order to speed the processing of evidence at crime scenes and thus deliver intelligence more quickly.[217]
   b) Vermont has had an active mobile crime laboratory since the mid-fifties, equipped to respond to and process the crime scene.[218]

[214] http://www.fbi.gov/hq/lab/org/hmru.htm
[215] Ibid.
[216] http://www.fbi.gov/hq/lab/labhome.htm
[217] http://networks.silicon.com/mobile/0,39024665,39130383,00.htm
[218] http://www.dps.state.vt.us/cjs/mcl.html

Specifications for Datacenter Module

A. Overview

The datacenter supports the Information Technology (IT) needs of the other TEU modules by hosting the servers, storing the data, and providing the technological capacity to perform any large tasks sent from the other modules. In addition, the datacenter includes backup power supply and backup data storage to minimize disruption and loss if something should fail.

B. Personnel

1. Navy Cryptologic Technicians[219] - includes Cryptologic Technician (Communications)[220], Cryptologic Technician (Maintenance)[221] and Cryptologic Technician (Administration)[222] ratings – coordinate, administer, and maintain networks. Expertise in/attention to redundancy of data and function, efficiency and rapid processing, and standard navy protocols for data transmission, handling, and security
2. Electronics Technician[223] - maintain and repair electronics equipment
3. Interior Communicationman[224] - install and maintain interior communications systems including telephones and audio-visual equipment
4. Information Systems Technician[225] - manage IP, LANs, software installation:
    a) Manager(s) for Windows
    b) Manager(s) for Linux/Unix
    c) Manager(s) for other operating systems, as needed
5. Equivalent civilian positions are in high demand, particularly for systems administrators.

C. Equipment

1. The datacenter TEU must contain:
    a) Servers (primary & backup)[226]
    b) Computing and network infrastructure
    c) Network security elements
    d) Network Operations Center – a monitoring system
    e) Environmental control systems – HVAC
    f) Fire prevention & suppression systems
    g) Power distribution and redundant power system
    h) Circuit breaker protection
    i) Redundant data communications
    j) Lighting[227]

---

[219] http://usmilitary.about.com/cs/navy/a/navyctn.htm
[220] http://usmilitary.about.com/od/enlistedjob1/a/ctm.htm
[221] http://usmilitary.about.com/od/enlistedjob1/a/cta.htm
[222] http://usmilitary.about.com/od/enlistedjob1/a/cta.htm
[223] http://usmilitary.about.com/od/enlistedjob1/a/et.htm
[224] http://usmilitary.about.com/od/enlistedjob1/a/ic.htm
[225] http://www.usarec.army.mil/hq/warrant/prerequ/wo251A.html
[226] http://www.moc.noaa.gov/rb/science/equipment.htm

The datacenter must have machines with the capacity to perform large tasks – including modeling, supporting the C^4I/IO TEU, etc. The datacenter should be virtualized in order to increase flexibility. Virtualization is a means of running multiple operating systems on one machine through use of software that makes each operating system act as if it had its own hardware. While the software uses some space, virtualization increases flexibility since operating systems can easily be added and deleted, and space used to support one can be repurposed to support another.

D. Environmental Considerations

1. Since the datacenter must be able to perform well in any situation as well as in a period of change, flexibility and robustness are key. Security of data is also very important, and encryption systems need to be considered in addition to the measures taken to protect the physical security of the TEU.[228]
2. To the extent possible, measures must be taken to minimize the risk of damage or disruption. For example, machines could be welded to the walls. All cables should be duplicated so that if one fails, a machine can switch to backup immediately and automatically alert the staff to the problem.

E. Agency Partnerships

1. There should be no need to work with non-Navy agencies.

F. Operations Center

1. If we set up a VPN or other encryption with strong access to the network, many of the IT staff can work remotely. At least one hardware engineer should be onsite in order to ensure that all disruptions can be fixed as quickly as possible. Remote staff would not be exposed to hazardous contaminants, which could reduce personnel costs. However, transmitting data remotely requires very strong security and encryption.
2. Information systems technicians could be remote if there were in-band remote access to the network. In-band access refers to access through the network itself, such as a VPN.
3. Navy cryptology technicians, electronic technicians, and interior communicationmen would need to be onsite in the beginning, but if strong out-of-band access were available, most of them could leave and work remotely once everything was set up. Out-of-band access allows access to the network in such a way that staff can retain their connection even while modifying the network. For example, out-of-band access can be set up through a modem.

G. Similar Projects

1. Sun Microsystems has pioneered the development of a datacenter in a shipping container.

---

[227] http://www.siemon.com/us/white_papers/03-10-10-data_centers.asp?source=cnet
[228] http://www.objs.com/workshops/ws9801/papers/paper085.html

a) Called Project Blackbox, is designed to be easily portable and efficient in its use of energy and space.
b) Project Blackbox only requires three external resources: water[229], AC power, and networking.[230] We would need to account for these three resources on the ACS.
c) Project Blackbox incorporates design elements to allow the containers to be transported without damage; these should be confirmed and/or tested for stability in the ocean.

2. Rackable has already made at least one sale of a datacenter in a 40-foot TEU.[231]

---

[229]Sun Microsystems has designed an innovative cooling system that contributes to the efficiency of Project Blackbox. A panel of heat exchangers sits between each set of racks. A water-based cooling system with fans circulates cool air and extracts excess heat, reducing power consumption and allowing the datacenter to function without air conditioning. *Project Blackbox Interactive Tour* online at http://www.sun.com/emrkt/blackbox/index.jsp

[230] http://www.sun.com/emrkt/blackbox/index.jsp

[231]http://www.datacenterknowledge.com/archives/2007/Mar/30/rackable_selling_portable_data_center.html

Specifications for Media Module

A. Overview

The Media Module is a fully equipped press filing center. It has all the capacities that would be found at a filing center at a major trade conference or sporting event. It is intended to accommodate a Naval Public Affairs Officer and 2-3 media teams that each consist of a major media reporter (TV/Radio), a producer and technician.

B. Personnel

1. Naval Public Affairs Officer (Lieutenant, O-3 or above)
    a) Training- should be trained in dealing with media during highly sensitive incidents.
2. The Army has a classification of a Media Relations Officer[232]
3. The Marine Corps lists the training a Public Affairs Officer gets in dealing with the media in MCO 1510.62[233]
4. Equivalent civilian title would be Press Secretary or Communications Director

C. Equipment

1. 4-5 ISDN Phone lines
2. 802.11b wireless internet connection
3. Broadcast Media Mult Box
4. 4-5 Video Monitors
5. Electric Outlets (110 amp)
6. Capability for either Satellite or Microwave transmission
7. Backup power supply for all equipment
8. Lighting
9. Fire Prevention and Suppression systems
10. Power Distribution and redundancy systems
11. Environmental Control Systems- HVAC

D. Environmental Considerations

1. Exterior
    a) Shipping containers are specifically designed for maritime transportation and therefore are resistant to such dangers as waves, rain, high winds and fire.[234]
    b) Media module will be fully-insulated to protect against damage to equipment during extreme weather conditions.
2. All interior fixtures will be secured to prevent tipping during time at rough seas.

---

[232] http://usmilitary.about.com/library/milinfo/aroffjobs/blpa.htm

[233] http://usmilitary.about.com/gi/dynamic/offsite.htm?site=http://www.usmc.mil/directiv.nsf/df51342d9123 6d2685256517004eb026/29b8452aaf494844852568cc0060d779%3FOpenDocument

[234] http://www.bobvila.com/HowTo_Library/Converting_Shipping_Containers_for_Housing-Building_Systems-A2382.html

E. Agency Partnerships

The Naval Public Affairs Officer will work closely with the DHS Office of Public Affairs[235] and other government press offices as appropriate.

F. Operations Center

The Naval Public Affairs Officer aboard the ship will work closely with the other Public Affairs Officers in the Operations Center to get updates on the status of supporting activities and ensure that they are conveying “one voice” to members of the media.

G. Similar Projects

1. The Navy has dealt with the media in the following recent CBRN events:
   a) USS Hartford, 2003[236]
   b) USS Oklahoma City, 2002[237]
   c) USS Cole, 2000[238]

[235] http://www.dhs.gov/xnews/contacts/

[236] http://findarticles.com/p/articles/mi_qn4158/is_20031113/ai_n12732473

[237] http://findarticles.com/p/articles/mi_pnav/is_200212/ai_3520898847

[238] http://www.defenselink.mil/releases/release.aspx?releaseid=2814

Specifications for General Office Module

A. Overview

The General Office Module is a mobile unit providing managerial personnel with private office space and a location for small meetings. With several configuration options, the General Office Module is prepared to accommodate differing numbers of personnel and their needs. This TEU will be used throughout the duration of the decontamination process for all organizational and managerial tasks

B. Layout

1. Two private office spaces will be sectioned off at either end of the TEU.[239]
    a) Each office will be equipped with two personal desks and accompanying chairs.[240]
        1) Built-in filing cabinets and bookcases will be available at each desk area.
        2) Each desk will come equipped with a laptop docking port and printer.
        3) All personal desks and desk accessories will be constructed out of lightweight metal.
2. The center TEU section will be a meeting area consisting of one long table with seating for eight
    a) The table and all chairs can be folded to convert the meeting area into an all-purpose room for small groups.
3. One large closet in the meeting area will be used for storing all office and cleaning supplies.
4. A power generator will supply electricity for all computer accessories and lighting.

C. Environmental Considerations

1. Due to its mainly administrative purpose, the General Office Module will likely avoid contact with hazardous material and contaminated personnel.
    a) The inside of the General Office Module should be easily decontaminated in the event of exposure to CBRN agents.
2. Desks are built into the TEU walls to avoid shifting during transportation and rough seas.
3. All office supplies must be kept in closed, secure containers when not in use in order to prevent spilling.

D. Operations Center

1. Personnel using the General Office Module can stay in constant contact with the Operations Center via computer.

---

[239] http://www.mobileofficeinc.com/floor_50x10.html
[240] http://www.nationalonline.com/nof-desks/envyworks.htm?applicationid=4

a) What information will be relayed between the General Office Module and the onshore OC depends on which container ship personnel use the personal office space.

2. Video conferencing can be made available in the meeting area to connect personnel in the Operations Center with shipboard meetings.[241]

E. Similar Projects

1. SCIF Solutions, Inc.[242]

   a) Founded by a U.S. Navy veteran, SCIF has developed a mobile office trailer well-suited for rapid deployment to disaster and emergency sites, including military-related incidents.

   b) The Office Trailer SCIF can be used as a model for the General Office Module's construction and technical configuration.

2. Odd Cubes[243]

   a) The Office Container constructed by Odd Cubes comes complete with wall insulation, a ventilation fan, electrical wiring, and interior plumbing that can all be used as technical examples for the General Office Module.

3. Maristar[244]

   a) China-based Maristar produces 20' stackable office containers with various interiors that can helpful in determining which equipment and furniture will be best for the General Office Module's use.

[241] http://www.lifesize.com/products/lifesize_team/
[242] http://www.scifsolutions.com/office_trailer_scif.html
[243] http://www.oddcubes.com/office_container.html
[244] http://www.chinamaristar.com/products.htm

Specifications for Mess Hall Module

A. Overview

This module will act as mess hall for all personnel stationed on the platform/transport vessel. Consisting of several TEUs, it will have a self-contained kitchen, storage area, and eating spaces (Officers' and Enlisted Mess), with personnel to prepare and serve food.

B. Personnel

1. Culinary Specialists[245]

a) One or more CS ratings should be assigned to this module to prepare, serve and track food and food supplies.

C. Equipment

1. Within the kitchen TEU, standard cooking equipment will be used: stove, oven, sinks, etc. This TEU will have access to hot and cold potable water, as well as environmental systems that allow venting outside without bringing in possible contaminants. This TEU will double as a cleanup space after meals.
2. There will also be a 'larder TEU', providing space for food, tableware, and equipment storage in secure bins.
3. The Mess TEU itself will supply tables and chairs as well as other necessities for comfort.

D. Environmental Considerations

1. Standard maritime precautions should be taken to prevent spillage or breakage of materials.
2. TEUs will be modeled after already-existing Naval messes aboard ships.

E. Agency Partnerships

No agency partnerships expected.

F. Operations Center

This module will not need to communicate with the Operations Center.

G. Similar Projects

1. Konstructa

a) Konstructa is a commercial business offering for-hire modular mess halls. Available in a variety of sizes, they are not standard-sized but offer some guidance in making modular kitchens and mess rooms.[246]

2. Marine Rapid Deployment Kitchen and Field Sanitation Unit[247]

---

[245] http://buperscd.technology.navy.mil/bup_updt/508/OccStandards/CHAPTER%2054.htm
[246] http://www.konstructa.co.uk/mess-rooms.html
[247] http://www.usmc.mil/marinelink/mcn2000.nsf/0/a9b51c9f3f3df0858525701900211d6c?OpenDocument

a) A quickly set-up, modular on-site mess hall unit used by Marines, this Unit consists of three standard TEUs making up a kitchen and sanitation unit. The FFSS is set up for large-scale use, feeding hundreds of Marines two hot meals a day.

3. Deployable Rapid Assembly (DRASH) Shelters[248]

a) Created by DHS Systems, these are quick-erect, durable shelter systems that can be configured in a variety of ways. Although intended primarily for medical personnel, they do allow for the creation of a mess hall.

[248] http://www.alkanshelter.com/news/MMT_10_7.pdf

Specifications for Housing Module

A. Overview

The Housing Module is a simple solution to providing working personnel from both the contaminated vessel and the response vessels with private living quarters and all related accommodations. The modules' flexible design addresses the personal comfort and care of all personnel with spacious rooms and a high level of privacy. Each unit is well-suited to last for the duration of a maritime project.

B. Housing Unit Layout

1. A growing interest in the usage of shipping containers as housing structures has already produced numerous design possibilities to fit any amount of space and number of inhabitants.[249]
2. TEU containers will be stacked together into one large apartment-style complex encased by an easily assembled steel frame.[250]
3. One 40'x 8'x 8'6 container can be divided into several rooms to comfortably house two workers for an extended period of time.[251]
4. Accommodations include twin beds and bedroom furniture, storage space, and shared or private bathrooms, kitchens, and living space.

C. Required Utilities

1. Each housing unit should be equipped with the following:
   a) Water access and drainage
   b) Lighting and electricity
   c) Air ventilation system
   d) Climate control for heating and air conditioning
2. An installed loudspeaker system can be used in emergencies to alert personnel in all housing units.
3. A multi-level housing structure will provide all housing units with a shared utility system.

D. Environmental Considerations

1. Exterior
   a) Shipping containers are specifically designed for maritime transportation and therefore are resistant to such dangers as waves, rain, high winds, and fire.[252]
   b) Housing units will be fully-insulated to protect against extreme weather temperatures.
2. Interior

[249] http://www.fabprefab.com/fabfiles/containerbayhome.htm
[250] http://www.containerliving.com/index.asp
[251] http://www.tempohousing.com/products/manager.html
[252]http://www.bobvila.com/HowTo_Library/Converting_Shipping_Containers_for_Housing-Building_Systems-A2382.html

a) Furniture may be bolted to the walls and floor to prevent tipping during rough seas.

b) Safety handrails in showers and skid-resistant bathroom flooring will provide extra protection.

E. Similar Projects

1. Tempohousing by Keetwonen[253]

   a) This Dutch firm offers fully-equipped housing units constructed from recycled shipping containers.

   b) Multiple layout options are available, including welded-together containers accommodating twice as many inhabitants while providing a larger shared living space.

2. Urban Space Management Ltd[254]

   c) The Container City system designed by USM utilizes recycled shipping containers to construct highly versatile modular buildings.

   d) Several projects have already been completed in Great Britain and the United States, including live-in artist studio units, large children's centers, and classroom buildings.

   e) Container Cities demonstrate the time and cost benefits of using shipping containers for housing while still keeping an aesthetically-pleasing exterior appearance and a comfortable interior living space.

3. Target Logistics[255]

   a) Private and semi-private housing units are manufactured from TEU containers by Target Logistics.

   b) The rapid deployment and easy setup of these units make them ideal for use in emergencies.

[253] http://www.tempohousing.com
[254] http://www.containercity.com/home.html
[255] http://www.targetlogistics.net/

Specifications for First Aid Module

A. Overview

The First Aid Module is a mobile medical unit equipped to provide an array of health services and treatment options for all personnel working at the site of contamination. As the first line of treatment during the decontamination process, this TEU responds rapidly to both CBRN emergencies and everyday illnesses and accidents that may occur.

B. Personnel

1. Hospital Corpsman Third Class (HM3)[256]
  a) Civilian equivalent of this position is a Registered Nurse (RN).[257]

2. Estimate two personnel per TEU.

3. Responsibilities include the following:
  a) Perform preliminary assessment of and treat all foreseeable medical conditions
    1) External wounds and bodily injuries (including head, neck, and spine)
    2) Chemical intoxications, poisonings, and exposure to hazardous material
    3) Respiratory, cardiovascular, and gastrointestinal conditions
    4) General illnesses
    5) Infections
    6) Eye, ear, nose, and throat problems
    7) Dental emergencies
  b) Prescribe and dispense medications
  c) Dress and redress patients
  d) Monitor vital signs
  e) Determine when MEDEVAC support is necessary for critical conditions
  f) Enter patient data into a computerized information system
  g) Sterilize instruments and other materials
  h) Inventory all medical equipment and supplies
  i) Collect biomedical waste for removal
  j) Prepare examining beds

4. Extensive first aid training and medical experience is required.

5. All personnel will wear Personal Protective Gear when examining and treating CBRN contaminated patients.

C. Layout

1. The First Aid Module will consist of two 40-foot TEU containers welded together lengthwise for maximum space utility.

2. The TEU will include the following sections:

---

[256] http://buperscd.technology.navy.mil/bup_updt/508/OccStandards/CHAPTER%2040.htm
[257] http://www.bls.gov/oco/ocos083.htm

a) One small waiting/intake area
b) One personnel office
c) One large medicine closet to hold all supplies[258]
    1) Hospital garments for patients
    2) Scrubs, gloves, and surgical face masks
    3) Diagnostic instruments
    4) Gauze, bandages, and other rehabilitation aids
    5) Sterilization equipment
    6) Medications
d) Two separate consultation rooms each with one examining bed and additional storage cabinets

3. Both examining rooms will have access to water and drainage for use when decontaminating patients exposed to hazardous material.[259]

4. The entire TEU will be well-lit and well-ventilated.
    a) A generator will supply electricity for all lighting as well as for running all electric medical instruments and machines.

5. Climate control will regulate the TEU temperature for patient safety and comfort.

D. Environmental Considerations

1. Due to restocking limitations resulting from the maritime location of operation, the First Aid Module must be fully equipped to handle multiple cases of all foreseeable medical conditions.

2. Safety precautions such as non-slip floors and safety rails along the sides of examining beds will protect against injury during rough seas.

3. The medical supply closet and medical cabinets inside the examining rooms will have secured containers for supplies as well as safety locks on doors to protect against spilling.

4. The First Aid Module has the capability of decontaminating patients exposed to hazardous material in order to continue their treatment without threatening the stability of the TEU.

E. Operations Center

1. Computers will allow personnel from the First Aid Module to communicate at all times with the onshore Operations Center.
    a) Up-to-date information on patients' conditions can be accessed by the OC personnel through the computerized information system.

2. Medevac operations will be coordinated by the bridge, which will link the First Aid Module personnel to the medevac and onshore hospital personnel.

F. Agency Partnerships

1. Disaster Medical Assistance Teams[260]

---

[258] http://www.anandmedical.com/default.htm
[259] http://www.bt.cdc.gov/planning/personalcleaningfacts.asp
[260] http://ndms.dhhs.gov/teams/dmat.html

a) A Disaster Medical Assistance Team (DMAT) is a group of professional medical personnel working under the U.S. Department of Health and Human Services.
b) With experience in rapid-response to disasters and other events, DMATs can assist the First Aid Module personnel in handling emergency situations.

2. American Red Cross[261]

a) Although not an official government agency, the American Red Cross coordinates with federal committees and provides services to the U.S. military.
b) With extensive experience in disaster relief and first aid, workers from the American Red Cross can instruct medical personnel on how to best provide health services while facing environmental constraints and limited resources.

G. Similar Projects

1. Normesca AS[262]

a) As a leading supplier of rapid response solutions for medical emergencies and disasters, Normesca AS has produced a range of mobile clinics and hospitals using tents, trailers, and containers.
b) The Container Hospital and other first aid modules demonstrate how to best configure the First Aid Module in preparation for both emergency and non-emergency medical situations.

2. Uniteam[263]

a) Uniteam's Mobile Hospital Units are ideal models for what medical equipment to include in the First Aid Module.

3. Vekkla[264]

a) Vekkla specializes in producing mobile expandable buildings constructed out of TEU containers.
b) The first aid containerized modules are specially constructed to be fully-transportable medical units requiring very little setup time.

---

[261] http://www.redcross.org/services/disaster/0,1082,0_319_,00.html
[262] http://www.normeca.no/normeca/index.htm
[263] http://www.uniteam.org/shelter/mobilemedicalhospital.html
[264] http://www.vekkla.com/Vekklacontainersystem.pdf

Specifications for Airlock Module

A. Overview

This will be a purely functional module, dedicated to providing a space where personnel can safely move from the contaminated ship/environment to the network of TEUs without bringing contamination with them.

This module will be required for any personnel who may have been exposed to contaminants. Within the 'airlock', they can shed any HAZMAT gear that they have been wearing, and it will be safely collected for decontamination separately. The module will also contain shower systems so that personnel can completely clean themselves before returning to the TEU network.

The module will require access to water and power, have independent environmental controls and venting systems, and be carefully sealed and insulated against the outside environment. Due to the wide range of possible contaminants, it is particularly important that this module be configurable to respond to any situation.[265]

B. Personnel

No permanent personnel will need to be stationed in this module.

C. Equipment

1. Decontaminants
    a) Working in tandem with the General Laboratory Modules, Airlock Modules will be supplied with skin decontaminants appropriate to the environment that personnel will have been working in.[266] Due to the variability in CBRN contaminants, the interior of the module will simply be lined with an inert material, with minimal environmental and comfort modifications.[267]
    b) This module will also contain showers and appropriate clean clothing for personnel use.
2. Contaminated Materials Storage
    a) The module will be able to safely get and store contaminated materials, including HAZMAT suits and any CBRN detecting and/or decontaminating equipment personnel may have with them.
3. Testing Equipment
    a) After Personnel have shed contaminated clothes and equipment and cleaned up, they will be tested with handheld equipment for the presence of contaminants.[268]

---

[265] http://www.publichealth.thpct.nhs.uk/websiteadmin/uploads/S2d%20Response%20CBRN.pdf
[266] http://www.ecbc.army.mil/ps/download/ECBC_m291.pdf
[267] https://atiam.train.army.mil/soldierPortal/atia/adlsc/view/public/22662-1/FM/3-11.5/chap9.htm
[268]https://portal.navfac.navy.mil/portal/page?_pageid=181,4723547,181_4723553&_dad=portal&_schema=PORTAL

D. Environmental Considerations

1. Taking into account the level of contaminants that may be in this module, and its proximity to living and working spaces, Airlock Modules will have an independent venting system, electrical backup, and environmental controls. A system of anterooms should ensure that personnel do not carry decontamination with them into the main network of modules.
2. Airlock Modules will be carefully sealed against the outside environment, and will have minimal changes made to the interior, taking advantage of the security of the TEU model. The Modules will be lined with an inert material that can easily be decontaminated if necessary.
3. Any storage in this module will have the ability to be both securely fastened down and easily moved to another module for decontamination.

E. Agency Partnerships

There is no need for liaisons with other agencies.

F. Operations Center

This module will not need to communicate with the Operations Center.

G. Similar Projects

1. Personal Decontamination Kits
   a) Multiple commercial personal decontamination kits exist, to be used in tandem with decontamination showers. These include a bagging system for personal effects, towels and other cleansing apparatus, and clean clothes to change into. They are generally targeted at civilian populations.[269]
2. Decontamination Showers
   a) Similar to the kits discussed above, there are many commercially available shower systems dedicated to decontaminating personnel.[270]

[269] http://www.nor-e.com/IDecon.htm, http://www.homelandsecurityequipment.com/HomelandSecurityApproved%20EquipmentList.htm#8, http://www.allhandsfire.com/Merchant2/merchant.mvc?store_code=AHF&screen=PROD&product_code=SS-PPDK

[270] http://www.ppsgb.com/pages/products/decontamination_showers.htm, http://www.cbrneworld.com/capability_mavatech.html

Specifications for Corridor Module

A. Overview

This is a purely architectural module that will be used to connect the office, laboratory and living quarter modules safely. With the use of corridor modules, there should be no need for personnel to be on the deck of the ship unless they are in HAZMAT gear. Corridors will act not only to connect personnel, but also as conduits for infrastructural necessities, such as electrical wiring, pipes, and telecommunications.

There should be a variety of corridor modules, with easily-configured doors, in standard 20’ and extended 40’ lengths. Corridors should be insulated and sealed at the doorways to protect from possible airborne contaminants. For additional stability, they should be welded to the surface of the ship.

Corridors will be set up when the TEU ‘village’ is assembled according to a pre-planned map. Assembly work will primarily be done by longshoremen.

Specifications for Power Generator TEU

A. Overview

This TEU will consist solely of a standard electrical power generator[271]. Maintenance personnel will be onboard, but their primary station will be in an office module.

B. Personnel

1. There will be three Seabees, trained at the Prime Power School, to set up and maintain the generator(s)[272].

C. Equipment

1. Equipment will consist solely of one or more DOD Standard mobile electric power (MEP) generators.[273]

2. At time of writing, it appears that the military does not have a generator that is specifically TEU-sized[274]. In order to retain customizability, and add protection and stability to the existing generators, it is envisioned that one or more standard large generators (such as the legacy system MEP-012A[275]) might get packaged into a TEU.

D. Environmental Considerations

1. MEPs, as a result of being designed to spec by the DOD, are equipped to handle less-than-ideal environments.[276]

2. The packaging in the TEU should add an extra level of protection again possible CBRN elements in the atmosphere.

E. Agency Partnerships

1. 249th Engineer Battalion
    - a) This battalion, along with the Prime Power School offers training in maintaining electrical systems, specifically MEPs.
    - b) "The course last approximately 29 weeks and provides students with the necessary knowledge and skills to install, operate, and maintain medium voltage electrical power plants."
    - c) "The year long Prime Power Production Specialist Training Course trains Active and Reserve Army soldiers and Navy Seabees. Upon graduation, Army personnel are awarded **MOS 21P20** and **Navy** personnel awarded **NEC 5633**."[277]

2. Mobile Utilities Support Equipment (MUSE)

---

[271] http://www.globalsecurity.org/military/systems/ground/mep.htm
[272] http://pps.belvoir.army.mil/
[273] http://www.pm-mep.army.mil/
[274] Some generators are roughly TEU-sized, such as the MEP-PU-810A, which comes in at 21'x8'x8.5'. http://www.pm-mep.army.mil/technicaldata/dpgds.htm
[275] http://www.pm-mep.army.mil/technicaldata/750kw.htm
[276] http://www.globalsecurity.org/military/systems/ground/mep.htm
[277] http://249en.belvoir.army.mil/pps/ppsover.htm

a) MUSE primarily works with the US Navy and US Marine Corps to supply and maintain generators.[278]

F. Operations Center

No interaction with the Operations Center is expected to be needed.

[278] https://portal.navfac.navy.mil/portal/page?_pageid=181,3968553,181_3968596&_dad=portal&_schema=PORTAL

Specifications for Sewage Treatment Module

A. Overview

This module will handle sewage (or black water) treatment and storage while the platform/transport vessel is at sea.

B. Personnel

1. Three Seabees will be assigned to this module to set up and maintain the units that will be used on the mission. The number of units will be adjusted to cover the changing numbers of personnel on each mission.
2. Seabees should have received training in the maintenance of black and gray water treatment systems, as well as working in a contaminated environment.

C. Equipment

1. To protect the environment around the ship, the treatment system should be closed-loop, with no effluent discharged at any point. This is semi-standard in Naval gray water and black water treatment methods, as Navy shipboard wastewater may be more concentrated with contaminants than commercial wastewater.[279]
2. The treatment system, ideally, would fit into a standard TEU, or otherwise be able to easily integrate with the other containers, size-wise. Such modular treatment options have been developed already, for use in treating on-ship hazardous wastes as well as gray- and black water.[280]

D. Environmental Considerations

1. Modules will be fastened firmly to the deck, and not moved for the duration of the mission to ensure stability.
2. Wherever possible, modules should be contained within TEUs that have been specially prepared to protect the equipment from contaminants in the environment.
3. Otherwise, standard maritime precautions should be taken to protect against damage caused by water, high winds, or high seas.

E. Agency Partnerships

1. No agency partnerships should be necessary.

F. Operations Center

1. No input from the Operations Center should be necessary.

G. Similar Projects

1. Smith & Loveless FAST Systems[281]

---

[279] http://www.navysbir.com/n07_3/n073-207.htm
[280] http://stinet.dtic.mil/oai/oai?&verb=getRecord&metadataPrefix=html&identifier=ADA371422
[281] http://www.marinefast.com/

a) The FAST (Fixed Activated Sludge Treatment) biological treatment systems are lightweight, modular treatment systems developed for a wide range of ships, from small commercial vessels to ore carriers. S&L also has capabilities to convert already-existing Navy Containment Holding Tanks to the FAST system.

b) The FAST system is in use in Canadian maritime coastal defense vessels (MCDV), and has been tested on the HMCS *Moncton* for potential use onboard USN vessels.[282]

2. Aqua-Sans

a) Chrysler Space Division has developed a no-discharge, nonbiological sewage disposal system that uses mineral oil as the flush fluid. Waste is separated from the mineral oil by gravity in holding tanks, allowing the fluid to be reused, and the waste to be carried to an incinerator or other disposal facility.[283]

3. Navy SBIR

a) The Navy is currently developing a modular system specifically for handling the disposal of wastewater in Littoral Combat Ships. This system is envisioned as a supplement to existing disposal systems.[284]

[282] http://www.dt.navy.mil/wavelengths/archives/000068.html
[283] http://ntlsearch.bts.gov/tris/record/tris/00095344.html
[284] http://www.navysbir.com/n07_3/n073-207.htm

Specifications for Waste Removal Module

A. Overview

As the final component in the maritime decontamination process, the Waste Removal Module provides leak proof containment for all waste material remaining after decontamination. The TEU will safely transport a wide variety of hazardous waste material from the initial site of contamination to the home seaport for further processing. The comprehensive design of this module focuses on the need for security and versatility during the end phase of response to a CBRN incident.

B. Layout and Utilities

1. The TEU will be divided into two sections, with the front half designated for liquid hazardous waste and the back half for dry hazardous waste.
2. All areas must be well-lit and well-ventilated for the safety of personnel.
3. An integrated climate control system will monitor the temperature and humidity of the TEU interior.[285]
4. A sprinkler system installed into the ceiling will provide a means of fire suppression.[286]

C. Storage Capabilities

1. Fifty-five gallon closehead drums will contain all liquid waste.[287]
    a) The inside of the drums must be lined with a material that does not react with any chemical or biological agents.[288]
    b) The drums must safely hold and transfer a range of liquid waste.[289]
        1) Process wastes
        2) Lab chemicals
        3) Acids
        4) Solvents
        5) Polychlorinated biphenyls (PCBs)
        6) Flammables and combustibles
    c) Drums are lightweight and can be easily rolled on and off the TEU using a hand dolly.
2. Type A containers certified to transport radioactive materials will contain all nuclear waste.[290]
3. Permanent drum cabinets installed along the inside TEU walls will house the fifty-five gallon drums and Type A containers.[291]

---

[285] http://www.uniteamcontainer.com/container/wellheadelectricalinstallationbuilding.html
[286] http://www.crossfiretrade.com/controll.php?/customcontainers/viewui
[287] http://www.dixiepolydrum.com/drumscontainers.html
[288] http://www.uwgb.edu/BusFin/SafetyRisk/Policy/hazardous_waste/hazardouswastedisposal.htm#10
[289] http://www.newarkcarting.com/hazardous_wate.htm#TRANSPORTATION
[290] http://www.nrc.gov/reading-rm/basic-ref/teachers/11.pdf
[291] http://www.securallbuildings.com/hazardous_waste.asp

a) The front section of the TEU can hold eight cabinets each containing two drums and four Type A containers.

4. The back section of the TEU will house a permanent industrial skip capable of holding twelve cubic yards of dry hazardous waste.[292]
    a) A rolling dolly can be used to transport material to and from the dry waste skip.

D. Packing and Transport
1. Polyethylene containers will be used to transfer all liquid waste from the decontamination area to the fifty-five gallon drums.[293]
    a) Rather than pouring the waste into the drum, the filled polyethylene containers are placed inside the drum for ultimate protection.
    b) All open space is filled with an absorbent material such as vermiculite to contain accidental spills.
2. Multiple agents must be kept separate at all times to avoid reactions.
3. A computerized labeling/tracking system will create an inventory of the contents in each container.[294]
    a) The following information will be entered into the system upon packing:
        1) Type of waste contained
        2) Amount and concentration of waste
        3) Area of the contaminated vessel waste originates from
        4) Special considerations (flammable, reactant, etc.)
    b) A label with all the abovementioned information will be printed and applied to the container and drum cabinet.
    c) Each label will include a barcode that can be scanned for tracking purposes using a handheld reader.
4. Upon arrival in port, all hazardous material will be subject to recycling, incineration, sewering/water treatment, chemical landfill and/or other method of disposal.[295]
5. The interior of the TEU and all containers will undergo decontamination upon return to home port, allowing for rapid redeployment and reuse.

E. Environmental Considerations
1. Waste material will be protected from harsh maritime and weather conditions by the durable, watertight TEU exterior.
2. To prevent tipping, the dry waste skip/dumpster and all drum cabinets will be bolted to the TEU floor.
3. In the event of fire, the internal sprinkler system will automatically activate to suppress flames.

F. Personnel

[292] http://www.skipawayltd.co.uk/skipaway-skip-hire.htm
[293] http://palimpsest.stanford.edu/waac/wn/wn06/wn06-2/wn06-205.html
[294] http://www.pollutioncontrol.com/services/haz/hazwaste.html
[295] http://chemcare.univarusa.com/

1. Damage Controlmen Third Class (DC3) Navy rating[296]
    a) Civilian equivalent of this position is an Environmental Health and Safety Technician.
2. Responsibilities
    a) Securely pack all waste material
    b) Load and unload waste containers from TEU
    c) Enter all waste information into the computerized labeling/tracking system
    d) Inspect all containers during transport
3. Before deployment, training on proper packaging and handling of all waste material will be issued.
4. Knowledge of hazardous material properties is recommended.
5. All necessary Personal Protective Gear will be worn at all times as instructed by the Operations Center.
6. Estimate two personnel per TEU.
7. Additional personnel will be available upon arrival in port to oversee land transportation and final treatment/disposal of all waste material.

G. Operations Center
1. Experts in the onshore Operations Center will gain information on the waste material through the computerized labeling/tracking system.
2. Personnel from the Waste Removal Module will gain further instruction and guidance on handling waste material from the Operations Center.
3. The Operations Center will be responsible for preparing onshore personnel for the arrival of the waste material.

H. Agency Partnerships
1. PHMSA Office of Hazardous Materials Safety[297]
    a) Transportation Regulations Specialists are knowledgeable of all DOT regulations and can advise decontamination personnel on the proper containerization and transportation of hazardous material.
2. Environmental Protection Agency[298]
    a) Hazardous waste experts from the EPA can oversee the proper storage and handling of all hazardous waste in compliance with their official standards.
3. U.S. Department of Energy[299]
    a) Officials from the Office of Civilian Radioactive Waste Management can assist in the packing and transportation of nuclear material.

I. Similar Projects
1. Environmental Compliance Products[300]

---

[296] http://buperscd.technology.navy.mil/bup_updt/508/OccStandards/CHAPTER%2021.htm
[297] http://hazmat.dot.gov/
[298] http://www.epa.gov/epaoswer/osw/tsds.htm
[299] http://www.ocrwm.doe.gov/transport/index.shtml
[300] http://www.hazardous-material-storage-buildings.com/models.htm

a) ECP has designed and built multiple versions of a standalone modular storage building to house hazardous waste.
b) The facilities produced by ECP provide examples of the best storage configurations.

2. Uniteam International AS[301]
    a) Norway's Uniteam constructs small-scale containers for hazardous waste.
    b) The specially designed flooring, ventilation system, and other features of these containers serve as ideal models for the operational aspect of the Waste Removal Module.

[301] http://www.uniteam.org/shelter/hazardousprotection.html

Specifications for Water Purification Module

A. Overview

This module will consist of a dedicated water purification system, able to turn seawater that may have been contaminated into potable water. The water filtration system, storage, and delivery method will all be contained in a standard TEU, allowing multiple configurations as well as customizability for the specific number of personnel that will need potable water. The TEUs design will address the unique issues inherent in being self-contained, and in a hazardous situation, whether that is as a result of a CBRN incident or the issues inherent in being on a ship.

B. Personnel

1. Three Seabees will be assigned to this module to set up and maintain the water purification units that will be used on the mission. Number of units will be adjusted to cover the changing numbers of personnel on each mission.
2. Seabees should have received training in the maintenance of water purification systems, as well as working in a contaminated environment.

C. Equipment

Contained within this TEU will be:

1. Seawater intake
2. Purification system
    a) Reverse osmosis has been shown to be able to process seawater, as well as water contaminated with NBC agents, and make it potable[302]
3. Power source -- ideally this will be a generator contained within the TEU and separate from the power source for the rest of the TEUs.
4. Storage
    a) TEU will be able to safely store water as needed in inert containers contained within the TEU so as to prevent possible CBRN contact.[303]
5. This TEU will be completely self-contained and require minimum power, operation and maintenance costs, and have a rapid production rate, supplying water for drinking, cooking and cleaning to personnel and laboratory modules.
    a) Modular water purification systems already exist that require only a 60 KW generator to produce 250,000 gallons of water in 3 days, within a TEU-sized module.[304]

D. Environmental Considerations

1. The module will remain independent of both the ship's systems and the power system for the other TEUs, ensuring a dedicated power system.

---

302 http://enr.construction.com/sp_Projects/green/archives/050815b.asp

303 http://www.lexdon.com/article/SFAs_Defense_Product_Division_Receives/553.html

304 http://enr.construction.com/sp_Projects/green/archives/050815b.asp

2. Using existing Naval technology, this TEU should be able to operate despite environmental issues in a marine setting.[305]

E. Agency Partnerships

1. Naval Facilities Engineering Command (NAVFAC)[306]

a) NAVFAC offers testing, consulting, and evaluating services concerning water purification systems. They are particularly interested in reverse-osmosis methods, and have historically worked with the Navy before, particularly in training Seabees with TACOM (U.S. Army Tank-Automotive and Armaments Command).

2. EPA[307]

a) The EPA is tasked with tracking and evaluating the safety of the environment, with a particular emphasis on safe water resources. Their research and testing facilities can help the Navy create a faster, more efficient and safer water purification system.

F. Operations Center

1. This module should not need to interact with the Operations Center.

G. Similar Projects

1. Expeditionary Unit Water Purifier (EUWP)[308]

a) EUWP, designed by Village Marine Tec, is a large-scale water purifier, capable of handling 100,000 gallons of water per day. It is able to purify water from almost any source, including water with NBC contaminants. The EUWP is the size of two standard TEUs, and thus would be configurable with the TEU system. EUWP uses reverse osmosis to purify seawater, and has been used in both military and civilian situations where potable water is unavailable through usual means.[309]

2. Alion

a) Alion Science and Technology was recently awarded a contract with Naval Surface Warfare Center, Carderock Division – Philadelphia to design and fabricate a high-capacity, high-purity water purification unit.[310] Alion has a history of working closely with the Defense Department to develop technologies to aid in homeland defense.[311]

3. SFA-DPD[312]

a) Tactical Water Purification Systems

1) "The TWPS incorporates advanced micro-filtration technology to filter out silt and biological materials including disease-causing

---

305 https://portal.navfac.navy.mil/portal/page?_pageid=181,3997941&_dad=portal&_schema=PORTAL
306 https://portal.navfac.navy.mil/portal/page?_pageid=181,3997941&_dad=portal&_schema=PORTAL
307 http://www.epa.gov/epahome/aboutepa.htm
308 http://www.villagemarine.com/euwp.html
309 http://www.usbr.gov/pmts/water/research/EUWPkatrina.html
310 http://www.encyclopedia.com/doc/1G1-143715214.html
311 http://www.alionscience.com/index.cfm
312 http://www.sfa.com/DPD/dpd-products-twps.htm

microorganisms such as Cryptosporidium. It also includes advanced, high salt rejection, reverse osmosis technology to produce drinking water from the extremely salty seawater sources in the Middle East."

Specifications for Storage Module - Uncontaminated

A. Overview

This module will store objects during transport and throughout the decontamination ops. Unlike its sister module, this module is specifically dedicated to objects and materials that are uncontaminated and should not come into any contact with contaminated personnel or things.

The module, which will not need to be staffed, will be arranged with a series of shelves, each of which will contain securable bins that can easily be labeled. No water hookups are necessary, although the TEU will be converted slightly to better seal against the environment, and include lighting and environmental controls.

Specifications for Storage Module - Contaminated

A. Overview

This module is dedicated to storing objects during transport and decontamination, and is a sister module to Storage Module – Uncontaminated. This module will specifically store materials that are or may have become contaminated, as well as safely storing samples collected from the contaminated ship if necessary.

Although structurally this TEU will be similar to the other storage modules, with environmental, lighting and external adjustments, it will also contain sealable bins in which contaminated objects can safely be stored, and personnel may be able to enter and leave without coming into contact with previously-stored objects. Additionally, due to the sensitive nature of the contents, more rigorous security to access this module will be required.

Appendix 5: Economic Development Document

US Navy CBRN Emergency Response: An Opportunity for economic and industry development

Introduction: Currently the United States Navy (USN) is the only military service without a dedicated ability to respond to a CBRN event. Under contract with the DOD Office of Naval Research (ONR), we are working to propose a way to create an emergency response CBRN capability via a phased response system, specialized R&D, and small scale highly specialized manufacturing. The specialized R&D and manufacturing components of this project require a confluence of location and knowledge clusters which the Philadelphia area, and particularly the navy yard provides.

This document will lay out the context for our work with the Navy and the proposed phased emergency response system. Additionally the document briefly describes the functions and scope of the needed support activities including the pivotal role of the Philadelphia Center for research and manufacturing. Finally the paper suggests several other business opportunities that exist for the research and manufacturing cluster proposed.

Context and Scope: The increased operational tempo and changing mission profile driven by the Global War on Terror (GWOT) leaves the Navy, traditionally protected from CBRN risks by operating in deep, blue ocean, likely to see a rise in CBRN accidents and attacks. The Navy's changing mission profile, as it operates more and more in brown (rivers) and green (close to shore) waters, leaves the fleet more exposed to terrorists and asymmetrical attack. Currently if a Navy vessel were affected by a CBRN attack or accident the Navy would need to bring the affected vessel into port or sink it at sea.

Need: The ability to conduct consequence management/mitigation and rescue and restore operations as needed on both USN vessels and other vessels of national interest at sea to avoid the need to bring contaminated cargo/vessel into a port facility and if possible to restore Navy Vessels to active service as quickly as safe/possible.

Proposal: CBRN events have broadly similar patterns of divisible phases. In most cases the incident is sudden: caused by a fire, an explosion, a rapid change in pressure, an attack, a rupture. This acute phase must be successfully managed to limit the loss of life and human injury, to keep the ship afloat and as functional as possible, and to contain the incident initially. The second phase brings outside resources to the incident to begin containment, protection, and treatment. These resources (equipment and personnel) are logistically or cost prohibitive to have on each vessel as organic capability. The third phase involves more substantial, longer term efforts utilizing specialized equipment and personnel who must be able to conduct intensive clean up procedures while limiting risk and exposure to other ships and people, minimizing disruption, and culminating in the return of the ship(s) to active duty.

1. Phased emergency response concept

Timeline	Response	Activities
Prior to CBRN event	**Pre-event preparations**	
		• Entry level PPE and survival skills training for all Navy personnel • Entry level CBR-D training that includes basic chemical, biological, and radiological defense (CBR-D) training as outlined in the USN Basic Military Requirements for all Navy personnel • DC "A" School for all Navy Damage Controlmen, including the CBR-D element, followed by further on-the-job training • Periodic CBRN Unit Defense training for all Navy personnel • Pre-deployment CBRN Unit training exercises for all deployable units • Ship-wide DC readiness training onboard Navy vessels with a segment set aside for CBRN training • Training for Navy DC personnel at Army's Chemical School as outlined for Army CBRN specialists, with courses altered to be geared specifically toward Navy CBRN training • Apply Air Force's system of requiring additional training for personnel going to high-, medium-, and low-level threat deployment areas • CBRN defense needs should be taken into consideration during vessel design and purchasing procedures Training and Exercise Program Executed leveraging NORTHCOM Joint Exercise Program, to include table-top and/or command post exercises, ship breakout simulation exercise aboard JHSV
Within 12 hours of CBRN event	**Phase I: Local Response**	
<1 hour after CBRN event		• Contamination event identified by DC personnel • General & chemical alarms sounded by officer of the deck
<3 hours		• Designated onboard CBRN team (DC personnel) to evaluate extent & severity of incident • Commanding Officer notified of event
3-5 hours		• Ship's medical officers prepare for primary care for unit casualties • Mission oriented protection posture (MOPP) determined and implemented
4-7 hours		• Defense plan implemented • Proposed decontamination sites designated • CBRN detectors activated

		• The ship's Collective Protection System (CPS) used to seal off areas necessary to operation of ship that are uncontaminated
		• Use of PPE to re-enter contaminated part of ship
<12 hours		• Countermeasures washdown (CMWD) system used where possible
		• Triage and evacuation as needed
		• After preliminary stabilization complete, crew to respond in established manner for type of CBRN decontamination, if known (N,B,or C outlined in report)
		• Reports of ship's condition and any decontamination actions already taken are prepared in preparation for Phase II arrival
12-48 hours after CBRN event	**Phase II: Emergency & Expert Response**	
12-48 hours after event	Spiral Alpha: Airborne Element	• Arrival of airborne element formal evaluation team at site of incident
<1 hour after arrival		• Situation gauged by evaluation team, including shipbuilding engineers & scientific advisory group
		• Testing for CBRN contaminants
2-3 hours after arrival		• First external response unit onboard providing CBRN expertise in detection, decontamination and protection
		• Secure the vessel
4-6 hours after arrival		• Decontaminate personnel
		• Establish an Operations Chain of Command
		• Preliminary decontamination operations
48 hours to 2 weeks after CBRN event	Spiral Bravo: Fast Response Element	• Arrival of Fast Response Vessel containing C4I/IO (command, control, communications, computers, and intelligence/information office)
Upon arrival		• New Commanding Officer tasked with overseeing decontamination will take over
1-2 hours after arrival		• Fast Response Vessel to tie off to contaminated vessel
2-4 hours after arrival		• Full scale personnel decontamination and ability to provide interim life support pending medevac
		• Secure the vessel
		• Decontaminate personnel
		• Establish an Operations Chain of Command
		• Preliminary decontamination operations
Up to 3 weeks after arrival		• Containment of CBRN material and recovery and restoration conducted by USMC CBIRF including Recon, Decon, Medical, Security, Service Support
		• Commanding Officer evaluates the need for Phase III operations; if deemed necessary, the ship will be prepared for full-scale decontamination
		• Situation reports prepared for Phase III personnel
Areas shaded in gray take place simultaneously across Phase IIA and		

Phase IIB		
No later than 3 weeks after CBRN event	**Phase III: Thorough Decontamination Response**	
Arrival no later than 3 weeks after event		• Modular self-sustaining decontamination vessel arrives with relevant TEU modules onboard for decontamination based on situation reports from Phase II
Upon arrival		• All Phase II operations move to the Phase III vessel with all personnel reporting to the scene Commander
1-2 hours after arrival		• Decontamination vessel uses sensors and robotics to conduct a scan of the affected area(s) • Dedicated clean area onboard vessel is allocated to handle personnel and equipment as the platform/transport vessel operations are conducted
3-5 hours after arrival		• Commanding Officer selects the most appropriate of five possible delivery options, based on the size and condition of the ship, and the necessity of returning it to immediate active duty
	Option IIIA: In-Transit Variant Wet	• Necessary decontamination equipment is airlifted to the site • Decontamination vehicle will be sustained by pre-po vessel and security comport with USN TTP • Watertight envelope is maintained and vessel is capable of powering itself • Basic containment to mid-level decontamination occurs in-transit, with the result that the ship is clean enough to be accepted at port for entry
	Option IIIB: In-Transit Variant Dry	• Necessary decontamination equipment is airlifted to the site • Decontamination vehicle will be sustained by pre-po vessel and security comport with USN TTP • Vessel is deemed incapable of powering itself and is transported using heavy lift ship • Mid-level to complex decontamination occurs in-transit, with the result that the ship is clean enough to be accepted at port for entry
	Option IIIC: At Sea Full-Scale Decon Variant	• Equipment is sealifted using a decon vessel contingent capable of organic sustainment for up to 21 days • High-level decontamination takes place at-sea, with the result that the pre-po vessel is at minimal safety risk and fully capable of sustaining direct action
	Option IIID: At Sea Large-Scale Decon Variant	• Equipment is sealifted using a decon vessel contingent capable of organic sustainment for up to 21 days • If possible, large-scale complex decontamination may take place at sea with the result that the vessel is capable of supporting direct action • If the size of the vessel or level of damage is prohibitive, the ship is returned to port for refit

Option IIIE: Rapid Release Variant	• Occurs during war-time emergencies • Equipment is delivered via sealift with additional assets transported as needed • Decontamination vehicle externally supplied by pre-po vessel and other availables • Large-scale decontamination occurs at-sea, leaving the vessel as clean as possible within current tactical/strategic constraints • Vessel is returned to fleet at reduced capabilities for limited action

2. Operations center

Waterborne CBRN incident 911 call center, a 24/7, 365, uniformed officer staffed, with/reach-back to other relevant organizations such as EPA, CDC, etc. and also close working relationship with the engineering/R&D facility (the Philadelphia center for now)

3. Engineering, production maintenance research facility

Working in tandem with the Operations Center will be a manufacturing and research center located at the PNSY. While the Operations Center will monitor external affairs and function as a reach-back center, the Manufacturing and Research Center will specialize in the physical components of the decontamination method, ultimately designing and then creating and stocking state-of-the-art laboratories, communications facilities, living spaces and other TEU-based elements to be used during operations.

In the early phase of production, this Center will take the conceptual work already completed and design and prototype the TEUs and any new technology that will be used in them. As the project transitions to a program, the Philadelphia center will be responsible for high-end, low volume manufacturing of TEUs. While the primary focus of production will be TEUs for decontamination operations, a variety of laboratories, offices and living spaces will be created, and some could have roles and purposes beyond the scope of this project.

The Philadelphia Center, over time becomes the maintenance and repair hub for TEUs, most of which are sent to prepositioned locations around the globe. In tandem with designing and producing TEUs, the Center will feature a research branch dedicated to technological and pharmacological research, building on industries already heavily present in the Philadelphia area and allowing them expansion. Bringing new industry to the area, this research branch will also concentrate on innovations in decontamination methods, materials and technology. In its final state, the Philadelphia Center will be a manufacturing and research hub, able to serve both DOD and civilian needs, while supplying fully-stocked TEUs to nodes around the globe.

Working with Building 100 Innovation Center and PIDC, the Navy can create a series of custom research projects based on feedback from the field and known gaps in current capabilities. Due to the variety of situations these TEUs will be placed in, broad experience and research will be possible, as well as more targeted projects allowing a unique mixture of development and manufacturing.

The eventual goal is a small (100-200) person multiform/multi-sector cluster of companies that will work in tandem on CBRN consequence management research and development. The outcome will be a growing industry in a high tech/high skill environment. This method of remediation, with particular focus on at-sea environments, could develop into a method by which the Navy moves more expeditiously through deactivated fleet recycling.

Staffing for the Philadelphia Manufacturing and Research Center is envisioned to run along lines of 12-15 total uniformed Navy personnel, working in tandem with similar numbers of civilian DOD employees. The rest of the employees will be contractors and related firms that cluster in the area, attracted by the contracts, contacts, incentives and the informal knowledge networks that will spring up around this state-of-the-art center.

Local Benefits: The project would create 100-200 high tech, high skill jobs and create a cluster of companies and projects focused on consequence management, high end property recovery/salvage, and environmental remediation. In addition to the emergency decontamination issue, which is the purview of this project, the aspect of the phased response system could easily be used for other environmental remediation efforts including superfund sites, decommissioned navy vessels and brownfield locations among others.

Appendix 6: Current PNSY Activities

THE NAVY YARD BUSINESSES	# of Employees	Description	NACIS Code
Aker Philadelphia Shipyard, Inc.	1300 most work in Philly	Constructs world-class quality ships and owns vessels for bare boat charter	
AMSEC	29	A full service supplier to the Navy and commercial maritime industry, providing naval architecture and marine engineering, naval ship systems assessments, maintenance engineering, acquisition program development, shipyard industrial engineering, and complete logistics services from technical manual development to provisioning documents, to spare parts management and training	541712-R&D in the Physical, Engineering, and Life Science
Anthropologie	105	Clothing, jewelry, and objects for home	448120-Women's Clothing
AppTec Laboratory Services	45	Laboratory testing services for the following industries: Biotech/Biopharm Industries; Chemical Germicide Industry [Product efficacy testing for disinfectants and other products]; Medical Device Industry Biocompatibility [genotoxicology; sterilization, reuse and viral/process validations; quality assurance support, full-service microbiology, and package testing to help manufacturers meet regulatory requirements]	621511-Medical Laboratories
Barthco International, Inc.	250	Provides global logistics and freight forwarding services; arranges air and ocean transportation of its customers' cargo through a network of independent carriers; specializes in working with biotech companies and in handling shipments of fine art, valuables, and live animals; provides customs brokerage and warehousing and distribution services; manages over 700,000 shipments a year	488510-Freight Transportation Arrangement
Collegiate Consortium for Workforce and Economic Development	5	A non-profit organization that is a partnership of Drexel University and five area community colleges / provides a comprehensive, coordinated approach to developing a highly skilled workforce for the region	
Canadian Pacific Railway		Rail freight service	482111 (Scranton Branch)
Changing World Technologies	25	Identifies emerging technologies that specifically address the needs and problems in the energy and environmental arenas; revolutionizing renewable energy by changing the way in which organic waste materials are utilized, thereby providing a platform for sustainable development	32519 (Hempstead, NY)-Other Basic Organic Chemical Manufacturing

Chapel of the Four Chaplains		A chapel that was dedicated on February 3, 1951 by President Harry S. Truman to honor four Army chaplains (soldiers) of different faiths who were killed in action when the USAT Dorchester was hit by a torpedo and sank on February 3, 1943. They helped other soldiers board lifeboats and gave up their life jackets when the supply ran out.	
Connolly Consulting		Recovery auditor and consultant.	
Cushman and Wakefield of PA, Inc.	75	Real Estate Agent/Manager	
Del-San Environmental, Inc.	2	Trade contractor	562910- Remediation Services
DiNic's of Snyder Ave., Inc.		Bar, tavern	
Duke Energy Generation		Leading developer, owner and operator of power generation solutions; utilizing natural gas and various solid fuels, and currently manages over 5,000 megawatts of power generation / Their focus is to improve your profitability by reducing your energy costs, while increasing reliability and reducing environmental impact.	
EDO Corporation		Designs and manufactures a diverse range of products for defense, intelligence, and commercial markets, and provides related engineering and professional services / EDO's advanced systems are at the core of the transformation to lighter, faster, and smarter defense capabilities.	334511 (New York, NY)
EG&G	13,000 (in 2005)	Provides program management, systems engineering and technical assistance, and operations and maintenance services to a variety of federal agencies, primarily the Departments of Defense and Homeland Security	561210 (Gaithersburg, MD)- Facilities Support Services
Excel Welding	10	Offer a full line of welding, cutting, tools, safety, and industrial supplies to support building, manufacturing, and fabrication	
Free People	75	Clothing	
Freedom Sciences, LLC	3	Medical, Dental, and Hospital Equipment and Supplies	423450-Medical, Dental, Hospital...Wholesalers
Frog Commissary Catering	150	Catering	
Geo-Centers, Inc.	1	Engineering services	541330-Engineering Services
General Dynamics Corporation		Ship Building and Repairing	
George Young Company	49	Installations of Baggage Handling Equipment, handling large works of fine art, hygienic equipment installations for the pharmaceutical industry, high hoisting and installation of power generation and distribution equipment.	238290-Other Building Equipment Contractors
Gibbs & Cox, Inc.	4	Naval architecture and marine engineering firm	541330-Engineering Services

Hargrove, Inc.	185	Custom exhibit, special event, and trade show contractor	
Healthmark Incorporated		Offers comprehensive worker's compensation medical services to help employees who have had an accident, injury, or illness make a smooth transition to the workplace	
International Cruise Terminal		Cruise ships	
Iofy Corporation		Sells audiobooks / multimedia company	no search results
Iroko Pharmaceuticals LLC	15	Acquires, develops, and maximizes the potential of currently marketed pharmaceutical products	325412-Pharma. Preparation Manufacturing
Jamie Record Company			no search results
Landmar Enterprises, Inc.	12	New Construction & Renovations Of Commercial Buildings	236220-Commercial and Institutional Building Construction
Life Cycle Engineering	21	Engineering services, industrial machinery	541330-Engineering Services
Living Naturally, LLC	40	Leading provider of innovative technology and marketing services to the natural health industry	
Lockheed Martin		Research & Development Of Space Launch Vehicles	
McAllister Towing of Philadelphia, Inc.	350	Marine towing and transportation companies	
McKean Defense Group	25	Engineering and Information Technology (IT) consulting company	
MetroKids Publications		Creates monthly publications that help Delaware Valley families take advantage of the vast resources — both educational and recreational — available in our culturally rich and diverse community	
Menasha Packaging Company, LLC	150	Manufactures Corrugated/Solid Fiber Boxes	322211-Corrugated & Solid Fiber Box Manufacturing
MinusNine Technologies	5	Nano adhesives, coatings & polymers	MFG Adhesives/Sealants (no NAICS code available)
Moran Towing Corp		Operates the largest and most versatile fleet of harbor tugs servicing the major port cities and facilities located on the Delaware River	
Mothers Work, Inc.	380	Retails Maternity Clothing	
Nason Construction, Inc.	5	Nonresidential Construction Industrial Building Construction	236220-Commercial and Institutional Building Construction
NAVMAR Applied Sciences Corp.	100 - 250	Professional engineering, assists in strategic and responsive problem solving for the DOD and other organizations	
Northrop Grumman Systems Corp.		Global defense and technology company	
P&A Associates	3	Real Estate developers	522298-All Other Nondepository Credit Intermediation
Penn State Great Valley	43 full-time, 66 part-time faculty	Data Processing School	

Pennsylvania Horticultural Society		Provides great events, activities, and publications for novice gardeners & experienced horticulturists	
Philadelphia Industrial Development Corp.	55	Promotes economic development throughout the city	
Philadelphia Shipyard Development Corp.		Working together with ShipyardXchange to establish integrated websites, with access to all of the 14 Kvaerner shipyards throughout the world, to provide exchange and collaborative capabilities for all the suppliers in their network	
Port of Philadelphia & Camden		Cruise terminal	
Potomac Navy Yard, LLC			no locations found in Philadelphia
Printcrafters, Inc.	30	Commercial printing	
Q.E.D. Systems, Inc.	over 400	Information Technology (IT), Engineering, Industrial Services and Logistics	no locations found in Philadelphia
Quaker Electrical & Mechanical Contractors, Inc.		Electrical and mechanical engineering	no locations found in Philadelphia
Rebellion Pictures, LLC		Film production company	
Resource America, Inc.	224	A specialized asset management company that uses industry specific expertise to generate and administer investment opportunities for its own account and for outside investors in the real estate, equipment finance, structured finance and private equity sectors	522292-Real Estate Credit
Rhoads Industries	1	Sheet metal industrial services company	238990-All Other Specialty Trade Contractors
River Associates	15	Water Transportation of Freight & Tugboat Services	483211-Inland Water Freight Transportation
Rotem Company	215	Rail Car Builder	(Rotem USA Corp) 336510-Railroad Rolling Stock Manufacturing
Sautter's Café		Restaurant	
Securitas Security Services USA, Inc.	12	Largest provider of security officer services in the United States	561613-Armored Car Services; also 561612-Security Guards & Patrol Services
Steven L. Gershman, Esquire		Law firm	no search results
Stonehenge Advisors, Inc.	80	Real Estate Management firm	no search results
Team Clean	250	Building Cleaning and Maintenance Services	561720-Janitorial Services
Torcon Incorporated	275	Construction management services	236220-Commercial and Institutional Building Construction
Thackray Crane Rental, Inc.	50	Heavy Construction Equipment Rental and Leasing	
Unique Industries		Manufacturing and distributing party merchandise	no locations found in Philadelphia
Urban Outfitters, Inc.	105	Clothing, jewelry, and objects for home	
U.S. Dept. of Agriculture		Responsible for the safety of meat, poultry, and egg products	

U.S. Navy		National Security	
Vericom Technologies	1	Mobile Resource Management; manages vehicle fleets, mobile workforce and remote assets	561499-All Other Business Support Services
VITETTA		Architectural and engineering corporation	
WHYY, Inc.	160	Radio Broadcast Station Television Station	
Wilmington Steel Processing Co.	25	Provides steel processing, weldments, shearing & flame cutting services	331111-Iron and Steel Mills

Appendix 7: Profiles of Relevant Companies

Key

(light blue)	TEU-like containers
(light grey)	May be of interest
(dark grey)	Likely of interest
(light green)	In Phila Navy Yard
(cyan)	Most interest in TEU- related products/services

Company Name	Company Description	NAICS	Industry	Location
Andrew B Duffy Inc	Over 30 years experience in the design, testing, fabrication and repair of various regulated containers; IBCs	33243	Metal Can, Box, and Other Metal Container (Light Gauge) Manufacturing	Thorofare, NJ
AK Packaging, Inc	bulk boxes, warehouse storage- website under construction			Bristol, PA
Aker Philadelphia Shipyard, Inc.	constructs world-class quality ships and owns vessels for bare boat charter			Navy Yard
AMSEC	a full service supplier to the Navy and commercial maritime industry, providing naval architecture and marine engineering, naval ship systems assessments, maintenance engineering, acquisition program development, shipyard industrial engineering, and complete logistics services from technical manual development to provisioning documents, to spare parts management and training	541712	R&D in the Physical, Engineering, and Life Science	Navy Yard
BE&K Engineering	Engineering projects for govt, Dupont, other industrial and manufacturing companies; large variety of projects	541330 (?)	Engineering Services (?)	Newark, DE
B E Wallace Products Corp	work with military, hundreds of crane models available for situations- portable, adjustable height, various weight capacities	333923	Overhead Traveling Crane, Hoist, and Monorail System Manufacturing	Malvern, PA
Capitol Environmental Services, Inc	waste reuse, treatment and disposal; environmentally friendly, variety of services	562211	Hazardous Waste Treatment and Disposal	Wilmington, DE
Cargo Plus Inc	shipping containers	4831	Deep Sea, Coastal, and Great Lakes Water Transportation	Pennsauken, NJ
Changing World Technologies	identifies emerging technologies that specifically address the needs and problems in the energy and environmental arenas; revolutionizing renewable energy by changing the way in which organic waste materials are utilized, thereby providing a platform for sustainable development	32519	Other Basic Organic Chemical Manufacturing	Navy Yard

Company Name	Company Description	NAICS	Industry	Location
Clean Harbors Environmental Services, Inc	managing hazardous, non-hazardous, wet and dry materials. Specialized services include chemical cleaning, hydroblasting, liquid/dry vacuuming, sodium bicarbonate blasting, steam cleaning, and railcar cleaning and inspection. Locations?	562211	Hazardous Waste Treatment and Disposal	Philadelphia, PA
Compact Membrane Systems, Inc	air ventilation and quality improvement, oxygen and nitrogen enriched air, vapor processors			Wilmington, DE
Container Research Corporation	services from concept and prototyping through production and testing, on-site manufacturing operation, adheres to strict, government- and industry-accepted quality control procedures throughout our operations; custom containers including electronic enclosures	33243	Metal Can, Box, and Other Metal Container (Light Gauge) Manufacturing	Glenn Riddle, PA
Crowley Liner Services, Inc	engineering, loading, and transportation/delivery services; Titan Salvage is a marine salvage and ship wreck removal company under Crowley; teams of marine engineers and naval architects	4831	Deep Sea, Coastal, and Great Lakes Water Transportation	Pennsauken, NJ
Current Environmental Solutions LLC	brownfields remediations, thermal treatment	562211	Hazardous Waste Treatment and Disposal	Langhorne, PA
Delaware River Stevedores Inc	utilizes specialized gear, mechanical equipment and the latest technology to provide efficient and damage free cargo services and the latest technology to provide efficient and damage free cargo services	488320	Marine Cargo Handling	Camden and Philadelphia
Delphinus Engineering Inc	design manufacturing, navy experience, program and project experience	33661	Ship and Boat Building	Eddystone, PA
Disposal Corp of America	waste removal, open and closed containers; mostly commercial	5622	Waste Treatment and Removal	
Duffield Associates	marine and coastal engineering, sustainable and environmental development and design	541330	Engineering Services	Wilmington, Phila, Cape May, NJ
D&S Warehousing, Inc	packaging, warehouse storage, and trucking	4931	Warehousing & Storage	Newark, DE
EDO Corporation	designs and manufactures a diverse range of products for defense, intelligence, and commercial markets, and provides related engineering and professional services / EDO's advanced systems are at the core of the transformation to lighter, faster, and smarter defense capabilities; mostly technological products	334511		Navy Yard
EG&G	provides program management, systems engineering and technical assistance, and operations and maintenance services to a variety of federal agencies, primarily the Departments of Defense and Homeland Security	561210	Facilities Support Services	Navy Yard

Company Name	Company Description	NAICS	Industry	Location
Excel Welding	offers a full line of welding, cutting, tools, safety, and industrial supplies to support building, manufacturing, and fabrication; stocks Gases, Equipment, Electrodes & Wires, Power tools, Hand tools, Safety products and more. Excel specializes in servicing contractors, fabricators and maintenance/repair facilities			Navy Yard
FastShip, Inc	With the addition of very simple, low-cost military features that can be installed in 48 hours, the commercial FastShip can quickly be converted to a roll-on roll-off ship that can carry wheeled and tracked vehicles, containers and personnel	4831	Deep Sea, Coastal, and Great Lakes Water Transportation	Philadelphia, PA
Fluor Enterprises Inc	services with oil and gas, petrochemical, life science, manufacturing, government services,	562211	Hazardous Waste Treatment and Disposal	Media, PA
General Air Products Inc	air coolers and compressors, custom products available	333912	Air and Gas Compressor Manufacturing	Exton, PA
Gibbs & Cox, Inc.	naval architecture and marine engineering firm	541330	Engineering Services	Navy Yard
Gloucester Marine Terminal Inc	terminal for containers, steel products, food, heavy lift, project	488320	Marine Cargo Handling	Gloucester City, NJ
Howden Compressors Company LLC	products for contaminated air and gas; gas cleaning; blowers, compressors, industrial fans	333912	Air and Gas Compressor Manufacturing	Plymouth Meeting, PA
Hypex Inc.	Custom equipment, generally packaging for pharma and related industries	3327	Machine Shops; Turned Product and Screw; Nut and Bolt Manufacturing	Southampton, PA
ILC Dover, Inc	protective gear including a new CBRN hood and gas masks			Frederica, DE
Ingersoll-Rand Company	air compressors and treatment; also see lifting and material handling	333912	Air and Gas Compressor Manufacturing	Mount Laurel, NJ
Ingersoll-Rand Company	hoists, clamps, handling devices (vacuums, clamps, jhooks); custom devices	333923	Overhead Traveling Crane, Hoist, and Monorail System Manufacturing	Mount Laurel, NJ
Interocean American Shipping Corp	vessel operations, crew management, voyage repairs, shipyard overhauls, insurance and claims handling, quality in service and safety and pollution management	4831	Deep Sea, Coastal, and Great Lakes Water Transportation	Voorhees, NJ
K Line America	bulk carriers and shipping containers transportation	4831	Deep Sea, Coastal, and Great Lakes Water Transportation	Vincentown, NJ
Keystone Boiler, Inc	sheet and plate metal, bins, tanks, etc. in aluminum, steel, tin, and brass	3311	Iron and Steel Mills & Ferroalloy manufacturing	Philadelphia, PA (Pottstown?)
Marathon Engineering and Environmental Services	brownfields remediations, site development, environmental risk assessment,			Swedesboro, NJ
Matcon USA Inc	Matcon specialize in providing solutions for handling and processing powders, granules, tablets and other materials in Intermediate Bulk Containers; international	333923	Overhead Traveling Crane, Hoist, and Monorail System Manufacturing	Sewell, NJ
Mc Dal Corporation	hoists, cranes, monorails; new and used equipment, service	333923	Overhead Traveling Crane, Hoist, and Monorail System Manufacturing	King of Prussia, PA
McAllister Towing of Philadelphia, Inc.	marine towing and transportation companies			Navy Yard

Company Name	Company Description	NAICS	Industry	Location
Met Pro Corporation	air and liquid purification, pollution control	3332	Industrial Machinery Manufacturing	Harleysville, PA
Miller-Remick Corp	design and structural engineering	541330?	Engineering Services?	Cherry Hill, NJ
Moran Towing Corp	operates the largest and most versatile fleet of harbor tugs servicing the major port cities and facilities located on the Delaware River			Navy Yard
Mxi Inc	Trucking services to transport hazardous household or other waste to disposal facilities using environmentally friendly standards	562211	Hazardous Waste Treatment and Disposal	Langhorne, PA
Navmar Applied Sciences Corp.	professional engineering, assists in strategic and responsive problem solving for the DOD and other organizations			Navy Yard
P D C Machines, Inc	mostly custom products; design, engineering, manufacture, installation, commissioning, service, and support of equipment for the chemical, petrochemical, pharmaceutical, and specialty gas industries	333912	Air and Gas Compressor Manufacturing	Warminster, PA
Packer Avenue Marine Terminal	cranes, toploaders, containers	488320	Marine Cargo Handling	Philadelphia, PA
Penn Terminals, Inc	cargo and container handling, loading docks	488320	Marine Cargo Handling	Eddystone, PA
Philadelphia Industrial Development Corp.	promotes economic development throughout the city			Navy Yard
Philadelphia Shipyard Development Corp.	working together with ShipyardXchange to establish integrated websites, with access to all of the 14 Kvaerner shipyards throughout the world, to provide exchange and collaborative capabilities for all the suppliers in their network			Navy Yard
PPG Industries	Coatings for packaging, marine, agricultural, industrial and chemical industries, other specialty products			Dover, DE
Pressure Products Industries Inc	large scale, purity compressors	333912	Air and Gas Compressor Manufacturing	Warminster, PA
Rhoads Industries	sheet metal industrial services company	238990	All other Specialty Trade Contractors	Navy Yard
Rock-It Cargo Holdings, LLC	loading and shipping cargo	4831	Deep Sea, Coastal, and Great Lakes Water Transportation	Huntingdon Valley, PA
Rowan Technologies, Inc	coatings for hazardous materials; in NJ?	333912	Air and Gas Compressor Manufacturing	Rancocas, NJ
Sea Box Inc.	has produced military containers, can customize or modify, for sale, lease, or rent; containers for Command and Control centers, personnel, emergency medical equipment, water purification	33243	Metal Can, Box, and Other Metal Container (Light Gauge) Manufacturing	Riverton, NJ
Sky-Trax, Inc	efficient and safe warehouse storage systems	4931	Warehousing & Storage	New Castle, DE
Sph Crane & Hoist Inc	hoists, cranes, monorails; lifting equipment and accessories	333923	Overhead Traveling Crane, Hoist, and Monorail System Manufacturing	Philadelphia, PA

Company Name	Company Description	NAICS	Industry	Location
Vacuum Processes, Inc	vacuum pumps, gauges and controllers; thermal process equipment; temp and humidity space simulation chambers; R&D, manufacturing, service, installation; helium leak detection; vacuum chambers	333912	Air and Gas Compressor Manufacturing	Levittown, PA
Wilmington Steel Processing Co.	Provides steel processing, weldments, shearing & flame cutting services	331111	Iron and Steel Mills	Navy Yard
Wilmington Tug	tug services			New Castle, DE
W.L. Gore & Associates	products for ventilation (packaging vents and dryfreeze) and filtration, sealants (gaskets, packing fibers, pumps), geochemical services (identification of environmental contaminants), and medical/healthcare (surgical, imaging, tools)			Newark, DE
Maritime Exchange for DE Valley and Bay	membership network for companies working in or related to DE River, offers hazmat training			Philadelphia, PA
Virtual Sciences	use blueprints (sketches, photos) to create animated graphics of locations			Parsippany, NJ
Technology Security Associates, Inc	DoD consulting, information assurance through testing and research, policy project support and expertise			Lexington Park, MD

Appendix 8: Environmental Remediation Business Cluster Case Study

During the budgetary hearings of August and September 2008, $1,000,000 is earmarked for the Office of Naval Research to design and produce prototypes of the TEUs that will be part of the Emergency Response System to CBRN incidents.

After reviewing the final report ***Feasibility and Top Level Design of a Scalable Emergency Response System for Oceangoing Assets,*** the ONR decides to follow the report's recommendation to base the Emergency Response Research and Design Center (ERRDC) in Philadelphia. After evaluating a short list of sites, ONR determines that Philadelphia is the cost effective option that optimizes project requirement fulfillment. The Philadelphia region also offers the potential for successful business cluster growth and development. This case study illustrates how an environmental remediation business cluster develops from the ONR project activity at the PNSY.

Phase 1: TEU Research, Design and Manufacture at the ERRDC

In January 2009, ONR begins preparations for TEU research and design at the ERRDC. ONR contacts the engineering departments at Villanova and Drexel University and invites faculty to meet with ONR researchers assigned to the ERRDC. ONR also arranges meetings with individuals performing related research in the pharmaceutical industry. During the meetings, ONR, faculty, pharmaceutical researchers and process engineers discuss the laboratory specifications and other specialized requirements for TEUs that will house laboratories. ONR and faculty researchers also discuss approaches that could be used to coat and seal the TEUs against potential environmental contaminants.

Attracted by the US Navy Office of Naval Research's R&D collaboration with local universities and pharmaceutical companies, companies and entrepreneurs begin to express interest in a PNSY location. In response, PIDC forms the collaborative group Naval Yard Network (NAVYNET) and invites representatives from Select Greater Philadelphia, the Pennsylvania Department of Community and Economic Development, and ONR to join efforts to attract businesses. Through NAVYNET, PIDC recruits businesses that want to work in proximity to the ERRDC. In addition to one-on-one meetings with interested businesses and entrepreneurs, NAVYNET organizes happy hours and a softball league for existing PNSY tenants. These events increase the opportunity for informal networking and collaboration among the ONR, university, and business researchers who work at the Yard. NAVYNET also arranges internships between Villanova and Drexel University students with the ONR research project and with related businesses located at the Yard.

Once prototype research begins, the ONR prepares for TEU manufacturing. The ONR leases warehouse space with attached offices for research staff at the yard. The buildings are updated. Operation and maintenance procedures are implemented so that the site will comply with the Leadership in Energy and Environmental Design (LEED) standard for Existing Buildings. This renovation is another example of PSNY's leadership in environmental initiatives and sustainable design. To ensure availability of a trained workforce for the TEU manufacturing, ONR meets with the Philadelphia Workforce Development Corporation.

Phase 2: Emergence of the Environmental Remediation Business Cluster
Environmental remediation removes pollution or contaminants from soil, groundwater, sediment, or surface water in order to protect public health or to prepare a brownfield site for redevelopment. Remediation of a contaminated site increases a city or region's natural resource endowment of productive land. Potential benefits include increased property values, enhanced health and safety, reduced environmental health risks, jobs for local residents, revitalized neighborhoods, and a stronger municipal tax base.

At the end of 2009, the environmental remediation and consulting firm React Environmental Professional Services Group (React) opens an office at the PNSY. React's reputation as a leader in the field combines with the state-of-the-art laboratory research conducted at ONR's ERRDC to attract other environmental remediation service businesses to the Yard.

Having already established links between the ERRDC and universities; and between ERRDC and pharmaceutical companies, NAVYNET begins to organize networking events and recruits internship candidates for React and the other environmental remediation businesses. Invited to join NAVYNET, React enhances the networking opportunities available at the cluster by tapping into its professional relationships with community development corporations and other nonprofits that serve communities near brownfields. With NAVYNET as the interest champion and React as the anchor firm, an environmental business cluster begins to develop at PNSY.

Philadelphia has a large inventory of brownfield properties. Although the exact number is not known, the University of Pennsylvania's Cartographic Modeling Lab (CML) has started a GIS inventory and has completed the inventory for sections in North Philadelphia and along the Delaware River. In 2010, CML receives funding from the Pennsylvania Environmental Council to complete the brownfield inventory. At the same time, higher gasoline costs and reductions in the city business tax combine to generate interest in low cost land in Philadelphia.

With better information, entrepreneurs and nonprofit organizations start to plan businesses and projects that can be located on remediated land. This activity increases the demand for environmental remediation services. React and the other firms at the PSNY are well positioned to meet that demand. React has a history of working with community and environmental nonprofits and this reputation attracts business to the cluster. At the same time, NAVYNET efforts are cultivating informal contacts and discussions with ONR staff and their academic and business counterparts. As a result, the cluster businesses begin to establish a reputation for their state-of-the-art approaches to environmental remediation.

Later that year, Philadelphia and the Commonwealth of Pennsylvania partner to fund remediation of all the superfund sites identified when the CML inventory is complete. This project is part of a long-term marketing strategy to attract economic development and a skilled workforce to the city and it builds upon the momentum generated by CDC and other entrepreneurial activity around brownfield development.

In 2012, EPA increases the funds available through its brownfield grant program and accelerates efforts to clean up the remaining SUPERFUND sites in the Mid Atlantic region, which includes the District of Columbia, Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. The increased availability of federal funding adds to the demand for environmental remediation services in Philadelphia and throughout the Mid-Atlantic region. More businesses open offices in the PSNY environmental remediation cluster. Municipalities throughout the region know about the PNSY's reputation as an environmental remediation hub and contact companies for innovative approaches to remediation.

University participation in the cluster increases along with the demand for environmental remediation services. Inspired by their contacts with ONR, ERRDC staff, and members of the business cluster, Drexel and Villanova establish their own remediation research facilities at PSNY. Philadelphia University's Sustainable Design program opens an atelier that features student designs for redeveloped brownfields. Temple University partners with EPA's "Green Remediation" program to conduct demonstration projects. For these projects, Temple faculty and students work with EPA staff to remediate brownfields in ways that use natural resources and energy efficiently, minimize pollution, and reduce waste.

Full service remediation businesses continue to establish themselves at the cluster. They are accompanied by companies that specialize in the physical tasks of environmental remediation such as asbestos removal, soil removal, and waste management. In addition to the benefits of working closely with other remediation businesses, these companies have access to a high quality workforce trained through Philadelphia's "Green Collar" workforce development program.

Municipal infrastructure and quality of life factors contribute to the business cluster's momentum. The SEPTA transportation network expands to improve access to the Navy Yard. Clients and staff of the PSNY businesses have access to frequent rush hour hybrid bus shuttles between the major regional rail stations and the PNSY. The city continues to phase out the business privilege and net profits tax, creating a more attractive climate for all small businesses. At the same time, more people are moving to the city, attracted by shorter commutes and lower housing costs.

The high level of environmental remediation activity continues for several years. Working in close proximity to the businesses, the ONR ERRDC and the EPA Green Remediation project, university researchers develop the practical applications of their research. The environmental remediation cluster expands to include businesses that develop and market the products that result from university research of the chemistry, biology and engineering of remediation. The PNSY achieves a reputation for state-of-the-art technologies to extract and remove contaminants from soil and water and to transform the contamination into a harmless, and sometimes useful, material.

This case study envisions how a DOD contract will function as the catalytic converter that harnesses area assets and latent talent to achieve long-lasting economic growth and benefits. In this case, the ONR's research and development activities triggered the formation of the NAVYNET. This alliance of state and local economic development organizations has the interest and the resources to promote business cluster development. React's relocation to the PNSY fills the anchor firm role and establishes the environmental remediation presence at PSNY. From the very beginning, ONR's consistent outreach to local universities ensures their interest and involvement with the business cluster. Other success factors include financial and political support of federal, state, and local government and their expanding role as a client for environmental remediation services. The city's "Green Collar" workforce development effort is another contributing factor. Philadelphia's transportation infrastructure and low cost of housing are quality of life factors that support cluster development. The early and strong university participation lays the foundation for a process that converts bench science into marketable products. This product development will continue to drive the cluster after the inventory of Superfund and brownfield sites is depleted.

Appendix 9: Emergency Response Decontamination System Implementation Plan

Phasing concept detailing a three-phased scalable emergency response to an at-sea CBRN event.

Expand CBRN Training

- Identify members of the US Army CBRN School and US Navy who will sit on the Navy CBRN Training Committee. The committee's purpose will be to implement expanded training for specific CBRN procedures and roles for Navy damage control personnel and to define the requirements of a specific rating for personnel who can respond to a CBRN contamination.
- Convene CBRN Training Committee
- Establish meeting schedule, identify deliverables and set timeline for proposal to implement augmented CBRN training for DC personnel.
- Review training proposal recommendations
- Select recommendations for implementation
- Establish timeline for implementation of recommendations.
- Implement training recommendations.
- Execute Training and Exercise Program among stakeholders to include table-top exercise for proof-of-concept, and to incorporate lessons learned and concept improvements.

Integrate CBRN Procedure Components Into Ship Design

- Identify members of the US Navy who will sit on the CBRN Integration Into Ship Design Committee
- Convene CBRN Integration Into Ship Design Committee
- Develop procedures to include CBRN processes within existing Navy systems such as the Joint Warning and Reporting Network (JWARN), in conjunction with the Hazardous Material Information Resource System (HMIRS) and in conjunction with Ship Class Database and the Joint Acquisition CBRN Knowledge System (JACKS).
- Establish meeting schedule, identify deliverables and set timeline for the final document that describes procedures and schedule for CBRN integration.

Develop Twenty-foot Equivalent Unit (TEU) concept and describe the decontamination response using a shipping container supply system.

Conduct Research and Planning for Physical Prototypes of TEUs.

- Prepare design and written specifications for TEUs.
- Research and specify the lab equipment and other specialized requirements for laboratory TEU components.
- Conduct research and planning to quantify the methods used to cover and seal the TEUs against potential environmental contaminants while maintaining a hospitable interior environment.
- Research TEU manufacturers.
- Select TEU manufacturer(s) for project.
- Evaluate and select shipyard location(s) for TEU storage.
- Meet with representatives of local workforce development corporation to plan availability of trained workforce for TEU manufacture.
- Coordinate any necessary manufacturing training with workforce development and union officials
- Assess access to air, land, and sea transport for TEUs.
- Locate warehouse with attached offices for engineering staff.
- Prepare portfolio of predesigned maps for assembling customized TEU networks
- Construct physical TEU prototypes
- Test and adjust prototypes
- Produce blueprints for individual TEUs based on feedback received from the prototypes already created.
- Fabricate and/or modify TEUs. When necessary, perform additional sealing and install environmental controls to transform TEUs into modules for the decontamination platform
- Evaluate potential vessel delivery options for the Phase III response and select the best of the following three options:
    1. Retrofit existing Commercial or Navy Vessel (Individual or Ongoing Usage)
    2. Construct a Specialized DOD Vessel
    3. Use Existing Commercial or Navy Vessel Without Retrofit

If Option 1 is selected, identify existing vessel and contract for retrofit and negotiate lease terms.

If Option 2 is selected, prepare RFP to design and build the customized vessel.

If Option 3 is selected, identify existing vessel and initiate purchase or requisition procedures.

- Design training program for TEU personnel
- Identify TEU personnel candidates from the Navy, Marine Corps, FBI, CIA, EPA and the FDA.
- Finalize the four pre-positioning locations
- Develop detailed timeline for 8-10 year rollout of the Philadelphia node.

Reach-Back and Research Component.

Create a one-stop Operations Center to respond to and coordinate response to a CBRN event anywhere that the Navy operates

- Convene DHS and DOD stakeholders to select the most appropriate Operations Center site from existing locations.
- Develop procedures for communication between the expanded Operations Center and the Emergency Response Research and Design Center (ERRDC).

Establish a design, fabrication, and maintenance facility for the modular TEU units that this project will use extensively

- Lease warehouse space with attached offices for research staff.
- Update buildings.
- Implement operation and maintenance procedures for the manufacturing site.
- Purchase/lease and install manufacturing equipment.
- Meet with local workforce development organization to ensure availability of trained workforce for manufacturing.

Develop a dedicated research and innovation cluster that draws together DOD personnel, university and other researchers, and the private sector

- Convene ONR stakeholders to select location for the ERRDC.
- Convene working group of key local government and research institution stakeholders and US Navy personnel to determine locations for ERRDC where reach-back and research activities will take place.
- Identify individuals performing similar research at local businesses and universities.
- Set up meetings between ERRDC researchers and business and faculty researchers to discuss:

Laboratory specifications

Other specialized requirements for TEUs that will house laboratories

Approaches to cover and seal the TEUs against potential environmental contaminants.

- Open and staff the ERRDC
- Identify local and state groups that have the interest and resources to promote business cluster development around the ERRDC research site.
- Create business cluster interest champion by forming alliances with local and state economic development groups.
- As member of interest, champion alliance, work to recruit anchor firm for cluster, build relationships with local universities and investigate how local, state and/or federal government can step into the role of partner, investor, client and/or provide infrastructure improvements.
- As member of interest champion alliance, identify and recruit major environmental remediation firm to anchor of the business development cluster.

Appendix 10: Emergency Response System Case Study

I. Purpose Statement

This pre-mortem will act as a model for potential circumstances absent TTPs specifically applicable to the proposed scenarios. The goal of our test case is to validate assumptions made in the design phase of both the hard and soft elements of the project. This modeling should serve as a precursor to additional modeling to be performed on the technical components of the plan and in anticipation of future 'Flight 0' studies.

II. Situation

In the next 20 years the United States and the Navy will be confronted with multiple threats bearing weapons of varying composition and force.

China, declares a right to territory for which it traditionally has no claim. In the past, such moves occasionally drew censure from the international community but were mostly ignored. With energy resources dwindling, such oversights are no longer possible. Under international pressure to retract their false territorial claims, China makes a grab for the one remaining locale for which they have a traditional stake: Taiwan. Chinese naval vessels steam from ports across the Chinese mainland. With a substantial force put to sea, China seeks a blockade of Taiwan followed by ground invasion.

An ad hoc mix of Type 956 Russian-built *Sovremenny*-class and Chinese *Luhai*- and *Luhu*-class destroyers form a loose but efficient blockade. Alone, they are inferior by Western standards. However, they are joined by a potently armed pack of diesel-electric and nuclear powered submarines from the *Song*-, *Han*-, *Xia*-, *Shang*-, *Jin*-, and Russian *Kilo*-classes. Additional surface support is provided by the snub-nose of the growing fleet, Type 053 *Jianghu*-class frigates and *Houxin*-class missile boats. While the PLA is backstopped by millions of volunteer and conscripted soldiers, the PLAN is limited by capacity and must rely on additional strategic and tactical factors.

Despite a fleet of ships that is not comparable to the United States or other Western powers, the armaments deployed are largely Soviet or Russian origin and designed specifically to counter the AEGIS weapons system deployed aboard U.S. warships. To increase their reach and effectiveness, the PLAN has unsealed hundreds of chemical and biological munitions to serve as a deterrent and/or force multiplier.
Honoring treaty obligations, the United States responds to Taiwan's call for assistance. Orders are issued to SOCOM forces worldwide. PACOM is ordered to DEFCON 3. Despite official protests from the United States, Taiwan and most of the European powers, China remains undeterred. The blockade is at full force within days. Diplomatic efforts at the United Nations fail to yield results. PACOM moves to DEFCON 2.

Efforts to break the stalemate through diplomatic means have thus far proved unsuccessful. U.S. Naval forces are ordered to divide the blockade from the mainland, the maneuver breaks PLAN supply lines and isolates the largest components of the surface Fleet from their home ports.

U.S. forces have essentially blockaded the blockade force and frustrated Chinese political leaders and prevented full-scale invasion. The PLAN responds with ratcheted aggression, ordering their *Kilo*- and *Song*-class SSNs to bracket U.S. warships in the Strait.

Chinese shore-side missile batteries go live with stationary and mobile launch platforms gearing up to launch a rain of ordnance into Taipei. As the Chinese shore batteries open up, the U.S. Fleet responds with waves of interceptors.

To the conventionally armed JH-7s already airborne, the PLAAF begin to arm units on stand-by with YJ-81s carrying a chemical payload. They also load a mix of Q-5s with dedicated chemical or HE 250kg bomb payloads. No longer a deterrence asset, chemical weapons are being prepared for battlefield use.

J-11s from Suixi AB in South China launch a strike mission targeting Kaohsiung along Taiwan's western shore. F/A-18s and F-35s scramble from the battle groups positioned East and South of Taiwan on a deterrence mission. Though numerically inferior, the Chinese aircraft press on for Taiwan.

U.S. combined air power responds with B-1 and B-2 strikes on shore batteries of surface-to-surface missiles and two-ship formations of F-22As penetrate Chinese radar and strike tac-air assets in-country, withdrawing without detection. The Chinese stand-up all shore side batteries and prep for a phased barrage against Taiwan. Anticipating U.S. countermeasures to the missile strike, all Chinese aircraft are set to launch. The PRC issues a final warning to the U.S. and its allies. When U.S. assets do not withdraw, missiles launch.

The first phase of missiles is away. Battleships are tracking and destroying inbounds, plotting firing solutions and prosecuting counterstrikes. The shipboard self protection systems destroy most inbound missiles and the standard Sea Sparrow suite engages incoming bomber aircraft. While sections of some ships are struck by debris there are no direct hits.

The last phase of Chinese conventional ground-launched missiles is away. Remaining PLAN and PLAAF assets with mixes of conventional and chemical munitions launch and target the same centers of gravity. This time the multitude of simultaneous functions prevents complete denial. Chinese sea-skimming ASMs find their targets. Aircraft laden with HE and chemical-tipped YJ-81s launch against the starboard side of a 51-class DDG, two missiles impact the ship. The first, loaded out with a 165kg semi-armor piercing HE warhead, strikes aft of the first engine compartment less than 2m above the waterline. The second missile impacts just forward of the first, broadside, above deck.

The destroyer is damaged, with a Class Bravo fire burning between engine compartments, fed by a sheared JP-5 line. Related explosions have caused Class Alpha and Charlie fires in adjacent areas. The impacts of the two chemically charged missiles, however, are potentially more lethal. Using armor piercing warheads, both the missiles penetrate the lighter armor and discharge internally, rapidly filling adjacent compartments and deck areas with gaseous and liquid forms of a highly lethal and persistent chemical warfare agent. Decisions made in the hours to come are critical

III. Procedure

The ship, already isolated into general quarantine (GQ), begins working through its internal procedures. In any damage control situation, preserving the watertight envelope of the ship is first priority. Second priority is to ensure buoyancy. Third priority is to eliminate hazards that threaten the vessel. Damage remediation is the last priority.

IV. Phase I

Damage Control Teams don gear and gather at their damage control stations. Within 10 minutes of the first impact, the decks below the waterline are sealed and hatches dogged down; the ship is compartmentally sealed, bow to stern. Investigators sweep fore and aft, deck-to-deck in search of damage.

Crewmen locate a hull breach between second and third decks on starboard, amidships. With a JP-5 line pierced, a fire rages in the compartments and aviation fuel threatens catastrophic damage. Quick action prevents additional fuel spillage and fire teams prepare to take down the Class Bravo with onboard AFFF supplies. The fire is contained and fully extinguished in a matter of minutes. Sea water has flooded into the affected compartments but it is containable. The affected compartments are sealed and the watertight envelope is preserved.

A second team locates secondary and tertiary damage points five and seven frames forward, which have penetrated the main deck and second deck. The team detects a Class Charlie in addition to a small scale Class Alpha fire. Both fires are handled within minutes utilizing the SOP for damage control operations.

The ship continues to transit out of harm's way under its own power but with two cruiser escorts and continuous over-fly. Once it has cleared the littorals, the damage control assessments reveal the presence of chemical agents. What was once just a damaged hull is now a mortal hazard.

The bridge initiates contact with Fleet command through the battle group and up the chain. The CO's assessment is that the ship is stable but the level of contamination cannot be determined. Following Fleet procedures for chemical weapon contamination, the CO requests a decontamination assessment team. The Fleet approves and the CONUS and Outside the Continental United States (OCONUS) assets begin to spin-up.

V. Phase II

The decontamination elements' Deuce ALPHA and BRAVO components go hot. All personnel from the CBIRF component are immediately recalled and the assets readied for immediate departure to the incident scene.

Deuce ALPHA or Phase II 'Alpha' will be the first external response unit on scene. With the crew onboard and Fleet escorts having performed those tasks necessary and required to secure the vessel and its watertight envelope, personnel begin to triage casualties and provide primary intelligence on the vessel and its contaminants, the airborne element will provide specialized expertise in CBRN detection, decontamination and protection. A *Wasp*-class LHD (amphibious assault ship) provides interim overwatch for the vessel and will also serve as a launch and recovery site for 35Bs and MV-22s.

Within 24 hours of the attack, the airborne ALPHA element deploys aboard five Ospreys – four containing 22 personnel and 2,000 lbs of cargo each and the fifth loading out with up to 10,000 lbs of cargo and supplies. Because of the unique capabilities of the MV-22, it deploys from CONUS and traverses directly to the *LHD*.

While the ALPHA component deploys to the incident scene, BRAVO team transits to the AOR to accept its assets and run pre-deploy checks on their equipment. Although one stock of the system is pre-positioned in Guam, the Diego Garcia unit has better tactical advantages. BRAVO sets to sea aboard a fast response vessel to be determined with its standardized set of core response capabilities that provide a command and control structure and the tools necessary to commence full-scale personnel decontamination operations.

As Deuce BRAVO elements deploy, Phase III assets are already going hot. When the ALPHA *Ospreys* set down on the LHD, TEUs are prepping to roll onto a Phase III response vessel.

Deuce ALPHA A/C 01 arrives first on scene, transferring manpower aboard the LHD to two waiting *Seahawks* for immediate transfer to the affected ship, enabling the new scene commander to embark. The first team, the Recon Element consists of the following:

- Recon Component, 18 (10 Enlisted, 7 Corpsmen and 1 Medical Officer)
- Support Component – HQ, 2 (1 Enlisted and 1 Officer)
- Security Component, 2

Recon coordinates arrival of the other team components, locates the HQ element, and detects, classifies and identifies the contaminant. If they are unable to identify an agent with their equipment, members collect samples for available agencies to identify.

Deuce ALPHA A/C 02 carries the Decontamination Element consisting of the following:

- Decontamination Component, 18
- Support Component – HQ, 2 (1 Enlisted and 1 Officer)
- Security Component, 2

Decon pre-stages aboard the LHD in the helo hangar.

Deuce ALPHA A/C 03 carries the Medical Element consisting of the following:

- Medical Component, 10 (7 Corpsmen and 3 Officers)
- Support Component – HQ, 2 (1 Enlisted and 1 Officer)
- Security Component, 2
- Support Component – Supply, 2

Med Element likewise pre-stages in the LHD Hanger deck.

Deuce ALPHA A/C 04 embarks the Support Element consisting of the following:

- Support Component – HQ, 4 (2 Enlisted & 2 Officer)
- Support Component – Supply, 2
- Support Component – Engineering, 3
- Support Component – Embark, 6
- Security Component, 7

Support element utilizes deck space to the degree necessary to hold equipment.

Deuce ALPHA A/C 05, the Cargo Element, is unloaded and equipment stowed below deck.

VI. Phase III

ALPHA Recon meets first with the vessel CO and begins a complete assessment of conditions onboard. Once the element achieves full situational awareness, the scene commander determines if the condition of the ship and the status of the crew warrant a Phase III-D response. With a physical hull breach, the scene commander cannot certify that a temporary repair to the outer watertight envelope can be sustained until port call in CONUS. The order is sent and Phase III personnel and kit deploy directly to the affected DDG as it continues under its own power toward Diego Garcia with its escort vessels. A heavy lift vessel is en route to Diego Garcia and the pre-po stocks there and in Guam go fully hot.

Phase III assets hop to the LHD where they are transferred to the DDG via *Seahawk*. The scene commander withdraws unnecessary Phase II forces, mainly security and support components and prepares to return Command and Control to the affected ship's bridge for the remainder of the time at sea prior to rendezvous with the heavy lift. The ship CO and XO, unaffected by the chemical agents present onboard and testing negative, resume command of the vessel with continued close monitoring from the decon and med elements of Phase II, who will remain aboard to monitor conditions.

By D-Day +21, the contaminated ship is loaded aboard the heavy lift ship. The Damage Control teams have buttoned up the contaminated areas and sealed ventilation and transit spaces. The contamination is effectively contained to the immediate impact zones, the deck adjacent to the impact zone, the ventilation system and spaces one deck above and one deck below the immediate impact areas. Transit fore and aft is still possible by port side corridors, though less convenient.

A U.S. repair facility cannot accept the ship in its current condition. The chemical contaminants must be cleared. The exterior must be fully remediated. Internal spaces require only a mid-level decontamination prior to arrival at the repair yard. Mid-level decontamination is defined as containing all contaminants and ensuring that human exposure poses an acceptable risk, though special categories of population may experience deleterious effects with long-term exposure.

The decontamination solution that performs most optimally against the VX-like agent is a Vaporized Hydrogen Peroxide (VHP) solution. Please note the attached Army study on VHP decon compounds. Due to the complex textures and facets within a DDG, the decon process is painstakingly slow and it is difficult to remove contaminated materials given the tight quarters. However, the trunk wells provide sealed access to and from the contaminated area and serve as dedicated toxin removal corridors. Since these spaces are designed to be free of clutter, they require less decontamination after materials are removed through that space.

The ventilation system presents the most difficulty. Teams utilize chemical detection equipment in every space serviced by the affected ventilation system and recirculation lines to determine the extent of exposure throughout the vessel before, during and after the removal and replacement of those lines. Upon the satisfactory removal of all directly contaminated equipment and resealing of hot zones, the decon team uses its VHP mixture to essentially steam-clean the ship's innards.

VII. Case Study Conclusions

Satisfactory completion of the VHP phase with continued monitoring ensures that the ship will be accepted at the repair dock and will prevent public outcry in response to the mooring of a highly toxic vessel. The ship is decontaminated to a mid-level state. A very rough estimate of the total cost of decontamination would be less than $20 million to develop and deploy a baseline decon capability. By comparison, the estimated cost to build a ship comparable to the *Zumwalt* is $1.4 billion.

Appendix 11: Clusters, Development and the Power of Agglomeration

Since the mid-1990's, the identification, growth and leveraging of clusters has been the hallmark of workforce and industrial development. The following key characteristics define these clusters:

- Complementary industries
- Systematic relationships
- Geographically bound
- Life cycle driven

By using a cluster approach and determining the disparate types of industries that are needed for the project, the DOD can integrate nationally renowned technical science programs[313] – mechanical, nuclear, aerospace, industrial, manufacturing, electrical, computer and computer science engineering and robotics – to develop answers to these complex problems associated with consequence management, decontamination and remediation.

Clusters are not a new idea. Beginning in the Renaissance, and for centuries after, much of the woven silk fabric came from a single neighborhood in Venice[314] where the weavers originally gathered around a large family-owned business, which would be known today as the anchor firm. Spin-offs resulted with specialty and subspecialty firms operating in niche markets. Specialization, resource access, informal knowledge networks and a skilled labor pool created a substantial competitive advantage over similarly sized firms located in other parts of Europe. Similar clusters developed in the United States beginning in the early 19th century. Examples include the establishment of Fabric Row in Philadelphia, Wall Street in New York, steel production in Pittsburgh, chemical manufacturing in Delaware. These clusters experienced the same advantages that enabled the Venetian cluster to dominate the woven silk fabric industry. A more recent example is the growth and development of Silicon Valley that arose from the combination of the California population and defense spending boom. Silicon Valley, together with its countless imitators (Silicon Alley, Silicon Fen, Silicon Glen, Silicon Hills and Silicon Desert among them), demonstrate that clusters continue to thrive and counter intuitively may have an even greater impact in our high technology world than they did in the past.

Despite the long history of cluster success, several questions remain for economic developers and strategists: Can government, business, or universities intentionally create, grow and sustain clusters? If these institutions, acting singly or jointly, can create and sustain clusters, what actions are needed to do so? If institutions can create and sustain

---

[313] Ibid.
[314] Lesser, Guy "Keeping a Tradition Alive: Venice's Silk Weavers" International Herald Tribune August 17, 1993

clusters, what lessons are to be learned for our proposed phased response system and the R&D and manufacturing functions inherent to its success?

To answer these questions, an analysis of a series of regional clusters throughout the United States is presented below in case study form. While it is always hard to define the boundaries of a cluster, there are some common elements:

- A high level of R&D performed inside the geographic boundaries of the cluster
- Wages that are higher than average for the respective Metropolitan Statistical Areas (MSAs)
- Higher levels of educational attainment
- A significant number of firms and employees in the lateral complementary specialties that are geographically linked in a way that allows close collaboration and cross pollination of ideas and practices as employees move among firms.

In the case studies presented here, the clusters were conceived in many different ways with an array of situational and practical parents. For example, Houston's oil and gas industry cluster developed from a natural resource endowment that required constant monitoring and maintenance. By contrast, Pittsburgh's Life Science Greenhouse arose out of a conscious government effort to leverage local assets to create jobs and investment in an area reeling from years of disinvestment and job loss. In North Carolina, Research Triangle Park was the result of a university idea brought to life by a private developer that the universities approached.

Regardless of how a cluster is born, the case studies illustrate several factors that must be present in order for the clusters to survive and thrive. The factors are[315]:

- Natural Resource Endowment and/or Interest Champion
- University Involvement – In most clusters the local university/ies play the key role
- Anchor Firm - One or several firms that are large enough to create spinoffs and are involved enough to act as interest champion or to play a close supporting role
- Networks/Collaboration - The cluster succeeds or fails based on informal networks such as softball games and lunch gatherings as well as more formal linkages cultivated by employee transfer, partnerships and cluster-based cooperative marketing and idea exchanges
- Government Involvement – Governments support the cluster as clients, partners, and investors and most importantly as providers of infrastructure and quality.

[315] Factors cited are a distillation of several sources including Michael Porter's corpus of work, the US Economic Development Agency Reports, The Presidents Council on Global Competitiveness, and the ongoing work of the Stanford Institute for Economic Policy Research.

Governments also need to provide low regulatory interference and higher than average quality of life to attract and retain employees

When the case studies are evaluated for their applicability to the proposed R&D cluster, the case studies of Research Triangle Park and the Life Science Greenhouse in Pittsburgh demonstrate that not all factors need to be present in order for a cluster to thrive. Research Triangle Park had little if any natural resource advantages at its conception and limited technological or research in the area upon which to draw. In addition, the cluster site was a tightly defined space smaller than Philadelphia's Fairmount Park and not much larger than the proposed Navy Yard site. Pittsburgh's Life Science Greenhouse was the result of an overarching study of local assets that were then rebranded and focused with relatively modest government start up funding.

Software Technology Route 128 – Boston, Massachusetts

Establishing the nation's largest software technology cluster was not part of the Route 128 design plan. It was constructed simply to circumvent Boston. However, the city's historical attraction for inventors, its access to skilled professionals and research funding, and physical infrastructure combined to create the software development industry cluster along the Route 128 corridor.

Boston has a historical attraction for inventors. By the mid-19th century, the city had a national reputation as a center for technological innovation, and attracted many inventors and professionals who were seeking opportunities to expand in their fields.[316] Over the years, several industries established themselves in the region, including the auto industry, telecommunication, and minicomputers. However, each of these industry clusters eventually relocated to other cities like Detroit, New York, and Silicon Valley, respectively.[317] In spite of these losses, the Massachusetts economy continues to recover, due in part to the strong influence of MIT and other universities, which make a significant contribution to the area's high level of education, large number of start up companies, and elevated per capita patent rates.

Route 128 was built in the 1920s to eliminate traffic congestion. The area attracted businesses from the very beginning. Real estate agents and corporations recognized the corridor's growth potential due to the availability of land and easy access to universities and other research bases in the city.[318] Raytheon was already located along the 65-mile highway span in 1951 when the state expanded the strip and additional industrial parks were built around it. The Federal Government's post World War II provided large

[316] Manning, Kenneth R. Nov. 21, 2005. "The Culture of Invention in Boston" Accessed on Nov. 26, 2007 via http://edison.rutgers.edu/latimer/cultinvt.htm and Boston History and Innovation Collaborative. Accessed on Nov. 26, 2007 via www.bostoninnovation.org

[317] "Boston's Lessons in Sparking Innovation." Bob Krim and Janey Bishoff August 24, 2007. The Boston Globe. Accessed on Nov. 26, 2007 via http://www.boston.com/news/globe/editorial_opinion/oped/articles/2007/08/24/bostons_lessons_in_sparking_innovation/

[318] Mass Moments. Accessed on Nov. 14, 2007 via http://www.massmoments.org/moment.cfm?mid=246

amounts of research and development funding to universities and the technology industry, which increased the number of skilled professionals in the region.[319] In the 1970s and 1980s, funding from the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) supported high technology and led to the creation of a minicomputer industry.[320] However, faster innovation and a younger, highly skilled workforce in California drew the minicomputer industry away from the Boston area.

The study of The Silicon Valley cluster consists of more risk-taking, start up businesses, and Saxenian (1995) identifies that a "distinguishing feature of the Silicon Valley economy is its unparalleled rates of new firm formation….In 1992, for example, some $800 million in venture capital investments went to 152 Silicon Valley start-ups out of a pool of $2.5 billion invested nationwide."[321] On the other hand, the Boston region produces more stable, centralized corporations. Of the historical leaders of the region, Campbell (1995) says "…their ethic of work and their emphasis on authority and prudence still influence New England's communities,"[322] Alan Earls attributes the differences between Silicon Valley and Route 128 to the fact that in Boston "…firms had become entrenched, had sought to foster loyalty and long-term commitment in their employees, and so on, because that was the key to their success up to that point."[323] In stride with the Boston culture of loyalty, Massachusetts law gives businesses more power to contain employees than other states. Massachusetts also has less government restrictions on the software industry than other states, causing the return of businesses and skilled professionals to the Boston area.[324] Other cultural attractions like parks, museums, and the maritime industry, along with more room for residential expansion has been drawing companies away from the Silicon Valley.[325]

Although the minicomputer industry relocated to the West Coast, the presence of MIT and Harvard, combined with the previous establishment of the computer industry makes this region extremely attractive to new businesses. MIT, in particular, has played a leading role in the growth and establishment of the software industry by providing students with the skills necessary to build and sustain companies in the area.[326] The university's founding philosophy of "learning by doing" established a practical, academic

---

319 "Refining the University-Industry Relationship for Manufacturing Excellence." Eager, et al. September 20, 1993 accessed on November 21, 2007 via http://eagar.mit.edu/EagarPapers/Eagar146.pdf

320 Mass Moments. Accessed on November 14, 2007 via http://www.massmoments.org/moment.cfm?mid=246

321 Saxenian, AnnaLee. "Creating a Twentieth Century Technical Community: Frederick Terman's Silicon Valley." November 1995. Accessed on Nov. 28, 2007 via http://people.ischool.berkeley.edu/~anno/Papers/terman.html

322 Campbell, John. "Mid-life Crisis on Route 128" Regional Review. Summer 1995, vol. 5 issue 3

323 "Watching the Rise of Route 128, the Road to Nowhere" Interview with Alan Earls. From Newslink, Vol. 7, No. 2, Winter 2003.

324 "MIT: The Impact of Innovation." March 1997, Bank Boston. Accessed on Nov. 21, 2007 via http://web.mit.edu/newsoffice/founders/Founders2.pdf

325 Saxenian, AnnaLee. "Creating a Twentieth Century Technical Community: Frederick Terman's Silicon Valley." Nov. 1995. Accessed on Nov. 28, 2007 via http://people.ischool.berkeley.edu/~anno/Papers/terman.html

326 Etzkowitz, Henry. 2002. MIT and the Rise of Entrepreneurial Science. Routledge; London

culture in the region that has been a key factor in the success of Route 128. MIT was established by William Barton Rogers in 1861 with the goal of industrializing the region. His vision was to teach and encourage students to use scientific knowledge they learned in classes and apply it to industries of interest. Professors are encouraged to teach current problems of industry, encouraging students to understand and solve problems they might encounter after graduation.[327] MIT also supports networking and retaining close ties between professors and students, so that advice and expertise of MIT faculty and other supporters can help graduates' businesses survive.[328] The MIT Industrial Liaison Program, which allows alumni to tap into faculty and staff research to support technological and managerial innovation, is another academic resource that helps attract skilled labor, and innovation[329]

Currently, about 150 companies with MIT connections are established each year. The largest portion of these companies is in the electronics industry, which includes computers, semiconductors, instruments, telecommunications equipment, and electrical machinery. Other industries that attract MIT startup companies are software and engineering consulting.[330] Although less than 9 percent of MIT students are from Massachusetts, 45 percent of MIT-related companies are located in the Boston area, which suggests that graduates prefer establishing their entrepreneurial efforts in the region. University access has a strong influence on the entrepreneurs among MIT graduates. In a Bank Boston survey, MIT alumni stated that proximity to the University has a greater influence when choosing to start a company than any other business cost.[331]

Access to a skilled workforce is another important factor to consider when founding a company. In 2005, 37 percent of the Massachusetts labor market had at least a bachelor's degree, placing it 10 percent higher than the national average.[332] In Boston, approximately 55 percent of the population has at least some college education.[333] Patent activity also demonstrates the region's high level of education. In 2006, Boston led the nation in patents per capita, receiving 54 per 100,000 people.[334]

However, the cost of housing is beginning to exert its influence on the workforce. Massachusetts is experiencing an affordable housing shortage, and rising housing costs

[327] "MIT: The Impact of Innovation." March 1997, Bank Boston. Accessed on Nov. 21, 2007 via http://web.mit.edu/newsoffice/founders/Founders2.pdf
[328] Ballon, Marc "Entrée to Riches: Winning at MIT." March 1998. Accessed on Dec. 5, 2007 via http://www.inc.com/magazine/19980301/882.html
[329] MIT Industrial Liaison Program. Accessed on Nov. 21, 2007 via http://ilp-www.mit.edu/display_page.a4d?key=H1
[330] "MIT: The Impact of Innovation." March 1997, Bank Boston. Accessed on Nov. 21, 2007 via http://web.mit.edu/newsoffice/founders/Founders2.pdf
[331] MIT Industrial Liaison Program. Accessed on Nov. 21, 2007 via http://ilp-www.mit.edu/display_page.a4d?key=H1
[332] Speech by Susan Hockfield given on Sept. 14, 2005. Accessed on Nov. 26, 2007 via http://web.mit.edu/hockfield/speeches/2005-chamber-of-commerce.html
[333] "Boston's Dynamic Workforce." Accessed on Dec. 3, 2007 via www.cityofboston.gov/bra/pdf/documents/20-34report.pdf
[334] The Boston Indicators Project. Accessed on Dec. 3, 2007 via www.bostonindicators.org

are driving residents from the region.[335] [336] Specifically, the Greater Boston area is experiencing a lack of workforce housing, i.e., single family homes for young families with children. The Greater Boston Housing Report Card 2005-2006 states that "The lack of housing for this important market segment continues to discourage 25- to 34-year-olds from remaining in the region or moving here." However, in 2006 Boston housing prices did decrease—by 2 percent—for the first time since 1990.[337] While this is an important trend, Massachusetts acknowledges the importance of creating more affordable housing and zoning to improve the quality of life for its residents.[338]

While collaboration between universities, industry, and government has led to successes within various industry clusters, the importance of regional factors is evident when studying the Boston software technology industry. Massachusetts is unusual in its ability to produce strong clusters throughout history, and research has attributed this capability to cultural elements. The recounting of regional innovation and invention has fostered a tradition of creativity while maintaining stability. MIT has also been influential in producing a skilled workforce, providing a strong compilation of business expertise, and building and retaining businesses for economic growth. While Massachusetts housing affordability is low, there have been slight improvements in the last year. The improvement in housing accessibility, along with the impressive workforce statistics and patent rates makes the Boston region well-suited for the software technology cluster.

Research Triangle Park – Raleigh-Durham, North Carolina

The Research Triangle Park (RTP) in Raleigh-Durham, North Carolina, was founded in 1959 in response to an economic crisis in the region.[339] Private and state government leaders organized to address the lack of skilled employees and the area's low per capita income. Karl Robbins, a private investor, bought about 4,000 acres of pineland to begin the research center. The Pinelands, a for-profit company, became the first shareholder and helped recruit more investors and companies.[340] The University of North Carolina and Duke University then became involved to form the Research Triangle Foundation, a nonprofit organization that runs the park. The landscape forms a triangular campus linking the University of North Carolina - Chapel Hill, Duke, and North Carolina State University. RTP is 7,000 acres, stretching 2 miles wide and 8 miles long.[341]

---

335 "MIT: The Impact of Innovation." March 1997, Bank Boston. Accessed on Nov. 21, 2007 via http://web.mit.edu/newsoffice/founders/Founders2.pdf

336 "The Greater Boston Housing Report Card 2005-2006." Retrieved from www.bostonindicators.org on Dec. 5, 2007

337 The Boston Indicators Project. Accessed on Dec. 3, 2007 via www.bostonindicators.org

338 "We Can't Afford Business as Usual" 2006 Massachusetts Housing Partnership Annual Report. Accessed on Dec. 5, 2007 via http://www.mhp.net/uploads/resources/low_res_mhp_2006_ar.pdf

339 http://www.rtp.org/files/Fact%20Sheets/overview_presentation.pdf Accessed on Dec. 28, 2007

340 Link, A. N. & Scott, J. T. "The Growth of Research Triangle Park" Accessed on Dec. 28, 2007 via http://www.dartmouth.edu/~jtscott/Papers/00-22.pdf

341 http://www.rtp.org/files/Fact%20Sheets/rtp_general.pdf Accessed on Dec. 28, 2007

The Research Triangle Institute was the first company to locate in RTP.[342] Since then, companies like IBM, GlaxoSmithKline, and government agencies like the EPA have established bases in the area, creating jobs in software engineering,[343] statistical analysis,[344] and biological and health sciences.[345] The opportunity for businesses to locate near large research universities and other companies gives RTP an advantage over clusters that are more spread out. According to Harvard economist Michael Porter, "geographic, cultural, and institutional proximity leads to special access, closer relationships, better information, powerful incentives, and other advantages in productivity and innovation that are difficult to tap from a distance."[346] Transportation access is another advantage of the location. Research Triangle Park's proximity to the Raleigh-Durham International Airport, several major highways and railways, and Wilmington and Moorehead City ports make it easily accessible.

Research Triangle Park was formed mostly by private interests and the government has played a minimal role in its development. Private sector groups decided that the concept behind the Research Triangle project idea was valid and should be undertaken as a private effort with participation of the three flagship universities rather than sponsored by the state or Federal government.[347] Research Triangle Park has collaborated to form several organizations which maintain and promote growth within and among industries. The Research Triangle Foundation manages and develops RTP while regulating that the Park's environmental and aesthetic dimensions are maintained.[348] RTI International, originally the Research Triangle Institute, which was the first company in the Park, is currently a leading research organization that works to "harness the intellectual capital of the area's three major universities."[349] RTI offers innovative solutions to governments and businesses in the fields of technology, health, education, economic and social development, and environmental issues. The Triangle Universities Center for Advanced Studies, Inc. (TUCASI) maintains and encourages university involvement in the RTP. TUCASI works with the three universities to oversee projects and research that will improve the status of RTP and the schools.[350]

When RTP was founded, private and academic local leaders wanted to improve North Carolina's economy by creating higher paying jobs, increasing the level and quality of

---

[342] http://www.rti.org/newsroom/page.cfm?nav=830 Accessed on Dec. 28, 2007

[343] http://careers.peopleclick.com/Client40_GLDTR/bu1/External_Pages/Showjobs.htm Accessed on Dec. 28, 2007

[344] http://us.gsk.com/html/career/jobsearch.html Accessed on Dec. 28, 2007

[345] http://www.epa.gov/rtp/employment/index.htm Accessed on Dec. 28, 2007

[346] Porter, Michael. "Clusters and the New Economics of Competition." *Harvard Business Review* 76 (Nov/Dec.1998): 80

[347] Weddle. R. L. "Summary of Remarks and Supporting Data Panel I: North Carolina's Changing Economy":4 Accessed on Dec. 28, 2007 via http://www.uscc.gov/hearings/2007hearings/transcripts/sept_6/rick_weddle.pdf

[348] Weddle, R. L, Rooks, E. & Valdecanas, T. "Research Triangle Park: Evolution and Renaissance" June 2006. Accessed on Dec. 28, 2007 via http://www.rtp.org/files/Fact%20Sheets/rtp_history.pdf

[349] http://www.rti.org/newsroom/page.cfm?objectid=811D5426-8352-4177-AB05DDE414A36804

[350] Harden, J. Presentation on RTP, Dec. 30, 2005. Accessed on Dec. 28, 2007 via http://www.klv.nl/hulsink/Hardin_Presentation____Research_Triangle_Park.pdf

education, and reducing unemployment.[351] Leaders also wanted to shift the local industrial focus from agriculture and manufacturing to research and technology. By positioning RTP between three major universities, the region was able to attract and maintain selective college students and graduates, increasing human capital in the state. Currently, 53 percent of the Raleigh-Durham population has earned a bachelor's degree or higher.[352] The Research Triangle Foundation also made a point to focus more on increasing capital than providing low wage employment for company profits. The RTP currently includes 157 companies and employs more than 39,000 individuals. By providing more than 40,000 housing units in the area, the Park has also made it easy for employees to access and live close to the center.

RTP holds a variety of cluster industries, including biotechnology and pharmaceutical sectors, information technology, professional and financial services, electronics, and environmental science.[353] Twenty-nine percent of RTP companies are in the biotechnology and pharmaceutical cluster. Nineteen percent of the companies are in the information technology cluster and 16 percent are in the professional and financial services cluster. These industries continually compete within and between clusters to increase innovation and profits.

The RTP also facilitates informal networks, which cultivate personal relationships among companies and employees while supporting information sharing and a sense of community. For example, four softball leagues with eight teams each play for recreationally.[354] The league stresses that the games are not related to work, and that there should be minimal competition between teams. Twice a month, on "Techie Tuesdays," employees from any company in the RTP can meet for drinks, socializing, and networking.[355] The RTP Owners & Tenants Association has also organized a SmartCommute association to help RTP employees carpool to work.[356] The SmartCommute program saves employees money and reduces traffic congestion and pollution in the surrounding areas. There are also several jogging and pedestrian trails for employees throughout the RTP.[357]

Research Triangle Park demonstrates that a cluster can thrive even when some of the success factors are absent. The location had no natural resource advantage and the interest champion, a consortium of private sector groups, wanted no government involvement. There were very few technological or research resources and opportunities at the outset. However, the presence of other success factors was strong enough to

---

351 Weddle, R. L, Rooks, E. & Valdecanas, T. "Research Triangle Park: Evolution and Renaissance" June 2006. Accessed on Dec. 28, 2007 via http://www.rtp.org/files/Fact%20Sheets/rtp_history.pdf
352 Weddle. R. L. "Summary of Remarks and Supporting Data Panel I: North Carolina's Changing Economy" : 4 Accessed on Dec. 28, 2007 via http://www.uscc.gov/hearings/2007hearings/transcripts/sept_6/rick_weddle.pdf
353 http://www.rtp.org/files/Fact%20Sheets/overview_presentation.pdf Accessed on Jan. 2, 2008
354 Research Triangle Softball League. Accessed on Jan. 2, 2008 via http://wiki.rtp.org/uploads/2007_Information_Packet.pdf
355 http://www.rtp.org/main/index.php?pid=132&sec=3 Accessed on Jan. 2, 2008
356 http://www.smartcommute.org/AboutUs.htm Accessed on Jan. 2, 2008
357 http://www.rtp.org/files/Fact%20Sheets/rtp_pedestrian_trails_102507.pdf Accessed on Jan. 2, 2008

overcome these absences. The University of North Carolina - Chapel Hill, Duke, and North Carolina State University were involved from the very beginning. The Park's compact geography placed businesses in close proximity to research institutions and to each other. This close proximity created the ideal conditions for the formal and informal network collaboration, idea exchanges, and competition that help a cluster thrive. The presence of these success factors, combined with a sufficient supply of affordable housing and an extensive and varied transportation infrastructure ensured the success of the RTP cluster.

Connecticut Maritime Cluster

Connecticut's maritime industry began to develop when the Electric Boat Company was founded in 1900 and other maritime companies grew around it.[358] Electric Boat was one of the state's largest employers and formed the core of a thriving maritime industry. However, as other regions increased their port activity and the EPA began to strictly regulate the industry, Connecticut began losing revenue and influence within the maritime industry.[359]

The state's recession in the early 1990s prompted the Governor to take a new approach to economic growth. A meeting with 100 top executives and various surveys were distributed to determine the state's strengths and weaknesses. This initiative generated five advisory boards, and in 1998 they produced the *Partnership for Growth: Connecticut's Economic Competitiveness Strategy*. This report established the foundation for Connecticut's current economic development strategy, using Michael Porter's approach to create formal clusters to increase competition and growth.[360] Connecticut was one of the first states to adopt an economic strategy of increasing growth and competition by intentionally developing industry clusters within the state.

The *Partnership for Growth II: A Competitiveness Agenda for CT* includes five categories of recommended goals to further the economic development of Connecticut's clusters. The first recommendation is to increase the competitiveness of the manufacturing industry, since this is where much of the state's employment is based. The report's second set of recommendations calls for maintaining a strong technology sector to help compete with high technology neighbors like Massachusetts. Connecticut also realizes that inner city revitalization will help attract and maintain businesses and customers to the area. Expanding business growth and improving safety and attractiveness of urban areas is the report's third recommendation. Next, Connecticut is focusing on increasing their economic base, which includes higher skilled workers,

---

[358] *Partnership for Growth II: A Competitiveness Agenda for CT*. March 2004. Accessed on Nov. 7, 2007 via http://www.youbelonginct.com/pupload/PforGreport_web.pdf

[359] Connecticut Maritime Cluster Strategic Plan. December 2001. Accessed on Nov. 5, 2007 via ctmaritime.com/downloads/2002%20CLUSTER%20STRAT%20PLAN.doc

[360] Connecticut General Assembly report, accessed on Nov. 7, 2007 via http://www.cga.ct.gov/2000/pridata/Studies/DOT%20Final%20Chapter%20IV%20.htm

improved transportation infrastructure, low taxes and other business incentives, and high quality of life. Finally, public and private collaboration is addressed as an important aspect of growth and development in the clusters.[361]

In order to reach these goals, the state has created a Maritime Policy under the Department of Transportation. This policy calls for dredging Long Island Sound in order to maximize use of traffic lanes for goods and passengers.[362] The Maritime Policy also provides funding for technologically advanced methods of removing sediment from the Sound, and calls for interconnecting multiple modes of transportation in order to increase the access to and amount of revenue for water ports. The Connecticut Maritime Coalition was established in 2004 to represent and unite maritime transportation organizations and agencies.[363] The Commission evaluates and suggests various projects and policies to increase the productivity of the maritime industry.

The maritime industry relies on Connecticut's three main ports: New Haven, Bridgeport, and New London. The cluster has worked with local and state governments, along with private leaders, to increase port size and improve physical structure. These ports are becoming increasingly limited in size and space, which has spurred the major effort to dredge these areas on Long Island Sound. Although Congress is responsible for funding the US Army Corp of Engineers' maintenance of channel depths, funding is often cut and the state has to supplement federal funding.[364] Therefore, the Connecticut Maritime Commission (CTMC), the Department of Economic and Community Development (DECD), and the Department of Transportation (CONNDOT) have worked to regulate and fund the dredging projects. This collaboration has resulted in the LIS Dredged Material Management Plan and the receipt of federal funding for the Innovative Dredged Material Treatment project in Bridgeport. The collaboration also created dredging coordinator positions under the Transportation Bill. In addition, in an effort to mitigate traffic on I-95, the Connecticut Maritime Coalition has helped create a Transportation Strategy Board to regulate the region's transportation flow.[365]

The maritime cluster industry includes five sectors: transportation, manufacturing and services, recreation, commercial fishing, and the environment.[366] Currently, the Connecticut maritime industry includes about 349 small and medium sized companies, and employs more than 12,000 people.[367] The DCED funds the campaign, *You Belong in Connecticut*. There are a broad range of efforts—all part of the *You Belong in Connecticut* campaign—to promote Connecticut's retention of well-educated and skilled

---

[361] *Partnership for Growth II: A Competitiveness Agenda for Connecticut*. March 2004. Accessed on Nov. 7, 2007 via http://www.youbelonginct.com/pupload/PforGreport_web.pdf
[362] Accessed on Jan. 4, 2008 via http://www.ct.gov/dot/cwp/view.asp?a=2314&Q=309828
[363] Connecticut Maritime Commission Annual Report 2006. Accessed on Jan. 3, 2008 via http://www.ct.gov/dot/lib/dot/documents/dcmtc/a2006.pdf
[364] Connecticut Maritime Commission Annual Report 2006. Accessed on Jan. 3, 2008 via http://www.ct.gov/dot/lib/dot/documents/dcmtc/a2006.pdf
[365] "You Belong in Connecticut." Accessed on Nov. 7, 2007 via www.youbelonginct.com
[366] Connecticut Maritime Coalition Report, accessed on Nov. 7, 2007 via ctmaritime.com/downloads/CMC%20Final%20Report.doc
[367] Connecticut Maritime Coalition, accessed on Nov. 7, 2007 via www.ctmaritime.com

workers, and to recruit and expand businesses.[368] The state has also reduced taxes for businesses and decreased the sales tax for labor in shipyards and marine industry.[369]

The focus of Connecticut's cluster development strategy is to increase the availability of education and job training in the marine industry. The Connecticut Maritime Education Working Group works with local schools and colleges, including the University of Connecticut, to increase the availability of jobs and individuals who may be interested in working in the industry. The University of New Haven offers a program in marine biology,[370] the University of Connecticut makes available undergraduate and graduate degrees in marine science,[371] and the Coast Guard Academy in New London has three areas of specialization available in marine and environmental sciences.[372] In New Haven, the Sound High School was founded to educate high school students who are interested in entering the aquaculture field.[373]

For the maritime cluster, government involvement played several roles in the success of the cluster. State government support began when the Governor and other officials assumed the champion role and laid the groundwork to intentionally develop industry clusters. The state's Competitiveness Agenda resulted in the creation of the Maritime Policy designed to maximize the economic potential of Long Island Sound and its major Connecticut ports. The state and local governments also engaged in network collaboration. Government organizations have partnered with each other and with private sector leaders to work on port improvement. Two state government departments and a commission collaborate to regulate and fund the dredging projects.

University and other educational institution involvement is focused on connecting youth to opportunities in the marine industries that take advantage of Long Island Sound's natural resource endowment. In particular, the Connecticut Maritime Education Working Group, which includes members from state government, maritime businesses and higher education institutions, works with universities and high schools to promote maritime training and education.

Energy Cluster – Houston, Texas

The petrochemical industry began in the Houston region with the discovery of oil on January 10, 1901, in the Spindletop oilfield.[374] By 1902, more than 500 companies had

[368] *Partnership for Growth II: A Competitiveness Agenda for CT*. March 2004. Accessed on Nov. 7, 2007 via http://www.youbelonginct.com/pupload/PforGreport_web.pdf

[369] Connecticut Maritime Cluster Strategic Plan. December 2001. Accessed on Nov. 5, 2007 via ctmaritime.com/downloads/2002%20CLUSTER%20STRAT%20PLAN.doc

[370] http://www.newhaven.edu/show.asp?durki=33 Accessed on Nov. 16, 2007

[371] http://www.marinesciences.uconn.edu/ Accessed on Nov. 16, 2007

[372] http://www.cga.edu/display.aspx?id=519 Accessed on Nov. 16, 2007

[373] The Sound School, accessed on Nov. 7, 2007 via www.soundschool.com

[374] "Paths to Prosperity: Strategic Job Growth Parameters for 'Opportunity Houston' Through 2015." The Perryman Group. Accessed on Nov. 12, 2007 via http://www.opportunityhouston.org/pdfs/PerrymanReport.pdf

migrated to the area, hoping to profit from oil production or related industries.[375] After 1902, the industry dwindled until post World War II, when the changing economy and greater uses for oil and oil products increased demand. Renewed development of the industry in the 1950s resulted in the discovery of new oil fields and an increase of employment and economic growth. Since 1990, however, US proven oil reserves have declined by approximately 20 percent.[376]

This decline has had a significant effect on the Houston area, where 48 percent of employment is related to the energy industry.[377] The industry has been divided into three sectors: oil and gas; electricity, coal, and nuclear sources; and renewable and sustainable energy[378]. The industry has devoted considerable research and development funding to market and advance the renewable resources sector in response to the recent decline in oil and gas production. An Energy Workforce Council was suggested to evaluate the industry workforce and to attract human capital to the region, and the Energy Advisory Group provides consultation and advice while advancing networking and communication.[379]

In October of 2004, Texas governor Rick Perry announced an economic strategy that would focus on the development of six industry clusters in the state, and would use existing business development to generate economic growth.[380] The Office of the Governor, the Economic and Tourism Division, and the Texas Workforce Commission collaborated to create teams for each cluster, consisting of private, business, and government leaders. The teams were then instructed to complete a competitive assessment, and determine the resources and funding each industry needed from the state. The energy cluster determined that natural resources and expertise are its greatest strengths, and that the industry should focus on marketing and research and development of natural energy sources.

The instability and variability of the oil and gas industry has led to advancement in other areas of the energy industry, specifically renewable and sustainable resources. Currently, Texas is the largest producer of wind energy in the nation.[381] Since oil and gas prices have historically been so volatile, the energy industry has adopted renewable and sustainable resources into their cluster initiative. British Petroleum also announced in 2006 that they would place their alternative energy headquarters in Houston, showing their commitment to the region.[382]

---

[375] The Handbook of Texas, accessed on Nov. 12, 2007 via http://www.tsha.utexas.edu/handbook/online/articles/SS/dos3.html

[376] http://hypertextbook.com/facts/2000/SohailAhmed.shtml Accessed on Jan. 9, 2007

[377] www.houston.org Accessed on Nov. 7, 2007

[378] Texas Energy Cluster report accessed on Nov. 12, 2007 via http://www.texasindustryprofiles.com/PDF/twcClusterReports/TexasEnergyCluster.pdf

[379] Texas Energy Cluster report accessed on Nov. 12, 2007 via http://www.texasindustryprofiles.com/PDF/twcClusterReports/TexasEnergyCluster.pdf

[380] Office of the Governor, Cluster Industry Initiative. Accessed on Nov. 14, 2007 via http://www.governor.state.tx.us/divisions/press/initiatives/Industry_Cluster/Industry_Cluster_SP/

[381] "Alternative Energy in the Houston Region." Greater Houston Partnership. Accessed on Nov. 14, 2007 via http://www.houston.org/blackfenders/16BW035.pdf

[382] http://www.bp.com/genericarticle.do?categoryId=7014&contentId=7026292 Accessed on Jan. 8, 2007

The Bauer College of Business at the University of Houston has established the Global Energy Management Institute to inform and prepare students for involvement in the energy cluster.[383] The University of Houston has also worked with the Department of Energy (DOE) to research and develop opportunities for renewable energy resources.[384] The Lone Star Wind Alliance is a collaboration among the University of Houston's Cullen School of Engineering, Texas A&M University, the University of Texas at Austin, and other neighboring universities. This partnership has focused on increasing the innovative efforts and funding for renewable energy, and works to obtain state and federal support.

Texas has been experiencing a "demographic cliff" in recent years. Baby boomers are preparing for retirement, the state has an elevated high school dropout rates, and new professionals are not replacing those leaving the industry.[385] The Texas Industry Cluster Initiative identified workforce challenges as "the single greatest factor that will limit job creation and capital investment in the Texas energy industry of the future."[386] This *Cluster Report* also identified a lack of employees with skills needed for industry development, and showed that there are not enough employees with adequate skills; therefore companies are forced to compete for workers. Because many of the industry professionals have typically been foreign-born, there has also been a sharp decline in the industry workforce due to the strict immigration laws implemented recently.

Michael Porter's Cluster Mapping Project highlights the lack of an overarching cluster organization for the Houston energy industry.[387] Without an agency or organization to provide opportunities for networking, it is more difficult for the cluster to utilize the information resources needed for growth. Business collaboration and informal networking were not given much preference by leaders in the industry, according to surveys and interviews in the state.[388]

A factor contributing to the success of the Houston energy cluster was the ability to take advantage of a natural resource endowment of renewable and sustainable energy sources and the economic experiences gained from another natural resource endowment: petrochemicals. This cluster provides another example where the state assumed the interest champion role. In this case, the Governor launched a strategy to develop six industry clusters throughout Texas. The Governor's office collaborated with the Economic and Tourism Division and the Texas Workforce Commission on Energy Cluster development. The Energy Cluster also benefited from the US DOE's

[383] http://www.bauer.uh.edu/gemi/ Accessed on Jan. 9, 2007
[384] http://www.uh.edu/news-events/archive/nr/2007/06june/062507windcenter.html Accessed on Jan. 9, 2007
[385] Texas Industry Cluster Initiative: Briefing Document. Accessed on Jan. 8, 2007 via http://www.twc.state.tx.us/news/ti_crosscutting.pdf
[386] Texas Energy Cluster Report p. 5 accessed on Nov. 12, 2007 via http://www.texasindustryprofiles.com/PDF/twcClusterReports/TexasEnergyCluster.pdf
[387] http://www.isc.hbs.edu/MetaStudyTemplateHoustonOilAndGas.pdf Accessed on Jan. 8, 2007
[388] Texas Energy Cluster Report. Accessed on Nov. 12, 2007 via http://www.texasindustryprofiles.com/PDF/twcClusterReports/TexasEnergyCluster.pdf

collaboration with the University of Houston on renewable energy research and development. However, all of these efforts have been insufficient in maintaining a strong and thriving energy cluster. This case study is an example of a cluster that developed based on a non-renewable natural resource which is too unpredictable to be depended on. The absence of informal networks and strong university involvement has left companies within the industry competing for employees who often are low-skilled. While the state has played a large role in attempting to revive the cluster, it remains relatively stagnant.

Pittsburgh Life Science Greenhouse – Pittsburgh, Pennsylvania

In the spring of 2001, the University of Pittsburgh and Carnegie Mellon University collaborated to propose the BioVenture initiative, which called for the growth and development of the bioscience industry in the region.[389] The BioVenture is expected to create 5,000 jobs over 10 years, and the endeavor will cost $600 million.[390] This project integrated community input into the plan's development by interviewing more than 120 people and conducting community sessions with individuals and organizations from the life science industry, academia, health services, economic development organizations and government officials.[391] Their proposal was based on the previously established Pittsburgh Engineering Greenhouse, a successful engineering cluster in the region. In November of that same year, then Governor Tom Ridge allocated $40 million to the initiative through the Tobacco Settlement, a multi-state program focused on tobacco use prevention.

Active partners and organizations, including the Pittsburgh BioVenture, University of Pittsburgh Medical Center, Pittsburgh Regional Alliance, and business and government leaders agreed to integrate their ongoing efforts into what is now known as the Life Science Greenhouses.[392] There are currently three Life Science Greenhouses in the state of Pennsylvania: Philadelphia, Harrisburg, and Pittsburgh. The goal of the Pittsburgh Life Science Greenhouse (PLSG) enterprise is to increase the size and productivity of the life sciences industry, and within a 10-year span to make Pittsburgh the leader in the biosciences.[393]

University investments, especially those of the University of Pittsburgh and Carnegie Mellon, have made the bioscience industry growth extremely successful. Six regional universities graduated almost 8,000 science and engineering students in 2003, increasing

[389] Pittsburgh BioVenture/Life Sciences Greenhouse Prospectus. Oct 2001. Prepared by Technology Partnership Practice, Batelle Memorial Institute, Cleveland Ohio. Accessed on Nov. 2, 2007 via http://www.pittsburghregion.org/public/cfm/homepage/pdf/BioVentureSummary.pdf

[390] "Pitt, CMU seek $600 Million to Build up Biotech Industry" Nov. 11, 2001 Post-Gazette.com. Accessed on Jan. 7, 2007 via http://www.post-gazette.com/businessnews/20011120bioven1120p2.asp

[391] "BioVenture/Life Sciences Greenhouse Aims to Develop Bioscience Industries" Dec. 5, 2001. Carnegie Mellon News. Accessed on Nov. 1, 2007 via http://www.cmu.edu/cmnews/011205/011205_bioventure.html

[392] Pittsburgh Life Science Greenhouse website, accessed on Nov. 2, 2007 via http://plsg.com/index.php?option=com_content&task=view&id=12&Itemid=26

[393] Pittsburgh Life Science Greenhouse website, accessed on Nov. 2, 2007 via http://plsg.com/index.php?option=com_content&task=view&id=12&Itemid=26

the amount of relevant skills in the labor force. The University of Pittsburgh and Carnegie Mellon sponsor the Pittsburgh Nuclear Magnetic Resonance (NMR) Center for biomedical research,[394] and work together on the Center for the Neural Basis of Cognition (CNBC) which develops methods and researches neural and cognitive abilities.[395] The NMR Center and the CNBC are instrumental in strengthening the research and innovation capacities of Pittsburgh's life science industry. A recent $25 million dollar donation to Carnegie Mellon University from the Richard King Mellon Foundation will help the school play a larger part in the life science industry by providing funding for students and labs.[396]

The University of Pittsburgh created a Center for Industry Studies in 2001 to facilitate communication and interactions between faculty and industries.[397] The Center is meant to emphasize the importance of relationships between academia and business when planning and developing industries. The Center includes individuals from backgrounds in economics, business, labor relations, and engineering, among others. Therefore, "[the Center] hope[s] to build partnerships that yield educational opportunities and promote economic development."[398]

Venture capitalists have also invested close to $100 million in the cluster, and federal research and development spending in the region exceeds the national average.[399] Healthcare and life science jobs have grown 12 percent in Pittsburgh, compared with 7 percent nationally from 1999 to 2004.[400] Greenhouse interim CEO Donald Smith Jr. stated that "the job growth experienced by the local life sciences industry sector puts the Greenhouse ahead of its initial goal of creating 1,000 regional jobs in its first five years of existence."[401] The EPA has given a grant to Carnegie Mellon for a Brownfields Job Training program, and a Development Demonstration Pilot, which gives scholarships to low income individuals and helps with job placement after training.[402]

Organizations like the PLSG have ensured that small, start-up companies have the resources they need to flourish. They have established a program called the Executive-In-Residence program, which employs experts and executives to provide advice and

---

[394] http://www.cmu.edu/nmr-center/ Accessed on Jan. 7, 2007

[395] http://www.cnbc.cmu.edu/ Accessed on Jan. 7, 2007

[396] "CMU Given Big Grant for Life Sciences" 10/23/2007. *Pittsburgh Post Gazette*. Accessed on Jan. 7, 2007 via http://www.post-gazette.com/pg/07296/827683-298.stm

[397] http://www.industrystudies.pitt.edu/index.html Accessed on Jan. 7, 2007

[398] http://www.industrystudies.pitt.edu/sloanindustrystudies/index.html Accessed on Jan. 7, 2007

[399] Porter, Michael E. "Clusters of Innovation Initiative: Pittsburgh." Accessed on Oct. 29, 2007 via http://www.compete.org/pdf/pittsburgh_ex.pdf

[400] "Job Creation in the Pittsburgh Region." Pittsburgh's Future. Accessed on Jan. 7, 2007 via http://www.pittsburghfuture.com/economy.html#industries

[401] Greenhouse interim CEO Donald Smith Jr. in article "Greenhouse Launches Two Life Sciences Funds" Pittsburgh Business Times, Nov. 14, 2003. Accessed on Jan. 7, 2007 via http://www.bizjournals.com/pittsburgh/stories/2003/11/17/story2.html

[402] " Carnegie Mellon Creates Biomedical Engineering Department To Meet Demands of a Growing Biotechnology Industry" Sept. 9, 2002. Carnegie Mellon News accessed on Oct. 31, 2007 via http://www.cmu.edu/PR/releases02/020909_bioeng.html

strategies to new and mature businesses.[403] The PLSG also provides financial support to university and research programs to accelerate the growth and innovation of these centers. The Pittsburgh Technology Council unites businesses within dominant industries, including life science, and establishes networks for each industry.[404] The life science network encourages industry members to socialize and share information through lectures and other events throughout the year.

Between 1999 and 2003, Pittsburgh has experienced a 51 percent growth in research and development expenditures, which reached $647 million in 2003.[405] The 10-year plan proposed to create 5,000 new jobs in the bioscience industry, and the start-up of 110 new companies. As of 2004, there were 3,229 life sciences firms counted throughout southwestern Pennsylvania, employing a total of 115,000 people. The life science cluster's total payroll for that year was $560 million, and the average salary was about $56,700 which is well above the national average.[406] The plan also projected that a total of $330 million would be invested in the region.[407]

Pittsburgh area universities were significantly involved in all of the factors that led to PLSG success. The University of Pittsburgh and Carnegie Mellon University were the interest champions of the BioVenture initiative, which spun off the PLSG. The involvement of these universities has also included major financial investments and contribution of a large number of skilled graduates to the bioscience workforce. University participation has also dominated the networks and collaboration success factor. The University of Pittsburgh's Center for Industry Studies facilitates communication and interactions between faculty and industries. Government involvement has also led to a strong facilitation of federal research and development grants and funding for the region.

---

[403] Pittsburgh Life Science Greenhouse website, accessed on Nov. 2, 2007 via http://plsg.com/index.php?option=com_content&task=view&id=12&Itemid=26

[404] http://www.pghtech.org/Networks/life/ Accessed on Jan. 7, 2007

[405] Pittsburgh Life Science Greenhouse website, accessed on Nov. 2, 2007 via http://plsg.com/index.php?option=com_content&task=view&id=12&Itemid=26

[406] Porter, Michael E. "Clusters of Innovation Initiative: Pittsburgh." Accessed on Oct. 29, 2007 via http://www.compete.org/pdf/pittsburgh_ex.pdf

[407] "BioVenture/Life Sciences Greenhouse Aims to Develop Bioscience Industries" Dec. 5, 2001 Carnegie Mellon News accessed on Nov. 1, 2007 via http://www.cmu.edu/cmnews/011205/011205_bioventure.html

Chapter 2 – Chemical Warfare Agent Remediation

Villanova University—Dr. Randy Weinstein

Executive Summary

A robust and fast method for neutralizing accidental or intentional contamination of water is needed. This method must be able to be deployed on a fast response vessel to anywhere in the world. The method must be applicable to any type of chemical contaminate and cannot be complex as to interfere with its ease of deployment and effective use. The goal of this method is to quickly neutralize or deactivate the contaminate. A second step requiring further purification and cleaning of the water may be required.

We examined using UV light (sunlight) along with metal oxide nanoparticles as the destruction method. Three test compounds, *m*-dinitrobenzene (DNB), dimethyl methylphosphonate (DMMP), and thiodiglycol (TDG) were used to simulate chemical warfare agents and simple pesticides. These test compounds were studies in fresh and salt water, with and without the addition of dissolved oxygen, and in dirty water. In all cases TiO_2 was the best nanoparticle of those tested for destroying the contaminants. Salt water and dirty water both slowed the destruction process, but it was still able to proceed. Finally, the addition of dissolved oxygen increased the destruction rates and was essential for the destruction of DMMP. The use of UV light, TiO_2 particles, and H_2O_2 (hydrogen peroxide) as the source of oxygen would allow for contaminate destruction. Additional studies are required to explore the byproducts formed and to develop methods for complete oxidation or removal of all contaminants and byproducts formed.

Background

There is a serious threat to our nation's surface waterways (ports, harbors, rivers, lakes, costal waters, as well as potable water supplies) from malicious chemical attacks as well as accidents and equipment failures. Except for the use of aerosols, attack to our nation's food and water systems would be the most effective means of distributing a chemical or biological agent (Kahn, 2001). Our nation requires a two thronged approach to chemical contamination in water. First an EWS (early warning system) must be developed which can monitor water and provide warning at the onset of contamination. The second requirement is a quick clean-up and decontamination method. This two phase approach of quick remote sensing followed by detailed analysis and treatment has gained growing support as the preferred method for chemical warfare agent monitoring (Hill and Martin, 2002).

There are already a number of commercially available sensors for chemical weapons detection in the water and there have been many publications addressing the area of sensor technology for environmental analysis and monitoring of pollutants, contaminants and chemical hazards (Janata, 1992; Ho et al., 2001; Murray and Southard, 2002; Wolfbeis, 2004; Ho et al., 2005). Many different types of sensors have been developed and several types have been found to be adequate for chemical warfare agent monitoring. Surface acoustic wave sensors, ion mobility spectroscopy, and gas chromatography sensors have had success with the military (Ho et al., 2001; Murray and Southard, 2002). Of course more development is underway to improve sensor selectivity, detection limits, robustness in the environment, and to create sensor networks. However, what is not really adequate at this time is the ability to quickly contain and remediate chemical warfare agents once they have been detected in the water. The Navy needs to be able to dispatch containment and treatment facilities anywhere in the world once chemical warfare agents have been detected either onboard a ship (such as a Navy vessel or passenger cruise ship), in the water (open, ports, or drinking supplies), or on land (such as in custom areas in ports). The system would have to be able to treat a wide variety of possible chemical warfare contaminates and also be mobile. The system would need to be very reliable, robust, and require minimal man power to operate. In addition, other chemical pollutants which are detected in the water, such as pesticides, explosives, or ordinary organic chemical spills could also be treated with this system.

Chemical weapon destruction has been occurring for awhile. An excellent 130-page report by Pearson and Magee (2002) was recently published which evaluated all the proven methods for neutralizing and destroying all known chemical weapons. Dumping in any body of water, land burial, and open pit burning are not considered acceptable by the Chemical Weapons Convention (www.opcw.org) which was open for signature in January 1993, although those were some of the early and convenient methods for disposal. It is important to note that recently over 80% of the weapons destroyed have been done so by incineration with the remainder neutralized mainly though hydrolysis or reaction with bases (Pearson and Magee, 2002).

The most common method for destroying chemical agents is through incineration whereby all chemicals containing hydrogen, oxygen, and carbon are converted to carbon dioxide and water. However, many agents have halogen atoms as well as other atoms such as sulfur, nitrogen, and phosphorous. These components are generally converted to the acid halides, nitrogen dioxide, phosphorous pentoxide, and sulfur dioxide which can be removed by scrubbing (Pearson and Magee, 2002). As long as the temperature is high enough and sufficient oxidant (usually oxygen in air) is available the method is environmentally safe, robust, and allows very little escape of agent. However, aqueous solutions would be difficult to burn without the addition of significant amounts of fuel. Furthermore, making a portable incinerator to handle chemical warfare agents is not an easy task due to safety, fuel, and control issues. Supercritical water oxidation units have been developed which take aqueous solutions above the critical point of water (374 ^{o}C and 221 bar) whereby combustion reaction pathways can occur as an alternative to traditional incineration processes. These high temperature, high pressure reactors need to be made out of high nickel alloys as corrosion is often a problem when halogenated agents are treated. Furthermore, salt water would be a significant problem with these reactors as clogging and pitting often occur when salts are present as ionic species have very low solubility in supercritical water. Some unique reactor designs have been developed to overcome some of the technological short comings of supercritical water reactors (Hodes et al., 2004; Marrone et al., 2004). It is believed that a traditional or supercritical water incinerator would take significant time to get onsite and make operational and therefore would not be deemed a fast response treatment method. These techniques would be a great follow-up to a quicker process which can be used to possibly deactivate chemical warfare agents, converting them to less hazardous materials, but not making them totally inert.

The most frequently used low temperature procedure for chemical warfare agent neutralization is through simple hydrolysis by the addition of water and slight heat (~90 ^{o}C) (Pearson and Magee, 2002). Contaminated surfaces and environments are often flushed with large quantities of water to dilute and wash away agents and then this waste water can be heated for treatment. Although frequently used, it is not suited for all possible agents and really has only been employed for mustard. Besides simple hydrolysis, sodium hydroxide in aqueous environments has been employed to neutralize many nerve agents. In addition, amines and other chemicals have also been added to help neutralize a variety of chemical compounds. It is important to note that all of these low temperature destruction methods are very robust but only for a select few warfare agents. In addition, complete destruction to fully oxidized compounds is not achieved and although the agent has been neutralized, the environment is still chemically contaminated. Therefore, alternative methods for chemical warfare agent neutralization in the environment are required. Ones that are robust, work for a large number of possible agents, require minimal manpower, are easily transported, can operate quickly, and have the ability to cross-over and treat other types of organic contaminates (such as explosives or pesticides) need to be developed.

There are numerous methods for chemical contamination remediation in water such as vapor striping, thermal adsorption, fluid extraction and others (Khaitan et al., 2006; Sawicki and Mercier, 2006), but none has shown as much promise as the use of several metal oxide nanoparticles (Sawicki and Mercier, 2006; Zhang and Karn, 2005; Karn et al., 2004). Bromberg and Hatton (2005) showed that magnetic nanoparticles could destroy several nerve agent surrogates as well as pesticides in aqueous environments. It was an important discovery as many nerve agents were found to be stable over a range of pH and temperature in many other hydrolysis processes. Others have also been able to degrade other pollutants using nanosized metals (Meyer et al., 2004) and this new technology deserves a closer look for widespread use in warfare agent cleanup. These nanoparticles can be synthesized Fulton et al., 2006; Ahmadi et al., 1996; Karn et al., 2004; Lanthan et al., 2006 Oskam, 2006), stored, and easily transported to sites where chemical weapons have been detected.

Although the literature shows many ways of destroying or cleaning chemical contaminates from water, these methods are all very specific to an individual contaminate and/or require very unique processing equipment which is not necessarily mobile or easily operated with a minimally trained staff. What is needed for a fast response operation is a method for quickly neutralizing a water contaminate that does not specifically depend on the type of contaminate present. In addition, it should be easy to use and not require advanced personnel training. Without this type of system, our nation's waterways remain highly vulnerable to a deliberate or unintentional contamination which would linger and cause serious environmental and health problems.

Objectives

We studied the use of TiO_2 and ZnO nanoparticles' effectiveness at neutralizing and destroying chemical contaminates in water. We elected three carbon based chemicals to use as model contaminates in the first year of this study:

- *m*-Dinitrobenzene (DNB), a compound released in water during chemical explosive manufacturing and structurally similar to many explosives (Kamble et al., 2006)
- Dimethyl methylphosphonate (DMMP), a chemical warfare nerve agent surrogate (Syage et al., 2006)
- Thiodiglycol (TDG), a building block for many pesticides and similar to chemical warfare agents (Lachance et al., 1999)

These compounds were studied in both fresh and salt water in the laboratory. As results were obtained tracking the destruction as a function of time important controlling factors (such as salinity, available oxygen, available sunlight, etc.) were explored to attempt to optimize the neutralization process and understand the rate limiting steps in the destruction process.

Findings

Both of the nanoparticles were effective at neutralizing the model contaminates in water. However, different conditions were required to optimize the process for each model compound. Most importantly, the addition of dissolved oxygen in the water may be required for fast and complete destruction. Hence, a final system for destroying an unknown chemical waste in water might require the availability of several options to make the process feasible. These options will be kept at a minimum as to keep the process easy to implement. In addition to using pure nanoparticles for chemical destruction, attempts were made at using nanoparticles supported on graphite nanofibers (GNFs). The GNFs did not greatly alter the destruction efficiencies so those results are not presented in this report. The GNFs did adsorb a significant amount of the starting material as well as byproducts formed. Removal by adsorption should be examined in the future as an alternative method for cleaning of the water.

m-Dinitrobenzene (DNB)

m-Dinitrobenzene is often found at sites where explosives have been handled or disposed of. It has been treated previously by air stripping, activated carbon, and solvent extraction but none of these processes completely destroy or deactivate the DNB. Microbial degradation is possible, but it is very slow and requires careful control of the process, which is not considered feasible outside the laboratory.

Several other nitrobenzene molecules have been examined including 4-nitrophenol, 2-nitrophenol, 3-nitrophenol, and 2,4-dinitrophenol. However, all of these compounds degrade much faster than DNB and hence the breakdown of the DNB molecule will be the rate limiting step in this type of destruction processes. Several byproducts are observed during the break down, and include catechol, resorcinol, nitrohydoquinone, and 4-nitrocatechol. Occasionally 4-nitrophenol and 2-nitrophenol were observed. Although these are not as dangerous as the starting material, eventually they will need to be removed from the water.

With exposure to our simulated sunlight, DNB quickly decomposed in fresh water with either ZnO or TiO_2 particles present (Figures 1 and 2); however, the degradation with TiO_2 was significantly faster. No additional additives (acids, bases, oxygen, etc.) were required for quick neutralization of the DNB. Since these studies were performed in fresh clean water, the effect of salt and turbidity (dirt) on the results will be examined. All future tests explored the use of TiO_2 since it was significantly faster at neutralizing the DNB. Some simple tests with salinity and turbidly were performed with ZnO but they always produced slower destruction rates than those performed with TiO_2 so those results are not presented here.

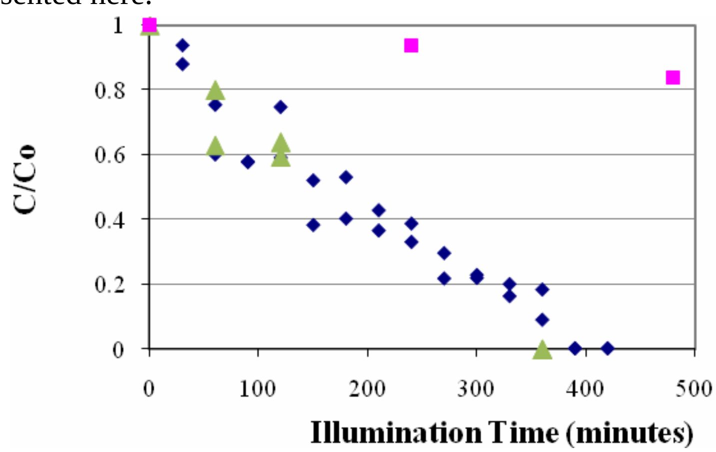


Figure 1: Destruction of DNB in fresh water; with 50 mg DNB/L initial concentration, 15 mg ZnO (dark blue diamonds), 10 mg ZnO (green triangles),or no nanoparticles (pink squares) present in each test vial.

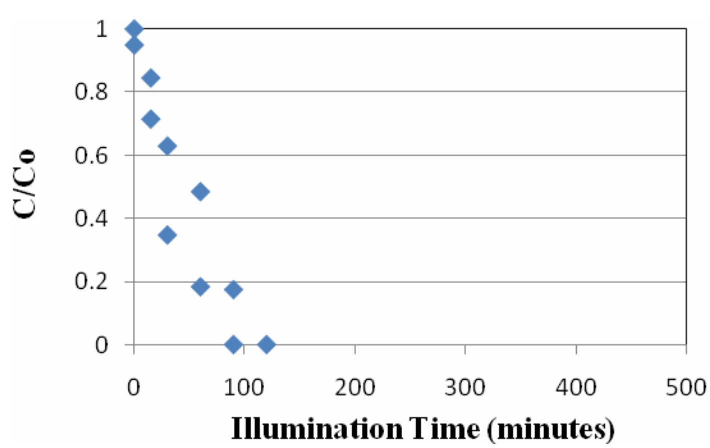


Figure 2: Destruction of DNB in fresh water;
with 50 mg DNB/L initial concentration and 10 mg TiO_2 in the test vial.

Figure 3 shows the effect of adding dirt to the solution of DNB in fresh water. The dirt used was potting soil which was dried in a 100 °C oven for 24 hours and then shifted through a 42 Tyler mesh to produce a uniform sample with very little or no adsorbed organic material on the surface of the dirt particles. High loading was equivalent to 8 mg/L while low loading was half that concentration. It is clear from Figure 3 that turbidity, or particulates that will block sunlight, have a negative effect on the speed of destruction. These results are supported by the fact that without sunlight very little destruction of the DNB takes place. The DNB is fairly stable in water with less than 4% of the material being destroyed in a 24 hour period without the use of sunlight and the nanoparticles. To help offset light blocking materials, mixing or higher intensity artificial lights could be employed.

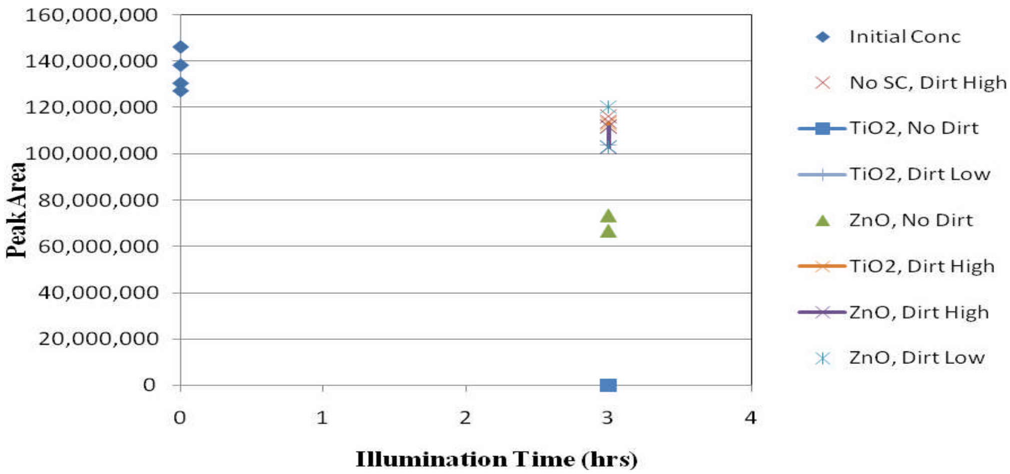


Figure 3: Destruction of DNB in fresh water;
with 50 mg DNB/L initial concentration, 10 mg TiO2, and with various loading of dirt in each vial.

All of the previous studies were performed in fresh water. The effect of salinity on the destruction efficiencies was tested using simulated sea water with our standard reaction conditions of DNB in water with TiO_2. Figure 4 clearly demonstrates that salinity slows down the destruction of DNB but does not prevent it from being neutralized in the water. It is unclear exactly what role the dissolved salt ions in water have on the destruction process, but they definitely slow down the destruction rates. Salt does not prevent all of the DNB from being neutralized.

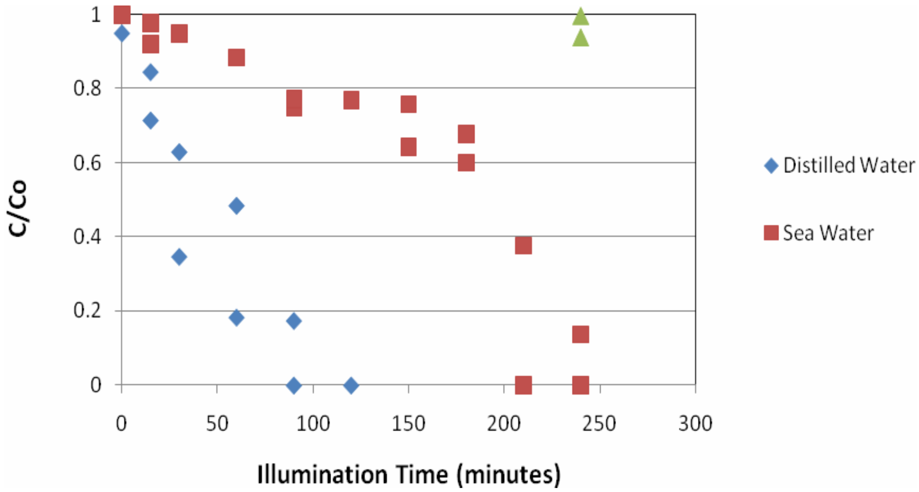


Figure 4: Destruction of DNB in fresh (distilled) and salt water; with 50 mg DNB/L initial concentration and 10 mg TiO2 in each vial. The green triangles have no nanoparticles added in sea water.

As expected, temperature also had a significant effect on the speed of destruction. Three separate experiments were performed at 28, 31 and 39 ^{o}C with DNB in fresh water with TiO_2. Initial rates of destruction were fairly constant but as time progressed the higher temperatures allowed for faster destruction of the DNB (Figure 5). If the reaction is assumed to be first-order with respect to DNB the activation energy for the destruction is calculated to be 10 kcal/mol. Using the irradiance and vial geometry, we estimate the quantum efficiency to be only 0.5%. Although a low quantum efficiency is not desirable, the low activation energy allows for the UV catalyzed reaction to proceed at a fast enough pace for practicality.

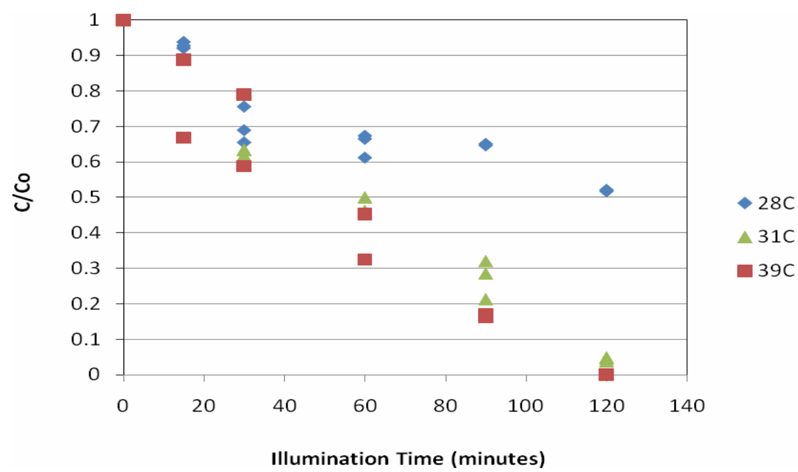


Figure 5: Effect of temperature on DNB destruction in fresh water with 50 mg DNB/L initial concentration and 10 mg TiO2 in each vial.

The role of dissolved oxygen on the destruction of DNB was investigated by removing oxygen from the water using a nitrogen purge. The purge was done to remove roughly half the oxygen and then to remove all the dissolved oxygen. As can be seen in Figure 6, dissolved oxygen does have an effect on the speed of the DNB destruction. The more oxygen present, the faster the destruction. However, it is important to note that oxygen is not required to destroy all the DNB in solution.

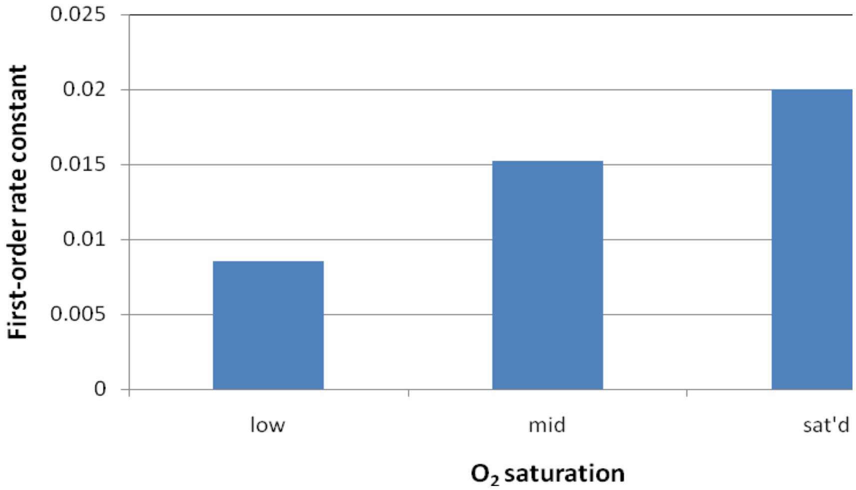


Figure 6: Effect of dissolved oxygen on DNB destruction in fresh water with 50 mg DNB/L initial concentration and 10 mg TiO2 in each vial.

Dimethyl methylphosphonate (DMMP)

DMMP is very close in structure to malathion, which is a pesticide that is widely used in agriculture, residential landscaping, and public recreation areas. It is also often used in public health pest control programs such as mosquito eradication. It is the most commonly used organphosphate insecticide in the United States. DMMP also has some of the same functional groups as sarin, a very toxic chemical warfare agent.

DMMP is fairly stable in water with either room light or sunlight exposure (simulated in a light box) as shown in Figure 7. Interestingly, with TiO_2 or ZnO particles the DMMP also remained fairly stable. The results for TiO_2 are shown in Figure 8. It is believed that the reaction quickly saturates with the nanoparticles present. This could be caused by surface sites being blocked on the particles by adsorbed products or the reaction requires additional oxygen and there is not enough dissolved oxygen present in the solution to sustain the reaction. The addition of more nanoparticles did not increase the destruction of DMMP; hence, surface saturation is not believed to be the cause of the slow destruction of DMMP. The addition of more dissolved oxygen (via the addition of H_2O_2, hydrogen peroxide) did increase the DMMP destruction as shown in Figure 9. Since TiO_2 showed faster destruction rates than the ZnO for this and other studies using DMMP, only results using TiO_2 are presented.

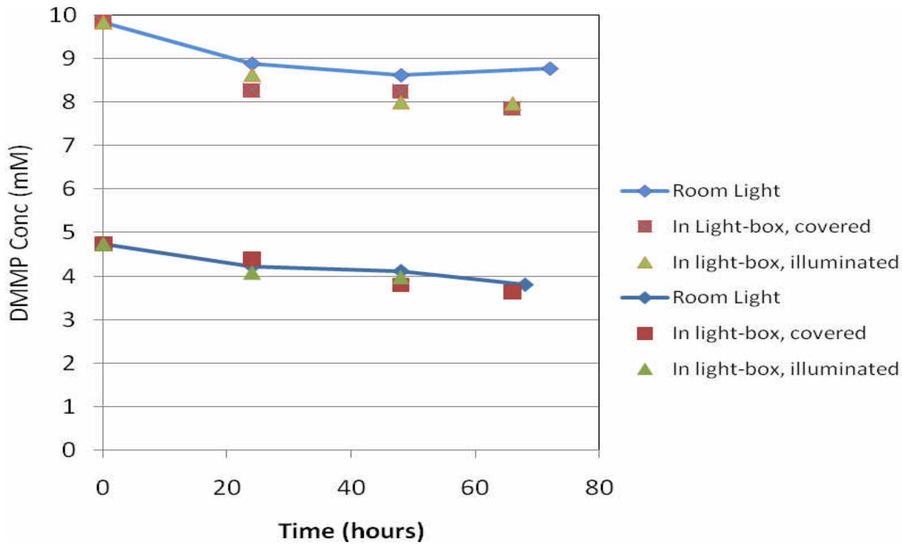


Figure 7: Stability of DMMP in water.

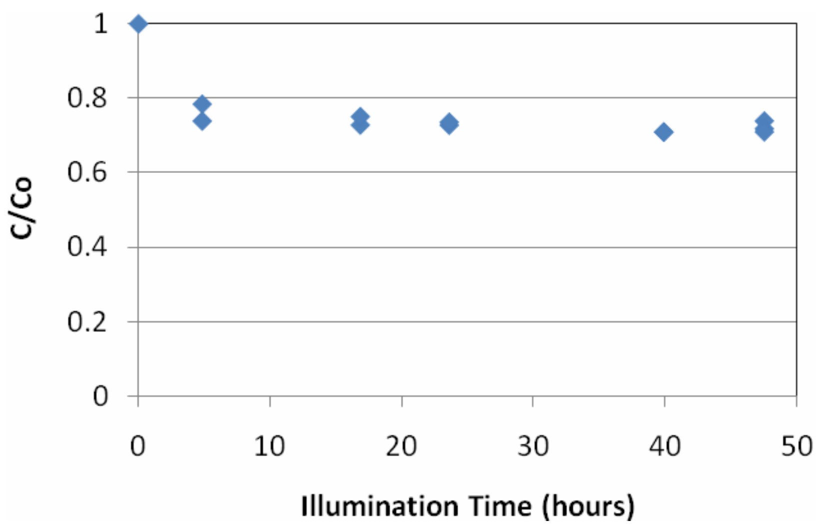


Figure 8: Destruction of DMMP in fresh water with 9.3 mM initial concentration of DMMP and 10 mg TiO2 in each vial.

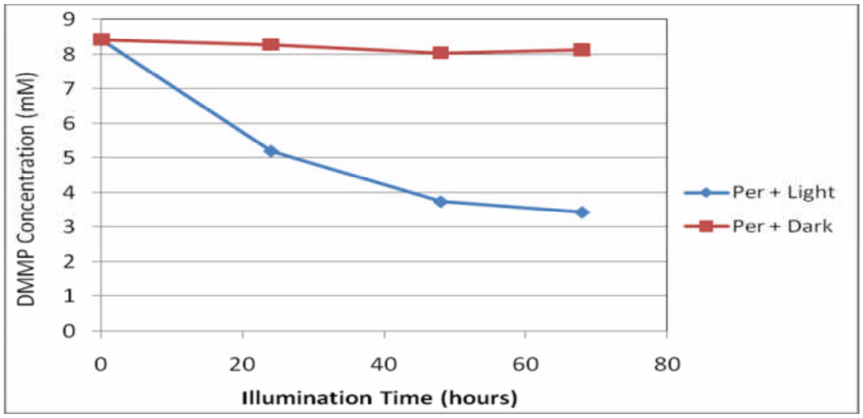


Figure 9: Destruction of DMMP in fresh water;
with 9.3 mM initial concentration of DMMP, 46.5 mM initial concentration of H2O2 (per), and 10 mg TiO2 in each vial.

We also explored the effect of salinity and turbidity on the destruction on DMMP and found similar results to the DNB destruction, both slowed down the reaction. However, DMMP seems to have dissolved oxygen as a major rate limiting step (Figure 9). When all the oxygen was purged from the water using nitrogen, there was none to very little destruction of DMMP. Hence we explored the use of hydrogen peroxide to attempt to fully destroy the DMMP. Figure 10 explores the effect of adding different quantities of H_2O_2 to DMMP aqueous solutions and monitoring the destruction of DMMP as a function of time. We were able to find a combination of nanoparticles, light, and H_2O_2 that could fully destroy the DMMP in a fairly quick manner. Although significantly slower than DNB neutralization, DMMP can still be destroyed quickly.

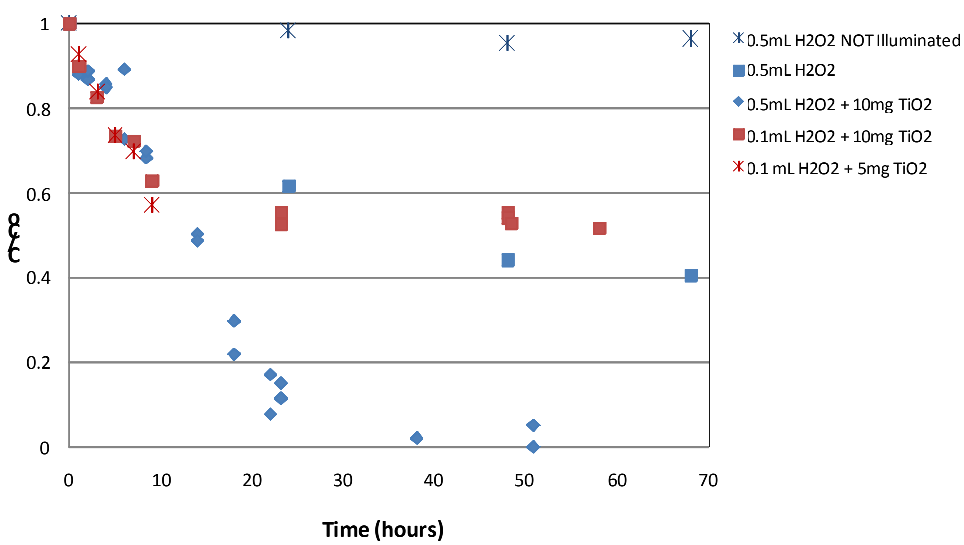


Figure 10: Destruction of DMMP in fresh water;
with 9.3 mM initial concentration DMMP and with various amounts of TiO2 and H2O2 in each vial.

Thiodiglycol (TDG)

TDG is a common pesticide used around the world. It is also the hydrolysis product of mustard gas. Only TiO_2 was used in attempts to destroy TDG as both DNB and DMMP were destroyed quicker with TiO_2 over ZnO. Similar results were found with the addition of oxygen (faster destruction), the addition of electrolytes or salt (slower destruction), and turbidity (slower destruction) as with the previous compounds explored. Oxygen was not as critical to the TDG destruction as it was with the DMMP. With our standard test conditions (50 mg/L initial concentration and 10 mg TiO_2 per vial) all the TDG was able to be destroyed in 26 hours with exposure to light without the need of peroxide.

Conclusions

TiO_2 and ZnO are both effective at destroying the three test compounds in fresh and salt water. Destruction rates were always faster with the TiO_2 over ZnO. In all cases UV light was critical for effective use of the nanoparticles. In addition, dissolved oxygen always played an important role, but for the DMMP it was critical to obtain complete destruction. Destruction rates were slower in salt water when compared to fresh water and turbidity of the water always slowed down the rates of destruction.

Recommendations

Although we have proven that the initial contaminate can be oxidized in an efficient manner, we have not investigated completely which, if any, byproducts are formed nor a method for fully oxidizing or removing these byproducts. We have also explored graphite nanofibers as supports for the nanoparticle catalysts and preliminary results show they are effective at destroying the waste; however, they also acted as adsorbents. In the next phase of the research we will study the effectiveness of graphite nanofibers as adsorbents to help remove materials from the water that are not fully oxidized. In the first stage of this research we will identify byproducts that are formed during the neutralization of each of the model compounds as a function of time, dissolved oxygen, salinity, and initial concentrations of the contaminants and nanoparticles. During the neutralization process we will also add graphite nanofibers and monitor their ability to remove contaminates and byproducts from solution by adsorption. Finally, we will support catalyst on the nanofibers to find a set of conditions that will increase the oxidation process and also effectively remove any contaminates and byproducts for solution.

Our first approach for making nanoparticles on nanofibers will be with TiO_2 through the hydrolysis and precipitation of titanium n-butoxide or $Ti(OBu)_4$. In our first processes we will mix 20 mL titanium *n*-butoxide with 10 mL of anhydrous ethanol. This solution will then slowly be added at about 1 drop per 5 seconds to a 30 mL of a 50 % ethanol aqueous solution with vigorous stirring in which the carbon nanofibers are suspended. Upon contact with water, titanium *n*-butoxide instantly hydrolyzed to form TiO_2 particles and released a vapor byproduct and heat. This addition will be done in an inert nitrogen atmosphere. SEM and TEM images of the dried nanofibers with catalyst particles will be obtained to know the coverage density and size of the particles. Stirring, concentration, and quantity of fibers used can be altered to improve the size and distribution of the nanoparticles on the fibers. Once formed, these nanofibers will be tested at how effectively they destroy the initial contaminates in aqueous solutions as was done previously with the nanoparticles alone.

Summary

In less than 24 hours we were able to completely neutralize the three chemical contaminates tested in both fresh and salt water and with and without the addition of particulates (dirt). TiO_2 is the nanoparticle of choice for the fastest destruction. Sunlight is also required for the destruction along with dissolved oxygen (for DMMP). To maximize the destruction rates, high loading of nanoparticles and hydrogen peroxide would be employed along with the maximum amount of UV light available. After the first stage of neutralization, investigations into methods for adsorbing the byproducts onto nanofibers or completely oxidizing them need to be performed.

References

Ahmadi, T. S.; Wang, Z. L.; Green, T. C.; Henglein, A.; El-Sayed, M. A. "Shape-Controlled Synthesis of Colloidal Platinum Nanoparticles", *Science* **1996,** 272, 1924.

Bessel, C. A.; Laubernds, K.; Rodriguez, N. M.; Baker, R. T. K. "Graphite Nanofibers as an Electrode for Fuel Cell Applications," J. Phys. Chem. 2001, 105(6), 1115-1118.

Bromberg, L.; Hatton, T.A. "Nerve Agent Destruction by Recyclable Catalytic Magnetic Nanoparticles," *Ind. Eng. Chem. Res.*, **2005**, *44*, 7991.

Byer, D.; Carlson, K.H. "Real-time Detection of Intentional Chemical Contamination in the Distribution System," *J. AWWA*, **2005**, *97*, 130.

Fulton, J.L.; Matson, D.W; Pecher, K.H.; Amonette, J.E.; Linehan, J.C. "Metal-based Nanoparticle Synthesis from the Rapid Expansion of Carbon Dioxide Solutions," *J. Nanoscience & Nanotechnology*, **2006**, *6*, 562.

Hill, H.H.; Martin, S.J., "Conventional Analytical Methods for Chemical Warfare Agents," *Pure Appl. Chem.*, **2002**, *74*, 2281.

Ho, C.K.; Itamura, M.T.; Kelley, M.; Hughes, R.C. "Review of Chemical Sensors for In-situ Monitoring of Volatile Contaminants," Sandia Report SAND2001-0643, **2001**, Office of Scientific and Technical Information, Oak Ridge, TN.

Ho, C.K.; Robinson, A.; Miller, D.R.; Davis, M.J. "Overview of Sensors and Needs for Environmental Monitoring," *Sensors*, **2005**, *5*, 4.

Hodes, M.; Marrone, P.A.; Hong, G.T.; Smith, K.A.; Tester. J.W. "Salt precipitation and Scale Control in Supercritical Water Oxidation—Part A: Fundamentals and Research," *J. Supercritical Fluids* **2004**, *29*, 265.

Janata, J. "Chemical Sensors," *Anal. Chem*., **1992**, *64*, 196R.

Kahn, A.S.; Swerdlow, D.L.; Jurnaek, D.D. "Precautions Against Biological and Chemical Terrorism Directed at Food and Water Supplies" *Public Health Reports*, **2001**, *116*, 3.

Kamble, S.P.; Sawant, S.B.; Pangarkar, V.G. "Photocatalytic Degredation of *m*-Dinitrobenzene by Illuminated TiO_2 in a Slurry Photoreactor" *J. Chem. Tech. and Biotech.* **2006**, *82*, 365.

Karn, B.; Masciangioli, T.; Zhang, W; Colvin, V.; Alivasatos, P. Nanotechnology and the Environment: Applications and Implications. Oxford University Press, 2004.

Klabunde, K.J. ed., Nanoscal Materials in Chemistry, Wiley-Interscience, New York, 2001

Khaitan, S.; Kalainesan, S.; Erickson, L.E.; Kulakow, P.; Martin, S.; Karthikeyan, R.; Hutchinson, S.L.L.; Davis, L.C.; Illangasekare, T.H.; Ng'oma, C. "Remediation of Sites Contaminated by Oil Refinery Operations," *Environ. Progress*, **2006**, *25*, 20.

Kopec, T.C.; Weinstein, R.D.; Fleischer, A.S.; D'Addio, E.; Bessel, C.A. "Thermal Analysis of Phase Change Materials with Embedded Graphite Nanofibers for Thermal Management of Electronics," **2006**, Proceedings of IMECE2006.

Lachance, R.; Paschewitz, ; J.; DiNaro, J.; Tester, J.W. "Thiodiglycol Hydrolysis and Oxidation in Sub- and Supercritical Water," *J. Supercritical Fluids*, **1999**, *16*, 133.

Lanthan, A.H.; Williams, M.E. "Versatile Routes Toward Functional, Water-Soluble Nanoparticles Via Trifluoroethylester-PEG-Thiol Ligands," *Langmuir*, **2006**, *22*, 4319.

Marrone, P.A.; Hodes, M.; Smith, K.A.; Tester, J.W. "Salt Precipitation and Scale Control in Supercritical Water Oxidation—Part B: Commercial/Full-scale Applications," *J. Supercritical Fluids* **2004**, *29*, 289.

Meyer, D.E.; Wood, K.; Bachas, L.G.; Bhattacharyya, D. "Degradation of Chlorinated Organics by Membrane-immobilized Nanosized Metals," *Environ. Progress*, **2004**, *23*, 232.

Murray, G.M.; Southard, G.E. "Sensors for Chemical Weapons Detection," *IEEE Instruments & Measurements*, December **2002**, 12.

Oskam, G. "Metal Oxide Nanoparticles: Synthesis, Charaterization and Application," *J. Sol-Gel Sci. & Tech.*, **2006**, *37*, 161.

Pearson, G.S.; Magee, R.S. "Critical Evaluation of Proven Chemical Weapon Destruction Technologies (IUPAC Technical Report)," *Pure Appl. Chem.*, **2002**, *74*, 187.

Sawicki, R.; Mercier, L. “Evaluation of Mesoporous Cyclodextrin-silica Nanocomposite for the Removal of Pesticides from Aqueous Media,” *Environ. Sci. & Tech.*, **2006**, *40*, 1978.

Skaf, D.W.; Kandula, S.; Harmonay, L.; Shodder, P.; Bessel, C.A.; Weinstein, R.D. “The Kinetics of the Oxidation and Chelation of Cu(0) and Cu_2O in Hexanes or Condensed Carbon Dioxide by t-Butylperacetate and 1,1,1-Trifluoro-2,4-pentanedione,” *Ind. Eng. Chem. Res.*, **2006**, *45*, 8874.

Syage, J.A.; Cai, S.S.; Li, J. M.D. Evans “Direct Sampling of Chemical Weapons in Water by Photoionization Mass Spectrometry,” *Anal. Chem*., **2006**, *78*, 2967.

Weinstein, R.D.; Renslo, A.R.; Danheiser, R.L.; Harris, J.G.; Tester, J.W. “Kinetic Correlation of the Diels-Alder Reaction in Supercritical Carbon Dioxide,” *J. Phys. Chem*., **1996**, *100*, 12337.

Wolfbeis, O.S. “Fiber-optic Chemical Sensors and Biosensors,” *Anal. Chem*., **2004**, *76*, 3269.

Zhang, W.; Karn, B. “Nanoscale Environmental Science and Technology: Challenges and Opportunities”. *Environ. Sci. & Technol.*, **2005**, *39*, 94.

Appendix A: List of Figures

Figure 1: Destruction of DNB in fresh water; 191
Figure 2: Destruction of DNB in fresh water; 192
Figure 3: Destruction of DNB in fresh water; 192
Figure 4: Destruction of DNB in fresh (distilled) and salt water;.................................. 193
Figure 5: Effect of temperature on DNB destruction in fresh water............................... 193
Figure 6: Effect of dissolved oxygen on DNB destruction in fresh water...................... 194
Figure 7: Stability of DMMP in water.. 195
Figure 8: Destruction of DMMP in fresh water.. 195
Figure 9: Destruction of DMMP in fresh water;... 196
Figure 10: Destruction of DMMP in fresh water;... 196

Chapter 3 – Microarray Identification of Pathogens

Dr. Metin Duran – Villanova University

Executive Summary

The overall goal of the initial study was to investigate the feasibility of establishing a fully-functional genomics facility within an oceangoing decontamination system that could be used for rapid detection of microbial pathogens including bioterrorism agents. For that purpose, two genotypic approaches for pathogen detection, namely polymerase chain reaction (PCR) based pathogen identification and microarrays, were evaluated between May 2007 and August 2008. The results suggest that PCR-based pathogen identification may not be a feasible technology for on-site use in an oceangoing vessel due to the fact that using this technology to screen for a large number of possible microbial pathogen might take a long time since each primer pair targeting a particular species has to be analyzed independent of the primer pair targeting another species. Microarrays, the so called gene chips, on the other hand were shown to be feasible for that purpose. During the feasibility assessment, the research team developed an effective protocol for extracting intact nucleic acids, both DNA and RNA, from highly complex matrices such as ocean water and biosolids, a step long considered as the biggest challenge in application of microarray technology for detecting pathogens in the environment.

Background

Rapid onsite detection of pathogens in water environments remain as one of the major challenges in eco¬toxicology, public health maintenance, and, more recently, bio¬terrorism prevention. This is partly due to the fact that conventional pathogen identification methods rely on culturing pathogens from water samples. Culture-based methods have two major drawbacks. First, some pathogens may not be culturable and thus they are not detected by conventional technologies. Moreover, it may take days to culture and identify the pathogen and therefore timely response is impossible in many cases.

Microarray technology or commonly referred to as “gene chips” have recently emerged as a highly innovative and promising technology for pathogen detection. National Research Council (in 2001) and subsequent National Drinking Water Advisory Council (in 2004) recommended identifying pathogens in water environments in new ways that involve genomics. Microarray technology is one of the most promising genomic technologies for detection of pathogens, in part due to rapid advances in identification of pathogen-related genes and developments in array technology within the last decade. U.S. Environmental Protection Agency (EPA) has made microarray technology one of its top research priorities in public health arena. Moving in that direction, EPA held an expert workshop in Cincinnati, Ohio on March 22-23, 2005 to explore the feasibility of using microarray technology for detecting waterborne pathogens. The overall conclusion of the workshop was that despite some issues in terms sensitivity and matrix interference, the microarray technology may be ready for detection of small number of pathogens and that with carefully directed research the technology is likely to become dominant means of pathogen detection within next decade (EPA, 2005).

Objectives

The overall goal of this study was to investigate the possibility of establishing a fully-functional genomics facility within an oceangoing decontamination system that can be used for rapid detection of microbial pathogens including bioterrorism agents. For that purpose, feasibility of two genotypic approaches for pathogen detection was evaluated: 1) A polymerase chain reaction (PCR) based pathogen identification; 2) microarrays.

Findings

Feasibility of PCR-based pathogen detection

In this part of the study, efficacy of using a relatively simple genomic analytical tool, polymerase-chain reaction (PCR), for identification of microbial pathogens was investigated. The evaluation involved a set of six species-specific PCR primer pairs and proceeding agarose gel electrophoresis to identify six different species of Enterococcus, the model bacterial organism used in this part of the study. The bacterial cultures used for PCR identification were part of a culture collection of Enterococcus species from different primary hosts, i.e., human and animal sources, developed since 2005. The primer sets were used for species-level genotypic identification. In addition, the isolates were subjected to phenotypic and additional genotypic identification protocols to confirm the results of PCR identification. All of the isolates identified by PCR method were typed phenotypically by API 20 Strep system (bioMerieux). In cases where PCR and API identification were in agreement, the isolates were considered identified. When, PCR and API results contradicted each other, the isolates were typed by partial 16S rRNA sequencing, the golden standard of bacterial identification.

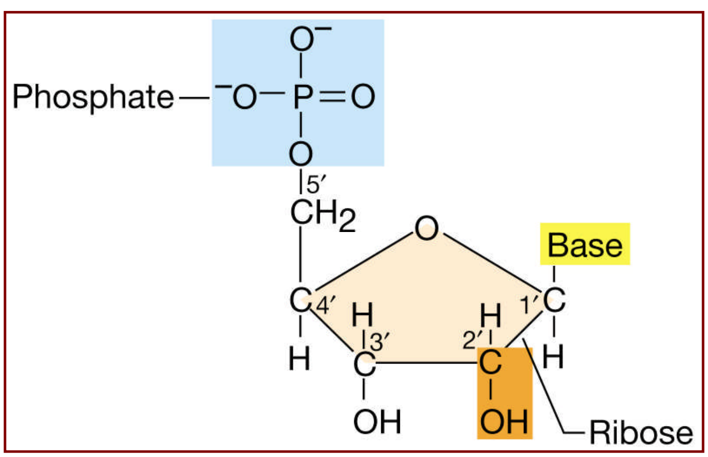


Figure 1: Structure of a nucleotide with ribose backbone (adopted from Alcamo, 2001)

Although phenotypic methods of identification have been used for microbial identification since the discovery of the microscope, genotypic identification procedures are still a relatively new technology. No matter what the specific genotypic procedure is, all genomic identification analyses depend upon the structure of the deoxyribonucleic acid (DNA) or ribonucleic acid (RNA) molecules of organisms. DNA forms the very genetic material of the chromosomes carrying the hereditary information whereas RNA carries out several functional roles such as transcription and translation of information from DNA to protein synthesis and formation and providing a site for protein assembly. Therefore, all information pertaining to the development and functioning of a living thing is housed within the DNA's structure. Both DNA and RNA molecules are made of repeating units of nucleotides. Each nucleotide has three separate components: a carbohydrate molecule, a phosphate group, and a nitrogenous base (see Figure 1). The phosphate and carbohydrate groups collectively form the spine of the helix structure of DNA while the bases connect each strand of the double helix together (see Figure 2).

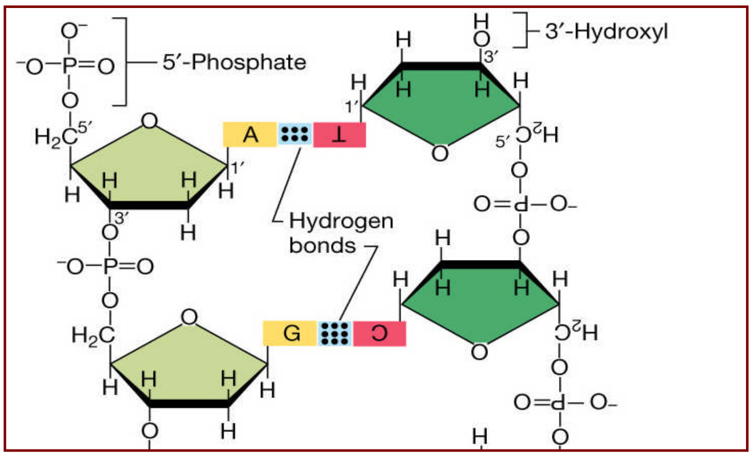


Figure 2: Structure of a DNA molecule showing hydrogen bonds between four nucleotides (Adenine, Guanine, Thymine, and Cytosine) that form the double helix. (adopted from Alcamo, 2001)

The nitrogenous bases are of most significance with regards to genotypic identification. This is because the order of the bases dictates the unique genetic code of each living thing. There are five bases: guanine (G), cytosine (C), thymine (T), adenine (A), and uracil (U). Among these, T is exclusive to DNA molecules, U is found only in RNA molecules, and the remaining three are found in both. Furthermore, the bases are complementary such that cytosine will only form three hydrogen bonds with guanine. Likewise, only adenine will pair with thymine via two hydrogen bonds. The bonding of these base pairs lends the DNA molecule its famous double-helix configuration. The order of the bases on each strand of the helix is what determines the precise codification of the genetic information for a particular species. In other words, the change in sequence of those four nitrogen bases in a DNA molecule is the basis for all genotypic identification approaches.

Of all the current genotypic procedures to examine the order of the bases, the combination of PCR with gel electrophoresis is one of the more accurate and accessible. Compared to other genotypic and even phenotypic techniques for the identification of pathogens, PCR and gel electrophoresis are markedly less time-consuming, requires far less expensive equipment, and can produce very precise identifications. The PCR technique is used to amplify the DNA. In cells, DNA is naturally replicated when new cells are formed in a process known as DNA replication. Yet, for PCR, it must be amplified using primarily synthetic elements. The most important of these elements are the primers. A primer is a fragment of genetic code which is complementary of the target and thus it directly binds to a given code on the DNA sequence that is to be replicated. Then DNA polymerase, an enzyme that synthesizes DNA molecules, adds to the 3'-OH end of the primer the complementary nucleotide and the process continues one nucleotide at a time until a complementary copy of a single stranded DNA molecule is synthesized. Therefore, the primer used DNA or each species must pertain directly to a particular code that is exclusively shared within a given species. Typically, genetic sequences pertaining to the synthesis of superoxide dismutase (*sodA*) and enzyme production (*ddl*) are unique to all cells within a given species, making them prime candidates for primer codification. This ensures the precision of the identification process.

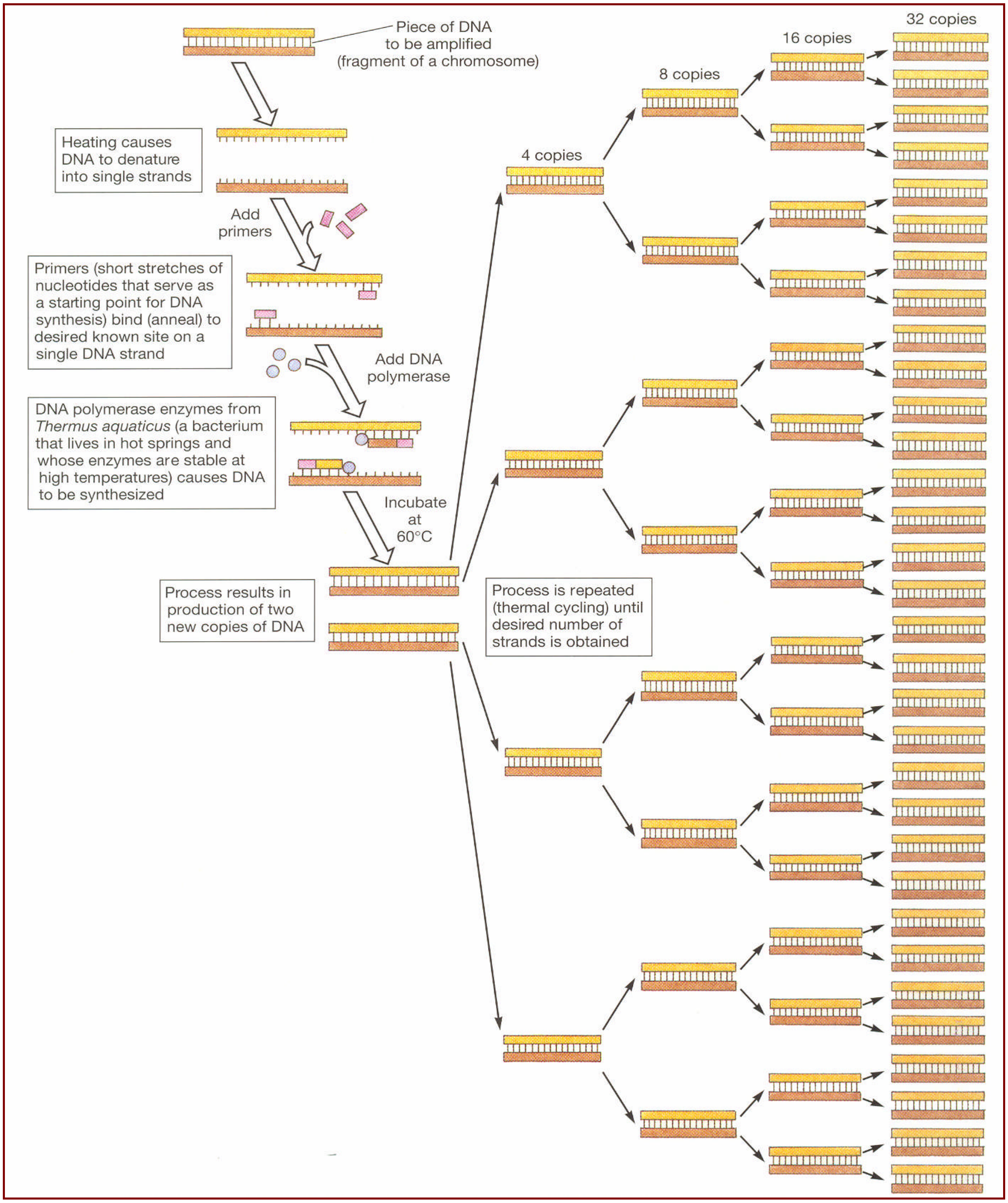


Figure 3: Principles of PCR amplification
(adopted from Black, 1999)

When the primers are exposed to the DNA of the proper species and the surrounding temperature is raised, the hydrogen bonds which connect the base pairs will break. Hence, the two strands of the DNA double-helix will separate. This allows the primers to bond to the corresponding sequence of bases. Cooling allows the two portions to anneal together, resulting in two new double-helix sections of the desired DNA sequence. When this process is repeated several times, with the amount of DNA growing exponentially, concentrations high enough to perform gel electrophoresis can be obtained. Figure 3 shows the principles of PCR procedure.

Gel electrophoresis is a technique which utilizes a porous agarose gel medium to spatially separate DNA strands by base length. Since the phosphate groups within the nucleotide of the DNA molecule are negatively charged, they can be carried by an electric current. However, the longer the base length of the strand of DNA, the shorter the distance it can travel through a given gel porosity in a given time. Typically, a DNA ladder which contains strands of known, uniform lengths is used as a reference point to base one's findings on. Since the number of bases in each species-specific primer is known, the spatial-separation can therefore be used to properly identify individual species.

Enterococcus isolates were collected and cataloged as part of a larger microbial source tracking study based on fatty acid methyl ester profiles of the isolates (Haznedaroglu et al, 2007). The frozen isolates (-80^{o} C) were grown in TSB broth for 24 hours at 35^{o} C for DNA extraction and upstream PCR amplification. Total genomic DNA of the isolates was extracted using GenElute Kit (Sygma-Aldrich) following the manufacturers procedure. Optical density measurement were done on each sample in order to insure that at least 25 µg/mL was extracted for further PCR procedure. Total volume of PCR was 50 µL: 25 µL of Ready Mix solution (Sygma-Aldrich), at least 50 ng of template DNA and 50 pmole of each primer (Invitrogen). The solution was completed to the final volume with PCR dilution water included in the kit. The primer pairs used in this study are listed in Table A1 in Appendix A. American Tissue Culture Collection (ATCC) cultures that were used as positive controls were: ATCC 27332 and ATCC 19433 for *E. faecalis*; ATCC 35667 and ATCC 19434 for *E. faecium*; ATCC 14025 for *E. avium*; ATCC 49608 and ATCC 700426 for *E. gallinarum*; ATCC 19432 for *E. durans*; and ATCC 8043 for *E. hirae*. Amplified DNA fragments were separated and visualized using 2.2% agarose gel stained with ethidium bromide for visualization under UV light. Separation was achieved after 1.5 hour under 110 V current and the gels were scanned using a UV imaging system (Kodak Gel Logic 100). API 20 Strep system procedure was done following the manufacturers procedure. Results of API 20 Strep system were interpreted using free boiMerieux software: API 20 Strep, V6.0. An isolate was considered identified by API 20 Strep if percent identification was higher than or equal to 90% similarity index. Samples that were decided to be appropriate for 16S rRNA analysis were sent to a commercial laboratory for partial 16S rRNA sequencing.

Figure 4 shows an example of PCR amplification results. A total 23 isolates have been analyzed so far and the results are presented in Table A2 in Appendix A. Different sets of primers showed different efficiency of amplification. Overall 69% of isolates amplified using *sodA* gene targeting primers gave positive amplification, whereas it was only 57% for isolates amplified using *ddl* gene targeting primers. API 20 Strep system identified 91% of isolates.

It was observed that *sodA* gene targeting primers were giving better amplification than *ddl* gene targeting primers. In 96% of all experiments no amplification of ATCC culture by the F 1/F 2 set of primers was seen whatsoever.

All isolates identified with genotypic (PCR) method were identified as *E. faecalis* independent of their origin. API 20 Strep showed more diverse identification and the species identified by API 20 Strep included *E. faecium*, *E. faecalis*, *Globicatella sanguinus*, *E. durans*, and *Streptococcus bovis II* with 67%, 13%, 10%, 5%, and 5% of total identified, respectively. Sixty two per cent of isolates that were identified as *E. faecalis* by PCR, were identified as *E. faecium* by API 20 Strep system.

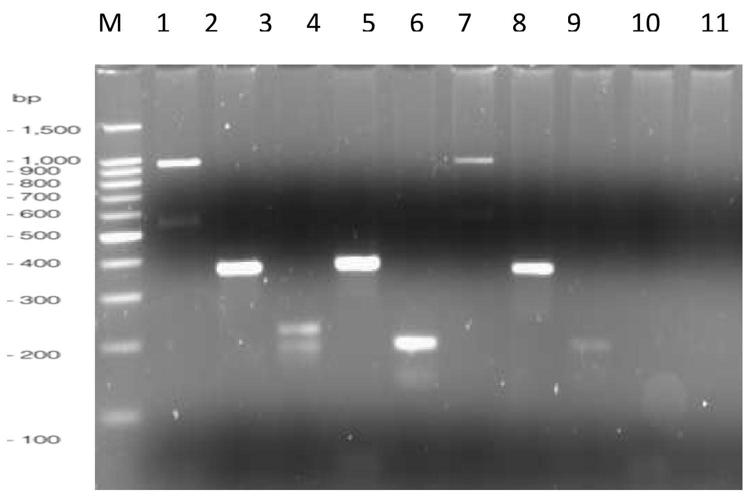


Figure 4: Amplified PCR products for identification of Enterococcus sp.
Line M: DNA Ladder; Line 1: ATCC 19433 (E. faecalis) using E1-E2 primers (positive control); Line 2: ATCC 19433 (E. faecalis) using FL1-FL2 primers (positive control); Line 3: ATCC 19434 (E. faecium) using FM1-FM2 primers (positive control); Line 4: ATCC 14025 (E. avium) using AV1-AV2 primers (positive control); Line 5: ATCC 700426 (E. gallinarum) using GA1-GA2 primers (positive control); Line 6: Swine isolate 9/9 identified as E. faecalis using E1-E2 primers; Line 7: Swine isolate # 9/9 identified as E. faecalis using FL1-FL2 primers; Line 8: Swine isolate # 9/9 using FM1-FM2 primers (no PCR product); Line 9: Swine isolate # 9/9 using AV1-AV2 primers (no PCR product); Line 10: Swine isolate # 9/9 using GA1-GA2 primers (no PCR product). Negative controls run is on the second raw of wells (results are not shown).

Agreement between phenotypic and genotypic (PCR) methods was observed only in 3 isolates. Out of 20 isolates that were not agreed on by phenotypic and genotypic (PCR) identification, 7 isolates were sent for the partial 16S rRNA typing. As a result, 6 isolates proved to be correctly identified by PCR-method. One PCR amplification gave negative result for the species that has been identified as *E .flavescens*, which proves PCR specificity, since no *E. flavescens* species specific primers were tested.
The results showed that:

- Using species-specific primers based PCR combined with gel electrophoresis is a highly accurate and sensitive genotypic method for identification of microbial species.

- In case of six Enterococcus species analyzed, *sodA* gene targeting PCR-primers proved to be more species specific and resulted in better amplification than *ddl* gene targeting primers.

- PCR-based genotypic method provides far more accurate identification than API 20 Strep based phenotypic identification as confirmed by partial 16S rRNA sequencing results.

- PCR-based genotypic method is faster than API 20 Strep based phenotypic identification method.

- Despite its sensitivity and accuracy, the PCR-based identification method is limited by the availability of species-specific primers particularly for species of interests to ONR. In other words, feasibility of using PCR-based identification approach in a mobile naval emergency unit depends on availability of primers for pathogens of interest such as bioterrorism agents.

- Although the PCR-based identification method is relatively quick taking only 2 to 3 hours for accurate identification of a particular bacterial species, using the method to analyze for a large number of possible microbial pathogen might take a long time. This is simply due to the fact that each primer pair targeting particular species has to be analyzed independent of the primer pair targeting other species.

Feasibility of microarray-based pathogen identification

The microarray technology is based on the principle of hybridization (hydrogen bonding) between complementary nucleotides that make up the genomic material, DNA or RNA. The complementary base pairing and other factors such as ionic strength, temperature, and solvents of the environment are the driving forces for hybridization. The technology is based on Southern blotting techniques. However, the current procedure is following Northern and dot blotting techniques more commonly. Microarrays today are created by robotic machines that arrange minuscule amounts of hundreds or thousands of gene sequences, probes, on a single microscope slide or some form of a flexible membrane. Most recent microarrays contain up to 96,000 genes on a single 75x25 mm nylon membrane slide.

Microarrays for detection and identification of pathogens may be based on DNA or RNA. DNA-based microarrays have pathogen-specific DNA probes attached to them. These probes are complementary to a species-specific region of chromosomal DNA. Another approach is to fabricate microarrays using RNA probes that are complementary to one of the hyper-variable regions in the species 16S-rRNA. Latter approach is more commonly used in clinical microbiology and food safety fields since 16S rRNA based approaches are the golden standards for identification pathogens.

Regardless of nucleic acid used, successful application of microarray technology depends upon extracting sufficient quantities of uncontaminated and intact DNA or RNA from cells. In fact, that is the most challenging step limiting wider application of microarrays. When target cells are in complex matrixes such as ocean water, extraction of nucleic acids for upstream applications become even more challenging. Salt water is a highly complex microbial ecosystem with thousands of microbial species from the domains bacteria and Archaea, as well as with significant eukaryotic organisms. In addition, they have an enormously complex abiotic component interacting with microbial species. Naturally, such complexity makes it very difficult to isolate intact nucleic acids, particularly RNA, in the quantities necessary for amplification (Chen et al., 2006; Mangan et al., 1997; Mumy and Findlay, 2004; Rose et al., 2003; Sheridan et al., 1998; US EPA, 2005).

Since extraction of intact nucleic acid, particularly RNA, is the “bottle neck” of using microarray technology for microbial pathogen detection, the research team had invested significant efforts on developing and optimizing a nucleic acid isolation and purification protocol. Several commercially available RNA extraction kits had been tested for their effectiveness in extracting intact RNA from biosolids and recently from ocean water. The results are highly encouraging suggesting that the use of microarray technology on an oceangoing vehicle is possible.

The results on RNA extraction from biosolids were presented in the previous report (see Systems Concept Report submitted in March 2008). The same kit, MO BIO Laboratories’ RNA PowerSoil™ Total RNA Isolation Kit, that was found to be most effective for extracting nucleic acid from biosolids, was used to extract nucleic acids from ocean water samples seeded with *E. coli* and *Salmonella sp.* after autoclaving. The protocol is based on phenol extraction, with proceeding capture-column purification. The protocol provided by the manufacturer was followed to extract RNA. The quantity and purity of extracted mRNA were determined by spectrophotometric analysis (A260 nm, A260/A280 nm, and A260/230 nm) using a NanoDrop™ 1000 spectrophotometer (Thermo Scientific, Wilmington, D, USA). Acceptable ranges for the purity at A260/280 nm and A260/230 nm are approximately 2.0 and 2.0-2.2, respectively. The integrity of RNA was analyzed on formaldehyde-denaturing agarose gel electrophoresis. “Agarose Gel Electrophoresis of RNA” protocol by Ambion® was slightly modified in order to increase the accuracy of the information on RNA yield. The protocol was adopted from Ambion® Denaturing Agarose Gel Electrophoresis of RNA supplemental protocol and changed as follows:

1. Prepare the gel:
    - Heat 1 g agarose in 72 ml water until dissolved, then cool to 60°C.
    - Add 28 ml of 10X MOPS formaldehyde buffer (Ambion® AM 8776)
    - Pour the gel using a comb that will form wells large enough to accommodate at least 25 µl.
    - Assemble the gel in the tank, and add enough 1X MOPS running buffer to cover the gel by a few millimeters. Then remove the comb.
2. Prepare the RNA sample and markers:
    - To 1-3 µg RNA, add 0.5-3X volumes NorthernMax® Formaldehyde Load Dye (AM 8551) to get the same volume for all the samples

- Prepare an aliquots of 2 μg (2 μl) RNA Millennium[tm] Markers (AM7150) with 3X volume of NorthernMax® Formaldehyde Load Dye
- Add ethidium bromide at a 50 μg/ml concentration (it is important to use the same amount of ethidium bromide in all the samples)
- Heat denature samples at 65°C for 15 min.

3. Electrophoresis:
   - Load the gel and electrophorese at 5-6 V/cm until the bromophenol blue (the faster-migrating dye) has migrated at least 2-3 cm into the gel, or as far as 2/3 the length of the gel. After electrophoresis, each denaturing gel was visualized on a UV transilluminator to determine intactness of RNA.

The appearance of 16S and 28S rRNA bands on the gel was considered an indicator of intact RNA. In case gel electrophoresis results were questionable, due to indistinct rRNA band when extracted RNA is not in sufficient quantity, the samples were analyzed on an Agilent 2100 Bioanalyzer (Agilent, Wilmington, DE, USA). During the bioanalyzer tests, presence of distinct 16S and 23S ribosomal peaks, the absence of smaller well-defined peaks between the two ribosomes, and the flatness of the baseline and absence of small rounded peaks between 29 seconds and 16S ribosome were taken as indicator for intact extracted total prokaryotic RNA.

Figure 5 depicts extracted nucleic acid from three different ocean water samples: blank (autoclaved ocean water sample without seeding); autoclaved ocean water seeded with *E. coli*; and autoclaved ocean water seeded with *Salmonella*. Lane M represent the RNA marker (standard) while Lane 1 through 3 represent the ethidium bromide stained nucleic acids extracted from the autoclaved ocean water samples with no seeding (blank), seeded with *E. coli*, and seeded with *Salmonella*, respectively. Lane 4 through 6 represent the same samples after DNAase treatment that removes any DNA extracted along with RNA.

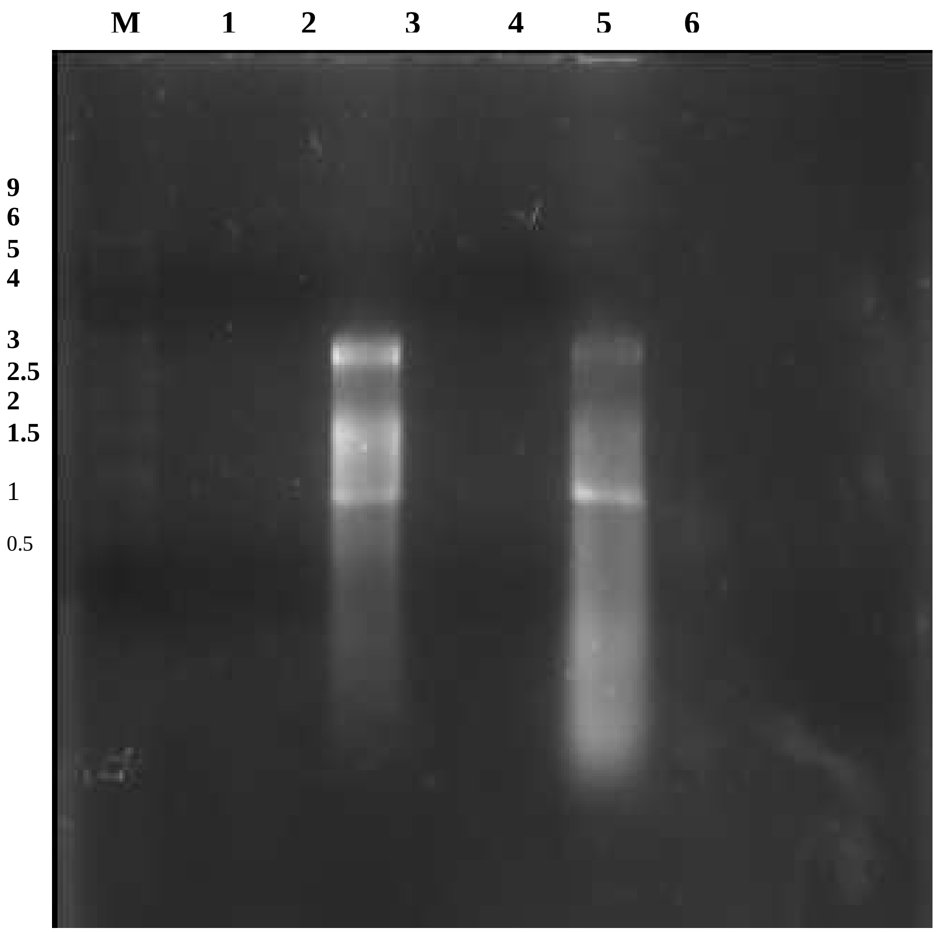


Figure 5: Formaldehyde denaturing agarose gel electrophoresis of nucleic acids extracted from the seeded ocean water samples.
Lane M: RNA Millennium™ marker (units kpb); Lane 1: Autoclaved ocean water sample (not seeded); Lane 2: Ocean water sample autoclaved and then seeded with *E. coli*; Lane 3: Ocean water sample autoclaved and then seeded with *Salmonella*; Lane 4: Ocean water sample autoclaved but not seeded (DNAase treatment); Lane 5: Ocean water sample autoclaved and then seeded with *E. coli* (DNAase treatment); Lane 6: Ocean water sample autoclaved and then seeded with *Salmonella* (DNAase treatment).

In order to verify that RNA was extracted, all of the three samples were treated with DNAase A (Sigma-Aldrich, Location) after the extraction. Lane 4 through 6 show the samples treated with DNAase. In other words, the samples shown in Lane 5 through 6 contain only RNA since any DNA in samples are degraded by actions of DNAase. Comparing samples in Lane 3 and 6, one clearly notices that the protocol is highly effective in extraction of clean (without DNA contamination) RNA from a complex matrix such as ocean water. Nucleic acid extracted from ocean water sample autoclaved and then seeded with *Salmonella* (Lane 3) basically showed no change after treatment with DNAase (Lane 6) indicating that the extraction solution was free from DNA, due most likely highly selective performance of the capture-column purification step. Two distinct bans in Lane 6, one about 3 kbp size and the other approximately 1 kbp, are likely to be 16S and 23S rRNA. Bands below 0.5 kbp are likely to be short messenger RNA pieces.

It should be noted that the results presented in Figure 5 are highly encouraging in terms of feasibility of using microarrays for pathogen identification. As mentioned earlier, extraction of sufficient clean and intact nucleic acid the main challenge in applying the technology for pathogen detection and the research team has shown this challenge can be overcome. In order to verify that nucleic acids were extracted from the seeded ocean water samples, the quantity and integrity of the RNA were also tested using an Agilent 2100 Bioanalyzer (Agilent, Wilmington, DE), standard RNA integrity analysis. The bioanalyzer analyses were conducted at the Core Genomics Facility of the Wistar Institute, Philadelphia, PA. Figure 6 and 7 show the electropherograms of RNA extracted from seeded ocean water sample.

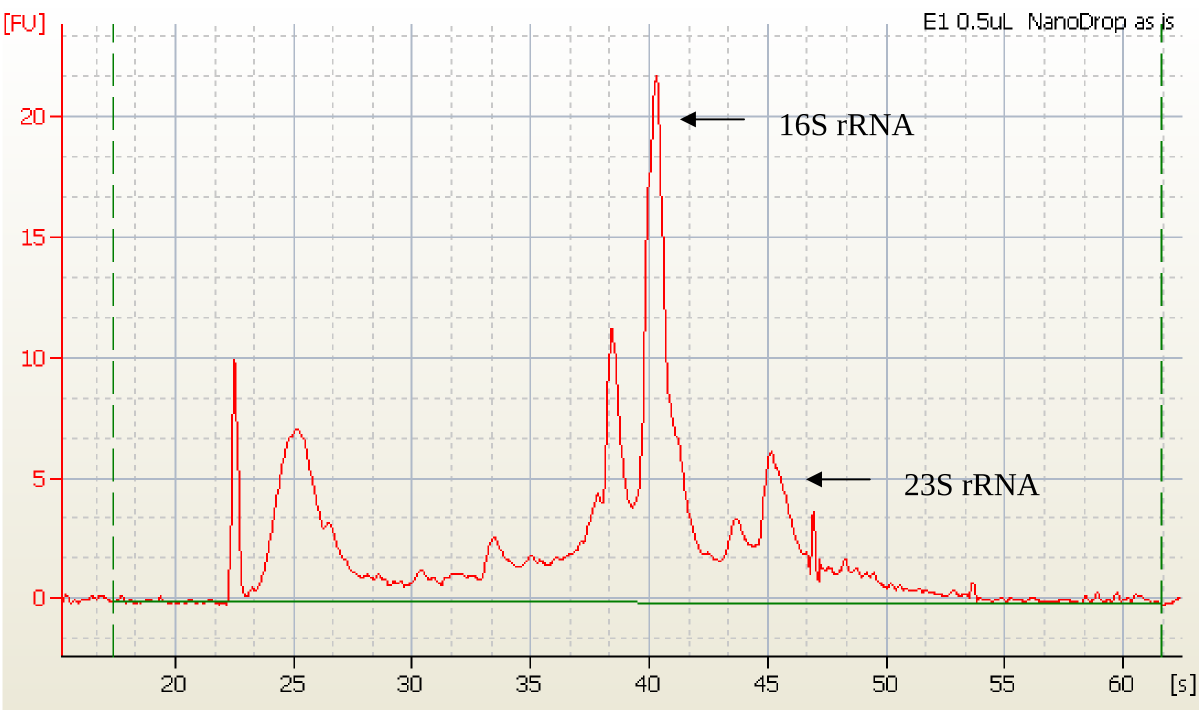


Figure 6: Agilent Bioanalyzer electropherogram of RNA extracted from ocean water spiked with E. coli.

The significance of bioanalyzer results lays in bands labeled as 23S rRNA in Figure 6 and 26. The 23S rRNA peaks are the indicators of RNA degradation since 23S RNA is the first form of RNA that degrades during extraction or preservation of extracted samples. Shorter 23S rRNA peak in Figure 6, which shows RNA extracted from ocean water sample seeded with *E. coli*, and following jagged signal indicate that RNA is at least partially degraded. Although it is still possible to achieve good microbial identification from 16S RNA in that sample, partially degraded RNA may not suitable for certain applications such as gene expression analysis. However, the sharp shape of the 23S RNA peak in Figure 7 and the smooth signal following it indicate that the RNA extracted from the other ocean sample seeded with *Salmonella* sp. is in perfectly intact condition, free of any degradation.

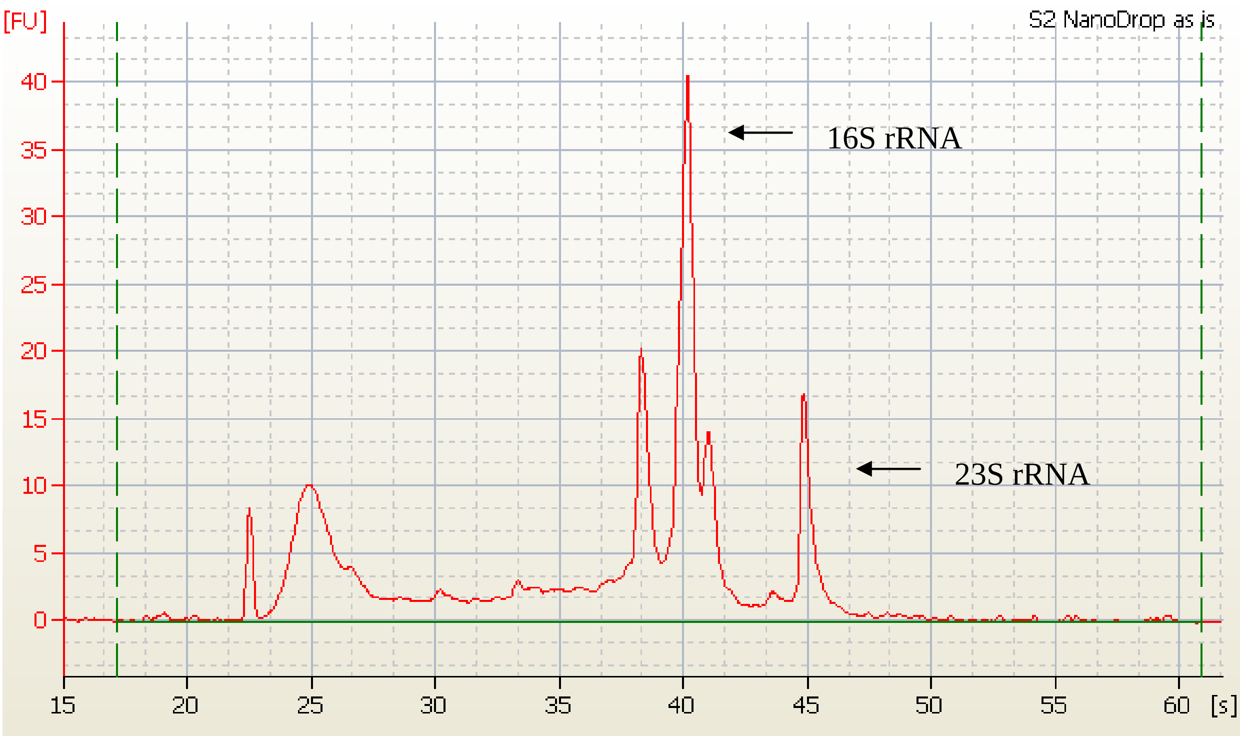


Figure 7: Agilent Bioanalyzer electropherogram of RNA extracted from ocean water spiked with Salmonella sp.

Figure 7 strongly suggests that the extraction protocol developed during this study can successfully be used to obtain sufficient quantities of intact RNA from seeded ocean water samples. It is important to note that partial degradation of RNA extracted from the ocean water sample seeded with *E. coli* might have happened during transportation of the extracted RNA from Villanova to Philadelphia and it may not be issue if samples could be analyzed on site immediately after extraction.

These results strongly suggest that extraction of sufficient quantities of intact nucleic acid, both RNA and DNA, from a complex matrix such as ocean water is possible using commercially available extractions kits and optimized extraction protocols. This is a significant development since application of any genotypic method to microbial identification in ocean water samples will require sufficient quantities of intact nucleic acid. The research team made significant progress towards overcoming this major challenge as evidenced by the results presented in this report. These findings indicate that a microarray-based pathogen identification approach is feasible on an oceangoing emergency decontamination vehicle.

Conclusions

Based on the findings above (in Section 4), the following overall conclusions can be drawn.

- PCR-based pathogen identification may not be a feasible technology for on-site use in an oceangoing vessel due to the fact that using this technology to screen for a large number of possible microbial pathogen might take a long time since each primer pair targeting a particular species has to be analyzed independent of the primer pair targeting another species.

- Microarrays, the so called gene chips, on the other hand, were shown to be feasible for that purpose. During the feasibility assessment, the research team developed an effective protocol for extracting intact nucleic acids, both DNA and RNA, from highly complex matrices such as ocean water and biosolids, a step long considered as the biggest challenge in application of microarray technology for detecting pathogens in the environment.

Recommendations

The results presented in this report strongly suggest that extraction of sufficient quantities of intact nucleic acid, both RNA and DNA, from a complex matrix such as ocean water is possible using commercially available extractions kits and optimized extraction protocols. This is a significant development since application of any genotypic method to microbial identification in ocean water samples will require sufficient quantities of intact nucleic acid. The research team made significant progress towards overcoming this major challenge as evidenced by the results presented in this report. These findings indicate that a microarray-based pathogen identification approach is feasible on an oceangoing emergency decontamination vehicle. The following are recommended as further research and development steps:

- Developing a list of potentially target pathogens of public health and bioterrorism threat (literature and database search).

- Fabrication and optimization of microarrays.

- Develop a list of equipments and supplies needed to establish a genomics facility on an oceangoing vehicle.

Summary

The overall goal of this study was to investigate the possibility of establishing a fully-functional microarray facility within an oceangoing decontamination system that can be used for rapid detection of microbial pathogens including bioterrorism agents. For that purpose, feasibility of several genotypic approaches, such as microarrays, for pathogens detection will be evaluated. The results showed that microarray technology is not only feasible but also very promising for timely detection of biological treatments in naval emergencies. There is further research and development efforts that must be undertaken to take full advantage of this novel technology.

References

1. Alcamo, I.E. 2001. Fundamentals of Microbiology.
2. Black, J.G. 1999. Microbiology: Principles and Explorations.
3. Chen, Y., Higgins, M. J., Maas, N. A., and Murthy, S. N. 2006. DNA extraction and *Escherichia coli* quantification of anaerobically digested biosolids using the competitive touchdown PCR method. Water Res. **40**: 3037-3044
4. Dutka-Malen, S., Evers, S., and Courvalin, P. 1995. Detection of glycopeptides resistance genotypes and identification to the species level of clinically relevant entorococci by PCR. J. Clin. Microbiol. **33:** 24-27.
5. Haznedaroglu, B.Z., Yurtsever, D., Lefkowitz, J.R., and Duran, M. 2007. “Phenotypic characterization of *Escherichia coli* through whole-cell fatty acid profiling to investigate host specificity”, *Water Research*, **41(4)**:803-809.
6. Jackson, C. R., Fedorka-Cray, P. J., Barrett, J. B. 2004.Use of genus- and species-specific multiplex PCR for identification of Enterococci. J. Clin. Microbiol. **42(8)**: 3558-33565.
7. Mangan, J.A., Sole, K.M., Mitchison, D.A., and Butcher, P.D. 1997. An effective method for RNA extraction from bacteria refractory to disruption, including mycobacteria. Nucleic Acids Res. **25**: 675-676.
8. Mumy, K.L. and Findlay, R.H. 2004. Convenient determination of DNA extraction efficiency using an external DNA recovery standard and quantitative-competitive PCR. J. Microbiol. Methods **57** : 259–268.
9. Rose, P., Harkin, J.M. and Hickey, W.J. 2003. Competitive touchdown PCR for estimation of *E. coli* DNA recovery in soil DNA extraction. J. Microbiol. Methods **52**: 29–38.
10. Sheridan, G. E. C., Masters, C. I., Shallcross, J. A., and Mackey, B. M. 1998. Detection of mRNA by reverse transcription-PCR as an indicator of viability in *Escherichia coli* cells. Appl. Environ, Microbiol. **64**:1313:1318.
11. U.S. Environmental Protection Agency. 2005. Proceedings of the workshop on “Feasibility of using DNA/RNA microarrays and related technologies for high through-put detection of waterborne pathogens”. Cincinnati, OH.
12. Wang, D., Coscoy, L., Zylberberg, M. Avila, P.C., Boushey, H.A., Ganem, D., and DeRisi, J.L. 2002. Microarray-based detection and genotyping of viral pathogens. Proceedings of the National Academy of Sciences. **99**(24):15687-15692.

Appendix A – Primer characteristics

Table A1. Characteristics of the species-specific primers tested

Target species and genes	Primer		Primer Description		Product (bp)
	Forward	Reverse	Forward 5'-3' (Sense)	Reverse 5'-3' (Antisense)	
E. faecalis, ATCC 19433; amplified gene - sod A	FL 1	FL 2	ACTTATGTGACTAACTTAACC	TAATGGTGAATCTTGGTTTGG	360
E. faecium, ATCC 19434; amplified gene - sod A	FM 1	FM 2	GAAAAAACAATAGAAGAATTAT	TGCTTTTTTGAATTCTTCTTTA	215
E. avium, ATCC 14025; amplified gene - sod A	AV 1	AV 2	GCTGCGATTGAAAAATATCCG	AAGCCAATGATCGGTGTTTTT	368
E. gallinarum, ATCC 49673; amplified gene - sod A	GA 1	GA 2	TTACTTGCTGATTTTGATTCG	TGAATTCTTCTTTGAAATCAG	173
E. durans, ATCC 19432; aplified gene - sodA	DU1	DU2	CCTACTGATATTAAGACAGCG	TAATCCTAAGATAGGTGTTTG	295
E. hirae, ATCC 8043; aplified gene - sodA	HI1	HI2	CTTTCTGATATGGATGCTGTC	TAAATTCTTCCTTAAATGTTG	187
E. faecalis, V 583 (VanB); amplified gene - ddl	E 1	E 2	ATCAAGTACAGTTAGTCT	ACGATTCAAAGCTAACTG	941
E. faecium, BM 4147 (VanA); amplified gene - ddl	F 1	F 2	TAGAGACATTGAATATGCC	TCGAATGTGCTACAATC	550

The primer pairs FL 1/FL 2; FM 1/FM 2; AV 1/AV 2; GA 1/GA 2; DU1/DU2; and HI1/HI2 were developed by Jackson et. al., 2004 and the pairs E 1/E 2 and F 1/F 2 were developed by Dutka-Malen et.al., 1994

Appendix B: List of Figures

Figure 1: Structure of a nucleotide with ribose backbone 203
Figure 2: Structure of a DNA molecule showing hydrogen bonds between four nucleotides 204
Figure 3: Principles of PCR amplification.. 206
Figure 4: Amplified PCR products for identification of Enterococcus sp. 208
Figure 5: Formaldehyde denaturing agarose gel... 212
Figure 6: Agilent Bioanalyzer electropherogram of RNA.. 213
Figure 7: Agilent Bioanalyzer electropherogram of RNA.. 214

Chapter 4 – Enhanced Resolution Nuclear Radiation Detector

Dr. Rosalind Wynne – Villanova University

Executive Summary

Nuclear particle detection and identification are of growing importance to the military and to society as a whole. Threats of nuclear attacks or accidents exist[1] which have the potential to affect deployed vessels and to affect civilian populations at nearby ports. A compact, light weight, reliable optical fiber based nuclear radiation contamination detector would be beneficial to a seagoing decontamination system. Glass optical fiber scintillation detectors for sensing neutrons and gamma particles are proposed. The detectors presented offer advantages such as ruggedness since they are not susceptible to nuclear radiation degradation, humidity, and drastic temperature variations which, in addition to portability, make the all glass fiber nuclear detection system a good candidate for oceangoing vessels. Oceangoing vessels can be subjected to weather conditions of severely cold or hot climates with precipitation and it is important to have instrumentation especially for ships with radioactive cargo that have reliable nuclear detection without sacrificing cargo space. The sensor components are also immune to electromagnetic interference from electromagnetic pulses EMPs which may accompany nuclear attacks or accidental explosions.

A portable nuclear radiation detector based on microstructured optical fiber technology was investigated. The detector was designed to sense gamma-rays that are common radiation artifacts of weapons grade nuclear materials. The proposed techniques allow for the composition of an all glass detection system that is nuclear radiation resistant and addresses the issue of signal degradation in glass by using an air-core light guide to transmit the scintillation signal to electronic processing equipment. The transmission length in the optical fiber is also increased by the introduction of an optical fiber amplifier to reduce the number of electronic signal processing stations that may be subject to electromagnetic interference.

The preliminary findings of this project indicate that conventional gamma ray detection capabilities suffer from low resolution (e.g. sodium iodide crystal) and limited operating temperatures (e.g. germanium detectors). It is recommended to employ a new class of scintillating detectors that consists of nano-composite materials that have scintillation properties that can be controlled via the assembling of nanometer sized semiconductor crystals. The important properties of QDs such as quantum efficiency and emission wavelength can be tuned by changing the geometry, composition and size of these components. A standard NaI(Tl) crystal emits scintillation at a wavelength of 460 nm. But the present photomultiplier tube (PMT) has a maximum efficiency of 25% at these wavelengths. It is possible to tune the output wavelengths when QDs are employed as the scintillating medium matching photodiode specifications with quantum efficiencies as high as 70%.[2] A compact QD-MOF nuclear radiation detector based on nano-

semiconductor and microstructured optical fiber technology has the potential to be developed. These detectors will sense neutrons and gamma-rays that are common radiation artifacts of weapons grade nuclear materials. Packaged detectors may be located aboard military vessels to monitor nuclear reactors that power ships and submarines, nuclear cargo, and nuclear warfare technology.

Background

Common weapons grade material used in warfare technology and possible cargo for Navy vessels can be composed of either plutonium or uranium radioactive material. Neutron detection is necessary for the identification of weapons grade plutonium[[3]]. Gamma-ray detection is also important in the detection of uranium. The goal of this project was to develop a compact neutron and gamma-ray nuclear detector that is immune to environmental interference. The detector will use a glass scintillator in an all glass optical fiber system that may provide radiation resistance to the detection system. The optical fiber amplifier will compensate for the attenuation normally associated with glass. A number of patents exist on optical amplification of nuclear radiation detection via conventional optical fibers[[4,5]]. However, the scenario of a MOF based optical fiber amplification system has become of recent interest to the technical community[[6]].

The proposed detectors incorporate a microstructured optical fiber to transmit and amplify the light signal from a scintillation material due to radiation exposure. Microstructured optical fibers (MOFs) are specialty optical fibers in which a series of carefully spaced periodic micron-sized cavities within an air-silica lattice in the cladding of the fiber provide extraordinary waveguide characteristics not demonstrated by standard optical fibers. (See Figure 1) One advantage of this approach is to possibly minimize the radiation absorption losses that can attenuate and distort the scintillation light by using air-core MOFs. Air-core MOFs demonstrate a modified photonic band gap confinement such that the fiber can be designed to support the propagation of light of a desired spectral range along the air-core [[7,8]]. This unique air guidance property may permit scintillation light to propagate through the air-core thereby avoiding the absorption that occurs at scintillation wavelengths in the solid-core region of a conventional optical fiber. This system may also offer the possibility of longer transmission fiber lengths such that the electronic signal processing equipment location can be removed from the radiation site avoiding both radiation and EM interference.

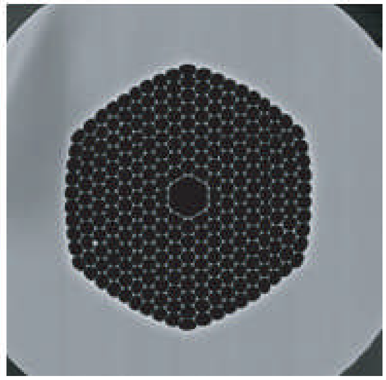


Figure 1: Cross-section of a Corning Photonic Band Gap™ specialty fiber. Typical core diameters range from 8µm to 12µm. The fibers are standardized to have a 125-150um cladding diameter.

The techniques discussed earlier allow for the composition of an all glass detection system that is nuclear radiation resistant and addresses the issue of signal degradation in glass by using an air-core light guide to transmit the scintillation signal to electronic processing equipment. The transmission length in the optical fiber is also increased by the introduction of an optical fiber amplifier to reduce the number of electronic processing stations. The detectors presented offer advantages such as ruggedness since they are not susceptible to nuclear radiation degradation, humidity, and drastic temperature variations, which in addition to portability, make the all glass fiber nuclear detection system a good candidate for oceangoing vessels. Oceangoing vessels can be subjected to weather conditions of severely cold or hot climates with precipitation and it is important to have instrumentation especially for ships with radioactive cargo that have reliable nuclear detection without sacrificing cargo space. The detector components are also immune to electromagnetic interference from EMPs which may accompany nuclear attacks or accidental explosions. The detector offers added benefits such as being chemically non-corrosive and having the potential to be “connecterized” to allow for low-technical-level-skilled personnel to install and operate the system.

Objectives

Radiation and nuclear material detection projects are currently being conducted at a number of facilities (e.g. Pacific Northwest National Laboratory and Sandia National Laboratory). The novelty of this proposed approach was to process signals in the optical domain to reduce detection system size and increase separation distance between the electronic signal processing equipment and radiation source location. The probability, P(x), that a photon travels some distance x along the optical fiber away from its position of origin in the scintillator is:

$$P(x)=A \exp(-\mu x) \qquad (1)$$

where A is a constant that is a function of the geometry of the scintillator, μ is the effective attenuation the photon experiences as it propagates along the fiber system. The attenuation is dependent on the scintillation wavelength which is due to the fiber material properties. If the effective attenuation can be reduced by transmitting of the photon via a low index or air transmission region, the likelihood of photons surviving the fiber transmission process may increase exponentially.

The proposed system consists of a scintillation material (e.g. lithium glass), an air-core MOF fiber filled with wavelength shifting (WLS) fluid and an optical fiber amplifier. (See Fig. 3) The WLS fluoresces when stimulated by the scintillator output such that it fluoresces at a longer wavelength. The fluorescent signal will be amplified as it is transmitted along an optical fiber amplifier. Optical amplification can be achieved by installing highly non-linear fiber to induce nonlinear effects such that Raman amplification may amplify a transmitted signal allowing longer lengths of fiber to be used for signal transmission. Raman amplification is based on stimulated Raman scattering (SRS), where a photon scatters in an atomic system such that it can be inelastically scattered by phonons and give energy to the medium. This can possibly reduce the number of the signal processing equipment occurrences such that many fiber optic extensions from detectors can be plugged into one hub.

The radiation source materials employed for detector calibration were cesium and cobalt (to support gamma ray emission). The inorganic, thallium activated sodium iodide for gamma-ray detection (Saint- Gobain Crystal NaI(Tl)™) scintillation material will be employed. A length of scintillating material will be cut and polished on the end face of the fiber to promote light confinement to the fiber. The scintillating fiber will be coupled to a length of a wavelength shifting fluid (Saint- Gobain Crystal BC-517P) filled hollow core microstructured optical fiber to shift the scintillation light to wavelengths that will not be absorbed by the optical fiber amplifier. (See Figure 2: Conventional scintillation measurement scheme
) The MOF will be joined by another unfilled length of hollow core fiber (Corning Photonic Bandgap Fiber™) for low loss transmission of the scintillation light. A length of an optical fiber amplifier will amplify the signal from the MOF and transmit the signal to the photodetector. All fiber components will be fusion spliced to reduce coupling losses between separate fiber sections. The PMT (Hamamatsu-Photonics R1635) will produce an amplified electrical current in response to the scintillation signal. The electrical signal is preamplified (Ortec digiBASE) and sent to be analyzed with a multichannel analyzer (MCA). The Ortec digiBASE is a 14-pin photomultiplier tube base for nuclear radiation spectroscopy applications with scintillation detectors. DigiBASE combines a miniaturized preamplifier and detector high voltage (0 to +1200 V bias) with powerful digital signal processing, multichannel analyzer, and special features for fine time resolution measurements that are all contained in a low-power (<500 mA), lightweight (10 oz, 280 g), small-size (63 mm diameter x 80 mm length) tube base with a USB connection.

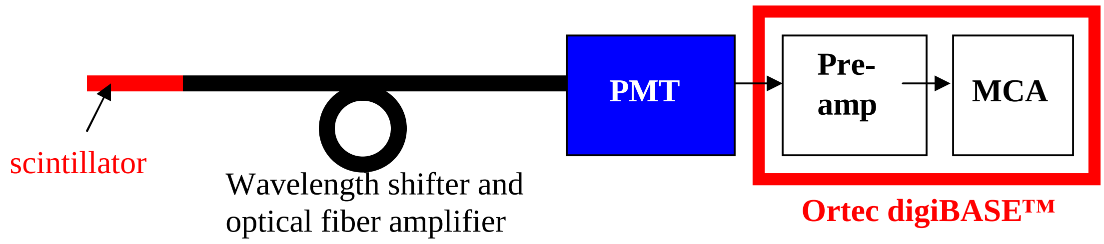


Figure 2: Conventional scintillation measurement scheme

Assembling the WLS filled MOF section required the development of a fiber filling procedure, apparatus and model. The model was first developed and tested using gas components. The fluid mechanical properties of filling the fiber with gas can be easily transferred to the properties governing the filling dynamics of the wavelength shifting fluid. The fiber loading apparatus consisted of sections of MOF fiber (Corning™ PBG-1550) with a transmission window between 1480-nm and 1640-nm which were prepared and inserted into the gas system. The prepared fiber ends were placed into two separate hermetically sealed aluminum housing components with a gas-filling or evacuation port. A light source was launched into the PBG fiber via a butt-coupled conventional single mode fiber. The transmitted light was coupled out of the PBG fiber through to a butt-coupled conventional multi-mode fiber. The output light was then transmitted to an optical spectrum analyzer (OSA) to monitor the gas filling dynamics.

Completed Tasks

Highly nonlinear MOFs have very strong nonlinear properties that may allow for optical fiber amplification due to stimulated Raman scattering processes. Raman amplifiers provide low noise amplification and an arbitrary gain band. The long interaction length of fibers leads to significant amplification where the gain band is determined by the optical pumping scheme. This process may amplify the emitted scintillation light in the all glass detector. The scintillation wavelength will be identified for the scintillation materials that experience the highest gain for the fiber amplification process. This information will also determine the appropriate settings for the PMT and signal processing electronics. The characterization process will measure the detector efficiency as a function of optical fiber amplifier and MOF length.

Future tasks

Due to time and budgetary constraints there are a number of tasks that remain to be performed, including complete detector assembly and field testing. In the future, the detector will be characterized to determine detector efficiency as a function of temperature, humidity, vibration and background radiation. These measurements will determine the reliability of the detector in environmental conditions that are common to oceangoing vessels. These sensors may have the potential to withstand fires and temperature variations that often accompany a nuclear incident.

Measurements will also be performed to determine the amount of radiation damage the all glass detection system will sustain before failure of the detector. Detection efficiency curves will be composed as a function of scintillation wavelength and comparisons will be made between results taken before and after extended exposure times and high radiation doses. This information will identify the lifecycle of these detectors for maintenance (i.e. annealing to reverse radiation damage) or replacement.
Finally, the detection system will be assembled in a compact and efficient arrangement. The detector will be packaged in a hermetically sealed container to promote ruggedness and system portability.

Findings

Filling MOF

The convection methods for filling the MOF with fluid are discussed in this report are referred to as "pressure-driven methods" of filling the hollow core fibers. The pressure-driven method of filling reported are proposed for filling fibers efficiently. Since these fibers are costly and may be difficult to recycle if improperly filled with fluids, the preliminary investigation was performed with gas samples rather than fluids. In the present method, the filling gas enters the fiber as a result of the pressure at the inlet to the fiber being higher than the pressure at the fiber outlet.

In the pressure-driven model it was assumed that the initial gas in the hollow core and the filling gas have different viscosities. Therefore gas A and gas B are treated as different gases/fluids. (See Figure 3) The filling rates were governed by a classical laminar flow. However, the regimes follow unsteady fluid dynamics theory [9], in which the filling gas displaced the resident gas in a "piston-like" fashion. Since the flow of gas through the fiber was assumed to be fully developed, one-dimensional, and laminar, all reasonable assumptions for the present problem, first order estimates were made of the filling time relative to the pressure differential. It was also taken into account that there was no mixing of gases as gas A filled up the fiber and displaced gas B. The end of the fiber was exposed to the ambient such that the outlet pressure was fixed. Due to the fact that the fiber was connected to a fixed-pressure gas cylinder, the inlet pressure was also fixed throughout the experiment. The properties of the gases, such as viscosity, density, etc, were assumed to be constant. The viscosity of acetylene and air were taken as 10.09×10^{-6} Nsm^{-2} and 18.17×10^{-6} Nsm^{-2} respectively [10,11]. The diameter of the sample hollow core was 12.5 μm. A fluid dynamic model based on the flow of gas in a tubular region is shown in Figure 3.

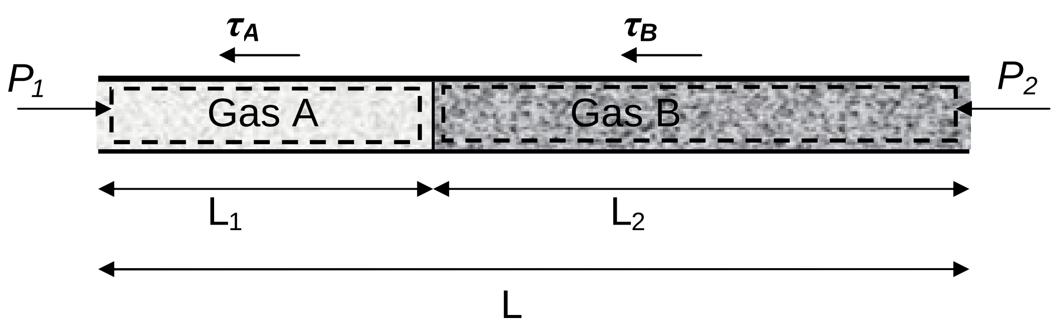


Figure 3: Schematic figure of the fiber fluid filling model.

A control surface is assumed around both gases, not including the fiber. The volume inside the control surface is called control volume. Writing a force balance on the entire control volume gives

force applied due to P_1 - force applied due to P_2 = (2)
force due to shear stress on gas A + force due to shear stress on gas B.

Substituting the formulation of each force in (3), we have

$$P_1A - P_2A = \tau \cdot \zeta \cdot L_1 + \tau \cdot \zeta \cdot L_2 \quad (3)$$

where $P_{1,2}$ are the pressures for gases A and B, A is the surface area of the tube, τ is the shear stress applied on the tube from the fluid, ζ is the perimeter of the tube (i.e. πD), and L is the length of the tube. In (4), pressure, surface area, length, and perimeter of the tube are known. The shear stress, τ is determined and expressed in terms of the other known parameters [[12]].

With the assumption of laminar flow, where D is the diameter of the tube, μ is the viscosity of the gas and $\bar{v}$ is the average velocity of gas, then the pressure difference can be written as ΔP. Therefore, the characteristic time for filling the fiber, t_f, can be written as

$$t_f = \frac{32}{\Delta P}\left(\frac{L}{D}\right)^2 \frac{(\mu_A + \mu_B)}{2}. \quad (4)$$

The expression for the filling time in (6) shows that the filling time is linearly dependent on the arithmetic mean of the two viscosities. Similarly, increased viscosity results in longer filling times. Also, t_f depends inversely on the pressure difference and fiber core diameter. It also depends directly on the fiber length such that that length and the core diameter of the fiber are significant factors in the filling time. In our experiments, the tube (fiber hole) was initially filled with air such that gas B is air in our theoretical modeling. The results obtained for a 0.365m length of MOF fiber filled with acetylene gas (C_2H_2) are in agreement with the theoretical predictions and lie within the upper and lower limits of the uncertainty of the model which can be attributed mainly to errors in the fiber length measurements. (See Figure 4)

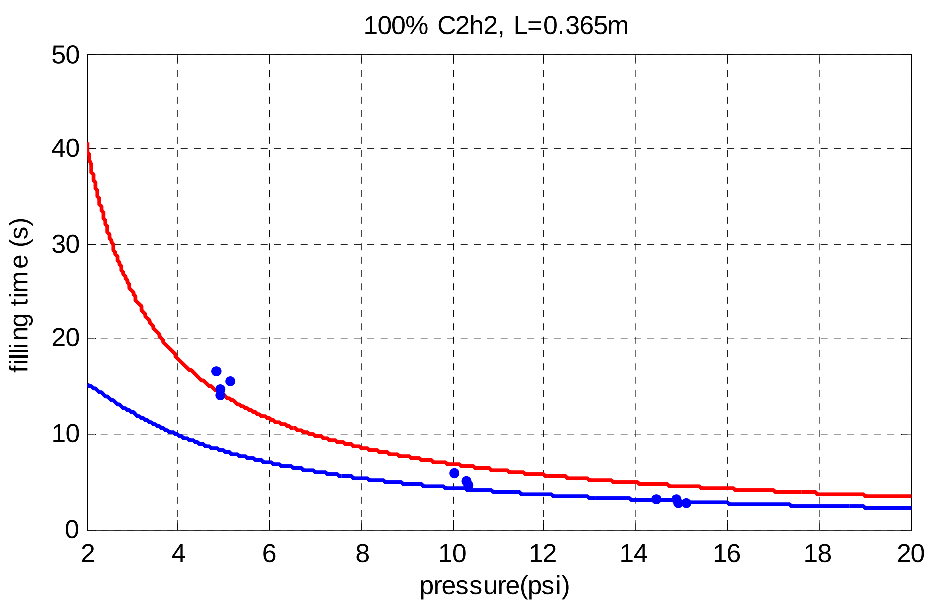


Figure 4: MOF fiber filling times as a function of driving pressure. Blue dots –measured tf, Red line- theoretical upper limit of tf and blue line lower theoretical limit of t_f.

Raman Amplification

In the present design, MOF fiber is coupled to polarization maintaining fiber (PMF-400), which is a silica based MOF and acts as an active nonlinear medium for Raman amplification. When compared to conventional optical fibers, Raman amplification is much more efficient in photonic crystal fibers[13].

Raman Scattering is a nonlinear effect. When subjected to intense light, the response of a dielectric medium, such as silica optical fiber, produces a Raman scattering effect. In this process, incident light on a medium is converted to a lower frequency. This is illustrated in Figure 5 [14]. When a molecule is excited to a virtual level due to the pump photon ν_p it decays quickly to low energy levels associated with the release of a photon at ν_s and the energy level difference between the signal and photon is released in the form of molecular vibrations of the host material (optical fiber). The frequency shift and shape of the Raman gain curve is determined by these molecular vibrations.

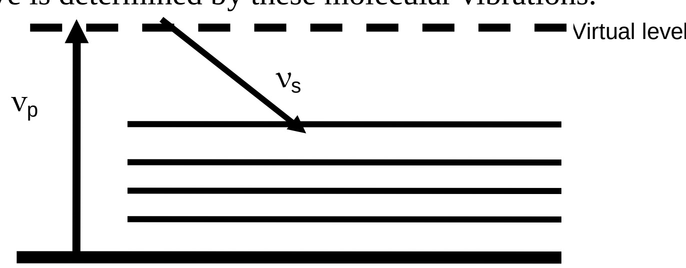


Figure 5: Schematic of the quantum mechanical process taking place during Raman scattering

When high pump powers are used, there is a rapid growth in the molecular vibrations which scatters light as most of the pump power is converted into scattered light. This process is known as stimulated Raman scattering, which is the gain mechanism of Raman amplification. Due to its high threshold, approximately 1W when using continuous-wave pump beams, it is not easy to observe stimulated Raman scattering in optical fibers. But when a low intensity light of suitable frequency is launched along with a continuous wave pump beam with pump power levels in the range of 100mW, the weak light can be amplified significantly [Error! Bookmark not defined.].

The equation that governs the pump power for a given gain [14] and wavelength is given by the following

$$G = \exp(\frac{g_R P}{A\alpha}(1 - \exp(-\alpha L)) . \qquad (5)$$

Here G is the signal gain; α is the sum of attenuation coefficients of both the polarization-maintaining fiber and PBG fiber; A is the effective area of the polarization-maintaining (PM) fiber; and g_R is the Raman coefficient of the fiber material, which is silica [Error! Bookmark not defined.]. For amplification purposes, the weak signal should be pumped with a strong signal of approximately 400mW at 407.7nm. The Raman coefficient at 407.7nm is

$2.45 \times 10^{-3} W^{-1} km^{-1}$. Based on the calculations for a gain of 1.3 m^{-1}, 300mW of power is needed for a fiber length of 50m. The gain in (5) corresponds to the total sum of attenuation coefficients in the PBG fiber and PM fiber. The results obtained using (5) are shown in Figure 6. It can be observed that for very high values of pump power, the required PM fiber lengths are short (e.g. < 30m). For example, an input pump power of 2.346 W requires a length of 5 m. But for an increased length of up to 30 m there is a decrease in the required pump power levels, which is in the range of 450 mW. For longer lengths of PM fiber, the required pump power levels approach a saturation level.

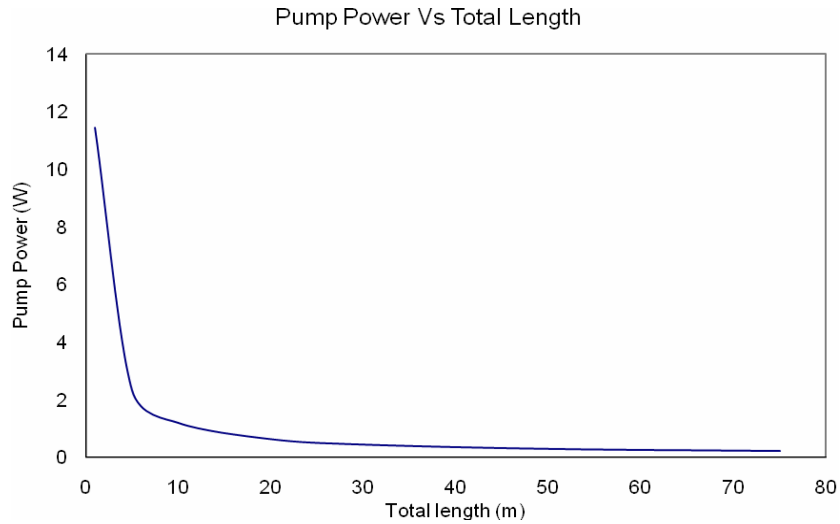


Figure 6: Pump power vs. total PM fiber length.

Conclusions

Based on the findings above (in Section 4), it appears that the current approach using a NaI(Tl) scintillator may not be an efficient option for the detection scheme presented. The costs for the proposed system increases significantly due to the limited system response at the current scintillation wavelengths requiring substantial Raman amplification via long PM fiber lengths and high power pumping lasers at unconventional wavelengths. Scintillation schemes based on quantum-dot-activated MOFs is recommended in the following sections for efficient, low cost, high resolution and compact nuclear radiation detection.

Recommendations

We recommend an alternative approach for developing a scintillation scheme that is a compact enhanced resolution nuclear radiation detector based on quantum dot (QD) and microstructured optical fiber (MOF) technologies. The preliminary version of the QD-detectors can sense gamma-rays that are common radiation artifacts of weapons grade nuclear materials. The next-generation of QD-detectors will detect neutrons and alpha particles. The proposed techniques allow for the composition of an inorganic semiconductor/glass detection system that is nuclear radiation resistant and addresses the issue of signal degradation in glass by using an air-core light guide coated with QDs to transmit the scintillation signal to electronic processing equipment. The transmission length of the QD coated optical fiber is also increased to improve scintillation detection and to reduce the number of electronic signal processing stations.

The scintillation of the QDs under gamma radiation demonstrate favorable energy resolutions to that of a standard sodium iodide NaI(Tl) scintillators similar to the design presented in the previous investigation in section 4 [16]. There are disadvantages to using conventional gamma radiation detection techniques such as bulk semiconductors (e.g. germanium) and glass scintillators (e.g. NaI(Tl)). Germanium which although provides good resolution, is limited in operation due to temperature dependencies that confines operation conditions to liquid nitrogen temperatures. The conventional scintillator, sodium iodide with thalium (NaI(Tl)), is not restricted to prescribed operation temperatures but suffers from poor energy resolution which is approximately 7% energy resolution at 662 keV [**Error! Bookmark not defined.**].

The main advantage of the reduced size of QDs is the increase in the material band gap energies which promotes the efficient emission of photons in the visible region [17]. This visible luminescence feature can be used for scintillation purposes. Efficient photon counting and high photon output are essential for photon detection of scintillation light. The QD coating process can be achieved using a recently developed pressure driven approach making mass production of these QD filled fibers practical [18].

Detection efficiency and energy resolution are key principles in gamma-ray radiation detection [19]. QD gamma- ray detection efficiency is typically low due to its low QD density and low average atomic number Z. The interaction length between the gamma rays and QD materials may be increased via coating the hollow core surface with the QDs. The total count of gamma-ray quanta that interact with the QD-activated detector may be enhanced. Additionally, the QD material can offer enhanced photon generation in the visible region for improved compatibility with existing scintillation collection schemes (e.g. photomultiplier tubes). (See Figure 8) For example, it has been reported that CdSe/ZnS QDs that luminescence at 510nm when exposed to gamma ray energies of 59 keV generate more visible photons than a conventional NaI detector [**Error! Bookmark not defined.**]. So, although the signal-to-noise ratio for the NaI crystal is attractive due to its higher detection efficiency (via its density and size), the energy resolution can be improved for composite QD materials due to the enhanced scintillation qualities.

From the measured energy resolution, ΔE/E, the number of photons generated in the material under gamma ray exposure at a given energy can be determined to accurately identify radiation sources. For an ideal scintillator the energy resolution[**Error! Bookmark not defined.**, **Error! Bookmark not defined.**] R is given by

$$R = (\Delta E/E) = \sqrt{\frac{1+v(M)}{N.p}}$$

N is the average number of photons generated at a given energy E, v(M) is the variance of multiplication factor of the PMT (for a typical PMT with a gain of 2 X 10^6, v(M) is approximately 0.08) and p is the average transport efficiency.

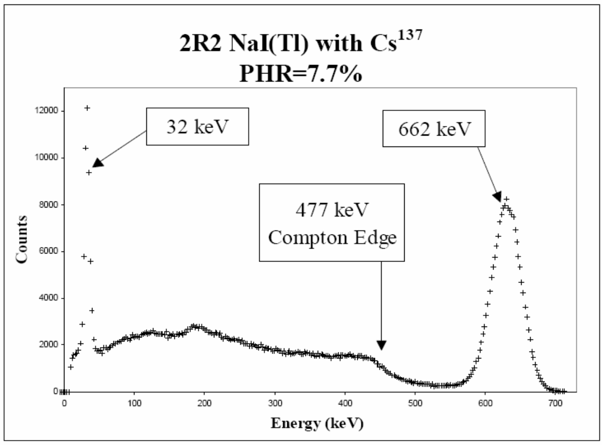


Figure 7: [137]Cs radioactive source measured with a 2”x2” NaI(Tl) detector [[20]].

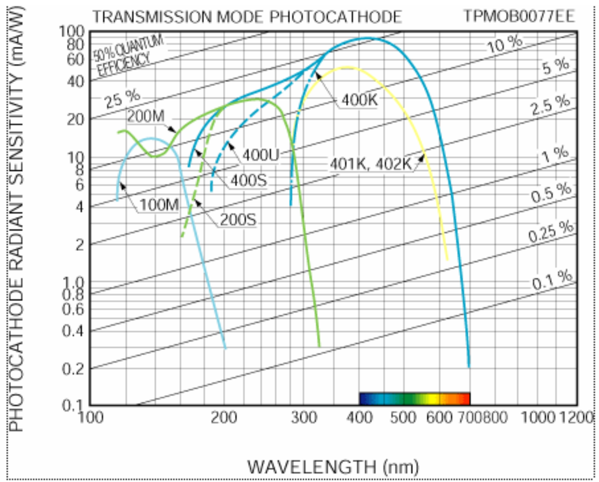


Figure 8: PMT spectral response of a Hamamatsu™ R1635 PMT (spectral response curve 400K)[[21]].

Recommended Enhanced Scintillation Scheme

The scintillator, for preliminary investigations, will be a QD material (e.g. CdSe/ZnS core–shell) coated length of hollow core fiber (Crystal Fibre HC-440-1 ™) with low transmission losses for the scintillation light transmitted to the photodetector. (See Figure 9) The low atomic number of the CdSe/ZnS dots results in a low stopping power. In order to detect high-energy gamma rays radiation sources for contamination remediation efforts, dots with a higher atomic number, such as PbS are recommended [**Error! Bookmark not defined.**]. The PMT (Hamamatsu-Photonics R1635) will produce an amplified electrical current in response to the scintillation signal. The electrical signal is preamplified (Ortec digiBASE ™) and sent to be analyzed with a multichannel analyzer (MCA). The system also has a graphic user interface for qualitative and quantitative spectrum analysis. (See Figure 10)

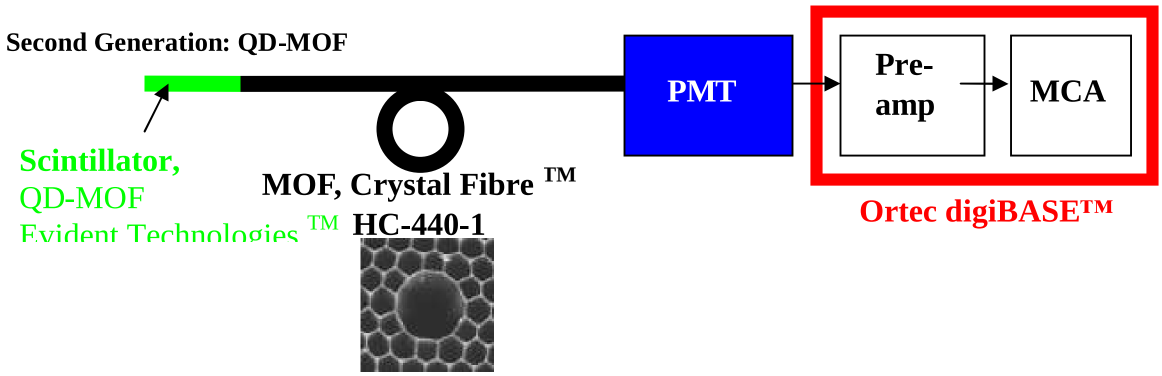


Figure 9: The gamma radiation detector concept: second generation.

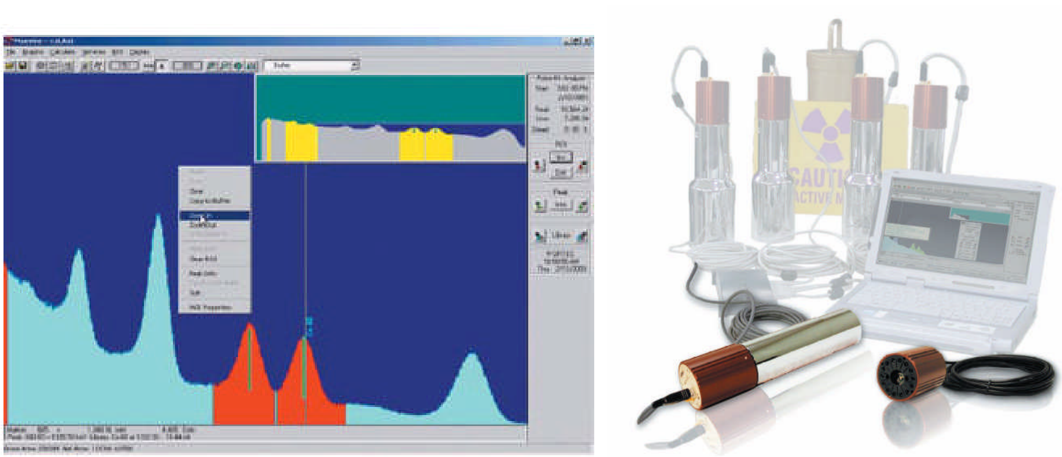


Figure 10: Typical Digibase spectral analysis and apparatus[22].

Summary

Common weapons grade material used in warfare technology and possible cargo for Navy vessels can be composed of either plutonium or uranium radioactive material. Nuclear particle detection and identification are of growing importance to the military and to society as a whole. A portable nuclear radiation detector based on microstructured optical fiber technology was investigated. The preliminary findings of this project indicate that conventional gamma ray detection capabilities suffer from low resolution (e.g. sodium iodide crystal) and limited operating temperatures (e.g. germanium detectors). It is recommended to employ a second generation quantum-dot-activated MOF scintillating detectors that consists of nano-composite materials that have scintillation properties. A standard NaI(Tl) crystal emits scintillation at a wavelength of 460 nm. But the present photomultiplier tube (PMT) has a maximum efficiency of 25% at these wavelengths. It is possible to tune the output wavelengths when QDs are employed as the scintillating medium matching photodiode specifications with quantum efficiencies as high as 70%. A compact QD-MOF nuclear radiation detector based on nano-semiconductor and microstructured optical fiber technology has the potential to be developed. These detectors will sense neutrons and gamma-rays that are common radiation artifacts of weapons grade nuclear materials. Packaged detectors may be located aboard military vessels to monitor nuclear reactors that power ships and submarines, nuclear cargo, and nuclear warfare technology.

References

[1] Department of Defense Chemical, Biological, Radiological, and Nuclear Defense Program: Annual Report Annual Report to Congress 1999, ISBN 1428983341

[2] S.E.Letant and T-F Wang, “Study of porous glass doped with QDs or laser dyes under alpha irradiation” Applied Physics Letters, Volume 88, 103110(1-3). 2006.

[3] Seymour, R. et al., “Portal, freight and vehicle monitor performance using scintillating glass fiber detectors for the detection of plutonium in the Illicit Trafficking Radiation Assessment Program,” *Journal of Radionanalytical and Nuclear Chemistry*, Vol. 248, No. 3, pp. 699-705, 2001

[4] Hoffman, D., “Fiber optic scintillator with optical gain for a computed tomography system and method of manufacturing same,” *US Patent 6775348*, Aug 10, 2004

[5] Gross, K., et al., “Radiation Detection Device,” *US Patent* 6,310,352, Oct. 30, 2001

[6] Alfeeli, B., et al., “Behavior of Random Hole Optical Fibers under Gamma Ray Irradiation and its Potential Use in Radiation Sensing Applications,” *Sensors*, Vol. 7, pp. 676-688, 2007

[7] Knight, J. C., Photonic Crystal Fibres, Nature, Vol. 424, pp. 847-851, 2003

[8] Russell, P., Photonic Crystal Fibers, Science, Vol. 299, pp. 358-362, 2003

[9] Fox, R. and McDonald, A., *Introduction to Fluid Mechanics.* New York: John Wiley and Sons, Inc. (1998).

[10]Bailey, B. J., “The viscosity of carbon dioxide and acetylene at atmospheric pressure,” *Journal of Physics D: Applied Physics*, **3**, 550-562 (1970).

[11] Seibet D. et al, “Viscosity Measurements on Nitrogen,” *J. Chem. Eng. Data 2006*, 51, 526-533

[12] Saxena, S.C. and Gambhir, R. S., The viscosity and translational thermal conductivity of gas mixtures, *Brit. J. Appl. Phys.*, 1963, VOL. 14

[13] Kazuhide Nakajima et al. “Raman amplification Characteristic at 850nm in a Silica Based Photonic Crystal fiber”, IEEE photonics technology letters, Vol.18, No.3, pp-451-453. February 2006

[14] Clifford Headley, Govind.P.Aggarwal, “Raman amplification in fiber Optical Communications “ Academic press, 2005

[15] Stuart Gray, “Raman Gain Measurements in Optical fibers” , Techincal Digest Symposium on Optical fiber Measurements, pp 151-156, 2000

[16] S.E.Letant and T.F.Wang –“Semiconductor QD scintillation under gamma-ray irradiation” Nano Letters, Vol. 6, No. 12, 2006

[17] Saleh and Teich, Fundamentals of Photonics, Wiley, Boston, 2007

[18] R. M. Wynne, K. Creedon and J. Merritt, “Simultaneously Sensing Multiple Gases Using a Single Length of Hollow-Core Photonic Bandgap Fiber with Sub-minute Response Times,” 2008 Proceedings of SPIE Volume 7056 - The International Society for Optical Engineering, Conference 7056, Paper 7056-32, San Diego, California, August 2008

[19] G. F. Knoll, Radiation Detection and Measurement, Wiley, New York, 1979

[20]http://www.detectors.saint-gobain.com/Media/Documents/S0000000000000001004/SGC%20Measuring%20Radiation%201104.pdf

[21]http://sales.hamamatsu.com/en/products/electron-tube-division/detectors/photomultiplier-tubes/part-r1635.php#

[22] http://www.ortec-online.com/pdf/digibase.pdf

Appendix A – List of Figures

Figure 1: Cross-section of a Corning Photonic Band Gap™ specialty fiber. 221
Figure 2: Conventional scintillation measurement scheme 223
Figure 3: Schematic figure of the fiber fluid filling model.. 224
Figure 4: MOF fiber filling times as a function of driving pressure............................. 225
Figure 5: Schematic of the quantum mechanical process.. 226
Figure 6: Pump power vs. total PM fiber length.. 227
Figure 7: ^{137}Cs radioactive source measured with a 2”x2” NaI(Tl) detector [20]. 229
Figure 8: PMT spectral response of a Hamamatsu™ R1635 PMT................................ 229
Figure 9: The gamma radiation detector concept: second generation. 230
Figure 10: Typical Digibase spectral analysis and apparatus[22]................................... 230

Chapter 5 – Flexbot

Ablaze Development Corporation, M5 Industries

Executive Summary

No emergency response robots are known to be capable of boarding and navigating throughout a ship, therefore the concept of FlexBot was developed though such a capability is required in order to respond effectively to at sea emergencies. In order to reduce danger to personnel, perform dangerous tasks in hazardous situations onboard ship, the FlexBot concept was developed. Though FlexBot was conceived to perform various hazardous onboard tasks, it is also fully capable of working on land as well. Although it looks nothing like a human being, it has a similar form factor and flexibility as a human, allowing it to travel within a ship anywhere that a person can travel, and to do so in extreme situations that are dangerous to humans. The FlexBot was determined to be feasible and it is recommended that development to prototype stage and beyond be continued.

Background

One of the primary concerns in responding to an emergency on land or at sea is the potential danger for the rescuers. In order to minimize danger to humans for land emergencies, remote control and autonomous robots are being developed to assist first responders and warfighters on land. Several systems are currently in use on land. Appendix A provides a brief catalog of existing robots intended for use in emergencies. As helpful as the existing robots may be for traveling roads and entering buildings, none are designed for shipboard use. It was therefore under the project that a robotic concept was developed to provide rescuers and investigators with a robot surrogate designed specifically for shipboard use. Because of the design and capabilities of the robotic concept, it was named FlexBot.

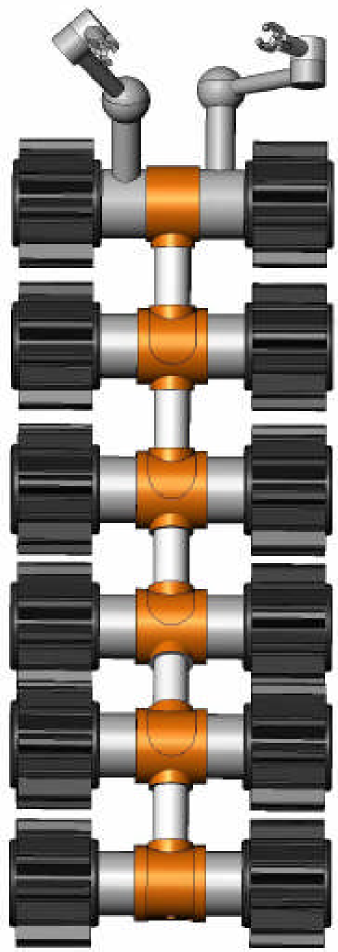


Figure 1: Flexbot prone - plan view

Objectives

The objective of the effort was to develop a robotic surrogate concept able to perform emergency response activities shipboard.

Findings

The FlexBot is an eight foot long articulated robot which is designed specifically for shipboard maneuverability in the event of an emergency on a ship that is potentially too dangerous for a human to investigate and remediate. Though the FlexBot does not look humanoid, it is designed to have the basic dimensions, agility and flexibility of a human. Standard robot designs would have a great deal of difficulty negotiating the narrow ship passageways, companionways, ladders, doors and hatches , as these were designed only for human access.

The FlexBot is capable of maintaining a basic human form and function in terms of the space and maneuverability it needs to move through a ship. It can stretch out to full length, or curl up in a fetal-like position while still maintaining mobility and balance. It can turn 180 degrees around a bulkhead and even roll back over itself to make a vertical U-turn in the middle of a narrow passageway. It can operate under water, climb over obstacles, climb up and down ladders, move between decks, drop into hatches and pull itself out again. It has strong but general purpose manipulators able to open doors and hatches using dogs, levers, hand wheels, drop bolts and grab handles. It does all of this without the complex need to balance on two legs. In fact, though it can stand upright to a height of six feet, it has no legs, but rather a number of articulated, wheeled nodes that can bend into many functional shapes depending on the task at hand.

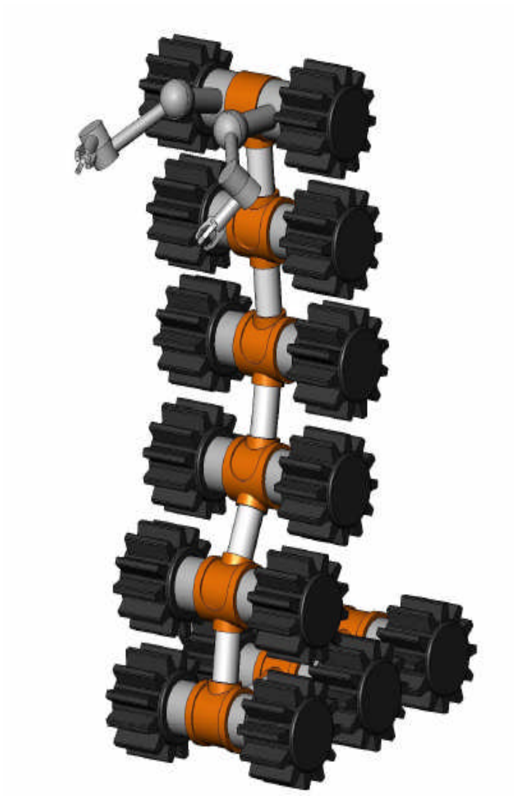


Figure 2: FlexBot standing upright

General Configuration

A typical FlexBot will consist of 8 nodes. Each FlexBot node is approximately 1 foot long, 2 feet wide and 1 foot deep, and contains a battery pack; command, sense, control and communications electronics; two independently controlled wheels for propulsion; and a motorized Hyneman Super Joint (HSJ) able to rotate in two axes. As a result of the segmented design, FlexBot will be able to form and move in a vertical position or in a prone one. It will also have a centipede like ability to allow it to negotiate debris, compromised structures, and near vertical surfaces like steep ladders.

It will have self contained power in the form of lithium ion battery packs. The exterior of the unit will be primarily aluminum tubing, which will provide a surface as well as the structure. Interior components will be contained within this tubing.

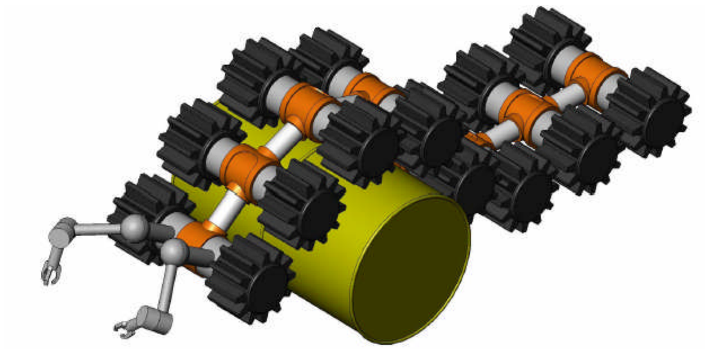


Figure 3: FlexBot crawling over an object

The node at the head of the FlexBot will also contain the tools / manipulators as well as a vision system. The last two nodes contain additional batteries and electronics. These two nodes act as a base when the FlexBot stands vertically. In the vertical mode, the back two nodes stay horizontal while the front 6 are raised one at a time and adjusted slightly off-vertical in a cobra -like manner so as to always keep the center mass of the front 6 nodes over the center of mass of the bottom two nodes to maintain stability. The focus of the arm design was not on strength, but rather on agility to be able to grab various handles, devices, wheels, etc. The majority of the strength needed to lift, turn, push, or pull is to be provided by a combination of the individual HSJ's twisting and flexing, much like a person's back and leg muscles can assist a human in performing heavy duty tasks.

Hyneman Super Joint (HSJ)

As mentioned earlier, the FlexBot will be constructed in eight segments; each segment with two axes of servo controlled movement provided by HSJ servos. The HSJ's provide a very high power to size and weight ratio, and this coupled with the segmented design will allow the robot to move in a vertical position or in a prone one.

Two motors (A,B) drive each joint. Each motor in each joint is individually controlled. Keeping in mind that each joint or node could be individually oriented differently in space, for the purpose of explanation, assume the direction of forward longitudinal motion of each individual node is X, side to side lateral motion is Y and vertical motion is Z. Rotation about the node's X axis is designated as roll; the Y axis pitch and the Z axis is yaw.

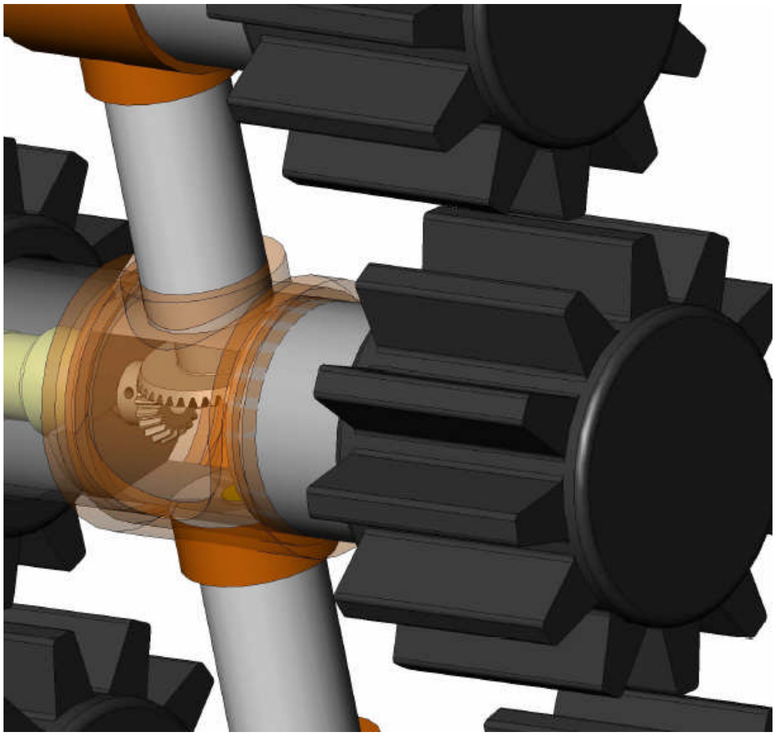


Figure 4: View of Hyneman Super Joint (HSJ) within a node

If, for an individual node / joint, motors A and B both run in the clockwise direction, the joint pitches around the Y axis clockwise. If motors A and B both run in the counterclockwise direction, the joint pitches around the Y axis in the counterclockwise direction. In this way the individual pitch attitude of each of the 8 joints be controlled, which in turn forms the various shapes of the FlexBot -- allowing it to stretch out prone, stand vertically, or fold into a compact shape.

If motors A and B rotate in opposite directions, the individual joint doesn't change in pitch at all, but rotates in roll. By reversing directions of the opposing motors, the rotation in roll also changes direction while maintaining the previously attained pitch angle.

Each joint also has a semi-passive one axis hinge that rotates about Z allowing it to yaw up to + / - 45 degrees. It is termed "semi-passive" because though it can act as a free rotating hinge, its position can be locked as needed. It is easiest to explain with two examples. When the FlexBot is in the prone position and maneuvers along the ship's deck the hinge is unlocked, allowing one joint to passively follow the joint in front of it (much like a parade of elephants). In this manner the FlexBot can make very flexible turns, including a tight U-turn (10 degrees). In the second example, if the FlexBot is in the standing position and wishes to turn a hand wheel, the yaw hinges are locked preventing any yaw motion and keeping each hinge firmly in place in terms of yaw motion.

Electronics

The FlexBot electronics includes the batteries, power management, motor controllers, communications, sensors and processor.

Batteries are included in the connection between each HSJ. Additional batteries can be carried by the end two joints which act as a base for some of the FlexBot configurations, such as when the FlexBot is standing upright. Lithium Ion batteries are rechargeable, and provide an excellent power density per weight ratio. Though they are complex to charge, the main concern is their violent reaction to water. They must either be packaged very carefully or a different power source must be found.

Power management includes battery charging as well as conservation. The primary power drain for the FlexBot will be driving the motors. Since each node contains four individual motors (two motors to drive the HSJ, one motor of each of the two propulsion wheels) the power management system can be used to carefully control the power to the individual motors. Each motor is used only when needed and only to the extent needed for the particular job. In many configurations, such as the vertical position, all of the motors except the propulsion motors in the bottom two nodes will be turned off.

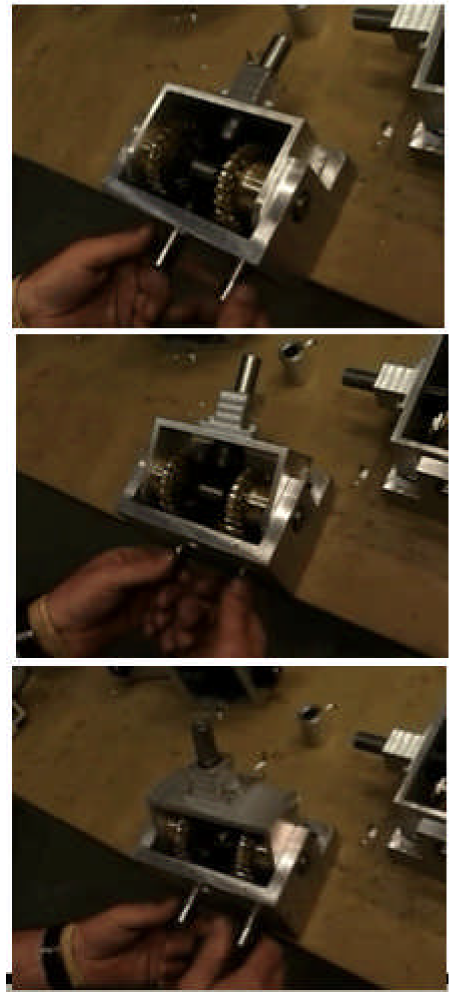


Figure 5: Demonstration of HSJ operation by hand

Identical, individual motor controllers will be used for each of the four motors in each node. These will be PWM (pulse width modulation types) to optimize power usage. The communications between the nodes will use wireless ZigBee, IEEE 802.15.4c. ZigBee provides secure (encryption), wireless short range communications (up to 50 meters per node), individual addresses (up to 65,000 individual nodes can uniquely operate within the wireless range), adequate bandwidth for inter-node communications traffic (250 kilobytes per second data rate), extremely low power and small size. The ZigBee module in the bottom FlexBot will be the Coordinator node all others will be FFD (full function devices) often termed router nodes.

This configuration allows for a self forming, self healing mesh network so that any one node in the FlexBot can talk with any other node. So if, for some reason a node's communications has failed, the other nodes in the FlexBot can still communicate with one another. The configuration also allows for seamless communications with any other FlexBot in range allowing them to work individually or in swarms.

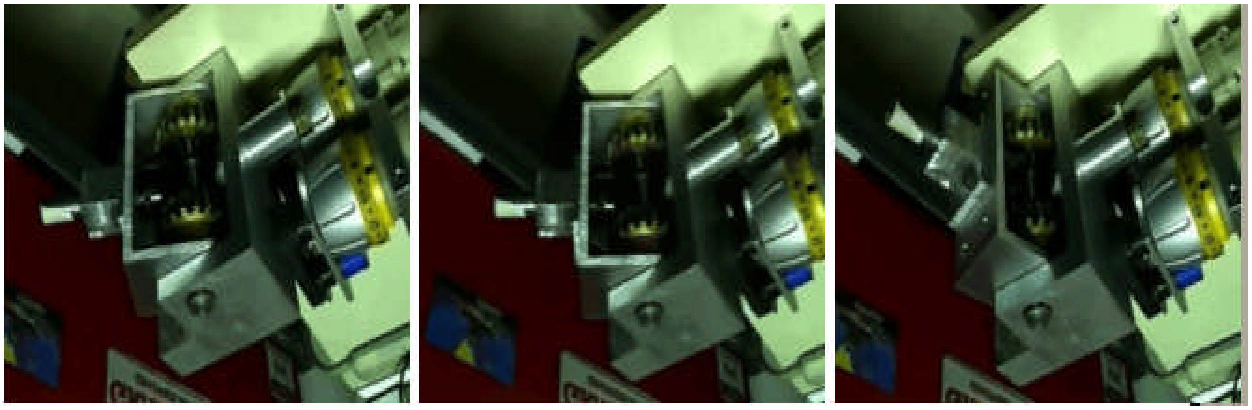


Figure 6: HSJ operated by simple motors

The Coordinator node will interface with the long range communications system located in the bottom two nodes. In initial FlexBot prototypes, it is envisioned that the system will be tethered, with the tether providing power and communications lines. It is envisioned that the production system will be wireless, providing two way data links as well as high definition video links. Such systems are commercially available as COTS items.

Two basic categories of sensors will be found in the FlexBot. One type of sensor will be for data collection, the other for control. The data collection sensors will include but not be limited to temperature, light spectrum, video, gas analysis, smoke detector, radiation detectors, etc. These will be distributed through the FlexBot hosted on different nodes. The other types of sensors will include but not be limited to vision, structures light, position encoders, speed encoders, force sensors, inclinometers, accelerometers, electronic compass, GPS, etc.

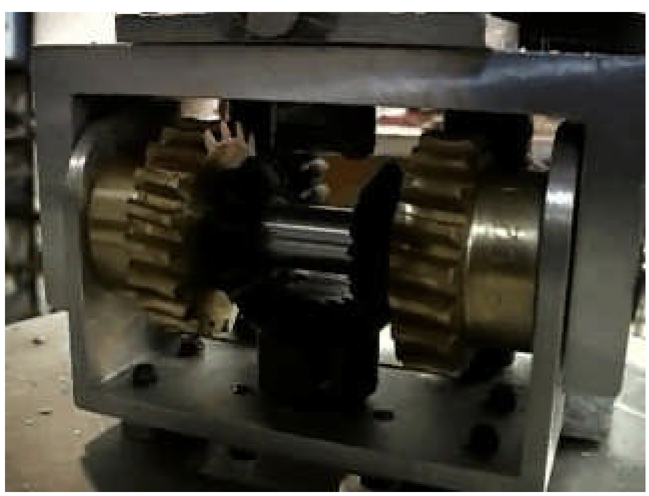


Figure 7: Closeup view of a working HSJ prototype

Each node will have a simple processor. The node hosting the ZigBee Coordinator will have a more powerful processor (Main-P) in order to handle the communications beyond the FlexBot. The Main-P will, though a number of methods to be described develop overall second by second goals or tasks for the FlexBot as a whole. These tasks will be read and interpreted by the processor in each individual node. Because each node is located in a different position within the FlexBot, and each has a different set of sensors and controls, the tasks sent by Main-P will be interpreted and acted upon differently by each node depending on its situation at the time the task is requested. To explain, some simplified examples are provided.

If the task from the Main-P is for FlexBot to prepare to move forward in the prone position, each node will insure that it is horizontal and its wheels are on the deck and have traction. If the task is to prepare to move FlexBot forward in the upright position, each node will insure that it is properly oriented (in the cobra shape) its relative attitude with the other nodes in the network; the bottom two nodes will insure that their wheels have traction while the other wheels turn off.
While the ultimate goal is have the FlexBot operate autonomously, initial prototypes, and perhaps early models, of the FlexBot will have a person "in the loop" in one of two ways. (The connection to the FlexBot can be via umbilical cable or wirelessly, it makes no difference in terms of a person in the loop).

In the first prototype, it is envisioned that a Waldo will be used by the operator. "Waldo" is a term used in the animatronics industry to describe a controller that is essentially a model version of the device to be controlled. The Waldo can be configured in many ways, but for FlexBot, it is envisioned that it will appear to be a miniature version of the FlexBot with all of its wheels and joints forming the articulated robots. However, instead of motors driving the joints and wheels, sensors such as encoders, potentiometers, linear transducers are embedded in the FlexBot Waldo. In this manner, the operator can bend and move the joints by hand and the wheels by sliding it on a surface. Directional orientation of the FlexBot Waldo can be determined in a number of ways such as a simple rotating potentiometer to indicate heading.

Though the Waldo may prove to be the best way to control the FlexBot in many applications, to help it evolve into a totally autonomous device, more advanced prototypes will be controlled in a more traditional manner. That is, the remote operator in the loop will use a computer outfitted with a few joysticks. With the computer the operator will be able to send general tasks to the Main-P of the FlexBot, which will in turn broadcast tasks to the nodes. Such tasks would be to lay prone, stand upright, climb ladder, grasp handle, engage specific sensors or actuators etc. The joysticks will allow the operator to perform basic navigation (move forward, move backwards, turn left, turn right), control speed and acceleration and to assist in the more detailed tasks such as grasping objects, turning handles. It is expected that the user will be assisted by real time video and sensory feedback from the FlexBot.

Conclusions

Based on a review of the design and the application, it is concluded that the FlexBot concept has merit and appears to be feasible from technical and application standpoints. Though the concept was developed specifically for shipboard use, it is also concluded that the design would be directly usable for land based applications as well.

Recommendations

It is recommended that the FlexBot effort continue in order to complete the concept development, top level design, construction and demonstration of a FlexBot prototype. The FlexBot addresses capability needs that the Navy and Marine Corps have identified but which have not yet been filled by other technology. Specifically, the FlexBot could become a vital technology for Navy Visit, Board, Search and Seizure (VBSS) teams conducting maritime interdiction operations (MIO) in the Persian Gulf, counter-drug operations in the Caribbean, or homeland defense patrols off the U.S. coast. Though the primary focus for this project has been on the response of oceangoing assets, the concept and results of the project have broader potential and could be equally applied to protecting land based assets and responding to natural disasters.

Summary

Since no emergency response robots are known to be capable of boarding and navigating throughout a ship, the FlexBot concept was developed. FlexBot has a similar form factor and flexibility as a human, allowing it to travel anywhere within a ship.

The FlexBot is an eight foot long articulated robot designed to have the basic dimensions, agility and flexibility of a human. The FlexBot is capable of maintaining a basic human form and function in terms of the space and maneuverability it needs to move through a ship. It can stretch out to full length, or curl up in a fetal-like position while still maintaining mobility and balance. It can turn 180 degrees around a bulkhead and even roll back over itself to make a vertical U-turn in the middle of a narrow passageway. It can operate under water, climb over obstacles, climb up and down ladders, move between decks, drop into hatches and pull itself out again. It has strong but general purpose manipulators able to open doors and hatches using dogs, levers, hand wheels, drop bolts and grab handles.

Figure 8: Jamie Hyneman holding a completed HSJ

FlexBot will be constructed in eight segments; each segment with two axes of servo controlled movement provided by HSJ servos. The HSJ's provide a very high power to size and weight ratio, and this coupled with the segmented design will allow the robot to move in a vertical position or in a prone one.

The FlexBot electronics include the batteries, power management, motor controllers, communications, sensors and processor.

While the ultimate goal is to have the FlexBot operate autonomously, initial prototypes will have a person "in the loop" either operating a Waldo-like controller or using a computer and joysticks.

It is recommended that the FlexBot effort continue in order to complete the concept development, top level design, construction and demonstration of a FlexBot prototype.

Appendix A – A Catalog of Rescue Robots

(Note: Descriptions are taken from supplier provided materials and other on line resources)

Name

Foster Miller Talon

Picture

Cost

The robot costs approximately $60,000 in its standard form. (http://en.wikipedia.org/wiki/Foster-Miller_TALON).

Capability and Size

The standard TALON robot is a modular system that includes a removable, double-jointed, 64-inch (1.6m) arm and gripper. It is controlled through a two-way RF or fiber optic link from an attaché-sized Operator Control Unit (OCU). Along with up to seven cameras located on the vehicle, the OCU provides continuous situational data for precise vehicle positioning. TALON's speed ranges from 4 mph (6.6 kmh) down to a creep with a continuous operational life of over four hours. It has been configured with more than 60 different mission packages and can carry more than 200 pounds (~90 kg) as a payload for maximum flexibility in any situation.

References

http://www.army-guide.com/eng/product1795.html?PHPSESSID=900a7b66e2817facf935467fbf29f25e

Full list of Foster Miller robots:
http://www.army-guide.com/eng/firm2688.html?PHPSESSID=49961

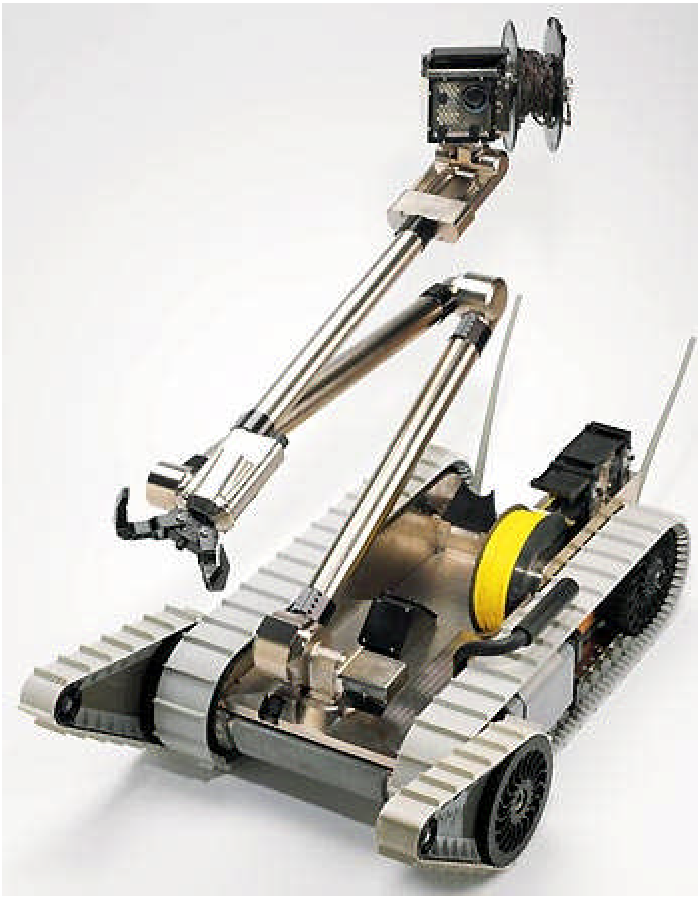
Name
Foster Miller Swords

Picture

Cost
The current price of one unit is $230,000; however, Foster-Miller claims that when it enters mass production the price may drop to between $150,000 and $180,000. (http://en.wikipedia.org/wiki/Foster-Miller_TALON)

References
http://www.army-guide.com/eng/product2673.html?PHPSESSID=900a7b66e2817facf935467fbf29f25e

Name
iRobot Packbot

Picture


(Additional pictures found on website) http://www.irobot.com/sp.cfm?pageid=171

Cost
iRobot's PackBots have generally been in the $120K-$150K range.
(http://robotstocknews.blogspot.com/2007/09/robotic-fx-gets-279-million-robot-order.html)

Capability and Size
Mobile

PackBot easily climbs stairs, rolls over rubble and navigates narrow, twisting passages. The robot's patented mobility platform features dual QuickFlip™ track articulations. These "flippers" are capable of continuous 360-degree rotation and enable PackBot to traverse rocks, mud, snow, gravel and other tough terrain. PackBot's flexible ToughTrac™ polymer tracks eject debris and move the robot over all surfaces with sure-footed efficiency. PackBot even climbs grades up to 60 degrees. PackBot 510 is 30 percent faster, capable of traveling at speeds of up to 5.8 miles per hour (9.3 km/h).

(more features listed on website)

References

http://www.irobot.com/sp.cfm?pageid=171
http://www.army-technology.com/contractors/mines/i_robot/

Name
iRobot Negotiator 200 w/ Civil Response Kit

Picture


(Additional pictures found on website) http://www.irobot.com/sp.cfm?pageid=138

Cost
The new Negotiator will also be much cheaper than the early edition: $20,000 a pop, "about the cost of a squad car," notes iRobot executive Joe Dyer. (http://blog.wired.com/defense/2008/08/irobot-starts-s.html)

Capability and Size
http://www.irobot.com/filelibrary/pdfs/gi/robots/iRobot_Negotiator.pdf

References

http://www.irobot.com/sp.cfm?pageid=138
http://thefutureofthings.com/pod/5548/irobot-negotiator.html

iRobot Negotiator specifications
http://www.irobot.com/filelibrary/pdfs/gi/robots/iRobot_Negotiator.pdf

Name
iRobot FCS SUGV; small unmanned ground vehicle

Picture


(Additional picture found on website) http://www.irobot.com/sp.cfm?pageid=219

Capability and Size
As a key partner in the U.S. Army's Future Combat Systems (FCS) program, iRobot is developing a next-generation SUGV, a portable, reconnaissance and tactical robot that can enter and secure areas that are either inaccessible or too dangerous for soldiers.

SUGV performs Surveillance / Reconnaissance while keeping troops out of harm's way.

SUGV is a highly integrated, waterproof and shockproof robot.
Weighing about 30 pounds, SUGV is small, rugged and modular.
SUGV is small enough to go where soldiers can't or shouldn't.

As a key partner in the U.S. Army's Future Combat Systems (FCS) program, iRobot is developing a next-generation SUGV, a portable, reconnaissance and tactical robot that can enter and secure areas that are either inaccessible or too dangerous for soldiers.

Minimize risk to soldiers during hostile urban and mountainous operations...
Get real-time intelligence and complete situational awareness...

Navigate collapsed buildings and other inaccessible areas...

iRobot SUGV300 Series specifications:
http://www.irobot.com/filelibrary/pdfs/gi/robots/iRobot_SUGV_300.pdf

References

http://www.irobot.com/sp.cfm?pageid=219

http://www.irobot.com/filelibrary/pdfs/gi/robots/iRobot_SUGV_300.pdf

https://www.istockanalyst.com/article/viewiStockNews+articleid_2145682.html

Name
iRobot Warrior

Picture

Additional picture found on website: http://www.irobot.com/sp.cfm?pageid=150

Cost
U.S. TARDEC awarded iRobot $3.75 million to build two "Warrior 700" robots. (The acronym-phobic may refer to it as the Army Tank Automotive Research, Development and Engineering Center.) (http://www.fool.com/investing/high-growth/2008/10/03/irobot-goes-terminator.aspx)

Capability and Size
iRobot Warrior specifications
http://www.irobot.com/filelibrary/pdfs/gi/robots/iRobot_Warrior.pdf

Successfully execute EOD, firefighting, reconnaissance and other missions...
Get real-time intelligence and complete situational awareness...
Move firearms, hoses and other heavy payloads...
Featuring an advanced digital architecture, the iRobot Warrior 700 is a powerful and rugged robot that carries 150-pound (68 kg) payloads, travels over rough terrain and climbs stairs while performing a variety of critical missions:

- Bomb Disposal / EOD (IEDs / VBIEDs / UXOs)
- Route Clearance
- Perimeter Patrol

- Surveillance / Reconnaissance

Product video: http://www.irobot.com/filelibrary/videos/gi/robots/iRobot_Warrior.html

References

http://www.irobot.com/sp.cfm?pageid=150
http://www.irobot.com/filelibrary/pdfs/gi/robots/iRobot_Warrior.pdf

Name
iRobot Transphibian

Picture

http://www.irobot.com/sp.cfm?pageid=428

Cost
Exact cost not found.

Capability and Size
The autonomous UUV and bottom crawler
Safely clear mines in surge-dominated waters.
Perform maritime surveillance and reconnaissance.
The iRobot Transphibian, a fin-powered vehicle that is both a mobile UUV and a bottom crawler, can autonomously insert itself into the water and operate in a very shallow area. The fins enable the robot to navigate with 6 degrees of freedom – even in surge – to avoid obstacles and maneuver in tight spaces. Expandable and adaptable, Transphibian supports a wide variety of defense, first responder and commercial applications.

- Mine Detection
- Harbor Defense
- Surveillance / Reconnaissance

References
http://www.irobot.com/sp.cfm?pageid=428

Name
iRobot High Speed UUV

Picture

http://www.irobot.com/sp.cfm?pageid=429

Cost
Exact cost not found.

Capability and Size
The fast UUV for threat closure
Protect submarines and ships in port and at sea...
Quickly identify and neutralize waterborne threats...
Keep personnel away from danger zones...
Developed for platform defense of submarines and surface ships at sea and in port, the iRobot High Speed UUV enables rapid transit with respect to a threat, such as a diver advancing toward a ship. Capable of being implemented in UUVs that are 3” in diameter and larger, vehicles can reach speeds greater than 15 knots while maintaining precise maneuvering control. High Speed UUV provides an array of tools for homeland defense, as well as force and fleet protection.

- Harbor Defense
- Surveillance / Reconnaissance

References
http://www.irobot.com/sp.cfm?pageid=429

Name
SPAWAR Man-portable Robotic Systems (MPRS)

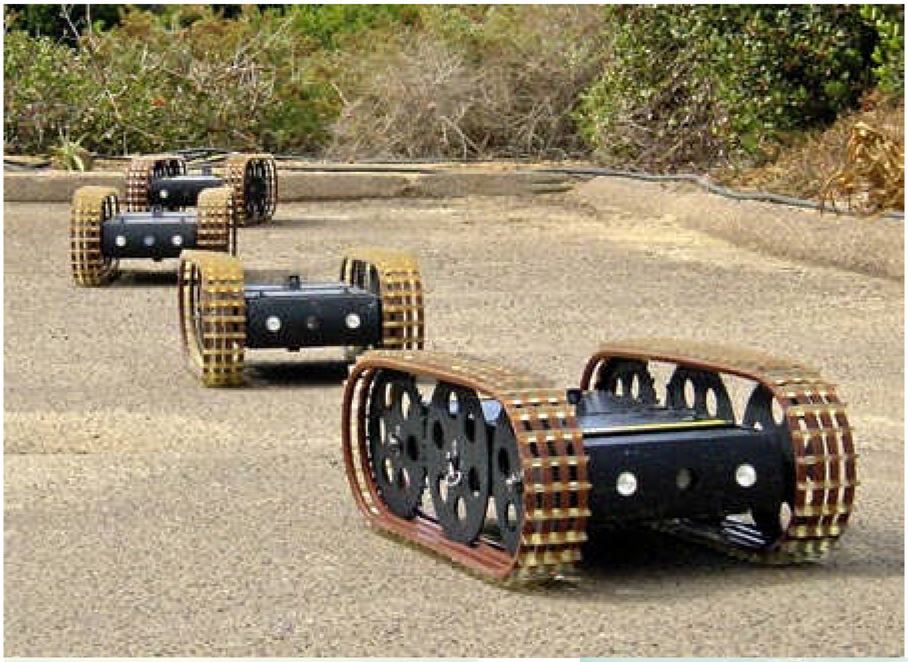
Picture


Figure 1. MPRS URBOT

Figure 2. MPRS URBOT OCU

Cost
Exact cost not found.

Capability and Size
In 1999 under the Joint Robotics Program (JRP) Man-Portable Robotic Systems (MPRS) project, SSC San Diego developed a small UGV intended for use by Army engineers for tunnel, sewer, cave, and urban structure reconnaissance. As originally developed, the UGV (called the URBOT for Urban Robot, Fig. 1), was strictly tele-operated from a wearable operator control unit (OCU) (Fig. 2). This allowed the soldier to manually drive the vehicle into high-risk areas and receive video feedback to assess the situation before entering. The system was used in several experiments at Fort Leonard Wood, MO, Fort Drum, NY, and Fort Polk, LA.[1]

References

http://www.spawar.navy.mil/robots/land/mprs/mprs.html

Small UGVs SPARWAR technical publications:
http://www.spawar.navy.mil/robots/pubs/SPIE_5804_2005_ps.pdf

Appendix B – List of Figures

Figure 1: Flexbot prone - plan view 235
Figure 2: FlexBot standing upright 236
Figure 3: FlexBot crawling over an object 237
Figure 4: View of Hyneman Super Joint (HSJ) within a node 238
Figure 5: Demonstration of HSJ operation by hand 240
Figure 6: HSJ operated by simple motors 241
Figure 7: Closeup view of a working HSJ prototype 241
Figure 8: Jamie Hyneman holding a completed HSJ 244

Chapter 6 - Cable Driven Monitoring and Decontamination Robotic System

Dr. Hashem Ashrafiuon – Villanova University

Executive Summary

The goal of this report is to provide analytical support for the feasibility of a versatile system capable of sensing, monitoring and manipulating possible contaminants onboard a ship. It has been proposed that the system will be a reliable and autonomous robotic device capable of motion adaptation and handling materials in volatile sea conditions and hence minimizing the risk of human contamination. The system must further be transportable to access hard-to-reach locations on a ship. The solution proposed to achieve these tasks is a cable-driven robot that is capable of isolating ship oscillations due to volatile sea conditions and carry out precise sensing and manipulation tasks.

Background

There are three major difficulties that have hindered the progress of cable-driven robots in volatile environments. The first is the workspace limitation due to continuous maintenance of cable tension resulting in limited rigid body motion, particularly in some of the six degrees of freedom motion such as sway and yaw. The second difficulty is due to lack of flexibility required in some applications such as those where the robot must get into tight spaces. The third difficulty arises from the suspension of the whole robotic system from the crane cable in volatile environments leading to instability.

While there has been a relatively wide range of research addressing kinematics, workspace, dynamics, design, and control of cable-driven robots. The difficulties mentioned above have not been effectively addressed. There has been little research to significantly increase the workspace or addressing obstacle avoidance by such a robot, which can be of particular importance if it needs to get into tight spaces. Further, while there has been some research in vibration isolation of such robots, the more difficult problem of rejecting large-scale disturbances when a six-cable system is suspended from a standard shipboard crane cable and supported only by taglines has not been addressed.

Objectives

The objective of this project is to introduce and analytically support a robotic solution versatile to sensing, monitoring and manipulating possible contaminants onboard ships in volatile sea conditions.

Findings

We present the model of the proposed cable driven robot, as shown in Fig. 1, along with a control law for position control to isolate sea motion. In order to simplify the problem, we present the kinematic and dynamic models of the cable-driven robot without the robotic arm and develop a control law that provides stability while the crane is in motion and accurate lower platform position and orientation. We then demonstrate the effectiveness of the control law through several simulations.

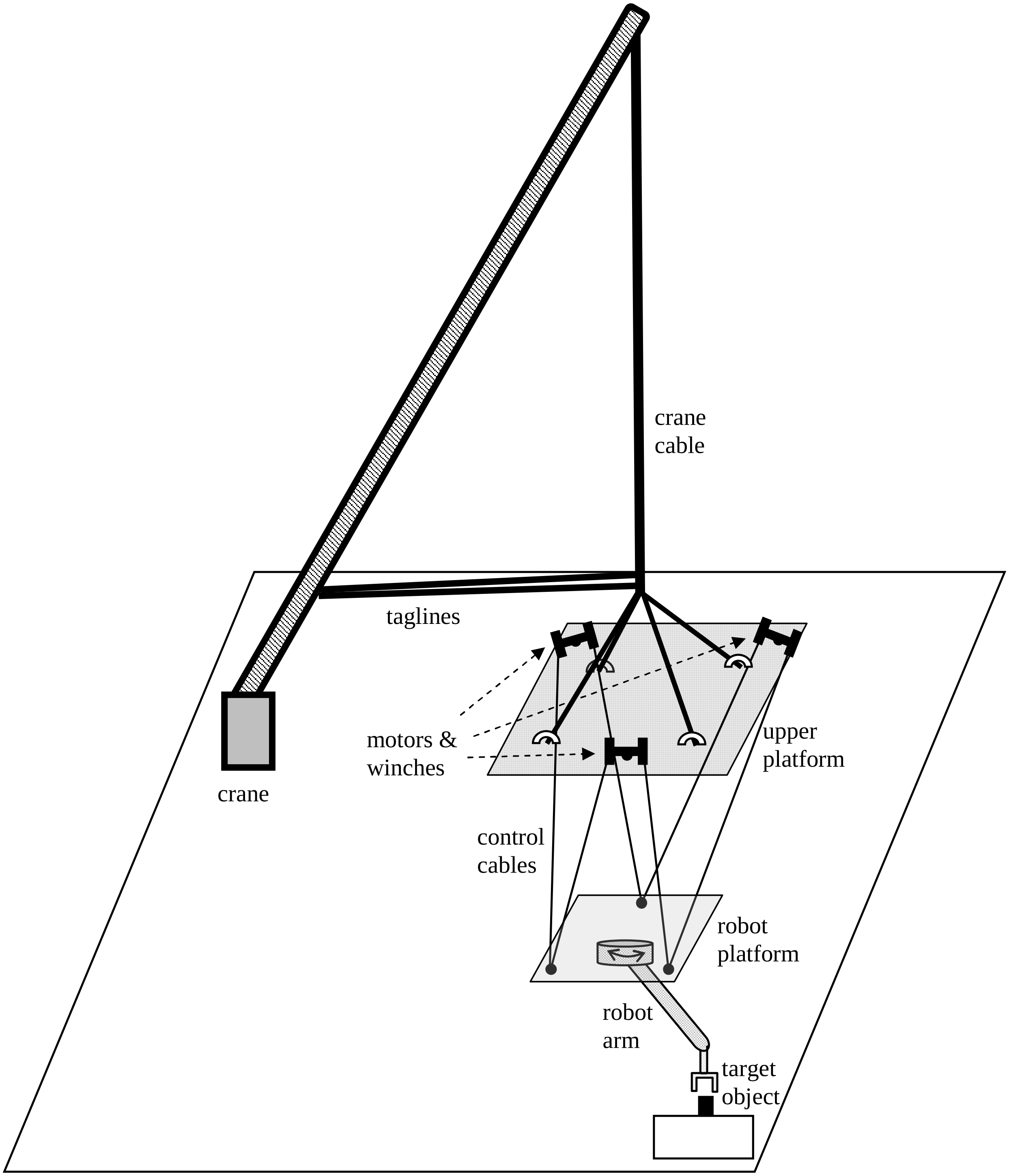


Figure 1: A cable driven monitoring and decontamination system with a robotic arm

System Model and Control Law

Kinematic Representation

The system consists of motion of two rigid bodies, upper and lower platforms, in space, as shown in Fig. 2. Each rigid body motion is represented by six degrees of freedom. A reference frame is attached to the center of mass of each rigid body to represent its linear motion and orientation. The linear motion is represented by surge (*x*), sway (*y*), and heave (*z*) and rotational motion by roll, pitch, and yaw, called the Euler angles. The position vector and Euler angles for the lower and upper platforms are written as:

$$\boldsymbol{r}_l = [x_l \quad y_l \quad z_l]^T, \quad \boldsymbol{\theta}_l = [\theta_{lx} \quad \theta_{ly} \quad \theta_{lz}]^T \tag{1a}$$

$$\boldsymbol{r}_u = [x_u \quad y_u \quad z_u]^T, \quad \boldsymbol{\theta}_u = [\theta_{ux} \quad \theta_{uy} \quad \theta_{uz}]^T \tag{1b}$$

Using the notation $S\theta \equiv \sin\theta$ & $C\theta \equiv \cos\theta$, angular velocities and accelerations are given as:

$$\boldsymbol{\omega}_j = B_j \dot{\boldsymbol{\theta}}_j, \quad \dot{\boldsymbol{\omega}}_j = B_j \ddot{\boldsymbol{\theta}}_j + \dot{B}_j \dot{\boldsymbol{\theta}}_j, \quad j = l, u \tag{2}$$

$$B_j = \frac{\partial \boldsymbol{\omega}_j}{\partial \dot{\boldsymbol{\theta}}_j} = \begin{bmatrix} 1 & 0 & -S\theta_{jy} \\ 0 & C\theta_{jx} & S\theta_{jx}C\theta_{jy} \\ 0 & -S\theta_{jx} & C\theta_{jx}C\theta_{jy} \end{bmatrix}, \quad j = l, u$$

$$\dot{B} = \begin{bmatrix} 0 & 0 & -C\theta_{jy}\dot{\theta}_{jy} \\ 0 & -S\theta_{jx}\dot{\theta}_{jx} & C\theta_{jx}C\theta_{jy}\dot{\theta}_{jx} - S\theta_{jx}S\theta_{jy}\dot{\theta}_{jy} \\ 0 & -C\theta_{jx}\dot{\theta}_{jx} & -S\theta_{jx}C\theta_{jy}\dot{\theta}_{jx} - C\theta_{jx}S\theta_{jy}\dot{\theta}_{jy} \end{bmatrix}, \quad j = l, u \tag{3}$$

The cables position vectors from their connection points on the lower platform to their winch locations on the upper platform are defined as:

$$\boldsymbol{d}_i = \boldsymbol{r}_u + A_u \boldsymbol{a}_{ui} - (\boldsymbol{r}_l + A_l \boldsymbol{a}_{li}), \quad i = 1, \ldots, 6 \tag{4}$$

where $\boldsymbol{a}_{li}$ and $\boldsymbol{a}_{ui}$ are the position vectors of the i^{th} cable connection point on the lower and upper platforms in their local reference frames, respectively. A_l and A_u are the direction cosine matrices of the local frames of upper and lower platforms, respectively. Cable velocities are derived by taking the time derivative of Eq. (4):

$$\dot{\boldsymbol{d}}_i = \dot{\boldsymbol{r}}_l + A_u \tilde{\boldsymbol{\omega}}_u \boldsymbol{a}_{ui} - (\dot{\boldsymbol{r}}_l + A_l \tilde{\boldsymbol{\omega}}_l \boldsymbol{a}_{li}) \tag{5}$$

where "~" is used for cross product and indicate $\tilde{\boldsymbol{\omega}} = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix}$.

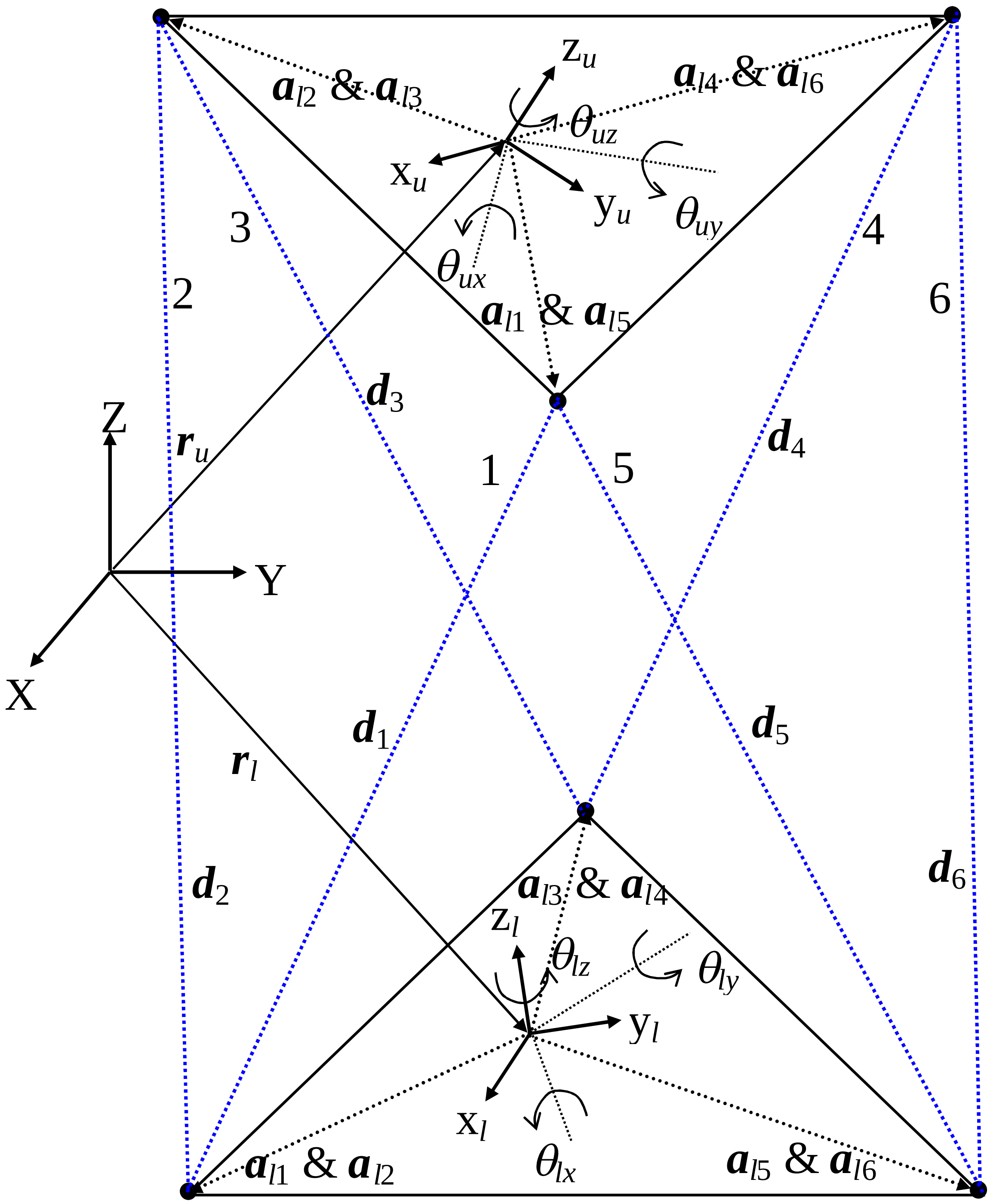


Figure 2: Kinematics of the upper and lower platforms with cable connections

Dynamic Model

The cable forces that act on the camera platform and with equal magnitude and opposite direction on the trolley platform are given in terms of control forces as:

$$\boldsymbol{f_i} = \frac{\boldsymbol{d_i}}{|\boldsymbol{d_i}|} u_i \ , \ i = 1...6 \tag{6}$$

where u_i is the i^{th} (positive) cable control/tension force. Based on the kinematic representation, we may derive the Lagrangian equations of motion in terms of the 12 degrees of freedom defined in Eq. (1) as:

$$m_l \ddot{\boldsymbol{r}}_l = (\sum_{i=1}^{6} \frac{\boldsymbol{d_i}}{|\boldsymbol{d_i}|} u_i) - m_l \boldsymbol{g} + \boldsymbol{f}_l' \tag{7}$$

$$M_{l\theta} \ddot{\boldsymbol{\theta}}_l = B_l^T (\sum_{i=1}^{6} (\tilde{A_l \boldsymbol{a}_{li}}) \frac{\boldsymbol{d_i}}{|\boldsymbol{d_i}|} u_i) - \boldsymbol{f}_{l\boldsymbol{\theta}} + \tau_l' \tag{8}$$

$$m_u \ddot{\boldsymbol{r}}_u = -(\sum_{i=1}^{6} \frac{\boldsymbol{d_i}}{|\boldsymbol{d_i}|} u_i) - m_u \boldsymbol{g} + \boldsymbol{f}_u' \tag{9}$$

$$M_{u\theta} \ddot{\boldsymbol{\theta}}_u = -B_u^T (\sum_{i=1}^{6} (\tilde{A_u \boldsymbol{a}_{ui}}) \frac{\boldsymbol{d_i}}{|\boldsymbol{d_i}|} u_i) - \boldsymbol{f}_{u\boldsymbol{\theta}} + \tau_u' \tag{10}$$

where m_l & m_u are the total masses of the lower and upper platforms, $\boldsymbol{g} = [0 \quad 0 \quad g]^T$ the acceleration due to gravity, and $\boldsymbol{f}_l', \tau_l', \boldsymbol{f}_u', \tau_u'$ represent the disturbance forces and moments acting on the lower and upper platforms. Also, noting J_l & J_u as the inertia matrices for the lower and upper platforms:

$$M_{j\theta} = B_j^T J_j B_j \ , \quad \boldsymbol{f}_{j\boldsymbol{\theta}} = B_j^T J_j \dot{B}_j \dot{\boldsymbol{\theta}}_j + B_j^T \tilde{\boldsymbol{\omega}}_j J_j \boldsymbol{\omega}_j \ , \quad j = l, u \tag{11}$$

Sliding Mode Control Law

Sliding mode control [49] is a simple and robust method well suited for real time control of mechanical systems. The goal of sliding control approach is to define asymptotically stable surfaces such that all system trajectories converge to these surfaces and slide along them until they reach their desired destination. Here, we define 6 first order surfaces to determine the control laws for the 6 cables. The surfaces may be defined based on the type of task to be performed. When the crane is transporting the system to a location the main objective is to keep the system stable. Hence the surfaces are defined such that the lower platform maintains its relative position to the upper platform. In this case, the surfaces are defined as:

$$\boldsymbol{s_r} = \dot{\boldsymbol{r}}_l - \dot{\boldsymbol{r}}_u + \lambda_r(\boldsymbol{r}_l - \boldsymbol{r}_u), \quad \boldsymbol{s_\theta} = \dot{\boldsymbol{\theta}}_l - \dot{\boldsymbol{\theta}}_u + \lambda_\theta(\boldsymbol{\theta}_l - \boldsymbol{\theta}_u) \tag{12}$$

When the crane is static, the objective is to accurately position the lower platform. In this case, the surfaces are defined in terms of tracking linear and angular position and velocity errors of the lower platform:

$$\boldsymbol{s_r} = \dot{\boldsymbol{r}}_l - \dot{\boldsymbol{r}}_{ld} + \lambda_r(\boldsymbol{r}_l - \boldsymbol{r}_{ld}), \quad \boldsymbol{s_\theta} = \dot{\boldsymbol{\theta}}_l - \dot{\boldsymbol{\theta}}_{ld} + \lambda_\theta(\boldsymbol{\theta}_l - \boldsymbol{\theta}_{ld}) \tag{13}$$

where subscript "*d*" indicates the desired trajectories.

We derive the nominal control law by setting the time derivatives of the surfaces equal to zero. The robust sliding mode control law is derived by adding a weighted "sign" function of each surface to the nominal one. Hence, the six cable control forces may be written as:

$$\boldsymbol{u} = M^{-1}[\boldsymbol{f} - \boldsymbol{k}\,\mathrm{sgn}(\boldsymbol{s})], \quad \boldsymbol{k} = \boldsymbol{\eta} + \boldsymbol{D} \tag{14}$$

where $\boldsymbol{\eta}$ is a vector if positive numbers representing the effort required for the system trajectory to the reach surfaces and $\boldsymbol{D}$ the bound for unknown disturbances and modeling uncertainties. The detailed equations for M and $\boldsymbol{f}$ depend on the type of surface and are presented in [27] for surfaces defined in Eq. (13).

Simulations

Disturbance Isolation

The objective of disturbance isolation is to isolate the ship motion due to wave and wind type disturbances from the robot motion. To simulate typical wave motions, we assume the ship is going through a sinusoidal motion in surge, sway, and heave directions as well as rolling motion. We assumed the period ship oscillation to be 5 seconds. The amplitudes of sinusoidal motions are considered to be 1 ft in surge, 2 ft in sway, and 3 ft in heave directions. The amplitude of ship roll is assumed to be 15 degrees.
Figures 3 and 4 show the controller is able to isolate most of the ship motion from the lower (robotic) platform after a small delay. Figures 5 and 6 show that while the lower platform is steady the upper platform absorbs most of the ship motion.

Motion Control

The objective motion control simulation is to simultaneously move the lower platform in all directions while keeping the upper platform as motionless as possible assuming the crane is static. We commanded the lower platform to move +2 ft in surge, + 2ft in sway, and –10 ft in the heave directions. We also commanded the lower platform to simultaneously rotate 45^{o} in roll, pitch, and yaw directions.

Figures 7 and 8 show that the controller achieves its goal in less than 20 seconds without any error in the linear or rotational motion, respectively. Figures 9 and 10 show that the upper platform motion is very small and stays stable in all linear and rotational motion directions. The maximum platform linear motion deviation is less than .3 ft and the maximum rotational deviation is less than 3^o. Figure 11 shows the six cable feed required to achieve the desired lower platform configuration. Clearly, the cable motion is very smooth. Figure 12 shows the six cable velocities are also smooth and stable. Figure 13 shows the cable forces are also smooth and remain well in positive region and hence remain in tension.

Conclusions

Based on the findings above, we can firmly conclude that a versatile robotic solution exists for sensing, monitoring and manipulating possible contaminants onboard a ship in volatile sea conditions. Such a system will be capable of isolating ship motion as a result of environmental disturbances such as waves and wind. Further, it will be able to carry out operations that may require precise motion control such as sensing and handling of volatile chemicals.

Referenced Figures

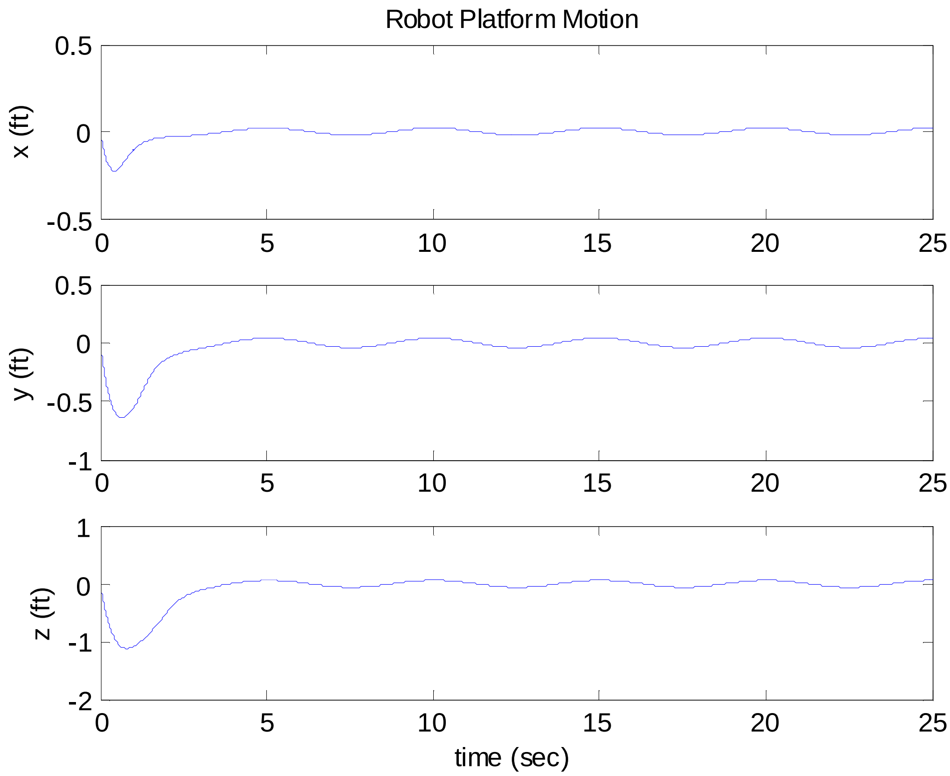


Figure 3: Vibration of lower platform in surge (x), sway (y), and heave (z) directions

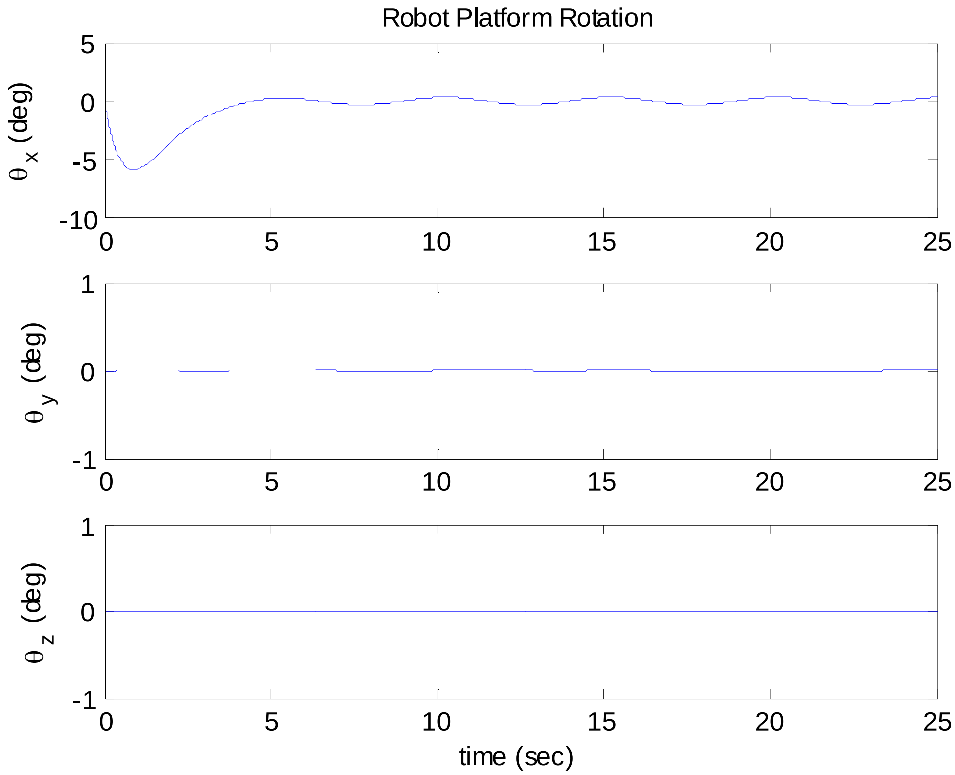


Figure 4: Roll (θ_x), pitch (θ_y), and yaw (θ_z) rotational vibration of the lower platform

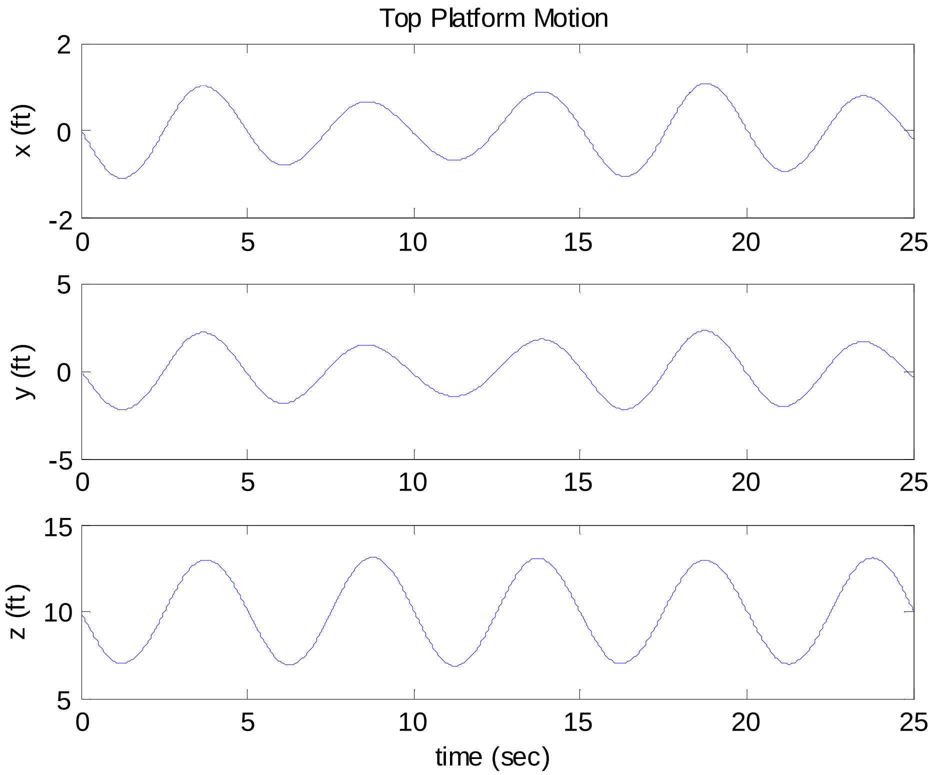


Figure 5: Vibration of upper platform in surge (x), sway (y), and heave (z) directions

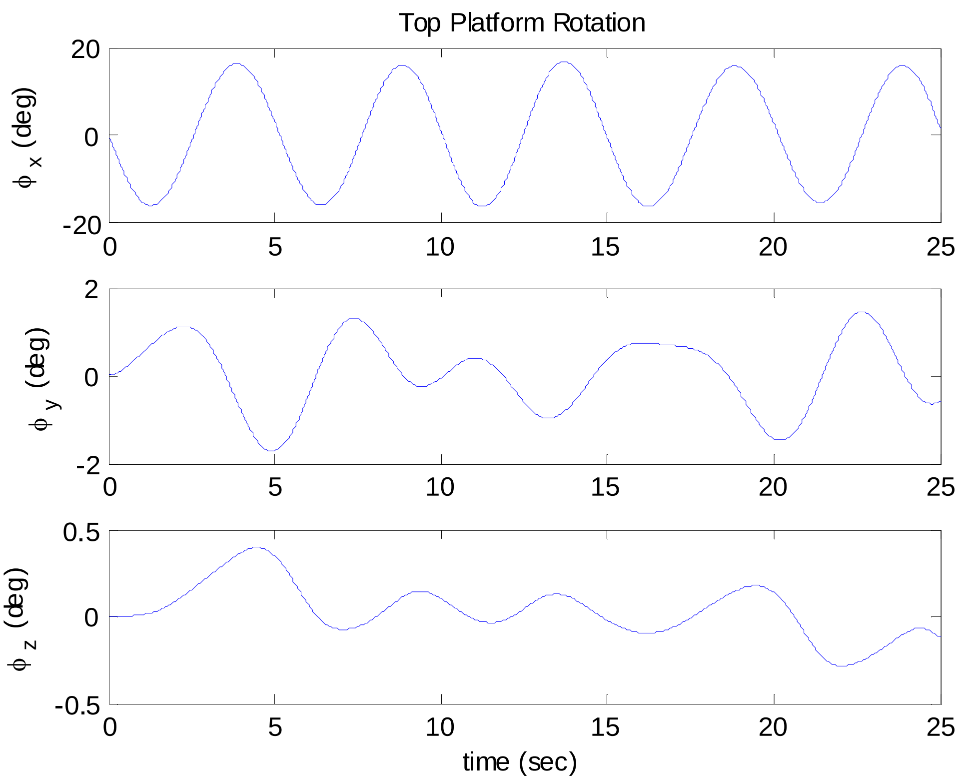


Figure 6: Roll (θ_x), pitch (θ_y), and yaw (θ_z) rotational vibration of the upper platform

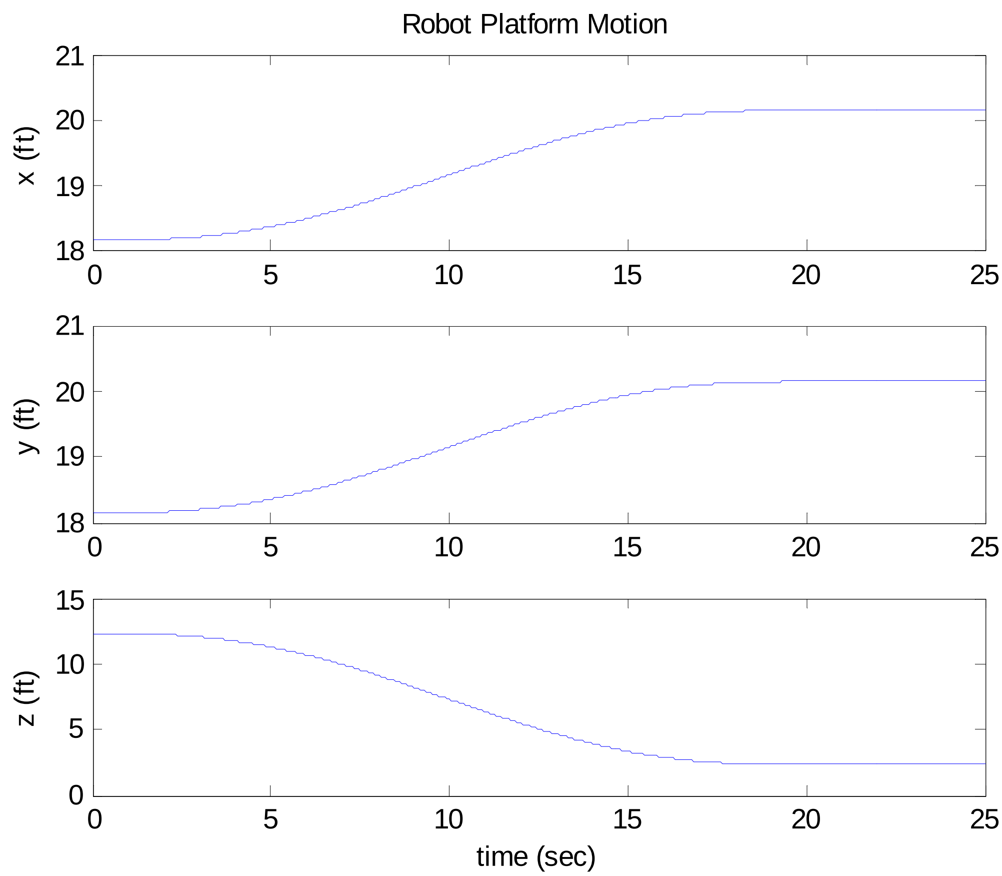


Figure 7: Simultaneous lower platform linear motion in surge (x), sway (y), and heave (z) directions

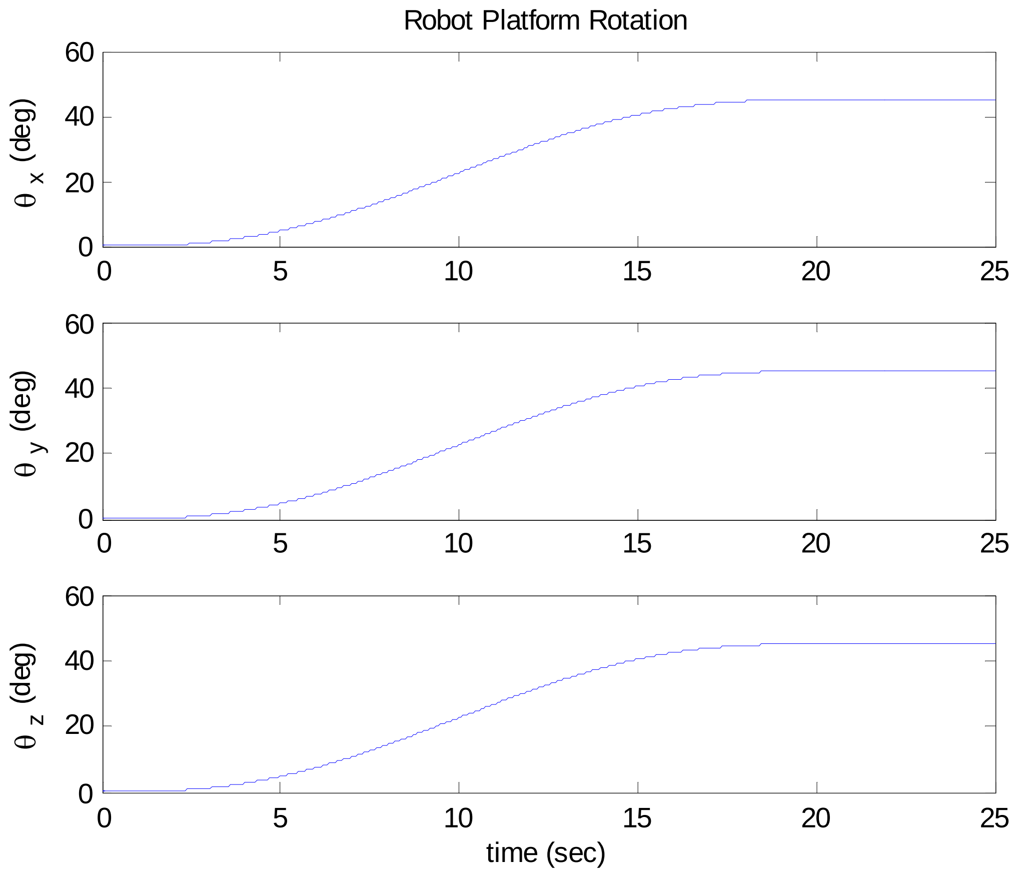


Figure 8: Simultaneous lower platform roll (θ_x), pitch (θ_y), and yaw (θ_z) rotations

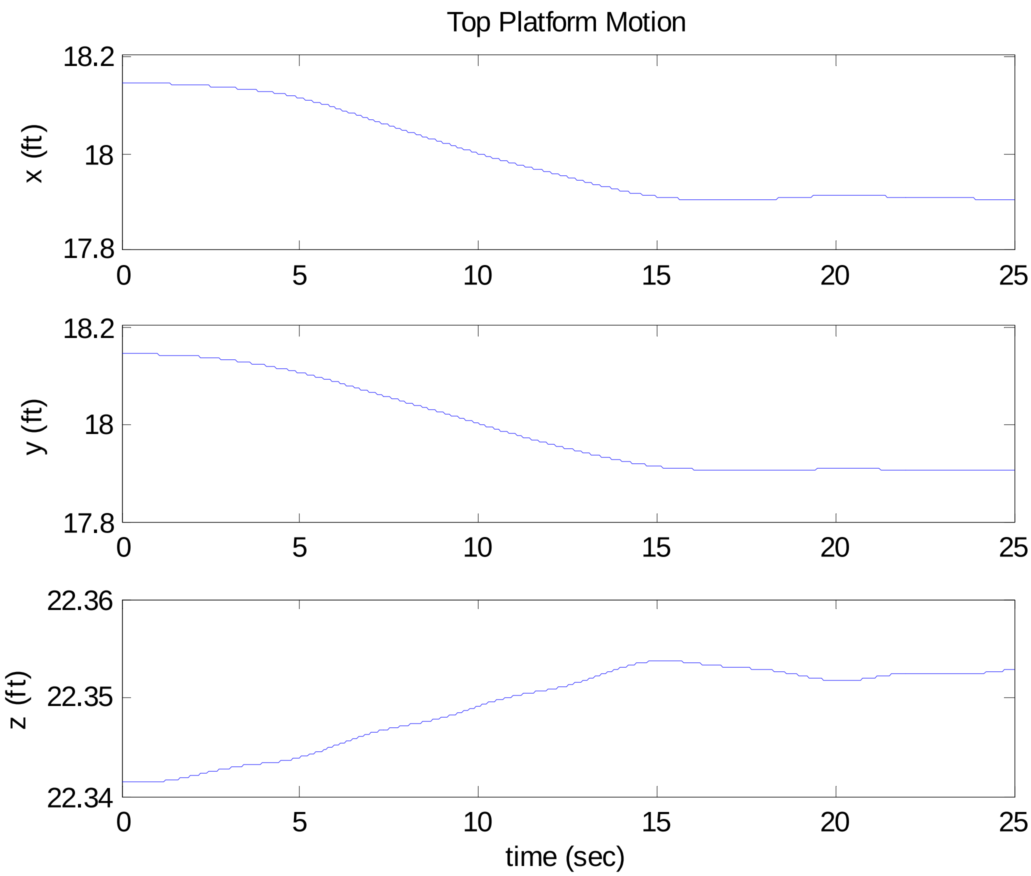


Figure 9: Upper platform uncontrolled linear motion in surge (x), sway (y), and heave (z) directions

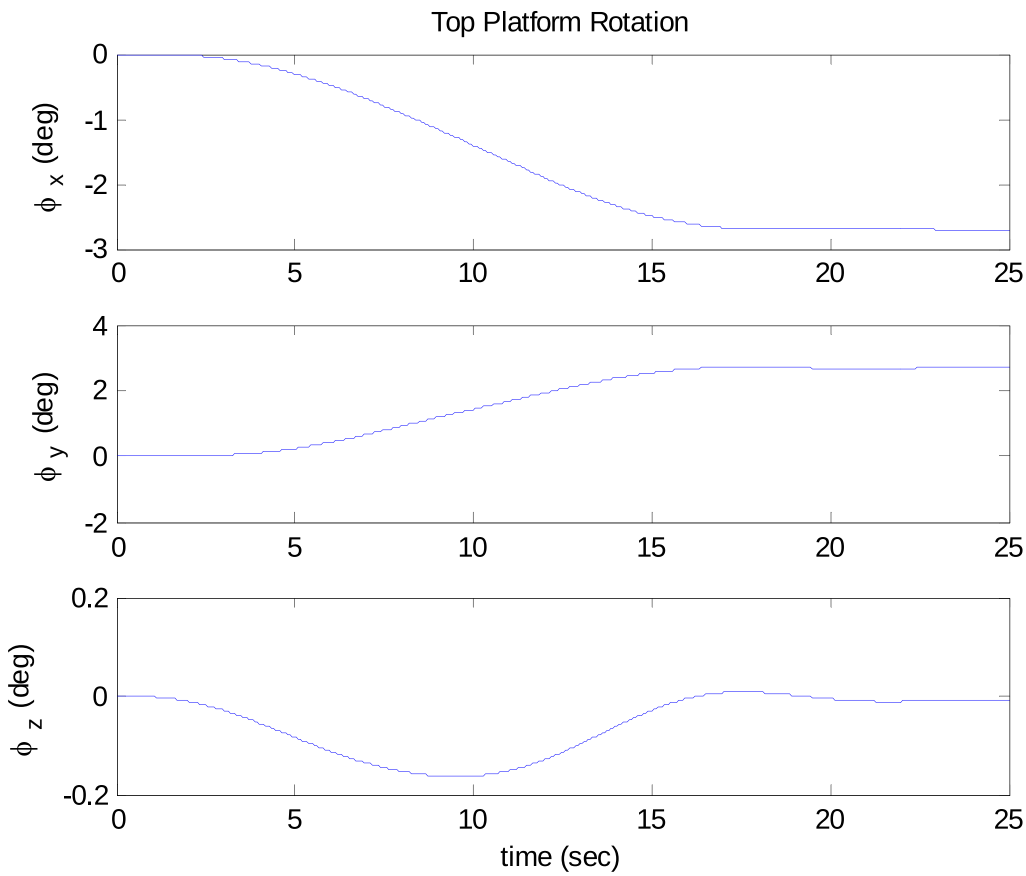


Figure 10: Upper platform uncontrolled roll (θ_x), pitch (θ_y), and yaw (θ_z) rotations

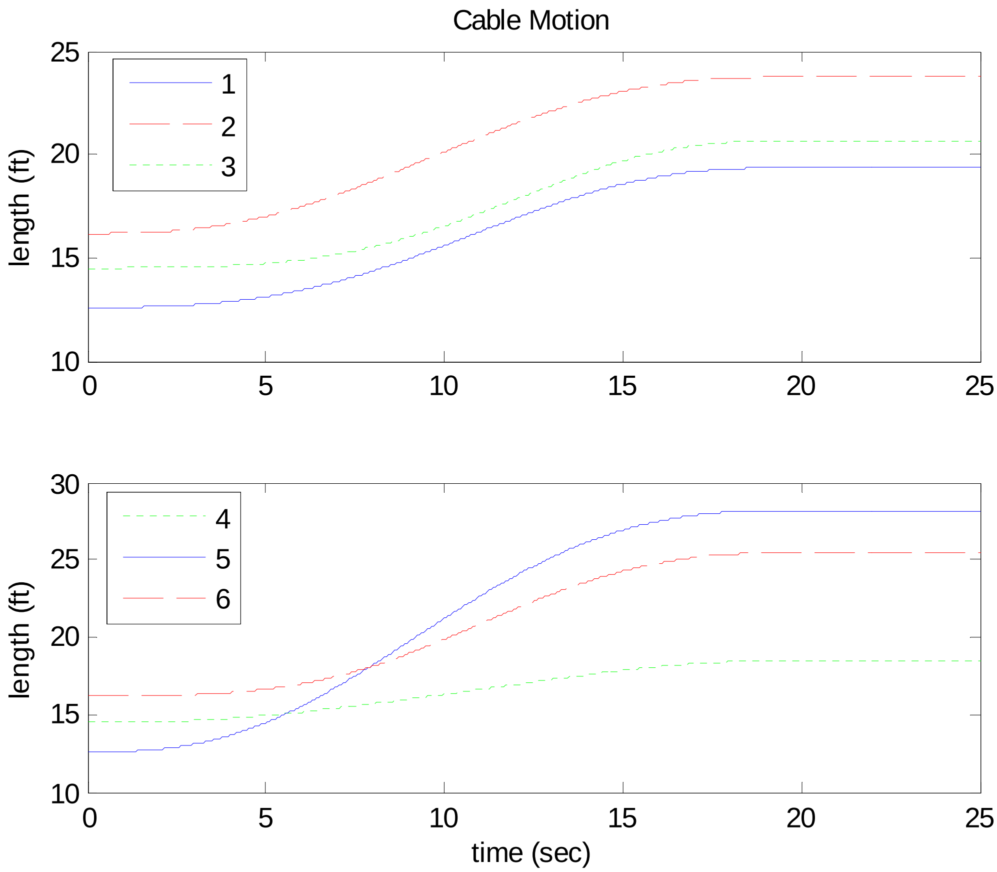


Figure 11: The cable motion required to achieve the desired lower platform configuration

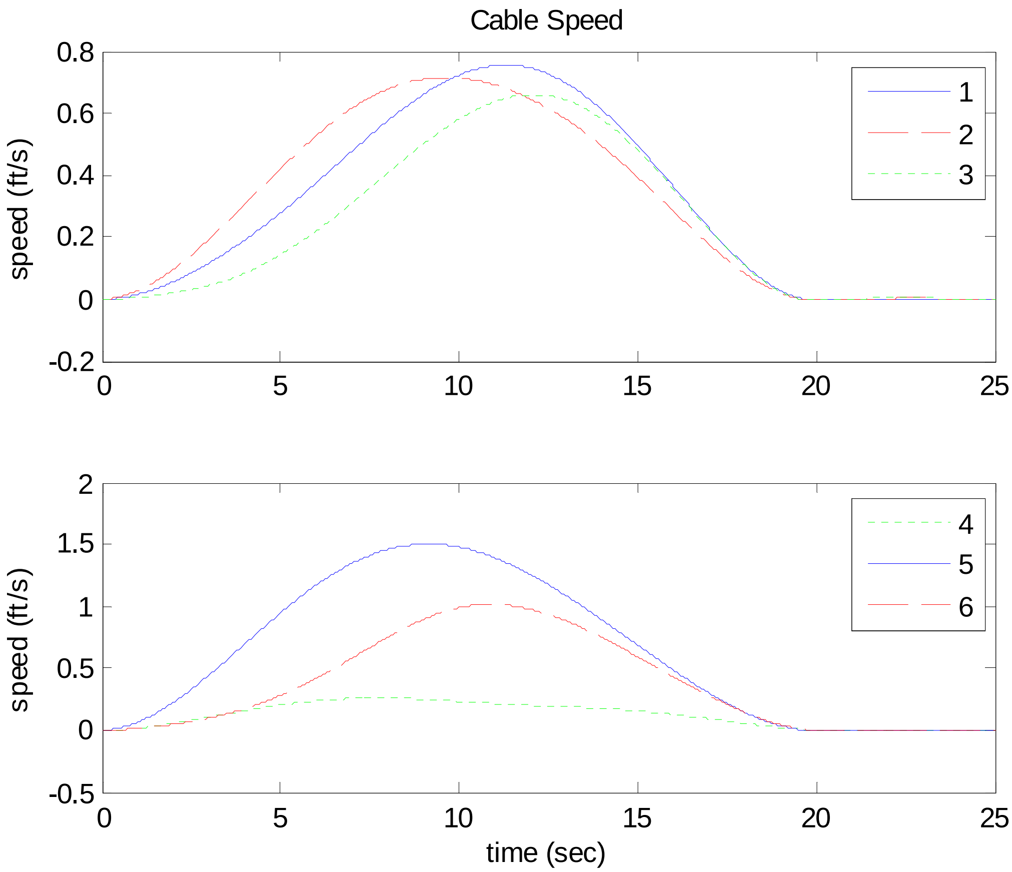


Figure 12: The cable velocity provided required to achieve the desired lower platform configuration

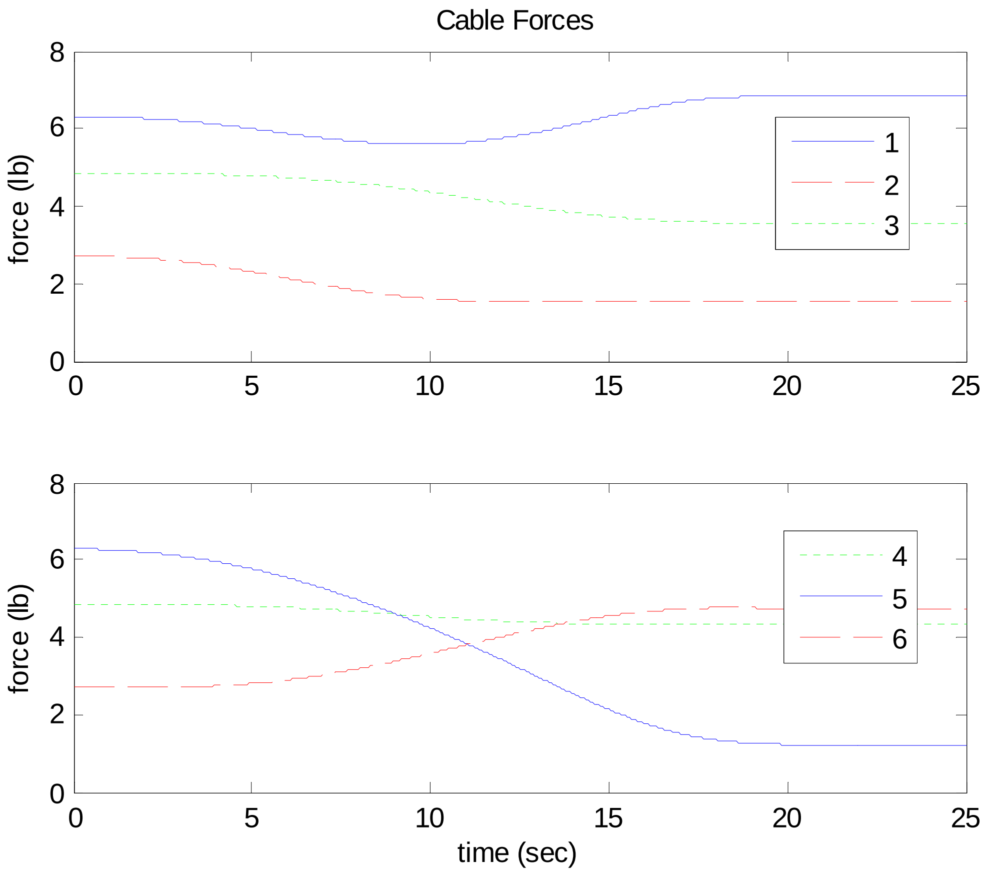


Figure 13: The cable forces during the lower platform operation

Recommendations

We recommend designing the proposed cable driven robot for monitoring, sensing, and manipulation of possible contaminants aboard Navy ships under sea states 3 and 4. The main purpose of the cable-driven platform robot is to isolate ship motion as a result of volatile sea conditions. We also recommend the addition of a robotic manipulator arm to the cable controlled platform to carry out more complex sensing and manipulation operations. Since successful operation of the proposed system strongly depends on implementation of a robust and effective automatic controller, we recommend installation of measurement devices that can monitor cable, lower platform, and upper platform motion. We also recommend the use of DC motors and motor controllers that can be programmed for automatic control and are capable of producing cable motions that can isolate high sea state ship motion.

Summary

We developed a kinematic and dynamic model of a proposed cable-driven robotic system. A robust control law was developed based on sliding mode control to evaluate the performance of the system model. The control was implemented and simulation software developed for robust ship motion isolation and position control of the system. The controller was shown to be able to isolate most of the ship motion from the robot operation. The control system simulations verify the effectiveness of the robotic system for unmanned operation.

References

1. Albus, J., and Bostelman, R., and Dagalakis, N., "NIST Spider, a Robot Crane," Journal of Research of the National Institute of Standards and Technology, vol. 97, no. 3, 1992, pp. 373-385.
2. Albus, J., and Bostelman, R., and Dagalakis, N., "TNIST ROBOCRANE," Journal of Robotic Systems, vol. 10, no. 5, 1993, pp. 709-724.
3. Al-Qassab, M., Nair, S., and O'Leary, J., "Dynamics of an Elastic Cable Carrying a Moving Mass Particle," Nonlinear Dynamics, vol. 33, 2003, pp. 11-32.
4. Ashrafiuon, H., Eshraghi, M., and Elahinia, M. H., "Position control of a Three-Link Shape Memory Alloy Actuated Arm," Journal of Intelligent Material Systems and Structures, vol. 17, no. 5, 2006, pp. 381-392.
5. Ashrafiuon, H., and Irwin, R. S., "A Sliding Control Approach to Underactuated Multibody Systems," Proceedings of the American Control Conference, Boston, MA, 2004, pp. 1283-1288.
6. Barrette, G., and Gosselin, C. M., "Determination of the Dynamic Workspace of Cable-Driven Planar Parallel Mechanisms," Journal of Mechanical Design, vol. 127, no. 2, 2005, pp. 242-248.
7. Bartolini, G., Orani, N., Pisano, A., and Usai, E., "Load Swing Damping in Overhead Cranes by Sliding Mode Technique," Proceedings of the IEEE Conference on Decision and Control, Sydney, Australia, 2000, pp. 1697-1702.

8. Bosscher, P. M., “Disturbance Robustness Measures and Wrench-Feasible Workspace Generation Techniques for Cable-Driven Robots,” Ph.D. thesis, Georgia Tech, Atlanta, GA, 2004.
9. Bosscher, P. M., and Ebert-Uphoff, I., “Wrench-Based Analysis of Cable-Driven Robots,” IEEE Conference on Robotics and Automation, New Orleans, LA, 2004.
10. Cheng, Y., Ren, G., and Dai, S., “The Multi-body System Modelling of the Gough-Stewart Platform for Vibration,” Journal of Sound and Vibration, vol. 271, no. 1, 2004, pp. 599-614.
11. Cheng, Y., Zhou, Q., Ren, G., and Zhang, Hui, “Six Degree of Freedom Active Isolation in Flexible Supporting Structures: Numerical Simulation and Experiment,” ASME IDETC/CIE, Chicago, IL, 2003, DETC2003/VIB-48365.
12. Cone, L. L., “Skycam: An Aerial Robotic Camera System,” BYTE, vol. 10, no. 10, 1985, pp. 122-32.
13. Cwiakala, M., and Langrana, N. A., “On the Feasibility of Platform Manipulators Using Cable Legs,” ASME, DE Division, vol. 15-3, no. PT3, 1988, pp. 97-103.
14. Fahimi, F., Ashrafiuon, H., and Nataraj, C., “Obstacle Avoidance for Spatial Hyper-Redundant Manipulators Using Harmonic Potential Functions and the Mode Shape Technique,” Journal of Robotic Systems, vol. 20, no. 1, 2003, pp. 23-33.
15. Gorman, J. J., and Jablokow, K. W., and Cannon, D. J., “The Cable Array Robot: Theory and Experiment,” IEEE International Conference on Robotics and Automation, Seoul, South Korea, vol. 3, 2001, pp. 2804-10.
16. Gosselin, C. M., and Wang, J., “Kinematic Analysis and Design of Cable-Driven Spherical Parallel Mechanisms,” ROMANY 2004, Montreal, Canada.
17. Harris, S. E., and Ballard, R. D., “ARGO: Capabilities for Deep Ocean Exploration,” Oceans, 1986, pp. 6-8.
18. Jiang, B., Sample, A. P., Wistort, R. M., and Mamishev, A. V., “Autonomous robotic monitoring of underground cable systems,” Proceedings of the International Conference on Advanced Robotics, ICAR '05, 2005, pp. 673-679.
19. Kamishima, H., Arai, T., Yuasa, K., Mae, Y., Inoue, K., Miyawaki, K., and Koyachi, N., “Hybrid drive parallel arm and its motion control ,” IEEE International Conference on Intelligent Robots and Systems, vol. 1, 2000, pp. 516-521
20. Kim, C.-W., Hong, K.S., and Lodewijks, G., “Anti-Sway Control of Container Cranes as a Flexible Cable System,” Proceedings of the IEEE International Conference on Control Applications, Taipei, Taiwan, 2004, pp. 1564-1569.
21. Kozak, Kris, Zhou, Q., and Wang, J., “Static Analysis of Cable-Driven Manipulators with Non-negligible Cable Mass,” IEEE Conference on Robotics, Automation and Mechatronics, Singapore, Singapore, 2004, pp. 886-891.
22. Kumar, R., and Issac, K. K., “Obstacle Avoidance and Minimum Time Control of Cranes Using Flat Outputs and Nonlinear Programming,” ASME IMECE, Anaheim, CA, 2004, IMECE2004-59532.

23. Liu, Q., Lorenc, S. J., Bernold, L. E., “Adaptive Control for a Crane-Mounted Inverted Stewart Platform,” Fourth International Conference on Robotics for Challenging Situations and Environments, Albuquerque, NM, 2000, pp. 126-132.

24. Lu, Y., Zhu, W., and Ren, G., “Feedback Control of Cable-Driven Gough-Stewart Platform,” IEEE Transactions on Robotics, vol. 22, no. 1, 2006, pp. 198-202.

25. Mayhew, D., Bachrach, B., Rymer, W. Z., and Beer, R. F., “Development of the MACARM - A novel cable robot for upper limb neurorehabilitation,” Proceedings of the IEEE 9th International Conference on Rehabilitation Robotics, 2005, pp. 299-302.

26. Nikkhah, M., and Ashrafiuon, H., “Robust Control of a Vessel Using Camera Feedback and Extended Kalman Filter,” ASME IMECE, Chicago, IL, 2006, paper no. IMECE2006-16164.

27. Nikkhah, M., Ashrafiuon, H., and Dougherty, E. J., “Motion Control and Design of an Aerial Robotic System,” ASME IDETC/CIE, Philadelphia, PA, 2006, DETC2006-99510.

28. Oh, S. R., and Agrawal, S. K., “Nonlinear sliding mode control and feasible work-space analysis for a cable suspended robot with input constraints and disturbances,” Proceedings of the American Control Conference, Boston, MA, vol. 5, 2004, pp. 4631-4636.

29. Oh, S. R., and Agrawal, S. K., “A Reference governor-Based Controller for a Cable robot Under Input Constraints,” IEEE Transactions on Control Systems Technology, vol. 13, no. 4, 2005, pp. 639-645.

30. Oh, S. R., and Agrawal, S. K., “Cable Suspended Planar Robots with Redundant Cables: Controllers with Positive Tensions,” IEEE Transactions on Robotics, vol. 21, no. 3, 2005, pp. 457-465.

31. Omar, H. M., and Nayfeh, A. H., “A Simple Adaptive Feedback Controller for Tower Cranes,” ASME IDETC/CIE, Pittsburgh, PA, 2001, DETC2001/VIB-21606.

32. Omar, H. M., and Nayfeh, A. H., “Gain Scheduling Feedback Control for Tower Cranes,” Journal of Vibration and Control, Vol. 9, 2003, pp. 399-418.

33. Omar, H. M., and Nayfeh, A. H., “Gain Scheduling Feedback Control for Tower Cranes with Friction Compensation,” Journal of Vibration and Control, Vol. 10, 2004, pp. 269-289.

34. Parker, G. G., Petterson, B., Dohrmann, C., and Robinett, R. D., “Command Shaping for Residual Vibration Free Crane Maneuvers,” Proceedings of the American Control Conference, Seattle, WA, 1995, pp. 934-938.

35. Proctor, F. M., and Shackleford, W. P., “Embedded Real-Time Linux for Cable Robot Control,” Proceedings of the ASME DETC, Vol. 1, 2002, pp. 851-856.

36. Qiu, Y. Y., Duan, B. Y., Wei, Q., and Du, J. L., “Elimination of force singularity of the cable and cabin structure for the next generation large radio telescope,” Mechatronics, vol. 12, no. 7, 2002, pp. 905-918.

37. Ren, G., Lu, Q., Hu, N., Nan, R., and Peng, B., “On Vibration Control with Stewart Parallel Mechanism,” Mechatronics, vol. 14, 2004, pp. 1-13.

38. Shiang, W.-J., Cannon, D., and Gorman, J., and “Dynamic Analysis of the Cable Array Robot,” IEEE International Conference on Robotics and Automation, Detroit, MI, vol. 4, 1999, pp. 2495-2500.

39. Slotine, J.-J. E., and Li, W., Applied Nonlinear Control. Prentice Hall, Englewood Cliffs, NJ, 1991.

40. Stewart, D., “A Platform with Six Degrees of Freedom,” Proceedings of the Institution of Mechanical Engineers, vol. 180, no. 5, 1965, pp. 371-386.

41. Stone, W. C., and Pfeffer, L. E., “Automation infrastructure system for a robotic 30-ton bridge crane,” Proceedings of the ASCE Specialty Conference on Robotics for Challenging Environments, 1998, pp. 195-201.

42. Su, Y. X., Duan, B. Y., Nan, R. D., and Peng, B., “Development of a pilot of an Arecibo-type large spherical radio telescope for the square kilometre array,” Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, vo. 215, no. 11, 2001, pp. 1321-1330.

43. Su, Y. X., Duan, B. Y., Nan, R. D., and Peng, B., “Mechatronics Design of Stiffness Enhancement of the Feed Supporting System for the Square-Kilometer Array,” IEEE/ASME Transactions on Mechatronics, vol. 8, no. 4, 2003, pp. 425-430.

44. Su, Y. X., Duan, B. Y., Wei, Q., Nan, R. D., and Peng, B., “Mechatronics design of vibration rejection of the feed supporting system for the square kilometer array,” Proceedings of IEEE/ASME International Conference on Advanced Intelligent Mechatronics, vol. 1, 2001, pp. 612-617.

45. Su, Y. X., Sun, D., and Duan, B. Y., “Active suppression of dynamic coupling of the feed supporting system for the square kilometre array using an electrorheological damper,” Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, vol. 218, no. 12, 2004, pp. 1569-1579.

46. Sun, J.H., Gu, D. M., Min, S.L., and Liang, G.R., “Dynamic Responses of Suspended Cable System Under the Moving Loads,” Computational Mechanics, Eds.: Cheung, LEE & Leung, 1991, pp. 1775-1779.

47. Tadokoro, S., Murao, Y., Hiller, M., Murata, R., Kohkawa, H., and Matsushima, T., “A Motion Base With 6-DOF by Parallel Cable Drive Architecture,” IEEE/ASME Transactions on Mechatronics,” Vol. 7, No. 2, 2002, pp. 115-123.

48. Usher, K., Winstanley, G., Corke, P., Stauffacher, D., and Carnie, R., “Air vehicle simulator: An application for a cable array robot,” Proceedings of the 2005 IEEE International Conference on Robotics and Automation, 2005, pp. 2241-2246.

49. Utkin, V. I., “Variable Structure Systems with Sliding Modes,” IEEE Transactions on Automatic Control, vol. 22, no. 2, 1977, pp. 212-222.

50. Viscomi, B. V., Michalerya, W. D., and Lu, L.-W., “Automated construction in the ATLSS Integrated Building Systems,” Automation in Construction, vol. 3, no. 1, 1994, pp 35-43.

51. Wang, Y.-M., "The Transient Dynamics of a Cable-Mass System due to the Motion of an Attached Accelerating Mass," International Journal of Solids and Structures, vol. 37, 2000, pp. 1361-1383.

52. Ye, P., Zhou, Q., Duan, G., and Ren, G., "The Stability Analysis of the Gough-Stewart Parallel Mechanism on Vibration Control," IEEE Conference on Robotics, Automation and Mechatronics, Singapore, Singapore, 2004, pp. 248-252.

53. Zhou, Q., and Zhang, H., "Simulation and Experimental Analysis of the Stewart Parallel Mechanism for Vibration Control," Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, vol. 4, 2003, pp. 3548-3552.

54. T-ACS/Robocrane, Suspended Cargo Acquisition and Stabilization, "http://www.isd.mel.nist.gov/projects/robocrane/html_presentations/TACS.pdf", Intelligent Systems Division, US Department of Commerce and NIST, Gaithersburg, MD, August 1996.

Appendix A – List of Figures

Figure 1: A cable driven monitoring and decontamination system with a robotic arm.. 261
Figure 2: Kinematics of the upper and lower platforms with cable connections........... 263
Figure 3: Vibration of lower platform in surge (x), sway (y), and heave (z) directions. 267
Figure 4: Roll (θ_x), pitch (θ_y), and yaw (θ_z) rotational vibration of the lower platform . 268
Figure 5: Vibration of upper platform in surge (x), sway (y), and heave (z) directions. 269
Figure 6: Roll (θ_x), pitch (θ_y), and yaw (θ_z) rotational vibration of the upper platform . 270
Figure 7: Simultaneous lower platform linear motion.. 271
Figure 8: Simultaneous lower platform roll (θ_x), pitch (θ_y), and yaw (θ_z) rotations....... 272
Figure 9: Upper platform uncontrolled linear motion.. 273
Figure 10: Upper platform uncontrolled roll (θ_x), pitch (θ_y), and yaw (θ_z) rotations 274
Figure 11: The cable motion required.. 275
Figure 12: The cable velocity provided required.. 276
Figure 13: The cable forces during the lower platform operation 277

Chapter 7 - Aquatic Mobile Robots: A Compliant Stingray Robot

Dr. C. Nataraj – Villanova University

Executive Summary

A novel compliant robotic stingray fish is proposed. Detailed studies of stingray motion are presented, and a conceptual robotic device is analyzed and preliminary designs are presented. Recommendations are outlined in order to carry this innovative research through its completion.

Background

Motivation

The concept of an ocean-going decontamination system has been proposed to effectively diagnose, contain and decontaminate the results of a possible nuclear, biological or chemical incident at sea. Such a decontamination system will need a set of autonomous devices which can be deployed to carry out various operations with least human involvement. In particular, the ability to sample the water or air for radiological, biological or chemical agents, and the ability to carry a sample from point to point for a short distance in water is of tremendous utility. It is this need that motivates the current proposal. In addition, it has been fairly well established in the scientific literature that good optimal designs can often be found in nature (which is after all what evolution is all about), and that it would be beneficial for engineering designs to emulate or "steal" concepts from nature. Therefore, this work is focused on fish-like mobile devices.

Background

Robots capable of legged, wheeled and tracked motion for land use have been developed over the past three decades; famous examples include the Mars Rover and more recently, the Honda humanoid robot. Many platforms of unmanned air vehicles with some limited autonomy have been developed. Many underwater vehicles have also been developed largely by the Navy. Our focus here is on robotic devices that can traverse the water on or just under the surface. Hence this literature survey is limited to any such existing devices.

In recent years, the interest in mimicking nature's approaches has increased in order to improve the performance of man-made mechanisms in liquid environments. This is mainly due to promising features that biomimetic mechanisms have, and conventional propeller driven (or water-jet) mechanisms lack. The majority of current liquid environment applications are characterized by high Reynolds numbers. As a result, present biomimetic mechanisms focus on fishlike swimming techniques since these outperform other aquatic creatures in these types of environments. Before we present a survey of swimming robots, it may be instructive to review fish swimming mode classifications (Lindsey, 1978) using the body's part used for propulsion. The pictures (widely available) are omitted for reasons of brevity.

- *Anguiliform*: The entire body is used to propel, and a muscle wave is propagated perpendicular to the body. The body is usually elongated, like in snakes or eels.
- *Carangiform*: About a third of the last part of the body is used for propulsion by oscillating the caudal fin and the caudal peduncle (tail). A subclass of carangiform is *thunniform*; such fish swim very fast. Their caudal fins have a high aspect ratio. An example is the red tuna, the fastest fish in the world, with speeds of up to 100 mph.
- *Subcarangiform*: this is a term used to define fish that are between anguiliform and carangiform. The oscillation is smaller than in anguiliform mode. An example is the salmon.
- *Ostraciiform*: only the fins are oscillated and the rest of the body does not move. The paired fins are mainly used to propel and the caudal fin is less used. The bodies of these fish are often inflexible. They mainly live in reefs and swim slowly, and so maneuvering is a more important aspect of the motion. Example: boxfish.
- *Labriform*: these are like ostraciiform fish except that the caudal fin is used as a rudder and pectoral fins are used for propulsion. Example: angelfish.

As stated above, many researchers have derived inspiration from the above swimming modes of natural fish. Current and recent work on fish-like robots includes the following:

- The National Marine Research Institute in Japan [23] has been working on multiple projects, including maneuvering, swimming performance and modular robotics for water.
- The University of Essex in England [10] has multiple interesting fish robot projects.
- Massachusetts Institute of Technology [24, 25] has developed a set of thunniform robots called RoboTuna; their objectives were to develop a more efficient and less noisy propulsion system for underwater vehicles; these robots are not autonomous. University of Michigan [4] has developed a robot called B1 which propels itself with two frog's muscles in a glucose solution.
- Mitsubishi Heavy Industries developed a fossil fish robot in 2001. The purpose was to display Coelacanth, an extinct fish, to the visitors in amusements parks.
- Beijing University in China [33-35] has built a semi autonomous underwater vehicle propelled by a fin for archaeological exploration, which resembles torpedoes.
- University of California has recently built a biomimetic micro underwater vehicle (12 mm long) with oscillating fin propulsion.
- Some robotic clubs have also built fish robots ("hobby" robots) like Dongle [9], a fish robot developed by the Seattle Robotic Society.

- Ecole Polytechnique has developed a Boxybot [14] among many other similar swimming robots.
- Amphibious robots typically rely on walking motion, where the robot is limited to the ocean floor. This greatly simplifies the design requirements, but limits the robot's ability to navigate obstacles. Examples include a mechanical hexapod, called Aqua [2], at McGill University in collaboration with York University and Dalhousie University, and Ecole Polytechnique in Switzerland [14] who have developed *AmphiBot I*, an amphibious snake robot capable of crawling and swimming as well as an elongated body robot resembling the lamprey.
- Some recent exotic versions of aquatic robots include the basilisk lizard (*Basiliscus plumifrons)* which has the unique ability [11] to walk across water (the so called Jesus lizard robot); practical issues especially in unruly sea conditions remain unsolved.

Some examples from the referenced web sites are shown in Fig. 1. Others may be found in the references listed at the end of the proposal. This is an evolving field, and with all of these research efforts, terrestrial and/or aquatic mobility, control, navigation, communication, obstacle avoidance, and payload remain critical issues to be resolved for successful operation.

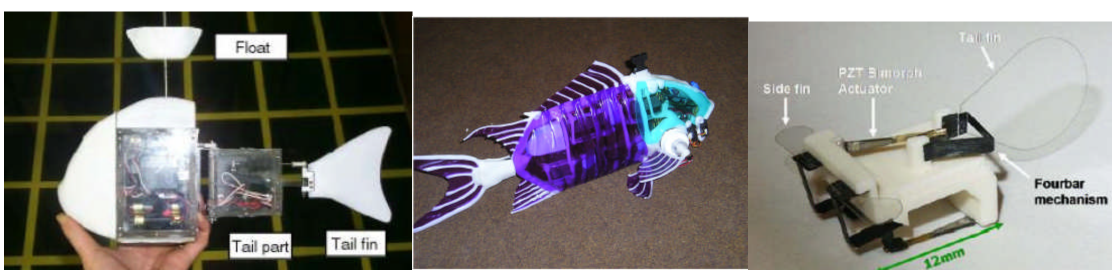


Figure 1: Example robotic fish
(PF300, G4, boxfish) from various sources listed in the Bibliography

Technical Issues

The technical issues associated with being able to achieve locomotion and autonomy for a robotic fish can be classified as follows.

1. Dynamics and hydrodynamics
2. Control design for locomotion
3. Localization
4. Navigation and Obstacle avoidance
5. Materials
6. Motive force design (motors, links, and other mechanisms)
7. Electronic hardware, sensors, communication devices, and power sources.
8. Mechanical design

Of the above tasks, 1 and 2 present the most difficulty and need fundamental scientific investigations. Although 3 and 4 are not trivial, they can be adapted from existing research in the general robotic field and from the PI's own research background. 5 can be an issue with the peculiar constraints the problem is likely to pose, but is more likely to reduce to an optimal selection from a wide variety of choices. 6, 7 and 8 are expected to be standard engineering design issues – not trivial, but not expected to result in technical breakthroughs. It is therefore expected that much of the effort in the initial phase will focus on 1 and 2.

There are other important issues which are worth mentioning. For example, several liquid environments are harsh and robots would be required to withstand high pressures, high temperatures, corrosive chemicals, and impact with debris. For this reason, robustness is an important factor in prolonging the life of the device. In addition, stealth and blending well with the surroundings are important in tactical missions that require avoiding detection. Finally, navigation in real environments requires control techniques to achieve tasks autonomously. Although all these are important issues we did not focus on them in the first phase of the project.

Dynamics & Hydromechanics

Clearly, the fish (or, any aquatic robot) moves through water by exerting forces on the water in accordance with a control law applied to a movable control surface. An accurate design needs an analysis of the hydromechanics, dynamics of the robot and a suitable control law. The three aspects are intertwined and cannot be easily separated for analysis. However, it is instructive to discuss the three aspects individually in order to elucidate the challenges clearly.

The dynamics of the robot (if it has only rigid components) is given by that of a rigid body in three dimensions. Such a rigid body has six degrees of freedom – three translational and three rotational. They are illustrated in Figure 2. The equations of motion are complex and are derived in detail as a supplement in the analysis section.

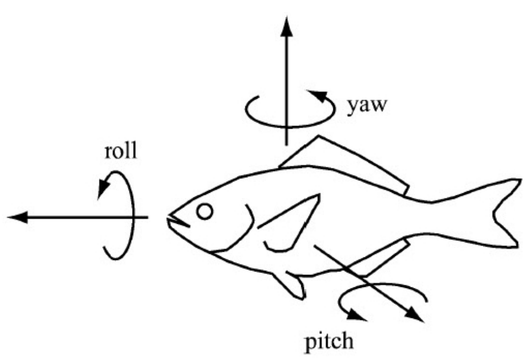


Figure 2: Degrees of freedom

A fish or the robot being ultimately conceived here is not rigid however. In fact, the flexibility of the fins is important and advantageous to effective and optimal control. Hence the dynamics involves infinite degrees of freedom, or in other words, is governed by partial differential equations with large motions. This is a nonlinear dynamic problem in itself (even without the hydrodynamics). Accurate modeling is important in order to be able to predict the dynamic behavior precisely; more importantly, accurate models make the control problem much more tractable.

Recent research in the performance of the fins and tails of live fish has revealed that the rhythmic, oscillatory motion of fish body and fins results from a matching of effective impedance between that of the dynamics of the actively controlled musculature and the fluid loads. This is a fluid-structure interaction problem that requires deep understanding of the control laws employed by fish, the mechanical and material properties of the actuating muscles and the body of the fish, as well as the fluid mechanics of the flow around the body. Published papers that include observations and studies of fish provide information on the body properties, while fluid mechanics studies provide insight on basic flow mechanisms [15-20, 28, 32]. Conceptual advances are still needed in order to simplify the problem of fish locomotion, and to provide engineering information to build robotic vehicles. Our vehicles will in fact employ actuation mechanisms and control laws that could be different from fish; so it is expected that the impedance matching (if indeed it is possible) would not be the same since the actuation methods are different.

A few fundamental questions then arise; answers to these questions would help arrive at an optimal robotic swimmer.:

- How is the motion of fish affected by the mechanical and material limitations of their own bodies and the control laws they employ?
- Is the final motion non-optimal (or sub-optimal) as far as fluid mechanics and dynamics are concerned, due to structural, material, and control-law limitations?
- How can we extract optimal flow mechanisms that can also apply to different actuation and control mechanisms?

Motion within viscous liquids (such as water) carries a heavy penalty on the energy required for locomotion and maneuvering if the motion is not optimized. It would pay, therefore, at least for the fastest and most agile animals, to explore optimization of the fluid mechanics of their locomotion at the expense of redesigning their structure and control laws subject to the limitations of the available materials. This must be achieved through optimization of body geometry and structure, as well as body actuation and control, and is the key to designing highly efficient robotic swimmers.

Although several factors contribute to successful autonomous exploration of liquid environments, the most important performance parameters include the following: locomotion efficiency, maneuverability, mechanism adaptability, mechanical robustness, and autonomy (or level of control). An efficient use of supply energy for locomotion would also permit longer mission ranges and smaller power supplies.

Maneuvering capabilities, enabled by the number of degrees of freedom, are needed for navigation in complex geometries. In addition, environment properties such as density, viscosity, or the surrounding geometry can change over the course of a mission. In such situations, mechanism adaptability is required in order to maintain locomotion performance.

Some recent advances will help in guiding our research. For example, studies [29] have suggested that gains in locomotion efficiencies could be achieved over traditional propelled devices when implementing fish swimming techniques. Studies have proposed that mechanisms implementing fish swimming techniques could also yield superior maneuverability by diminishing turning radii and improving acceleration capabilities. In order to improve performance, biomimetic mechanisms should optimally implement geometric and kinematic attributes from creatures with good performance in environments of interest. By mimicking both the motions and body shapes, we hope to recreate the dynamic interactions with the environment that yield superior locomotion characteristics. However, biomimetic approaches can only go so far with conventional discrete and stiff mechanisms used to implement them.

Most motions displayed by nature's creatures are kinematically complex. Therefore, there is an inherent disadvantage when trying to imitate these with discrete mechanisms since large numbers of degrees of freedom are required making the resultant structures very complex. The resultant complexity can diminish internal mechanical efficiencies mostly through frictional losses. In addition, the large number of parts reduces mechanical robustness since the flexibility required in biomimetic vehicles increases the challenges of sealing and protecting sensitive parts. Also, an increase in the number of degrees of freedom increases the sophistication of control techniques needed. These limitations influence the performance displayed by current biomimetic mechanisms [30].

In summary, most real fish appear to have much higher efficiency than the best robotic mechanisms. The oft-quoted advantages of biomimicry are: higher efficiency, greater range of motion, lower disruption to the environment and higher maneuverability. This could principally be because we have rigid mechanisms trying to imitate nature's beautifully evolved designs. We feel that flexible control surfaces may help us bridge this gap and is hence our intended design.

Control

Control of nonlinear processes is an evolving research area. There are roughly two categories: accurate model-based controllers and approximate heuristic methods. Model-based control procedures include optimal, adaptive, model predictive, sliding mode, and many other methods. Heuristic methods include fuzzy logic, neural network and combination procedures. Analytically sound model-based methods are accompanied by stability guarantees and are reliable and robust with predictable ranges of performance and accuracy, whereas, in general, heuristic methods do not come with any such assurances. However, it may be possible to get "quick and dirty" solutions using such methods.

Scalability

Scalability is an important consideration in the feasibility stage, as a design that is acceptable may be no longer so if a bigger or smaller design is needed for the application. This issue will be carefully considered using nondimensional models. In general, scalability will break down for much larger or for micro situations. In any event, the limits of such scaling should be eventually explored in order to guide future designs.

Objectives

The immediate goals of the project were to determine the feasibility of designing a robotic device that resembled a stingray in its motion mechanism. The long term goal (with sufficient funding, time and other resources) would be to complete the dynamic analysis, implement a suitable control system, and carry out experiments to validate, verify and optimize the design.

Findings

We carried out a preliminary investigation the results of which are reported here. The motion of a stingray fish has never been analytically investigated – our work represents the first such research. We also investigated and selected suitable active control materials for use in the design.

The Real Stingray

The first investigation is an analysis of the mechanism of motion of real stingrays and involved a detailed study of zoological sciences literature. Stingrays belong to the class of fish called batoid fish. They typically have dorsoventrally flattened bodies and pectoral fins that are fused to the head resulting in a broad, flat disc. Stingrays also have a greatly reduced tail and use pectoral-fin based locomotion which falls into three categories: undulation (rajiform locomotion), oscillation (mobuliform) and a combination of the two forms ("intermediate"). Numerous experimental studies have been conducted by zoologists to study various aspects of all three modes of stingray locomotion. For example, [31] found that, in undulatory motion, as swimming velocity increased, fin-beat frequency, wave speed and stride length increase, the number of waves decreased and the amplitude remained constant. [32] analyzed eight different species and found very interesting correlations between the various motion parameters, all of which are useful in tweaking the robotic designs.

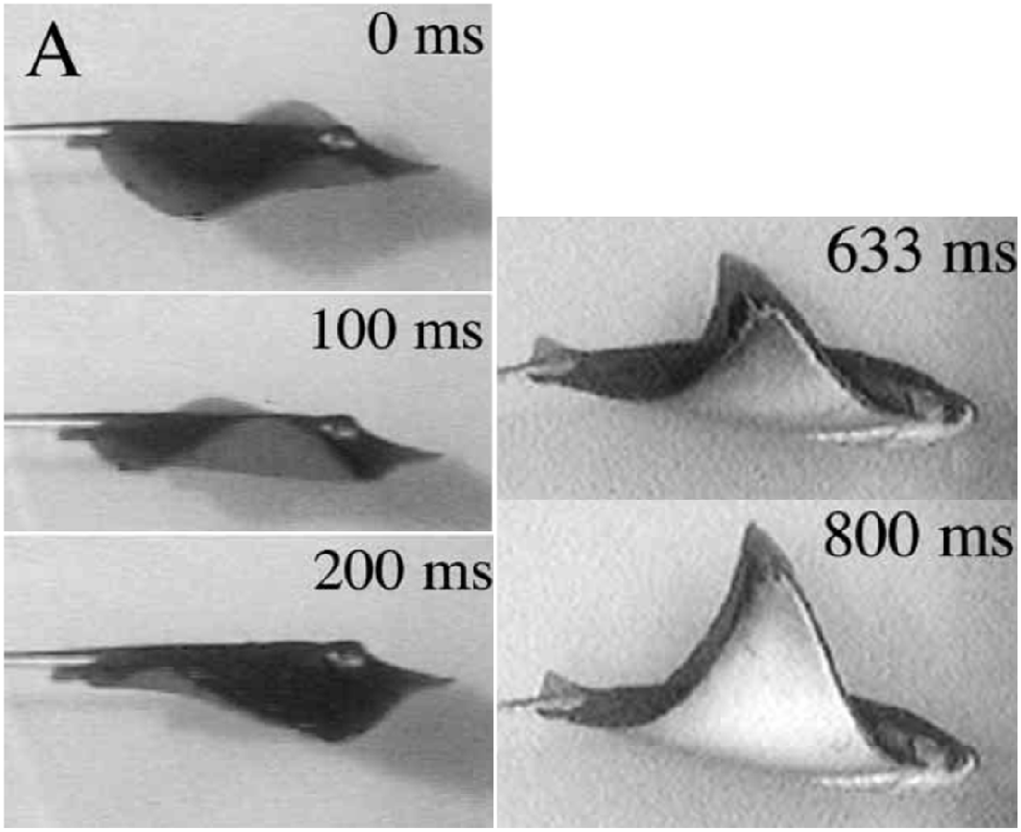


Figure 3: Oscillatory Motion [32]

In general, batoid fish show a surprising amount of diversity in their swimming behavior; in particular, there appears to be no simple division between undulatory and oscillatory mechanisms, but rather a continuum of behavior based on the wave number. In addition, some species such as *Gymnura micrura* show typical biological system adaptability: they alter their mechanism drastically depending on the ambient conditions in order to achieve optimality. For example, this species passes multiple waves along the fins when swimming slowly along the bottom, but switches to a flapping behavior when it swims in the water column; hence, it fits into both categories of undulation and oscillation. This is indeed a desired objective for any robotic device; although it could be difficult to achieve, adaptability needs to be considered at the preliminary phases of the design, and not be an afterthought.

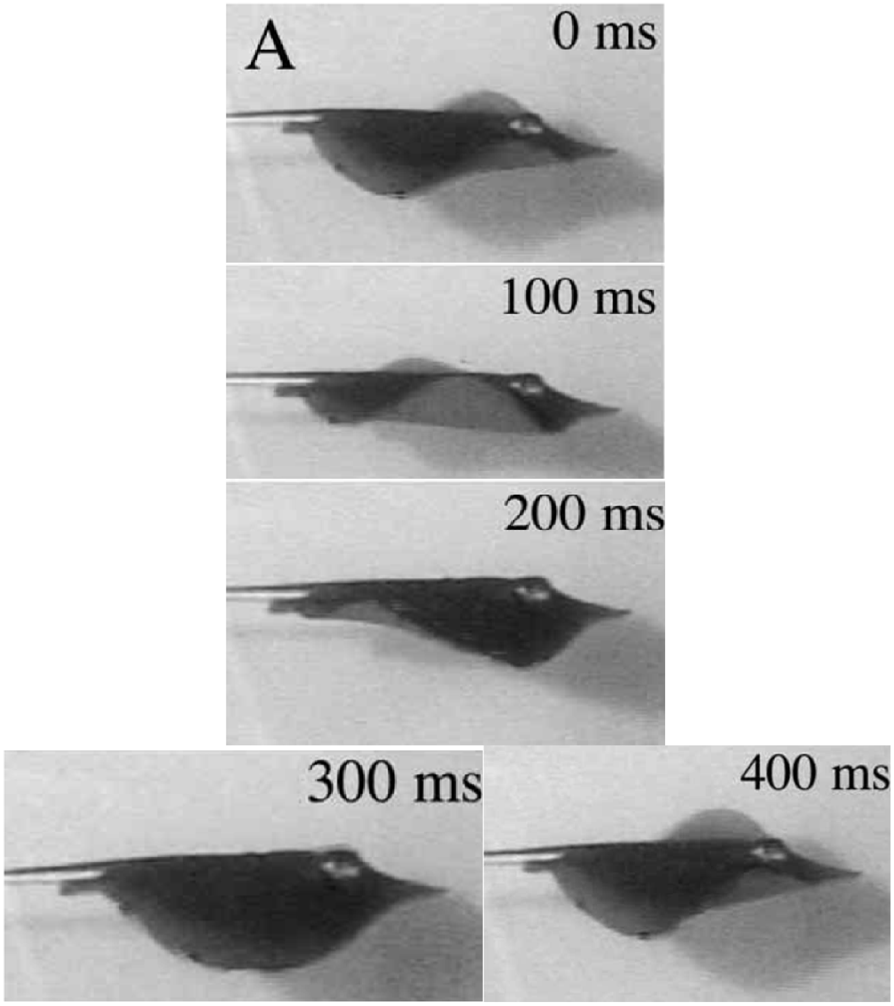


Figure 4: Undulatory Motion [32]

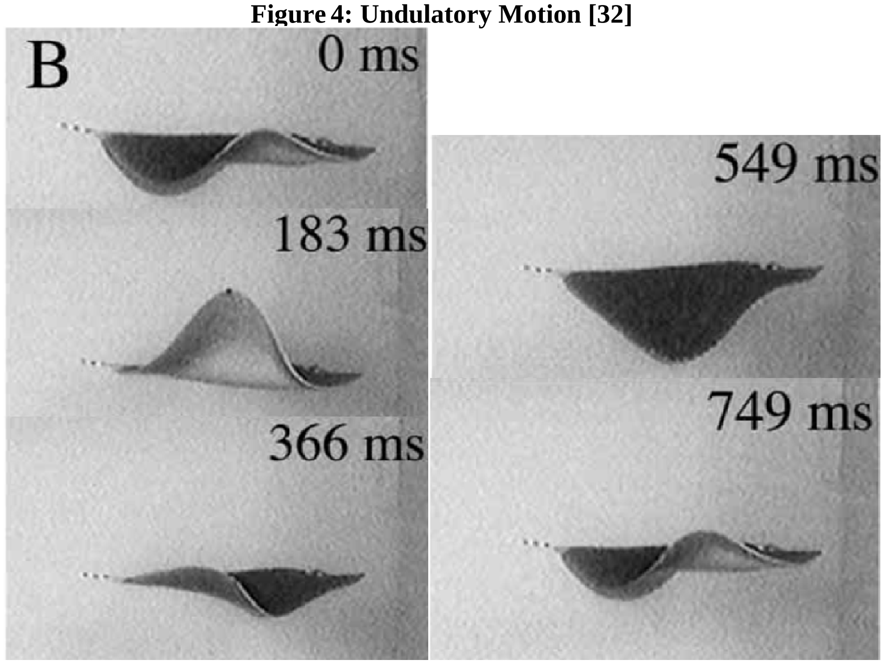


Figure 5: Mixed Motion [32]

Concept Robot

Our concept of a robotic stingray is shown in Fig. 6, and in a swimming configuration in Fig. 7; our initial design is meant to emulate the oscillatory motion Our device explores the exploitation of natural vibration modes of a flexible structure to achieve locomotion. This is indeed what the real fish do; fish rarely have stiff mechanisms! In fact, it is quite easy to show that the fish swimming speeds of as much as 10 body lengths/second is orders of magnitude larger than the maximum velocities achieved in current robotic fish equipped with rigid mechanisms – the important difference of course being that the fish bodies are *flexible*.

Our robotic device consists of an almost circular *flexible* membrane stretched over a stiffening structure with a central hub. The hub, or "spine" contains the microcontroller, sensors for position and velocity information, and a source of power. The primary actuation comes from thin IPMC strips; the next subsection explains this actuation mechanism.

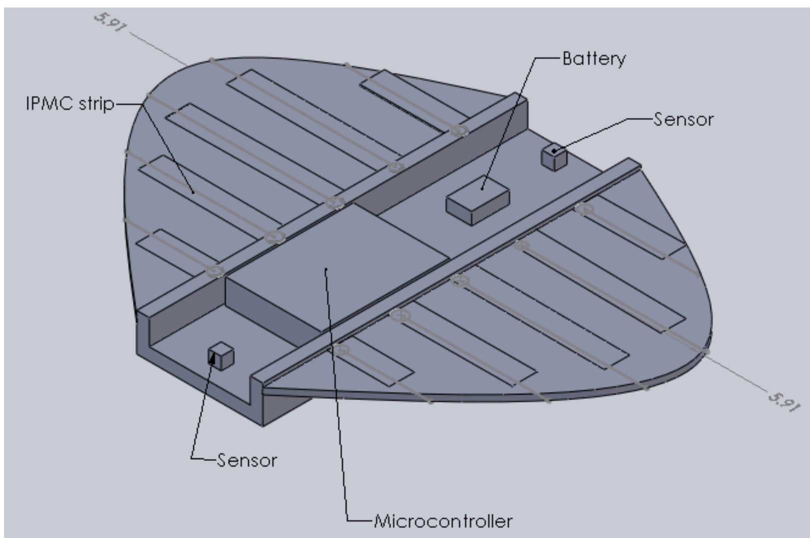


Figure 6: VU Robotic Stingray

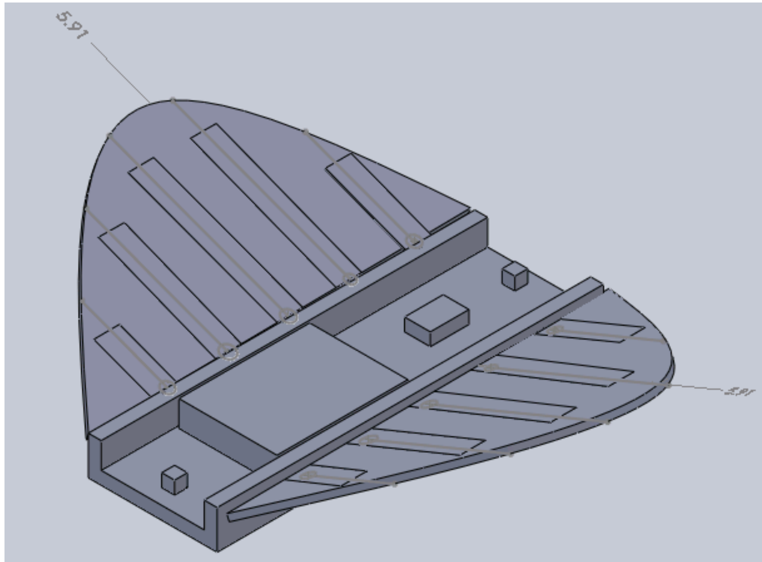


Figure 7: VU Stingray in motion

Actuation

Our design uses a class of “smart” material actuation which takes the place of muscles in real fish. In smart materials, an electric current is employed to change the shape, providing force and/or displacement. There are many smart materials which have been developed over the past three decades. Table 1 shows a comparison of three types that we evaluated for the current design.

Property	Ionic polymer-Metal Composites (IPMC)	Shape Memory Alloys (SMA)	Electroactive Ceramics (EAC)
Actuation displacement	>10%	<8% short fatigue life	0.1 - 0.3 %
Force (MPa)	10 - 30	about 700	30-40
Reaction speed	µsec to sec	sec to min	µsec to sec
Density	1- 2.5 g/cc	5 - 6 g/cc	6-8 g/cc
Drive voltage	4 - 7 V	NA	50 - 800 V
Power consumption	watts	watts	watts
Fracture toughness	resilient, elastic	elastic	fragile

Table 1: Comparison of some smart materials

After a detailed analysis we found that the Ionic polymer-metal composite (IPMC) is ideally suited for the current application. IPMC works well in water, its characteristics have been studied, it has the right frequency response necessary for a robotic device, and it has adequate load generation for the robotic stingray which it is able to achieve with a

voltage that can be applied in a device of the size we are considering. Note that SMA ha much higher load capacity, but is extremely inefficient.
The typical characterization curve for an IPMC strip is shown in Fig. 8. This characterization is important information for accurate design of the control system. We are in the process of developing our own calibration curves for IPMC strips in the laboratories at Villanova University.

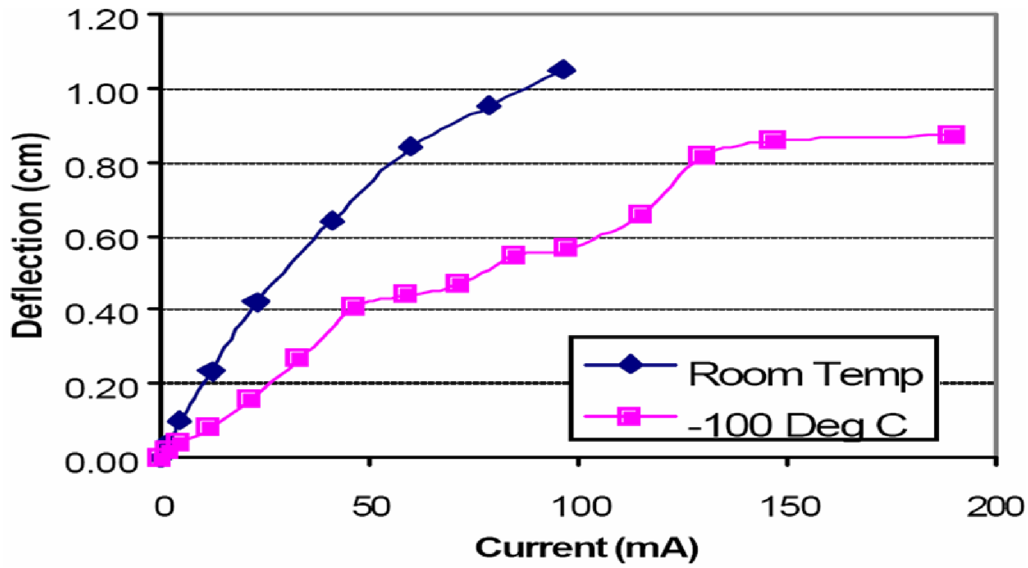


Figure 8: Typical IPMC characteristic [39]

There has indeed been one previously known instance of IPMC application for a swimming robot [40].

Analysis

Mathematical analysis is a necessary part of the system design and reduces blind experimentation. With regard to the analysis however, there have been a huge scarcity of papers on the subject of dynamic analysis of compliant bodies in liquid environments; one good publication has been by Alvorado et al. [30]. They consider a beam-like elongated structure which, however, is not relevant in this analysis.
The appropriate simple model for our robot stingray is the following linear partial differential equation:

$$\nabla^2 w + f = \frac{1}{c^2}\frac{\partial^2 w}{\partial t^2}$$

where, *c* is the wave speed in the material, and *w* is the displacement as a function of spatial coordinates and time. Note that, here we will be assuming that the effect of water is only to add damping. This is really not true since the fluid is affected by the motion of the robot (or the stingray fish), and the robot is affected by the fluid. In other words, this is a coupled fluid-flexible membrane problem that is quite complicated (and has not been

solved by anybody). This improved model will be used in the future phases of the project.
For a circular membrane,

$$\frac{\partial^2 w}{\partial r^2} + \frac{1}{r}\frac{\partial w}{\partial r} + \frac{1}{r^2}\frac{\partial^2 w}{\partial \theta^2} + f(r,\theta,t) = \frac{1}{c^2}\frac{\partial^2 w}{\partial t^2}$$

The excitation is given by the actuation material (IPMC) in a time variation as determined by the control system. The general solution of the free vibration problem is given by the following double infinite series (details are omitted – the author may be contacted for more information).

$$\begin{aligned} w(r,\theta,t) &= \sum_{m=0}^{\infty}\sum_{n=1}^{\infty} J_m\left(\frac{\omega_{mn} r}{c}\right)\left\{[a_{mn}\cos m\theta + b_{mn}\sin m\theta]\cos\omega_{mn} t\right. \\ &+ \left.[c_{mn}\cos m\theta + d_m n\sin m\theta]\sin\omega_{mn} t\right\} \end{aligned}$$

Here, *J* are the Bessel functions of the first kind.

Then, the forced response can be obtained by modal analysis which is made possible because of the expansion theorem and the remarkable orthogonality relationships of the eigenfunctions. The forces can be used appropriately to elicit the shape we need in the membrane by exciting the various modes of vibration by suitable amounts. To understand how we are able to do that it is instructive to look at the free vibration modes of the individual eigenfunctions the first five of which are shown here. The expressions shown are the natural frequency of vibration that depend upon the wave speed and the radius of the membrane. The wave speed depends on the mass density as well as the tension in the membrane which could be a design variable. Any and all the infinite modes can be excited (in theory) by suitable forces. This then translates to appropriate placement of the IPMC material in the body of the robot as well as the appropriate time variation of the voltages as determined by the control algorithm. For example, the first design of the IMPC integration would include just the excitation of the m=1,n=1 mode which would be quite close to the oscillatory locomotion mechanism.

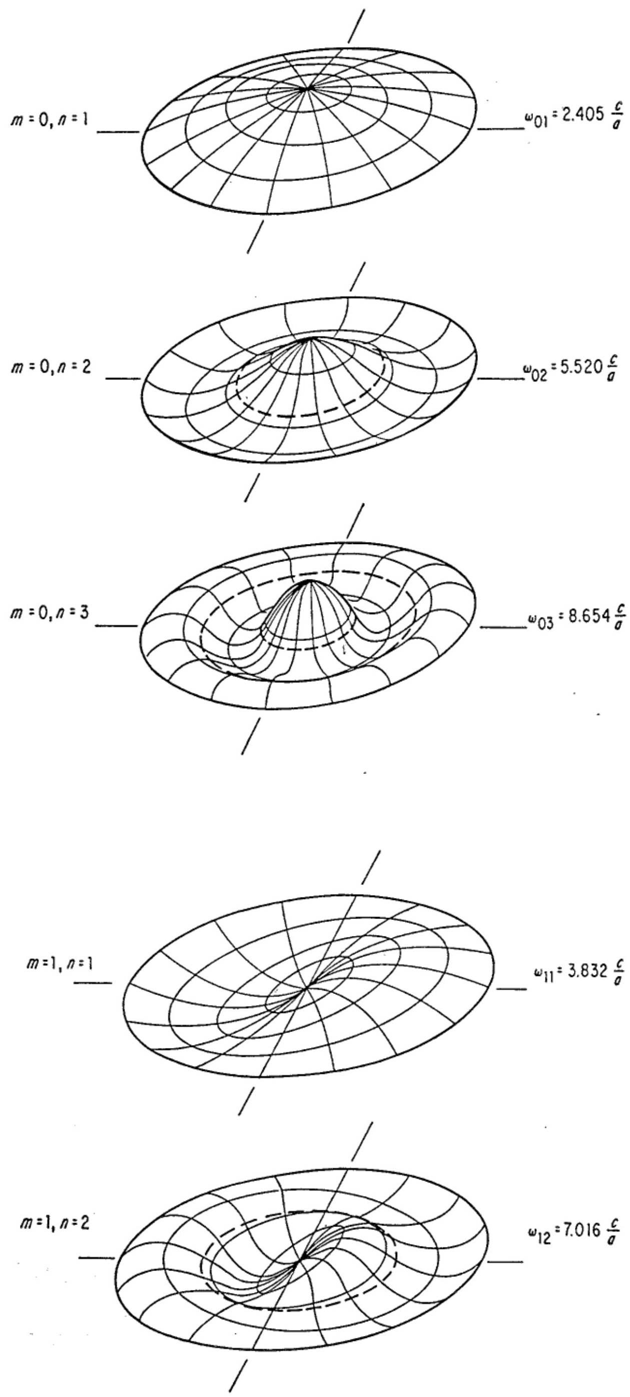


Figure 9: Vibrational modeshapes of a circular membrane

Conclusions

An investigation was carried out on the feasibility of constructing a robotic device that moves and functions like a stingray fish. A detailed study of motion mechanisms of real stingrays was conducted. A conceptual design was arrived at that would emulate the oscillatory motion of the stingray. Suitable smart material actuation was designed. Mathematical analysis was carried out to help design the placement of the IPMC actuation strips; this analysis will also guide the control system design to be accomplished in the next phase of the project.

Recommendations

The analysis and preliminary design carried out and reported in the previous sections demonstrate a revolutionary concept of a flexible robotic stingray, the first such device created anywhere in the world. Unfortunately, the funding was not sufficient ($20K) to achieve the complex mathematical analysis and experimental design necessary to bring this innovative concept to reality. Our recommendations would be to provide sufficient resources to carry out the necessary tasks as listed below.

Task 1: Carry out simple analysis as outlined to determine approximate locations of IPMC.
Task 2: Characterize IPMC using careful experimentation.
Task 3: Integrate into robotic design and carry out experimental studies with open-loop voltage application.
Task 4: Use results to modify simplified theory to include fluid-structure interaction as discussed.
Task 5: Use results of tasks 3 and 4 to design control system.
Task 6: Integrate control algorithms and implement on a microcontroller.
Task 7: Carry out theoretical and experimental studies to investigate real time performance and design modifications.
Task 8: Repeat Tasks 3-7 for mobuliform and mixed form of locomotion.
Task 9: Develop adaptive systems that can emulate any of the three mechanisms depending on the ambient conditions, performance needs and optimality.

Anticipated time: 3 years; Budget: $500,000.

Relevance to the Navy

Automation is an important priority for the Navy with the long-term objectives of reducing manning and decreasing casualties. In addition, many operations such as decontamination and handling hazardous substances are clearly better done by automated tools than Navy personnel to reduce injury and exposure to dangerous circumstances. As the Navy moves towards Sea Basing it is ever more important to collect a large set of automated tools that work in unison in high sea states to perform critical missions. The proposed project is one of several such automated tools that can considerably enhance the Navy's mission.

Anticipated Deliverables

The anticipated outcomes are as follows.

- A set of designs for the Stingray.
- Hydrodynamic analysis results for the conceptual designs under assumed sea conditions.
- Dynamic analysis results for certain standard locomotion modes.

- Control system design results integrating the hydrodynamics and dynamics
- Conceptual electro-mechanical design for integration of sensors, actuators and communication devices.

The above results will be delivered in the form of technical reports (including theoretical equations, graphs, tables, and experimental graphs), and computer codes (in MATLAB/SIMULINK/C). In addition, monthly and quarterly reports and presentations will be delivered as requested by the Project Manager. The research is likely to result in seminal papers to be published in archival journals.

Summary

This report reports on research that was performed under a subcontract from Ablaze to Villanova University (budget: $20,000). The research focused on aquatic mobile robots. The first section of the report outlines the background of existing robotic fish and outlines the common mechanisms. Next, a novel stingray robotic fish is proposed integrating a smart material called IPMC. Preliminary mathematical analysis is presented as well as a conceptual design. Future work is outlined along with an anticipated budget.

References

1. Alexander S. Boxerbaum, Philip Werk, Roger D. Quinn, Ravi Vaidyanathan, 2005, "Design of an Autonomous Amphibious Robot for Surf Zone Operation: Part I Mechanical Design for Multi-Mode Mobility," Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Monterey, California, USA, 24-28 July, 2005.
2. Aqua project, McGill University, http://www.aquarobot.net:8080/AQUA/AQUA/index html.
3. Barrett, D.S., Triantafyllou, M.S., Yue, D.K.P., Grosenbaugh, M.A. Wolfgang, "Drag reduction in fish-like locomotion," Journal of Fluid Mechanics, v 392, Aug, 1999, p 183-212.
4. B1, University of Michigan, http://www-personal.umich.edu/ bobden/biomechatronicdevices.html#Movie%20of%20our%20Biomechatronic%20Fish
5. Coelacanth fish, http://www.mhi.co.jp/enews/e 0898.html
6. J. E. Colgate, K. M. Lynch "Mechanics and Control of Swimming: A Review", IEEE journal of oceanic engineering, vol. 24, no. 3, July 2004.
7. Alessandro Crespi, Andr´e Badertscher, Andr´e Guignard, and Auke Jan Ijspeert, Swimming and Crawling with an Amphibious Snake Robot.
8. Xinyan Deng and Srinath Avadhanula, 2005, Biomimetic Micro Underwater Vehicle with Oscillating Fin Propulsion: System Design and Force Measurement. Robotics and Intelligent Machines Laboratory University of California, Berkeley, USA, 2005.
9. Dongle, Seattle Robotics Club, http://www.seattlerobotics.org/encoder /200211/autonomous robotic fish.html
10. Essex University, http://privatewww.essex.ac.uk / jliua

11. S. Tonia Hsieh, 2003, Three-dimensional hindlimb kinematics of water running in the plumed basilisk lizard (*Basiliscus plumifrons*), The Journal of Experimental Biology 206, 4363-4377.
12. Naomi Kato, "Control Performance in the Horizontal Plane of a Fish Robot with Mechanical Pectoral Fins", IEEE journal of oceanic engineering, vol. 25, no. 1, January 2000.
13. Eunjung Kim and Youngil Youm, Simulation Study of Fish Swimming Modes for Aquatic Robot System. Department of Mechanical Engineering, IEEE International Conference on Robotics and Automation, 2005, p 3330-3335.
14. Daisy Lachat, 2005, "BoxyBot, the fish robot, Design and realization," Project report, Ecole Polytechnique FL, Switzerland.
15. Lighthill, J., 1975, Mathematical Biofluiddynamics, Society for Industrial and Applied Mathematics, Philadelphia.
16. Lighthill, James, "Biofluiddynamics of balistiform and gymnotiform locomotion. Part 1. Biological background, and analysis by elongated-body theory," Journal of Fluid Mechanics, v 212, Mar, 1990, p 183-207.
17. Lighthill, James, "Biofluiddynamics of balistiform and gymnotiform locomotion. Part 2. The pressure distribution arising in two-dimensional irrotational flow from a general symmetrical motion of a flexible flat plate normal to itself," Journal of Fluid Mechanics, v 213, Apr, 1990, p 1-10.
18. Lighthill, James, "Biofluiddynamics of balistiform and gymnotiform locomotion. Part 3. Momentum enhancement in the presence of a body of elliptic cross-section," Journal of Fluid Mechanics, v 213, Apr, 1990, p 11-20.
19. Lighthill, James, "Biofluiddynamics of balistiform and gymnotiform locomotion. Part 4. Short-wavelength limitations on momentum enhancement," Journal of Fluid Mechanics, v 213, Apr, 1990, p 21-28.
20. C. C. Lindsey, "Form, function and locomotory habits in fish," Fish Physiology, Vol. VII Locomotion, edited by W.S. Hoar and D.J. Randall. New York: Academic Press, 1978, pp. 1-100.
21. Jindong Liu, Ian Dukes, Rob Knight, Huosheng Hu, "Development of fish-like swimming behaviours for an autonomous robotic fish," Department of Computer Science, University of Essex, United Kingdom, 2004.
22. Morgansen, K.A.; Duindam, V.; Mason, R.J.; Burdick, J.W.; Murray, R.M., "Nonlinear control methods for planar carangiform robot fish locomotion," Proceedings - IEEE International Conference on Robotics and Automation, Vol. 1, 2001, p. 427-434.
23. NMRI's robots, http://www.nmri.go.jp/eng/khirata/fish/index e.html
24. RoboTuna I, MIT, http://web.mit.edu/towtank/www/Tuna/Tuna1/tuna1.html
25. RoboPike, MIT, http://web.mit.edu/towtank/www/Pike/pike.html
26. Michael Sfakiotakis, David M. Lane, J. Bruce, C. Davies, "Review of Fish Swimming Modes for Aquatic Locomotion", IEEE journal of oceanic engineering, vol. 24, no. 2, April 1999.
27. SPC-II, http://www.vieartificielle.com/nouvelle/?id nouvelle=769
28. Dean J. Thorsen and Mark W. Westneat, "Diversity of Pectoral Fin Structure and Function in Fishes With Labriform Propulsion," Department of Zoology, Division of Fishes, Field Museum of Natural History, Chicago, 2005.

29. Triantafyllou, M. S., and Triantafyllou, G. S., 1995, “An Efficient Swimming Machine,” Scientific American, 272, No. 3, pp. 64–70.
30. Pablo Valdivia Y Alvarado and Kama Youcef-Toumi, “Performance of Machines with Flexible Bodies Designed for Biomimetic Locomotion in Liquid Environments,” Mechanical Engineering Department, MIT, USA, 2005.
31. Rosenberger, L. J. and Westneat, M. W., “Functional morphology of undulatory pectoral fin locomotion in stingray *Taeniura lymma*, Journal of Experimental Biology, Vol. 202, pp.3523-3539.
32. Lisa J. Rosenberger, “Pectoral fin locomotion in batoid fishes: undulation versus oscillation,” The Journal of Experimental Biology, Vol. 204, pp. 370-394, 2001.
33. Jason L. Ward, June 2005, “Design of a prototype autonomous amphibious WHEST Robot for Surf-Zone operations,” Master’s thesis, Naval Postgraduate School.
34. Wu, Theodore Yaotsu, 2001, “Mathematical biofluiddynamics and mechanophysiology of fish locomotion,” Mathematical Methods in the Applied Sciences, v 24, n 17-18, p 1541-1564.
35. Yu, J., Tan, M., Wang, S., and Chen, E., 2004, “Development of a Biomimetic Robotic Fish and its Control Algorithm,” IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics, Vol. 34, No. 4, pp. 1798–1810.
36. Junzhi Yu and Long Wang, “Parameter Optimization of Simplified Propulsive Model for Biomimetic Robot Fish. Intelligent Control Laboratory Center for Systems and Control,” Department of Mechanics and Engineering Science, Peking University, China, 2005.
37. Junzhi Yu, Min Tan, Shuowang and Erkui Chen, “Development of a Biomimetic Robotic Fish and Its Control Algorithm”, IEEE transactions on systems, man, and cybernetics, Part B: cybernetics, vol. 34, no. 4, August 2004.
38. Sia Nemat-Nasser , “Ionic Polymer-Metal Composites”, presented at the ASCE 16th Engineering Mechanics Conference, University of Washington, Seattle, 2003.
39. “Ionic Polymer-Metal Composites (IPMC) As Biomimetic Sensors and Actuators”, M. Shahinpoor, Y. Bar-Cohen, T. Xue, J.O. Simpson, and J. Smith, *Proceedings of SPIE’s 5th Annual International Symposium on Smart Structures and Materials*, 1998.
40. “A Biologically Inspired Ray-like Underwater Robot with Electroactive Polymer Pectoral Fins”, Andres Punning, Mart Anton, Maarja Kruusmaa, Alvo Aabloo, presented at the International IEEE Conference on Mechatronics and Robotics, 2004
41. Meirovitch, L., “Analytical methods in vibrations,” Prentice Hall, 1967.

Appendix A – List of Figures

Figure 1: Example robotic fish 286
Figure 2: Degrees of freedom 287
Figure 3: Oscillatory Motion [32]........ 291
Figure 4: Undulatory Motion [32] 292
Figure 5: Mixed Motion [32]........ 292
Figure 6: VU Robotic Stingray........ 293
Figure 7: VU Stingray in motion........ 294
Figure 8: Typical IPMC characteristic [39]........ 295
Figure 9: Vibrational modeshapes of a circular membrane........ 297

Appendix B – List of Tables

Table 1: Comparison of some smart materials 294

Chapter 8 – Technical Concepts in Support of an At Sea Emergency Response

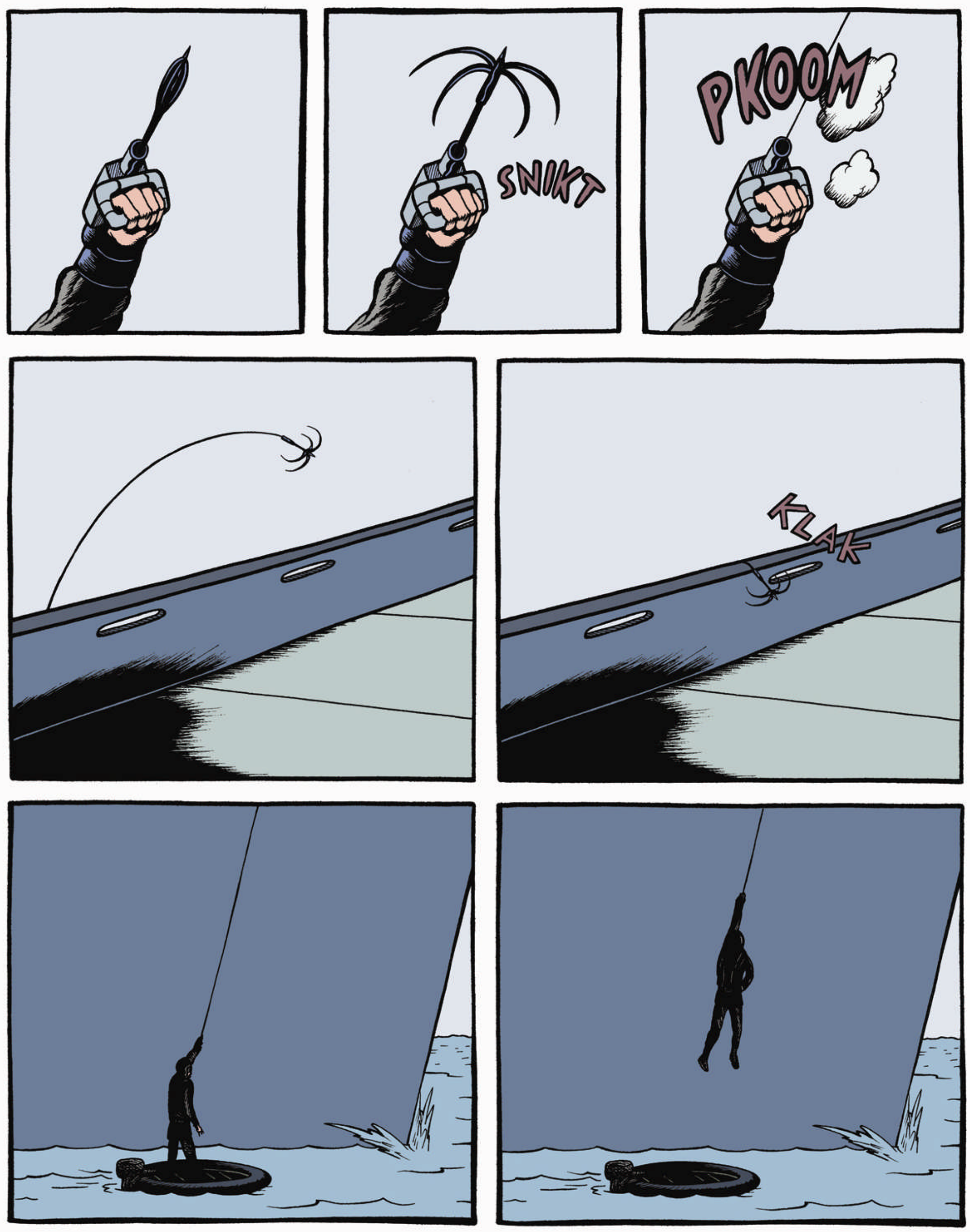
Introduction

A follow up to the initial brainstorming session was conducted to further identify and evaluate additional technology concepts that would help support the warfighter in and at sea emergency response operation. After much discussion and analysis of the several device concepts identified during the brainstorming sessions, it was concluded that the following should be considered further:

1. Personal Cable Climber
2. Hull Band-Aids
3. Hull Crawler
4. Personal Jet Pack
5. Magnetic Climbing System
6. Bee Stinger
7. Stinger Foam

The following are draft illustrations of the concepts identified.

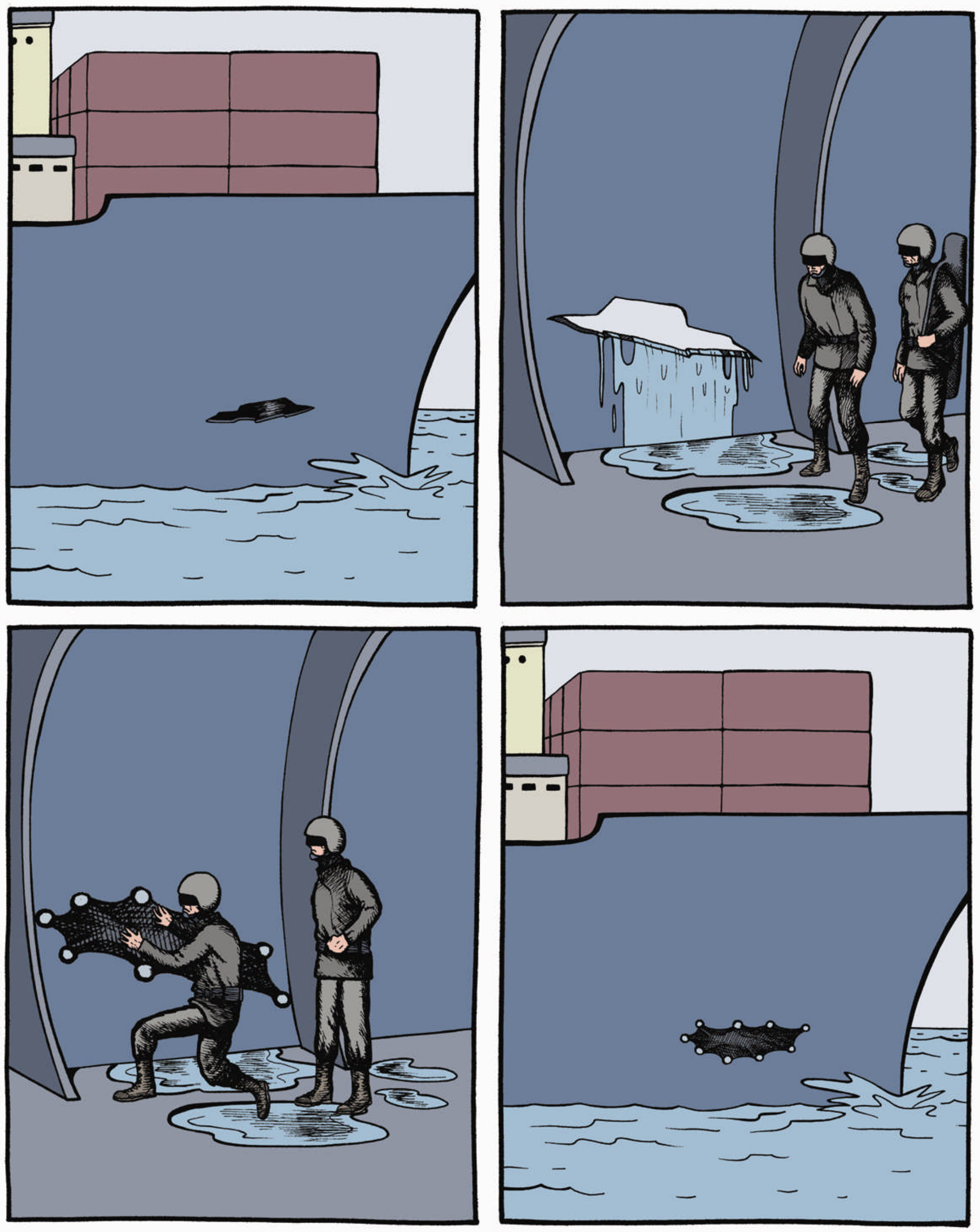
Personal Cable Climber



Cable Climber

Hull Band-Aids

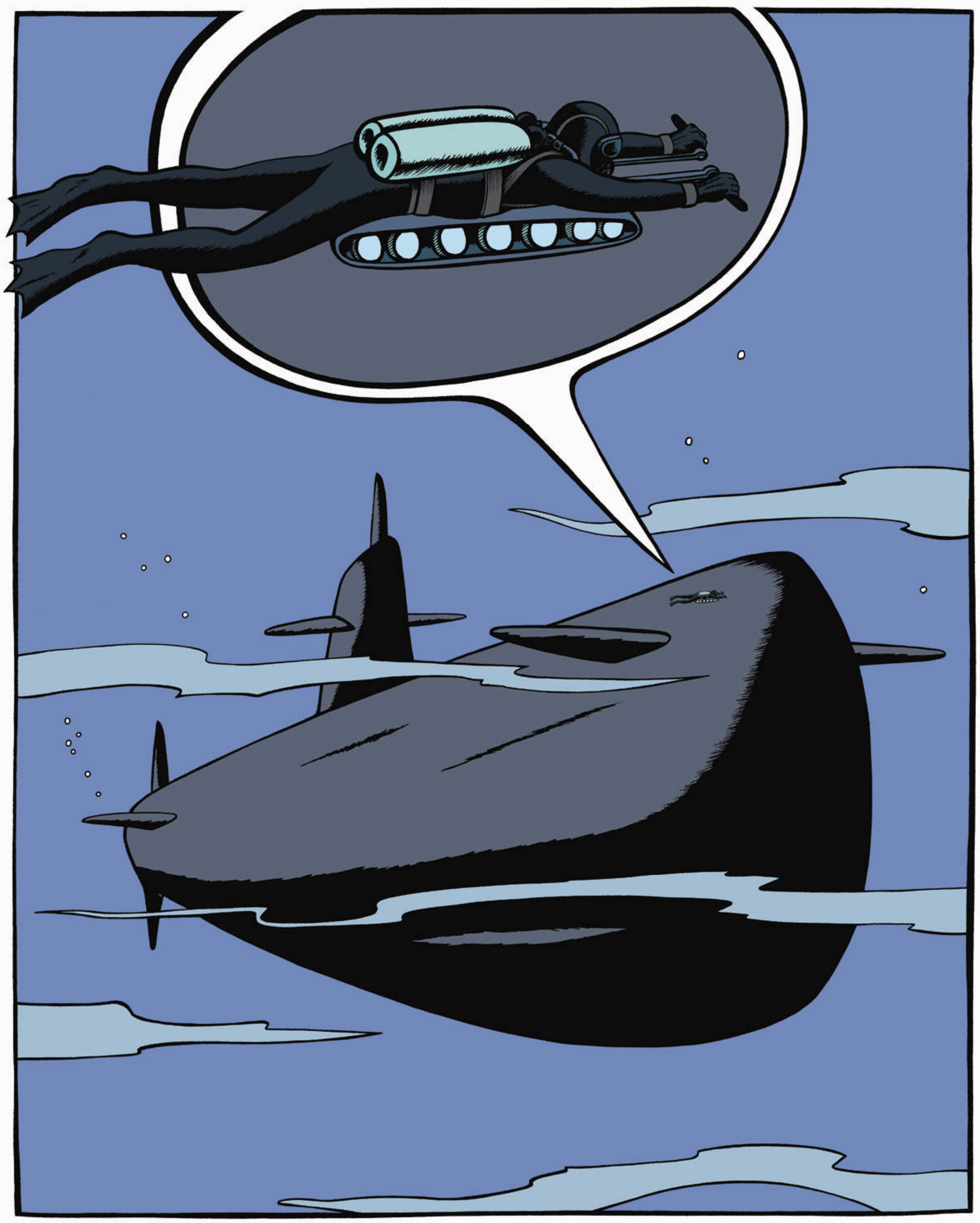
- A highly portable apparatus which will assist in the temporary repair of damage to the haul of a vessel until a permanent repair is made. The band-aid would be made out of non-permeable fabric attached by industrial magnets.



Hull Band-Aids

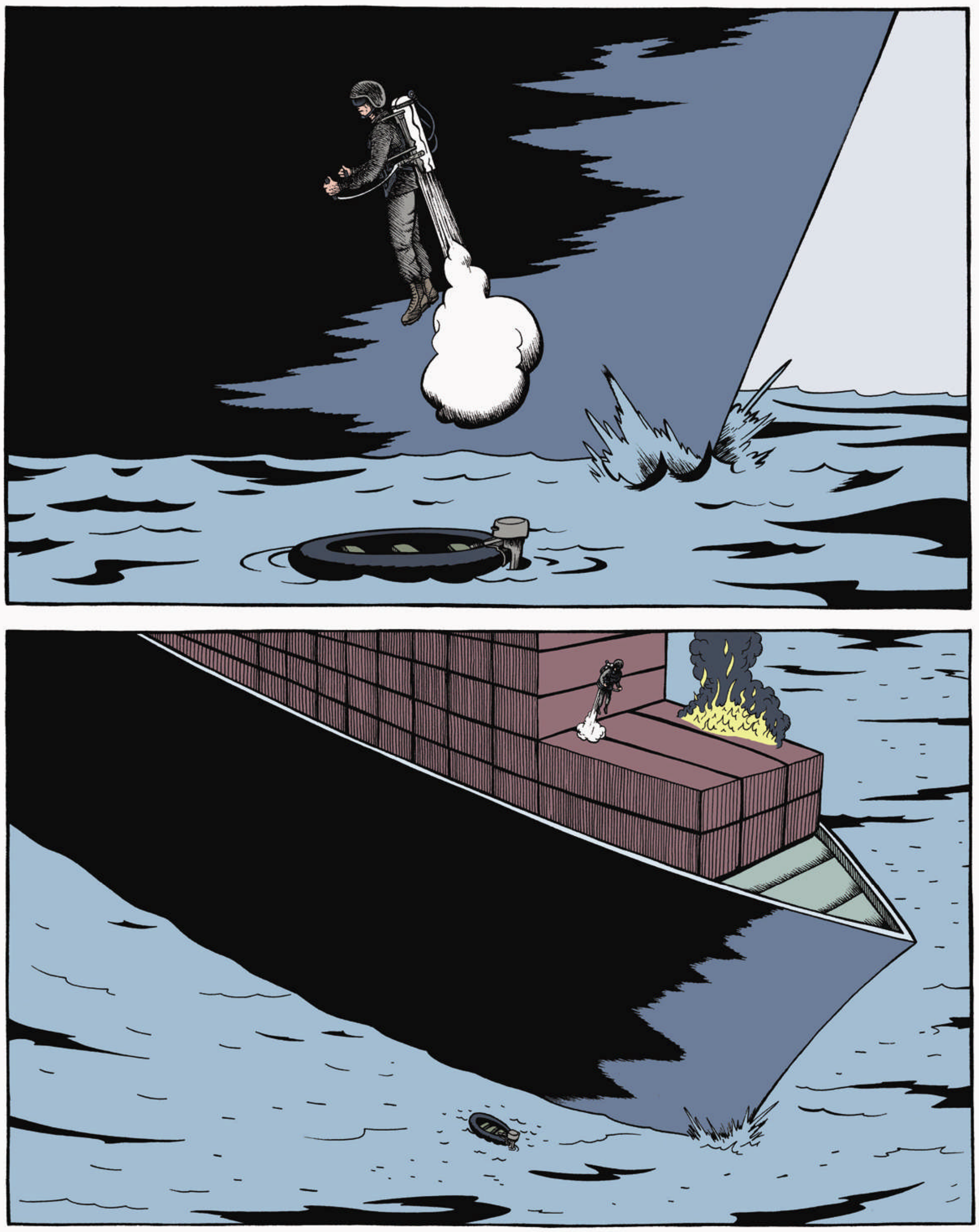
Hull Crawler

- A portable tow sled which will allow divers to transverse the exterior, including the underside, of a vessel or submarine hull to inspect, repair or maintain the ship.



Hull Crawler

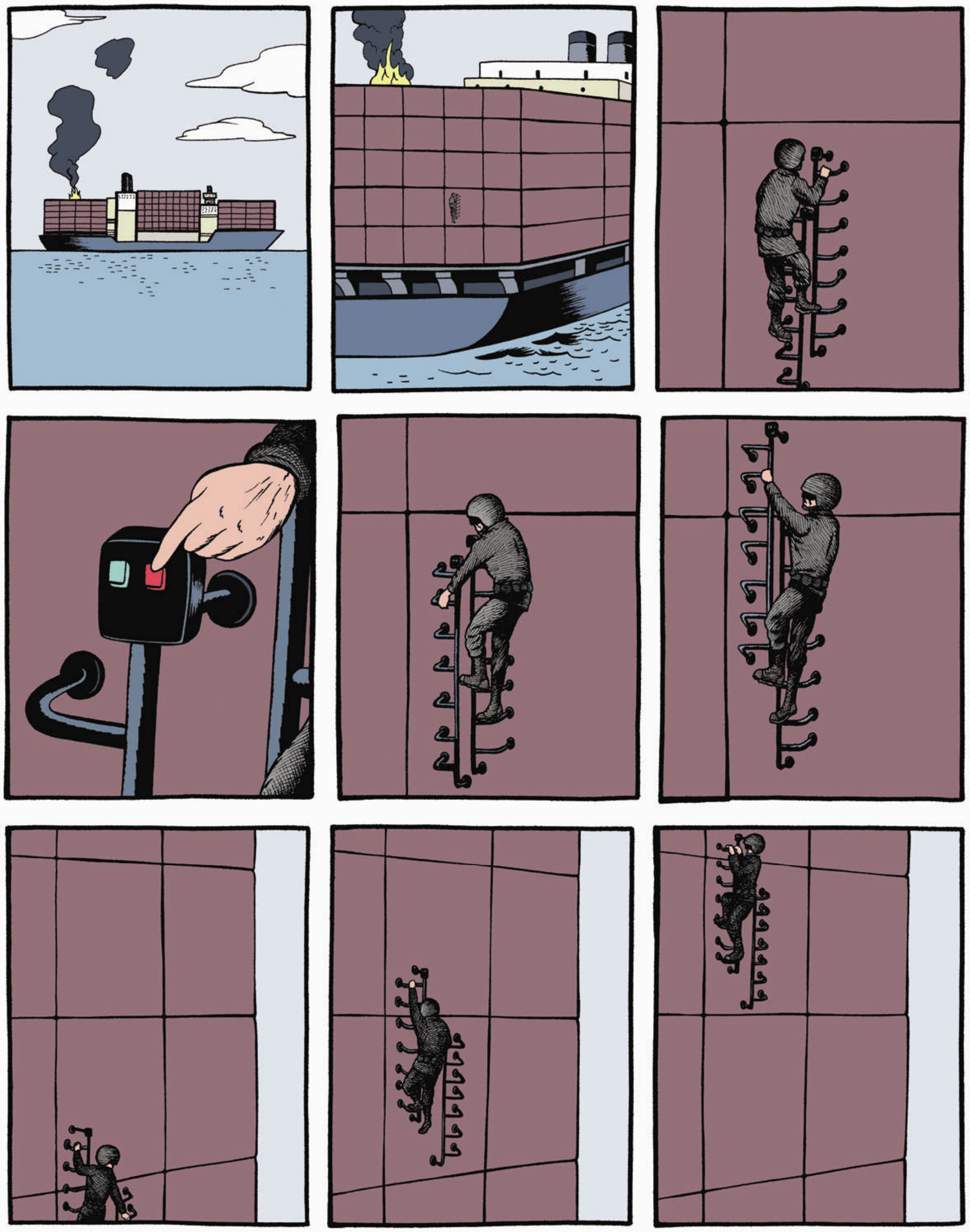
***Personal Jet Pack*.**



Jet Pack

Magnetic Climbing System

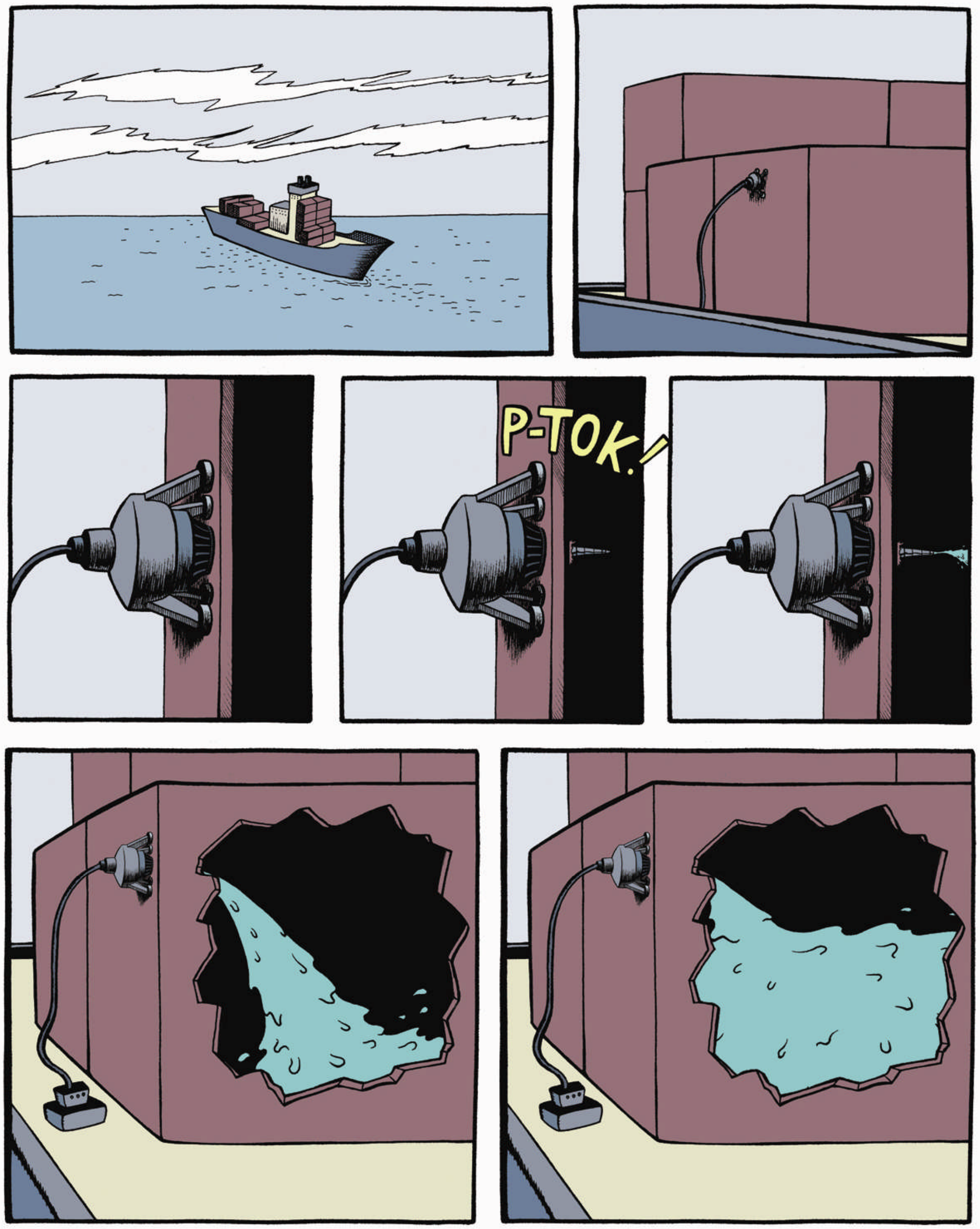
- Personnel equipment to allow inspection or maintenance teams the ability to easily and safely ascend and descend a stack of ISO containers or a hull of a vessel. *Alternate variation:* adapt for scaffolding system.



Magnetic Ladder Climber

Bee Stinger

- A highly portable device which will be able to penetrate steel (E.g. ISO container, sealed compartment on ship) creating a small hole which foam, decontamination fluids (i.e. Decon Green) or an aerosol could easily be passed via a sealer coupler. *Alternate variation:* adapted with fiber optic camera and sensor detection.



Stinger Foam

Chapter 9 – Observations and Recommendations for Program Development

Logistics Management Institute

"To address more effectively many security challenges, the Department (of Defense) is continuing to shift its emphasis from Department-centric approaches toward interagency solutions. Cooperation across the Federal Government begins in the field with the development of shared perspectives and a better understanding of each agency's role, missions and capabilities. This will complement better understanding and closer cooperation in Washington, and will extend to execution of complex operations."

- Quadrennial Defense Review Report, 2006, pages 84 - 85

"The United States must be prepared to minimize damage and expedite recovery from a terrorist attack or other Incident of National Significance that may occur in the maritime domain. Our experience dealing with the catastrophic effects of Hurricane Katrina reinforces this key point. The response to such incidents is implemented through the comprehensive National Incident Management System, governed by the National Response Plan, which coordinates public and private sector efforts and brings to bear all required assets, including defense support of civil authorities."

- National Strategy for Maritime Security, 2005, page 11

"To address more effectively many security challenges, the Department (of Defense) is continuing to shift its emphasis from Department-centric approaches toward interagency solutions. Cooperation across the Federal Government begins in the field with the development of shared perspectives and a better understanding of each agency's role, missions and capabilities. This will complement better understanding and closer cooperation in Washington, and will extend to execution of complex operations."

- Quadrennial Defense Review Report, 2006, pages 84 - 85

"The United States must be prepared to minimize damage and expedite recovery from a terrorist attack or other Incident of National Significance that may occur in the maritime domain. Our experience dealing with the catastrophic effects of Hurricane Katrina reinforces this key point. The response to such incidents is implemented through the comprehensive National Incident Management System, governed by the National Response Plan, which coordinates public and private sector efforts and brings to bear all required assets, including defense support of civil authorities."

- National Strategy for Maritime Security, 2005, page 11

Strategic Context

Capability development for scalable emergency response for maritime assets underpins the cultural mindset shift that the Quadrennial Defense Review (QDR) advocates for DoD, and that the National Strategy for Maritime Security (NSMS) advocates for the Department of Homeland Security (DHS) and the other National Security stakeholder organizations. Our current and future strategic environments, as assessed in the National Security, Defense and Maritime Security Strategies compels the development of truly transformational capabilities to meet likely challenges to our National interests head-on. Rapidly developing and fielding a Scalable, Maritime, Emergency Response System is just such a transformational capability and is directly in line with strategic guidance. Successfully developing and fielding this capability requires an innovative approach and a blending of resources, talent and processes among many stakeholder organizations. This paper explores options among myriad stakeholders, provides a high level discussion of key stakeholder equities, and recommends a way ahead for program development.

> *"Over 95 percent of U.S. international trade is transported by water, thus, the safety and economic security of the United States depends in large part on the secure use of the world's seaports and waterways. A successful attack on a major seaport could potentially result in a dramatic slowdown in the international supply chain with impacts in the billions of dollars. Therefore, the United States and its trading partners, have a common interest to facilitate maritime commerce and to protect against maritime-related terrorist, criminal, or other hostile acts".*
>
> *- Government Accountability Office (GAO) Report 08-672, Maritime Security, June 2008, page 1*

While accurate, this GAO observation is much too narrow in its focus. The ramifications of a successful attack should not be limited to "A successful attack on a major seaport", but should also include attacks on other maritime assets. As we saw with the attacks on September 11th, 2001, a successful attack on one or more commercial conveyances provides exponentially intensified initial effects, as well as profound second, third and fourth order effects – potentially within all four instruments of National Power (Diplomatic, Information, Military and Economic). While they comprise the first line of defense, prevention capabilities are but one aspect of a capability portfolio for the maritime domain. Consequence management and mitigation capability must also be developed and fielded.

> *"Maritime Infrastructure Recovery. Rapid recovery from an attack or similar disruption in the Maritime Domain is critical to the economic well-being of our Nation. A credible capability for rapid recovery will not only minimize an incident's economic impact but also serve as a deterrent. The Secretary of Homeland Security, in coordination with other appropriate officials, including the Secretaries of Defense, State, the Treasury, the Interior, Commerce, and Transportation, and in consultation with key industry stakeholders, shall be responsible for the development of recommended minimum Federal standards, where appropriate, for maritime recovery operations, and shall develop comprehensive national maritime infrastructure recovery standards and a plan, complementary to the national preparedness goals and standards required by HSPD-8."*
>
> *- National Security Presidential Directive (NSPD) 41, Homeland Security Presidential Directive (HSPD) 13, December 21, 2004, pages 7 and 8*

Stakeholder Equities

> *"In many instances each layer of maritime security is the responsibility of a different agency with multiple jurisdictions and functions. Integrating these disparate maritime security layers requires a clear delineation of roles and responsibilities and can not be achieved through cooperation alone. In particular, to achieve unity of effort and operational effectiveness, maritime security forces from both the U.S. Armed Forces and law enforcement agencies must have the capability and authority to operate in mutually supporting and complementary roles against the spectrum of expected security threats. These security forces must have a high degree of interoperability, reinforced by joint, interagency, international training and exercises to ensure a high rate of readiness, and supported by compatible communications and, where appropriate, common doctrine and equipment.".*
>
> *- National Strategy for Maritime Security, 2005, page 22*

Unity of effort can be achieved, but it will take considerable focus among myriad stakeholders taking into account their individual equities, but in the context of the mission to field and execute the capability.

Department of Homeland Security (FEMA, USCG, TSA)

Helps set National Policy; plans and implements National Strategy for homeland security; responsible for the National Maritime Infrastructure Recovery Plan; Homeland Security Council representative co-chairs (with representative from the National Security Council) the Maritime Security Policy Coordinating Committee

> *"The Maritime Security Policy Coordinating Committee (MSPCC) is hereby established, consistent with NSPD-1 and HSPD-1. The MSPCC, in consultation with the relevant regional and functional policy coordinating committees of the Federal Government, and without exercising operational oversight, shall act as the primary forum for interagency coordination of the implementation of this directive. As part of that effort, the MSPCC shall review existing interagency practices, coordination, and execution of U.S. policies and strategies relating to maritime security, and shall recommend specific improvements to all of them as warranted. The MSPCC shall provide analysis of new U.S. policies, strategies, and initiatives relating to maritime security for consideration by the Deputies and Principals Committees of the NSC and the HSC, and subsequently by the NSC and the HSC, and shall ensure ongoing coordination and implementation of such policies, strategies, and initiatives."*
>
> *- NSPD 41, HSPD 13, page 3*

"Although numerous entities are responsible for security in the maritime domain within the United States, the federal government has primary responsibility and shares this role with numerous other stakeholders in the state, local, and private sectors. For example, DHS—with its component agency, the U.S. Coast Guard, acting as executive agent—has the lead role in maritime homeland security Department of Defense…"

- GAO Report, 08-672, Maritime Security, June 2008, page 9

Department of Transportation (MARAD, PHMSA)

Develop transportation policies and programs that contribute to providing fast, safe, efficient, and convenient transportation at the lowest cost while supporting the national objectives of general welfare, economic growth and stability, and the security of the United States

USNORTHCOM

Combatant Command providing military support to civil operations; responsible for developing plans for homeland defense; executes a Joint Exercise Program; provides military subject matter expertise

Department of Justice (FBI, Bureau of Alcohol, Tobacco, Firearms and Explosives)

Law enforcement; potential lead agency at the outset of an incident/attack for investigative purposes; provides legal/law enforcement subject matter expertise

Central Intelligence Agency

Collecting intelligence from successful attacks/incidents in the maritime domain; subject matter expertise

Department of State

Vested interest in multi-national coordination and information sharing for attacks/incidents in the maritime domain; provides subject matter expertise

Department of Health and Human Services (Center for Disease Control, Food and Drug Administration)

Vested interest in health consequence mitigation resulting from a successful attack or maritime incident; provides subject matter expertise

Department of Agriculture

Vested interest in food-borne incidents; provides subject matter expertise

Department of Commerce (Bureau of Industry and Security, National Oceanic and Atmospheric Administration)

Vested interest in mitigating economic impact of attacks/incidents; provides subject matter expertise

Congress

Source of funding; oversight, constituencies for production of materiel solutions for overcoming capability gaps

National Defense Transportation Association (NDTA)

A non-profit, non-political professional association, for those employed in the global travel, transportation and distribution system and related industries and agencies; NDTA's goal is to maximize our contribution to National Security and the Economic Growth of the US; NDTA provides open forums linking the Armed Forces, Government departments and Industry for discussing critical National transportation issues; NDTA brings stakeholders together in several committees, including a Sealift Committee; provides maritime domain network/access and subject matter expertise

Commercial maritime companies

Partners in maritime situational awareness; security policy and process stakeholders; economic vested interest in an uninterrupted supply chain and unfettered access to the global commons; provides subject matter expertise

Recommendation

Recommend pursuing the Scalable Emergency Response System for Oceangoing (and Ocean-based) Assets as a Joint Capability Technology Demonstration (JCTD) candidate. The Deputy Under Secretary of Defense for Advanced Systems and Concepts (DUSD[AS&C]) administers the JCTD program to improve turnaround time from operational problem identification to operational capability. The JCTD process is outlined in specific detail through Practical Operating Guidelines.[408]

---

[408] More complete descriptions, templates, guidelines, instructions, points of contact, etc. can be found at *http://www.acq.osd.mil/jctd/whatsnew.htm*. In the navigation pane, click on Guidelines.

Rationale for a Scalable Emergency Response System for Maritime Assets JCTD

Three principle drivers exist.

- According to the National Research Council, the Navy has largely focused on contamination prevention at the expense of decontamination.[409]
- At the same time, the US Department of Transportation has documented more than 221 maritime incidents involving hazardous materials within the last ten years.[410]
- These situations, coupled with WMD proliferation and astute and dynamic adversaries (states, terrorists and criminals/pirates), who are committed to exploiting gaps in U.S. capabilities and vulnerabilities within our instruments of National power (Diplomatic, Information, Military and Economic), underscores the need for a robust, rapidly deployable, global consequence management and mitigation capability.

The envisioned capability would provide rapid, robust response options to chemical, biological, radiological, and nuclear (CBRN) accidents and attacks on U.S. warships, commercial vessels, offshore energy production infrastructure, seabases, isolated PREPO sites, and any other offshore conveyance, platform or infrastructures vital to U.S. interests or national security. The concept for the feasibility and design of a scalable emergency response system for oceangoing assets, using twenty-foot equivalent (TEU) shipping containers, is contained in the *Report on System Concept: Emergency Response Decontamination System*, August 2008. This report was prepared by the Ablaze Development Corporation for the Office of Naval Research (Contract No. N00014-06-C-0599). The report forms the basis, and provides the rationale necessary to engage in a proof of concept made available and led by the DoD through the JCTD process.

Sponsorship, Need, Nomination, and Socialization

> *"While defending the homeland in depth, the Department (of Defense) must also maintain the capacity to support civil authorities in times of national emergency such as in the wake of catastrophic natural and man-made disasters. The Department will continue to maintain consequence management capabilities and plan for their use to support government agencies. Effective execution of such assistance, especially amid simultaneous, multi-jurisdictional disasters, requires ever-closer working relationships with other departments and agencies, and at all levels of government. To help develop and cultivate these working*

[409] NRC-Naval Studies Board 2004

[410] Hazardous Materials Information System, U.S. Department of Transportation Table: Incidents By Mode and Incident Year http://hazmat.dot.gov/pubs/inc/data/tenyr.pdf (as of 3/2/2007)

relationships, the Department will continue to support the Department of Homeland Security (DHS), which is responsible for coordinating the Federal response to disasters. DoD must also reach out to non-governmental agencies and private sector entities that play a role in disaster response and recovery."

- *National Defense Strategy (NDS), June 2008, page 7*

Sponsorship

Interest and involvement in a subject as broad as a scalable emergency response system for maritime assets cuts across many agencies and activities. However, in the interest of pursuing a JCTD to demonstrate proof of concept, the following are suggested for sponsorship roles:

- USNORTHCOM – COCOM Sponsor
- USPACOM – Collateral Sponsor
- US Navy – Service Lead
- Office of Naval Research - Collateral Service Lead
- US Air Force – Collateral Service Lead
- Department of Homeland Security/US Coast Guard – Interagency Sponsor

Possible Collateral Sponsors:

- Department of State
- Department of Justice (FBI)
- Department of Health and Human Services (CDC, FDA)
- Department of Commerce
- Department of Agriculture
- Department of Transportation (MARAD, PHMSA)
- National Defense Transportation Association
- Commercial Maritime Companies

Need, Nomination, and Socialization

The process of constructing a potential JCTD candidate begins with a Combatant Commander preliminarily defining and confirming that a joint, coalition, or Interagency operational problem, or desired capability, exists. In the instance of a scalable emergency response system for maritime assets, it is recommended that the Chief of Naval Operations (N3/5, N4), and the Office of Naval Research, provide to the Director, Joint Staff, the findings, results, and recommendations contained in the ONR *Report on System Concept: Emergency Response Decontamination System*. The objective is to seek, through the Joint Staff, an avenue for USNORTHCOM to become the sponsoring Combatant Command for a scalable emergency response system for maritime assets JCTD program. A possible avenue to seek interagency involvement and cooperation is through the Under Secretary of Defense, Acquisition, Technology, and Logistics, to the Deputy Secretary of Defense, to the intended sponsoring Interagency Deputy Secretary. Socialization of this concept beyond the DoD will be critical to gaining broad acceptance from other USG agencies and activities, and perhaps U.S. allies.

To strengthen a potential JCTD nomination, the ten key questions in Formulation Step 1 must be addressed early in the conceptual process. These questions should be a part of the socialization process inside and outside of the Department. The ten questions to be affirmed are:

- Does the candidate address the COCOM's (and Interagency) needs?
- Is a significant Joint capability or operational advantage gained?
- Does the candidate clearly state and attain a goal or outcome?
- Have risks and costs been fully and frankly analyzed?
- Have all other doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF) means been fully explored?
- Is there an exit strategy to avoid endless development?
- Have consequences of inaction been fully considered?
- Can support be garnered from the Services and Congress?
- Are experienced people available to execute the effort?
- Can results be operationally demonstrated to JCTD champions?

Recommended way ahead

- Continue Concept Refinement; Finalize as a Scalable Emergency Response System for Maritime Assets

For the purposes of this directive, "Maritime Domain" means all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, and vessels and other conveyances.

- NSPD 41, HSPD 13, page 2

- Develop a Capability Briefing and field a briefing team for the Concept: Scalable Emergency Response System for Maritime Assets

- Socialize and schedule office calls/briefings to stakeholders to garner input/ascertain potential resource commitments; target MSPCC members and/or key staff.

- Lobby for scenario/capability inclusion in DHS, NORTHCOM, JFCOM, Navy, USCG and other agencies' exercise programs

"The standards and plan also shall describe a maritime infrastructure recovery exercise program consistent with the National Exercise Program administered by the Department of Homeland Security. The program shall address coordination with State, local, and private sector partners, and cooperation with foreign governments and international entities as appropriate."

- *National Security Presidential Directive (NSPD) 41, Homeland Security Presidential Directive (HSPD) 13, December 21, 2004, page 8*

- Nominate the capability as a JCTD (market as a truly transformational, pioneering, Joint, *Interagency, Multinational* Capability Technology Demonstration)

- Upon completion of the JCTD, possible procurement/fielding options include:

    1) Transition to a Joint (/Interagency/Multinational) Program Office

    2) Transition to Service-led program with agency resource application

- Leverage, develop and coordinate Scalable Emergency Response System for Maritime Assets processes with pre-existing stakeholder processes, policy, doctrine and plans.

Other considerations for global agility

- Riverine operations (barge, JHSV, hovercraft-based operations to incidents adjacent to inland cities and ports)

- Trailer-mounted configuration for transport and ground-based, interconnected operations allowing for multi-modal transportation of the capability (including precision aerial delivery)

Final Thoughts

> *"In another case, while the national strategy references the National Incident Management System and the National Response Plan under the strategic objective to Minimize Damage and Expedite Recovery, it does not identify which agency is to coordinate and lead such a recovery."*
>
> *- GAO Report 08-672, Maritime Security, June 2008, page 14*

The above GAO report finding is indicative of optimal conditions for championing this capability with appropriate stakeholders, but we must move quickly if we are to minimize current vulnerabilities and reduce risks associated with maritime incidents and attacks – before we find ourselves in a learning-by-doing disaster response/consequence mitigation operation. Often, by default and due to service-culture, the military finds itself assuming the lead in situations where no lead agency has been identified. Keys to success in the near term include finding the right representatives in the stakeholder organizations and initiating the dialog about this capability.