U.S. Coast Guard Research and Development Center
1082 Shennecossett Road, Groton, CT 06340-6048

INTERNAL R&D PROGRAM WORKING DOCUMENT

The strategic plan will be used as the basis for future R&D efforts related to HAZMAT response.

Oil and Hazardous Materials Spill Response Technology Development

Strategic Plan

October 2007

(Budget Estimates Removed May 2012)

1. Report No. CG-D-07-12	**2. Government Accession Number**	**3. Recipient's Catalog No.**
4. Title and Subtitle OIL AND HAZARDOUS MATERIALS SPILL RESPONSE TECHNOLOGY DEVELOPMENT, STRATEGIC PLAN		**5. Report Date** May 2012 **6. Performing Organization Code** Project 4140
7. Author(s) Mark VanHaverbeke		**8. Performing Organization Report No.** R&DC 785
9. Performing Organization Name and Address U.S. Coast Guard Research and Development Center 1 Chelsea Street New London, CT 06320		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Organization Name and Address U.S. Department of Homeland Security United States Coast Guard Washington, DC 20593-0001		**13. Type of Report & Period Covered** **14. Sponsoring Agency Code** Commandant (CG-533) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's technical point of contact is Mr. Mark VanHaverbeke, (860) 271-2754, Mark.G.VanHaverbeke@uscg.mil.

16. Abstract (MAXIMUM 200 WORDS)

A strategic plan to guide the investment of R&D funds for spill response has been developed. The plan is based on a review of past studies and analysis as well as a systems analysis of the current spill response situation. Areas for future efforts are prioritized based on U.S. Coast Guard and international investment considerations and risks and options for various investment amounts are provided. The plan also recommends that a similar analysis of prevention efforts should be carried out in the future.

17. Key Words oil, hazardous material, oil spill, pollution, response, systems analysis, technology investment, cost effectiveness.	**18. Distribution Statement** **Distribution Statement A:** Approved for public release; distribution is unlimited.

19. Security Class (This Report) Unclas/Public	**20. Security Class (This Page)** Unclas/Public	**21. No of Pages** 44	**22. Price**

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

EXECUTIVE SUMMARY

Tens of millions of U.S. Coast Guard (CG) Research and Development (R&D) funds have been invested in spill response over a period just short of four decades. Past R&D efforts have included spill detection, containment, and countermeasures in a variety of environments. Past efforts also included spill prevention, most notably crew endurance and tank ship design. The amount of oil spilled annually in the U.S. has been reduced dramatically since the passage of the Oil Pollution Act of 1990 introduced major changes in tanker design and significantly increased the liability for spillers. At the same time, significant improvements have been made in our ability to respond to an oil spill, but our ability to minimize the impact of significant spills is still lacking. If the EXXON VALDEZ oil spill were to occur today, the results would still be devastating.

This strategic plan focuses on oil and hazardous material (HAZMAT) spill response, a subset of the much larger program area of Pollution Prevention and Response, providing an investment plan for the next five to seven years. Continued investment by the CG is necessary in order to address the gap in spill response capability from an operational perspective. To make the most of limited funding we need to identify the critical investment areas out of the many opportunities. Significant investment has been made in the past in spill prevention, e.g., crew endurance, and future planning efforts should continue to include spill prevention.

With respect to HAZMAT, while the CG is the pre-designated Federal On-Scene Coordinator (FOSC) for the coastal zone, the response posture for all CG personnel other than members of the National Strike Force (NSF) is one of withdraw, monitor, and coordinate while trained HAZMAT teams conduct site entry. On the other hand, the NSF is among the elite nationally in HAZMAT response, being called in for such incidents as the Rayburn House Office Building anthrax contamination. In general terms, the FOSC needs information that supports the management of a HAZMAT incident that poses an acute and potentially rapidly changing public health and safety situation. The NSF normally arrives on scene after the initial emergency stage and needs the capability to assess and respond to a situation that is more static.

In developing this plan, a systems analysis of oil and HAZMAT spill response was conducted in an effort to identify leverage points in the spill response system which might provide substantial improvement in system performance. Past spills were examined for lessons learned, what capability gaps were identified, spill trends, the changing threat, and less tangible factors such as the potential political outfall from certain spill scenarios. The investment issue was also examined from several views: historical, political, and emerging threats. Unremarkably, no matter which view the problem of oil spills is considered through, the focus and investment priority remains the same: given that an incident has occurred, the oil must be found, contained, recovered and disposed of properly. Improvements are required in each of these steps for both floating and non-floating oils and in all environments, including ice. For HAZMAT the analysis was restricted to detection and assessment. For both the initial emergency and more managed response phases, technological improvements are needed in the ability to identify and track releases.

The following summarizes the more significant investments recommended by this strategic plan. In addition to the views mentioned in the previous paragraph, the investment considerations include other factors such as the need for specific CG Research and Development Center (RDC) resource investment and the R&D risk. For example, oil-in-ice research, while needed, is not recommended because there is already significant investment being made by other government agencies and industry, both in the U.S. and Europe.

Significant CG RDC Investment Areas:

Sinking oil: the RDC should continue the effort to identify, collect, and recover sinking oil. There is no other effort focused on these aspects in the U.S.

Airborne Remote Sensing: an economical platform carrying visual or other sensors linked to an oil recovery vessel would significantly improve efficiency.

Computer-Aided Management of Emergency Operation (CAMEO): continue development support in order to meet needs of the CG response community:

Drum contents identification: this is a chronic, time-consuming and expensive problem for the field.

Oil/water separation operating guide: Oil/water separators for spill response are constructed on an ad hoc basis and frequently undersized or otherwise unsuitable for the operating conditions.

Treatment of debris in remote areas: Moving the treatment facility to the debris (including recovered oil) may be far more economical than moving the debris to the treatment facility or landfill and may address issues relating to oil recovery in remote areas.

The plan itself includes time-phased investments based on three notional annual funding levels. The plan goes beyond addressing the expenditure of CG R&D funds and provides recommendations on customer outreach, partnership, and using the weight provided by the CG's responsibility as the FOSC for the coastal zone to leverage the research efforts of other organizations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ADAPTS	Air-deliverable anti-pollution transfer system
AE	Alcohol ethoxylates
ALOHA	Areal Location of Hazardous Atmospheres
AOSS	Airborne oil spill surveillance system
BAA	Broad Agency Announcement
BOSCA	British Oil Spill Control Association
BTEX	Benzene, toluene, ethylbenzene, and xylene
CAMEO	Computer-Aided Management of Emergency Operation
CEDRE	Centre de Documentation de Recherche et d'Expérimentation sur les pollutions accidentelles des eaux/Centre for Research into Accidental Pollution of the Seas
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CG	U.S. Coast Guard
CRRC	Coastal Response Research Center
EPA	Environmental Protection Agency
ERT	Environmental Response Team
FDSS	Fast-delivery sled system
FEMA	Federal Emergency Management Agency
FOSC	Federal On-Scene Coordinator
FWPCA	Federal Water Pollution Control Act of 1972
HAZMAT	hazardous material
IMarEST	Institute of Marine Engineering, Science and Technology, (United Kingdom)
IMO	International Maritime Organization
IPIECA	International Petroleum Industry Environmental Conservation Association
ISO	International Organization for Standards
ITOPF	Independent Tanker Owners' Pollution Federation Limited
MEA	monoethanolamine
MEPC	Marine Environment Protection Committee (of IMO)
MISLE	Marine Information for Safety and Law Enforcement
MMS	U.S. Minerals Management Service
MOE	Measure of Effectiveness
MOU	Memorandum of Understanding
NCP	National Contingency Plan
NPFC	National Pollution Fund Center
NOAA	National Oceanic Atmospheric Administration
NOSCA	Norwegian Oil Spill Control Association
NRDA	Natural Resource Damage Assessment
NRT	National Response Team
NSF	National Strike Force
OPA 90	Oil Pollution Act of 1990
OPRC	Oil Prevention, Response and Cooperation
OR&R	Office of Response and Restoration

OSC	On-Scene Coordinator
OSLTF	Oil Spill Liability Trust Fund
OSRO	Oil Spill Removal Organization
OWOCRS	Open water oil containment and recovery system
PAH	Polycyclic Aromatic Hydrocarbons
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
RDC	Research and Development Center
RP	Responsible Party
RRT	Regional Response Team
SAR	Search and Rescue
TIC	Toxic Industrial Chemical
TIM	Toxic Industrial Material
T/V	Tank Vessel
UNH	University of New Hampshire
USCG	U.S. Coast Guard
VHF	Very High Frequency
VOC	Volatile Organic Compound
VOSS	Vessel of Opportunity Skimming System
VSORS	Vessel submerged oil recovery system
WMD	Weapons of Mass Destruction
WX	Weather

1.0 BACKGROUND

1.1 Historic Perspective

The U.S. Coast Guard's (CG) "Spill Research and Development Program" has been underway for almost four decades. While the majority of the efforts have focused on oil spill response, hazardous materials response and spill prevention have also been investigated. The initial oil spill R&D efforts were triggered by two major oil spills: the 1968 TORREY CANYON grounding off the coast of England and the 1969 well blowout off Santa Barbara, California. During the early and mid-1970s, initial efforts included development of the airborne oil spill surveillance system (AOSS), the air-deliverable anti-pollution transfer system (ADAPTS) for removing oil from damaged tankers, the fast-delivery sled system (FDSS) for rapidly transporting equipment to the spill, and the open water oil containment and recovery system (OWOCRS) for removing oil from the water in offshore environments. These systems were the first of their kind as the CG demonstrated world leadership in developing capabilities that had not previously existed.

The R&D program continued throughout the late 1970s and 1980s, expanding to address spill response challenges in offshore environments such as the extreme weather conditions encountered during the sinking of tanker ARGO MERCHANT off Nantucket in December 1976. During that time, CG R&D implemented a program to upgrade vessel damage assessment and offloading technology and further develop and test oil spill containment and recovery equipment. In addition, oil exploration and development activities along the coast of Alaska, particularly in the Beaufort Sea, pointed out the need for developing techniques applicable to ice-infested waters. During the 1980s a wide variety of projects were pursued for Arctic response: development of systems and techniques for removing oil from ice-infested waters, technologies for detecting and mapping oil under ice, computer models for predicting the behavior and movement of oil spilled in the Arctic, and environmental atlases plus comprehensive field guides to support strategy development and response implementation.

In the mid-1980s, priority shifted to other demanding CG mission areas. The R&D oil spill program was scaled back, focused on assessing and documenting existing technology and providing the On-Scene Coordinator (OSC) with information and decision tools to effectively manage spill response.

On March 24, 1989, the EXXON VALDEZ ran aground on Bligh Reef in Prince William Sound producing the largest oil spill in U.S. history. Several reports analyzed the EXXON VALDEZ spill and called for upgrades in oil spill response strategies and technology. Subsequently, Title VII of the Oil Pollution Act of 1990 (OPA 90) established the thirteen-member Interagency Coordinating Committee on Oil Pollution Research (the Committee). The Committee was charged with coordinating a comprehensive program of research, technology development, and demonstration among federal agencies in cooperation with industry, universities, research institutions, state governments and other countries. The Committee last published the Interagency Oil Pollution Research and Technology Plan (http://www.uscg.mil/hq/g-m/nmc/gendoc/coop/coop.htm) in 1997. The plan used a systems approach as a basis, including a qualitative assessment of oil production and transportation system spill risks. The system definition was very broad but not developed in depth.

Concurrently, the CG Research and Development Center (RDC) developed and implemented an oil spill R&D strategy for the 1990s. Major advancements were made in spill response planning and management, spill surveillance, vessel salvage, onboard containment, cleanup, and alternative countermeasures. Details on the efforts performed since 1990 are contained in U.S. Coast Guard Oil spill Research & Development Program, A Decade of Achievement. (http://www.rdc.uscg.gov/Reports/2003/CGD0703Report.pdf) The report shows that for an investment of approximately $20M in CG R&D program in the 1990s, a return of up to one to two billion dollars could be realized over the next decade, subject to the number and nature of spills.

The 1990s R&D strategy and plan continued into the 21st century with further refocusing as performance gaps were identified. Oil spill-related projects addressing in situ burning and fast-water containment were completed in 2003. Additionally, research was conducted in the related field of hazardous materials (HAZMAT). Projects included a response manual for combating floating HAZMAT, evaluation of techniques to test protective clothing, an analysis of the causes of chemical spills between 1970 and 1995, and compiling a history of CG HAZMAT management.

After September 11, 2001, the spill response R&D focus was broadened to include response management in the event of an intentional release of HAZMAT. Traditionally, spills have been accidental in nature, but it is conceivable that they could be part of, or the result of, terrorist activity. Under the National Oil and Hazardous Substance Pollution Contingency Plan (referred to as the NCP) the CG, as the FOSC for the coastal zone, is responsible for responding to a wide array of hazards, including chemical, biological, and radiological materials. Many CG field units were outfitted in the 1970's to respond to spills requiring the highest level of personal protection equipment (Level A or "moon suits"), but that equipment was removed from the field in the early 1980's as it was recognized that field units could not sustain the level of training and readiness required to ensure safe operations in a contaminated environment. Instead, field units were required to maintain a Level D or "non-entry" posture. At the same time, the passage of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund), led to an NCP revision to address prevention, preparedness and response planning for an expanded list of hazardous substances. CERCLA required development of Local Emergency Planning Committees which supported training of community-based HAZMAT responders, generally the local fire department. The FOSC works with these local responders to prepare for a marine event with the goal of stabilizing the situation until special forces (e.g., NSF teams) can arrive.

1.2 Current Situation

While the number and volume of spills have declined in recent years, they still continue to occur at a significant rate. Post-9/11 data show a drop in the number of spills recorded in the Marine Information for Safety and Law Enforcement (MISLE) data system, from over 8000 per year to 4000. This has been attributed to numerous small spills not being recorded in MISLE because CG resources did not respond to spills of less than 100 gallons in order to focus resources elsewhere. These many small spills represent only a small fraction of the total volume of oil spilled per year, which remained near one million gallons over the same period. (Pollution Incidents In and Around U.S. Waters, http://www.uscg.mil/hq/g%2dm/nmc/response/stats/aa.htm). While the number and volume of spills are significant, the decline from just a decade ago has reduced public exposure and had a negative impact on the response community's hands-on experience. To put the decline in large spills into perspective, Hurricane Katrina in 2005 caused spills from a wide variety of sources including vessels, pipelines, shoreside storage facilities, and oil platforms, in a total quantity of over 8 million gallons including four spills of a million gallons or more each. (http://www.laseagrant.org/hurricane/archive/ports.htm.) Before Hurricane Katrina, the last spill of over one million gallons in U.S. waters occurred in 1990 while the decade between 1980 and 1990 saw four years in which over ten million gallons were spilled each year.

The decline in significant spills has resulted in a decline in the training and qualification of spill responders. During the workshops conducted in support of this project it was repeatedly stated that many people who were involved in response a decade ago have moved on due to a lack of steady work or a desire for less strenuous work as they age. This degradation of the workforce skill level comes on top of a response system which has been largely unchallenged in the U.S. in over a decade by a spill of national interest. As a number of spills have shown, our ability to minimize the impact of spills to the satisfaction of the public is far less than it needs to be in open waters and in all but the most forgiving inshore conditions.

During the initial planning effort for the project, the RDC Technical Director observed that, in the end, the results of major oil spills are still the same in spite of all the improvements over the years. He proposed that we undertake a systems analysis of spill response in an effort to identify "leverage points" which would allow us to significantly improve the end result of a major spill. The results of that analysis are discussed later in this document.

HAZMAT spills involving CG response are less frequent and for the most part have been handled safely under the non-entry guidelines for field units. On occasion, responders have entered the "hot zone" inadvertently (the area where entry is not safe without appropriate protective equipment). A potentially more significant problem is the rapid detection, containment, and mitigation in quickly evolving incidents. Such incidents have been problematic when they occurred, for the most part in the inland zone where the CG is not FOSC.

1.3 Future Situation

If significant spills continue to occur at the radically lower rate that has resulted from OPA 90, then the reduced response opportunities will continue to erode the spill-specific capabilities of the national response system. Included in this capability erosion are the CG's own skills, in part due to focus on other mission areas and the suspension of CG response to some minor spills. The response industry will continue to see a decline in training and capability as experienced responders retire or move on to more steady or less physically demanding employment. Training alone has not proven to be sufficient to make up for the lack of experience, perhaps because it lacks the scale or complexity of an actual response, or because it doesn't hone the judgment that comes with experience.

The threat of a major spill will continue to exist in spite of migration to all double-hulled tank vessels and increased industry liability. As imports rise, more oil will be transported by vessel. The Annual Energy Outlook by the Energy Information Administration states, "Total consumption of liquid fuels and other petroleum products is projected to grow from 20.7 million barrels per day [one barrel = 42 gallons] in 2005 to 26.9 million barrels per day in 2030…", almost a 30 percent increase. (http://www.eia.doe.gov/oiaf/aeo/index.html) Even if the EXXON

VALDEZ had been double hulled, the magnitude of damage to the vessel still would have produced one of the largest spills in U.S. history. Further, non-tank vessels will continue to represent a significant risk. The largest U.S. spill in 2004 was of over 330,000 gallons of intermediate fuel oil and marine diesel from the dry bulk carrier SELENDANG AYU. (U.S. Coat Guard Pollution Incidents In and Around U.S. Waters A Spill/Release Compendium: 1969 – 2004, http://www.uscg.mil/hq/g-m/nmc/response/stats/aa.htm.) In addition to tank and cargo vessels, spill sources could include pipelines, offshore oil platforms, and shoreside facilities.

Emerging threats include heavy oils (as refineries improve technology and squeeze more gasoline out of crude oil, the density of the remaining residual increases), bio-diesel (which is not yet understood as a pollutant) and an increase in both marine transportation and oil exploration and production in the arctic.

1.4 Pollution Prevention and Response Program External Relations

Research related to spill response is conducted in a number of organizations besides the CG, including the National Oceanic and Atmospheric Administration (NOAA), Minerals Management Service (MMS), Environmental Protection Agency (EPA), Coastal Response Research Center (CRRC), and industry. Additionally, the Science and Technology Committee of the National Response Team (NRT) provides a forum for the NRT to fulfill its NCP-delegated responsibilities in research and development. Specifically, the NCP lists as one of the NRT's responsibilities, "Monitoring response-related research and development, testing, and evaluation activities of NRT agencies to enhance coordination, avoid duplication of effort, and facilitate research in support of response activities." (40 CFR 300.110(g)).

NOAA's Office of Response and Restoration (OR&R) has a limited budget to support the development and maintenance of various response tools and job aids for themselves and for their role as Scientific Support Coordinator and adviser to the CG FOSC. Through this effort a variety of developmental products and field guides have been produced. RDC has co-funded some development work with NOAA's computer programs (CAMEO and ALOHA) to ensure CG maritime requirements are met. A memorandum of understanding (MOU) was signed between the CG and NOAA in 2004 establishing the basis for this support.

The CRRC was established by law as a partnership between OR&R and the University of New Hampshire (UNH) in 2004. This partnership stimulates innovation in spill preparedness, response, assessment, and implementation of optimum spill recovery strategies. The primary purpose of the CRRC is to bring together the resources of a research-oriented university and the field expertise of OR&R to conduct and oversee basic and applied research, conduct outreach, and encourage strategic partnerships in spill response, assessment and restoration. For FY07 the CRRC received $1.8 million in federal funding.

The CRRC has conducted several workshops to identify research needs and priorities in specific areas such as dispersants. The reports of those workshops are posted on the CRRC website at http://www.crrc.unh.edu/workshops/index.htm. The RDC regularly participates in CRRC workshops and provides peer review for both project proposals and project reports.

Minerals Management Service (MMS) has maintained a comprehensive, long-term research program to improve oil spill response technologies for over 25 years. The major focus of the program is to improve the knowledge and technologies used for the detection, containment and cleanup of oil spills that may occur on the U. S. Outer Continental Shelf. MMS funds $500-800K in research annually through a Broad Agency Announcement (BAA). Additionally, MMS is responsible for the operation of Ohmsett, the National Oil Spill Response Test Facility. The RDC assists MMS in evaluating responses to the BAA and, on occasion, co-funds projects of particular interest to the CG.

The Environmental Protection Agency (EPA) has an R&D budget of over $500 million, but currently does not have a strong oil spill response focal point. Hazardous materials are covered, but the focus is largely on toxicity studies or long-term remediation rather than response.

Various pockets of industry and individual states (e.g., Texas, Louisiana and California) maintain response-related R&D programs. The industry R&D programs are driven by an entrepreneurial desire to develop and provide better response services, or driven by the business need of petroleum interests to improve response capability in case there is a spill. State involvement tends to be focused on those areas where oil production or transportation imposes a higher risk of a spill. Known focus areas are improved oil dispersants, monitoring dispersants, oil trajectory prediction using radar calculated surface currents, and responding to oil in ice.

1.5 Authority

The two principal authorities for the CG pollution response program are the Federal Water Pollution Control Act of 1972 (FWPCA), as amended, (including OPA 90 and codified in 33 USC 1321), and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), (42 USC 9601, et seq.). Other statutory authorities include the Outer Continental Shelf Lands Act (OCSLA), (33 USC 1331, et seq.), the Intervention on the High Seas Act, as amended (33 USC 1471-1487), and the Resource Conservation and Recovery Act (RCRA) (42 USC 6901-6907).

The FWPCA and CERCLA provide the principle authority for the National Oil and Hazardous Substance Pollution Contingency Plan (NCP) (40 CFR 300 et seq.) which guides the federal response to an incident. Under the NCP, the Federal On-Scene Coordinator (FOSC) is responsible for ensuring an immediate and effective response to a discharge or threatened discharge of oil or hazardous substance. The CG provides the FOSC for oil and hazardous substance spills in the coastal zone. The coastal zone shore-side boundary is defined regionally by agreement between the CG and EPA. The coastal zone may include substantial land areas which result in the CG FOSC responding to land-based spills such as tank farms and rail transportation.

Under OPA 90, the Responsible Party, or RP, has primary responsibility for cleanup of a discharge. While the RP is legally responsible to clean up and restore the environment to pre-spill condition, the FOSC may assume total or partial control of removal activities if the RP's identification is not known or the RP is not acting properly, the RP's removal effort is inadequate, or assuming control would prevent the discharge or alleviate the substantial threat of discharge. Whether the RP or the FOSC is in control, federally owned resources may be used to conduct portions of the response when doing so improves the effectiveness.

2.0 NEEDS ANALYSIS

The following needs analysis identifies capability gaps through a variety of views. Each view provides a different perspective of spill response research and capability needs. However, while the perspectives are different, the needs overlap indicating focal points that should be addressed.

2.1 Systems View

In order to identify gaps in response capabilities, the spill response process was modeled as a system. "Systems Thinking" involves the study of a process as it exists in its environment. A process may be a complex grouping of people and machinery with a definite objective. A system includes the inputs to the process and may include feedback and control loops. A system also includes outputs which may be integrated to result in an outcome. A simplified version of the system defined and used for this analysis is shown below. The results of the spill response systems analysis may be found in the RDC document, "Oil and Hazardous Materials Spill Response Systems Analysis- Potential Solution Analysis Report."

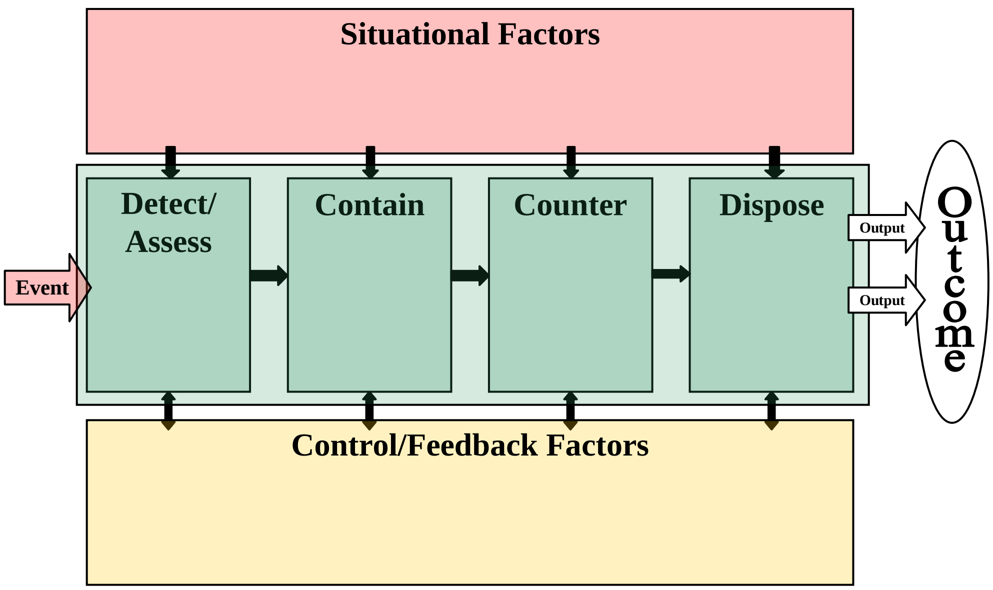

Figure 1. Generic Systems View.

In support of the systems analysis, a series of four workshops were held in the fall of 2006 in which federal, state, and industry spill response experts were asked to identify current capability gaps. Over 120 performance gaps were identified for oil spill response. Theses gaps were grouped by similarity into eleven "technology investment areas" for further analysis using a system model. (A listing of the gaps may be found in Appendix A. The complete report of the systems analysis is available through the RDC. The technology investment areas and related assumptions evaluated by the model are the following.

Spill Control Systems would limit the amount of oil released into the water in the event of an incident. Workshop participants suggested treating oil beforehand (as it is loaded aboard a vessel) or as it is released (perhaps in the outer portion of a double hull) so as to cause it to solidify within the double hull or before it spreads on the water. The model analysis assumed that the spill volume could be reduced by as much as half by the spill control system.

Oil Spill Mapping would provide a better all-weather, day/night detection capability to determine where the oil currently is located. (Current mapping systems, such as infrared and radar, have environmental limits on their capabilities.) The model analysis assumed that mapping improvements would result in improved containment and collection efficiency (but not as much as would be achieved by improved oil thickness estimation).

Oil Layer Thickness Estimation capability allows recovery resources to be directed to the heaviest oil concentrations, maximizing collection efficiency. The model analysis assumed that containment and collection efficiencies were significantly improved by better thickness estimation (more so than simply better mapping of the oil location).

Spill Trajectory Modeling improvements lead to better prediction and knowledge of the spill location, oil thickness, and other parameters that impact the efficiency of cleanup operations. The model analysis assumed that improved modeling would allow recovery efforts to extend into periods of reduced visibility and nighttime.

Command, Control, Communications and Information (C^3I) Technologies improve the ability to distribute resources more effectively and efficiently. They allow detailed knowledge of the location of all resources and the conditions at those locations, so a more agile response from all available resources is expected. C^3I improvements provide the ability to synthesize information into a common operating picture, usually including two-way communications between tactical units and between tactical units and the command center. C^3I improvements were assumed to result in an overall increase in system effectiveness.

Collection and Recovery Technologies improve collection of the product from the water or shore, removing oil from the environment, including separation of oil from water once collected. Improvements in collection and recovery would generally increase the amount of oil recovered over a given time frame and should lead to faster recovery of a certain amount of oil. Because of limitations in the model, improvements in collection and recovery were modeled by assuming an increase in the sweep rate (the rate at which an oil boom gathers oil in open water).

Containment Technologies improve the ability to divert oil or capture oil and include chemical herders and non-traditional measures. By diverting more oil to the collectors, improved effectiveness of the recovery systems is expected. Similar to the analysis of collection and recovery method improvements, the effect of containment improvements was modeled by increasing the effective sweep rate of the collection assets.

Logistics Technologies improve the response of resources, distribution of resources, and addition of more resources into the system. Improvements in logistics would speed the right containment and recovery equipment to the right location in a timely fashion, maximizing response effectiveness. As with C^3I, logistics improvements were assumed to result in an overall increase in system effectiveness.

Dispersants and In Situ Burning were not independent aspects of the final model. During modeling phase we realized that over half of the issues related to dispersants and in situ burning could be captured under the categories of C^3I or Logistics.

Training and Qualification were not independent aspects of the model but the impacts are considered to be analogous to C^3I because training and qualification touch all aspects of response.

"Other" was used for capability gaps that did not fall into one of the above categories. Other included financial management, detection of new and water soluble products, response to spills involving brine, and personnel monitoring.

The workshops also identified capability gaps related to chemical response, but that portion of the system was not analyzed to the same extent as for oil. The analysis was limited to Toxic Industrial Chemicals and Toxic Industrial Materials (TICs and TIMs) and did not include weapons of mass destruction. Recognizing that chemical response is a specialized area and very dependent upon the chemical involved, the analysis was further focused on detection and evaluation as the critical first response issues faced by the FOSC.

The potential impacts of system performance improvements are shown in the table below. (The eleventh category, "Other", was not included in the table. The table shows the improvement (the gain in percent of oil recovered) possible dependent on spill product, location, and visibility. The workshop participants considered poor visibility to be the aspect of weather which could most significantly improve response if addressed.

The system model quantified improvements in the amount of oil recovered (the study measure of effectiveness (MOE)) based on assumed efficiencies. The efficiencies were varied for location (bay and coastal scenarios), oil product (light or heavy), and visibility (clear or poor). The model assumed a ten-day response period and accounted for natural dispersion and evaporation using NOAA spill modeling tools.

Table 1. Potential Response System Performance Improvements.

		Bay Scenario				Coastal Scenario			
		Light Oil		Heavy Oil		Light Oil		Heavy Oil	
Technology Investment Area ↓	Avg. MOE[1] Gain	Poor Vis	Clear Vis	Poor Vis	Clear Vis	Poor Vis	Clear Vis	Poor Vis	Clear Vis
Spill Control Systems	235%	222%	200%	367%	250%	233%	136%	263%	210%
Oil Spill Mapping	33%	64%	14%	8%	47%	2%	48%	60%	20%
Oil Layer Thickness Estimation	52%	82%	23%	50%	86%	36%	57%	54%	24%
Spill Trajectory Modeling	99%	67%		133%		82%		113%	
Command, Control, Comms & Information	33%	64%	14%	8%	47%	2%	48%	60%	20%
Collection & Recovery	120%	78%		133%		109%		159%	
Containment	120%	78%		133%		109%		159%	
Logistics	52%	82%	23%	50%	86%	36%	57%	54%	24%
Dispersants & In Situ Burning	--	--	--	--	--	--	--	--	--
Training and Qualification	33%	64%	14%	8%	47%	2%	48%	60%	20%

Note 1: The Measure of Effectiveness (MOE) for the systems analysis was the amount of oil recovered. For example, the analysis showed that a 33% improvement in oil recovery performance could be realized by improving our ability to map the location of spilled oil.

The values listed in Table 1 in the column headed "Avg. MOE Gain" (Average measure of effectiveness gain") relate to the specific set of variable settings assumed for the associated "Technology Investment Area." Because the variable settings and assumed improvements were different for each Technology Investment Area, the MOE gains cannot be directly compared. For the systems analysis, a relative measure was employed in order to provide some indication of which technology improvements may provide the most return on investment. (Further explanation may be found in section 5.4 of the RDC document, "Oil and Hazardous Materials Spill Response Systems Analysis- Potential Solution Analysis Report.") By comparing the percentage MOE gain (percent improvement in oil recovered) to the percentage improvement required to achieve that gain (the increase in the variable used for that computer run), we get some insight into relative effectiveness. For example, in the Spill Control Systems Technology Area a 235% MOE gain is achieved by a 30% reduction in response time from the base case. In this example, a 235% MOE gain divided by a 30% variation in the base case variable yields an "improvement index" of 7.8. The improvement index in rank order for each technology area is presented in the table below. For the purpose of this study and recognizing possible uncertainty ranges with this and any potential relative cost estimates, the considered technology improvements were all viewed as within a range that constituted equal cost investments.

Table 2. Relative Cost Effectiveness Priorities for Technology Areas.

Technology Investment Areas	Ave. MOE Gain	Required Variation from the Base Case	Improvement Index	Cost Effectiveness Priority
Spill Control Systems	235%	30%	7.8	90th Percentile
Oil Layer Thickness Estimation Spill Trajectory Modeling	52% 99%	25% 50%	2.1 2.0	60th Percentile
Collection and Recovery Containment Oil Spill Mapping	120% 120% 33%	100% 100% 50%	1.2 1.2 0.7	30th Percentile
C^3I Logistics	* *	- -	- -	Undetermined

Note: * The results for the computer runs relating to C^3I and subsequently Logistics were determined to be invalid, but C^3I improvements might be equivalent to those of Mapping, and Logistics investments may parallel Oil Layer Thickness Estimation.

Not included in the above table are the categories of "Training" because it is primarily an operational issue, "Dispersant and In Situ Burning" because they did not lend themselves to analysis using the computer model and were only seen as a gap in the workshops in terms of decision making and therefore a C^3I issue, and "Other."

In summary, the computer modeling identified response system improvements (in terms of how much oil can be collected) resulting from technological improvements in each technology investment area. This enabled a determination of each technology investment area's comparative effectiveness. In addition, a measure of relative cost effectiveness was obtained. With these two basic values, relative return on investment was estimated. The relative return on investment indicated that Spill Control Systems and Oil Layer Thickness Estimation were the highest investment priority, followed by improved Collection and Recovery Methods and Containment.

An examination of candidate technologies in each of these technology investment areas indicates that conducting research to improve Spill Control Systems technologies may be very expensive and represent considerable risk based on the low level of technology readiness. Given the modest CG research budget, limited research dollars may be more effectively applied to lower ranked areas. Collection and Recovery and Containment are mature technology areas and improving the current technology by 100 percent (Required Variation from the Base Case) is not likely without a major technology breakthrough.

Several capability gaps were not directly evaluated as "technological investment areas" using the computer model but are included here because they repeatedly were brought up as gaps during the workshops and may have technological solutions. They are more fully explained in the RDC document, "Oil and Hazardous Materials Response Systems Analysis Summary."

> Night operations could theoretically double the amount of oil collected in the early days after a spill but must overcome two significant hurdles: (1) worker safety, and (2) the gross inefficiency of trying to skim oil that can't be seen in the darkness.
>
> Getting temporary storage into a location is often difficult, whether an Alaskan island or the marsh areas along salt and fresh water coasts. Getting that same storage out once loaded with recovered oil is often a nightmare, particularly if it's a bladder. Emulsified oil compounds the problems as it increases the required storage capacity and doesn't decant. Look at options for the full process related to temporary storage, from delivery to the scene to final disposal and decontamination. For example, on-scene incineration of recovered oil and debris may alleviate the need to transport full storage units, but decon issues remain. Improving emulsion breakers may reduce the volume of the waste stream.
>
> Decanting is seen as a necessary evil in order to maximize efficiency on-scene and to minimize disposal ashore, but what is allowed varies by locale, constructing an actual facility ashore or on a barge takes a lengthy amount of time, and even then the design or capacity may be inadequate. Standards (design and capacity) for decanting systems are needed and may address local environmental concerns.
>
> Chemical response discussions were focused on stand-off capabilities. The general consensus was that responders need a remote sensing capability to identify hazard type (if not the exact substance), quantity or concentration, and extent of spread without entering the hot zone. The capability is needed for both airborne hazards (emanating from either a land or water surface spill) and waterborne chemicals which may float, sink, suspend or be soluble.
>
> While the focus of this project was on spills of greater than 10,000 gallons, at workshop participants highlighted lost or abandoned drums and other containers as a significant, chronic problem in terms of a drain on resources. Responders need the capability to identify the contents of a container (drum) while still in the field, ultimately without even opening the drum.

The key system improvements recommended by the system analysis are then:

- Develop the capability to remotely measure the thickness of an oil layer.
- Improve trajectory modeling to the point that it allows recovery operations in periods of reduced visibility and at night.
- Develop an all-weather, day/night oil spill mapping capability.
- Ultimately, develop a 24-hour on-water recovery capability by automating skimming operations by adapting remote thickness measurement and improved oil spill mapping capabilities.

- Improve the handling and disposition of recovered materials through better decanting, treatment, and disposal or incineration.
- The above apply to submerged as well as floating oils.
- For HAZMAT, the fundamental issues are detection, classification, and projecting the trajectory of chemicals whether in the air, water, or a drum.

2.2 Historical View

In developing this view, a number of sources were reviewed to identify spill trends, known capability gaps, and complementary research efforts. A bibliography of significant references reviewed in developing this plan is included in Section 5.0. CG spill data show a general downward trend in the number of spills and a significant downward trend in spill volume. Additionally, a review was made of the significant spills over the past 10 years. The most prevalent issues were noted as follows:

- Locating, quantifying, tracking, and predicting the trajectory of oils, both surface and subsurface.
- Recovery of viscous oils from the shoreline.
- Recovering sinking oils.
- Logistics, particularly in remote areas, as in the SELENDANG AYU spill on the Aleutian Chain.
- Remote detection and assessment of HAZMAT releases.
- Command, control, communications, and information sharing, particularly in complex and rapidly changing situations.
- Recovery of oil from sunken wrecks in deep water.

2.3 Political View

Certain spill scenarios will invite public criticism of the response effort and particularly the CG either for failure to prepare for what some consider "the obvious" or because the response methodology is a polarizing issue (i.e., the use of dispersants). The following are three such potentially politically-charged scenarios.

- Locating, tracking, containing and removal of submerged oils. In response to the ATHOS I oil spill, the "Coast Guard and Maritime Transportation Act of 2006" (H.R. 889 [109th], Public Law No: 109-241) amended OPA 90 to include a submerged oil program. While focused on the Delaware Bay region, it required NOAA and the Coast Guard to "…establish a program to detect, monitor, and evaluate the environmental effects of submerged oil". The Act went on to require, "The Commandant of the Coast Guard, in conjunction with the [NOAA] shall conduct a demonstration project for the purpose of developing and demonstrating technologies and management practices to remove submerged oil from the Delaware River and other navigable waters." The Act authorized to be appropriated $2M per year for FY06-FY10 to fund the demonstration project. While the funds were never appropriated, the bill language is an indicator that some members of Congress consider this to be an important research area.

- Locating, tracking, containing and recovering oil in and under ice. The probability of an arctic spill is increasing as pressure builds for North Slope oil development, the melting polar ice cap increases the probability of vessels using the Northwest Passage (although economic viability is still a long way off), and recent international interest in natural resource development rights to the polar region.
- Dispersant decision making has in the past been a moot point because response organizations generally lacked the resources to dispense dispersant by air within the critical 12-24 hour time window. Pending CG regulations will require certain oil transporters to have this capability on-scene in a timely fashion. When those regulations come into effect, industry can be expected to press the use of dispersant in offshore spills. This will require the FOSC to make the decision to use or not use dispersants in a timely manner. This decision will rest in part on determining "net environmental benefit," a determination that is rife with opportunity for second-guessing and lawsuits. A standard, defensible, and timely decision process is needed.

2.4 Emerging Threats View

The emerging threats view includes both new and increasingly probable spill sources. While the threats are only minimally represented in past spills, the sense of the spill response community is that the probability in these areas is significantly increasing.

- Bio-fuels: the increased production and marine shipment of biodiesel and gasoline/ethanol mixes (such as E85) may pose significant spill threats, but they have yet to be fully evaluated. For example, biodiesel may be found to be relatively benign and assimilated into the environment, or it may present the same smothering problems as palm oil while attracting and coating shore birds. The web is replete with the statement, "Ethanol also degrades quickly in water and, therefore, poses much less risk to the environment than an oil or gasoline spill," but no source is cited. Responders are concerned that the ethanol portion of E85 may increase dissolution of the gasoline component into the water column, increasing environmental impacts.
- Sinking Oil: the improved processing of gasoline from crude oil is producing a heavier residual oil, in some cases even heavier than saltwater. When spilled, locating, tracking, and recovering sinking oils are significant capability gaps. In November of 2004, a spill of heavy Venezuelan crude oil led to the closure of a nuclear power plant because a portion of the oil sank. The capsizing of the tank barge DBL-152 thirty (30) miles off the Texas coast in November 2005 resulted in a spill of over 3 million gallons of heavy oil which sank in 50 feet of water. While some oil was recovered from depressions on the floor of the Gulf of Mexico, most of the oil slowly drifted in the bottom current. A significant effort was made to track and recover the oil between winter storms, but efficiencies were so low as to be ineffective.
- Increased arctic operations: As discussed in the Political View above, the probability of an arctic spill is increasing as pressure builds for North Slope oil development; the melting polar ice cap increases the probability of vessels using the Northwest Passage, and recent international interest in developing natural resource in the polar region.
- Deliberate HAZMAT release: HAZMAT is transported and stored in significant quantities throughout populated areas in the U.S. coastal zone. Accidental releases have

highlighted the difficulty in managing the initial emergency phase of an event. An example of the threat is the January 6, 2005, rail accident in Graniteville, South Carolina. Three tank cars carrying chlorine were ruptured, resulting in fatal injuries to eight citizens and one railroad employee, injuries to 630 people, and the evacuation of 5400 local residents. (Graniteville's population is about 7200.)

2.5 Oil Spill Liability Trust Fund (OSLTF) and Natural Resource Damage Assessment (NRDA) Views

The OSLTF and NRDA views were not fully developed but may have significant implication for future investment decisions. While not a direct driver in most spill response decisions, the CG has a vested interest in limiting expenditures from the OSLTF which result from the responsible party exceeding its limit of liability. The 2007 National Pollution Fund Center's (NPFC) "Report on Oil Pollution Liability Limits" cites 40 cases in which removal costs exceeded liability limits. Almost half (18) of the spill sources exceeding their liability limits were fishing vessels, but actual OSLTF costs were much higher for other vessel types. The NPFC has informally indicated that they are unable to identify spill cost drivers as they do not have complete records of spill response expenditures in those cases in which the responsible party assumes financial responsibility. A cursory review of those cases indicates that one common element is the spill involves heavy, viscous oils (heavy fuel oil. #6 fuel oil, intermediate fuel oil, and crude oil).

More recently the Government Accountability Office issued a report on the financial risks presented by major oil spills in U.S. waters, MARITIME TRANSPORTATION: Major Oil Spills Occur Infrequently, but Risks to the Federal Oil Spill Fund Remain (http://www.gao.gov/new.items/d071085.pdf). Using data acquired by a private contractor, the report considered 51 oil spills that have occurred since 1990 and for which the cleanup costs exceeded $1M each. The report identified the three main factors affecting the cost of spills as location, time of year, and the type of oil spilled. With respect to location, the primary factors that affect cost are remoteness (as was a factor in the SELENDANG AYU grounding in the Aleutians), proximity to shore (as with numerous inshore spills that paint the shoreline with oil before it can be contained) and proximity to economic centers (as with the ATHOS I which caused the closure of the Delaware river and the shutdown of a nuclear power plant.) Time of year factors include local economies related to resource usage (e.g., tourist beaches) and the challenges of seasonal weather, particularly winter. The type of oil may be a double-edged sword. Light oils tend to evaporate quickly but are highly toxic to marine life on those occasions when heavy weather drives the oil into the water column. Medium and heavy oils are less toxic but more difficult to recover. Spills involving heavy oils were the most prevalent among the 21 examined. Heavy oils may sink or require intensive shoreline and structural cleanup, situations which can lead to time consuming and expensive response operations.

While NRDA concerns don't play directly into the decision-making of the FOSC, they do tangentially as the "best response" would result in minimizing natural resource damage. (The CG Incident Management Handbook (COMDTPUB P3120.17) defines "Best Response" as "a successful response based on achievement of certain key success factors," which includes environmental factors among others.) The NRDA process results are very dependent upon the spill scenario, but an analysis of significant spills may identify common cost drivers that should be addressed.

3.0 STRATEGIC PLAN

The strategic plan was developed based on the preceding needs analysis, the RDC "Strategy and Business Plan 2006" (http://rdcms-iis.main.ads.uscg.mil/DNN/LinkClick.aspx?link=Strategy+Biz+Plan+FINAL+4+MAY+06.pdf&mid=612), and the Pollution Prevention and Response high-level program area objectives from the annual program review (an internal document).

3.1 Spill Response Vision

Develop the capability to efficiently overwhelm any oil spill so as to minimize the impacts on society and the environment.

3.2 Spill Response Mission

Support the CG FOSCs oil and hazardous material spill response efforts:

- Conduct applied research & development, and test & evaluation of existing and emerging oil and hazardous material spill response technologies in support of the CG's operational and regulatory oil and hazardous material pollution response programs.
- Maintain an active outreach program so as to be aware of emerging threats and changing response community priorities.
- Participate in research forums and other opportunities to shape programs to support the needs of the CG FOSC.
- Support other RDC program areas such as Weapons of Mass Destruction and Boarding Team Tools where potential exists to address common issues.

3.3 Spill Response Goals and Objectives

The goals and objectives translate the mission into actionable R&D. The goals follow the response system diagram developed as part of the analysis process. The objectives are current gaps of elements of the goal that currently hinder attainment.

Goal: Detect and assess spills of oils and hazardous material on the surface, in the water column, and on the bottom.

Objectives:

- Include spill thickness measurement and trajectory in all weather, day or night, surface and sub-surface, and in various ice conditions.
- Track the development of emerging sensor technologies.
- Make the detection and assessment capability fully sensor-based and "automated" so that it can feed information to other systems (e.g., oil skimming).
- Refine system automation to the point where operations can safely and effectively continue around the clock.
- Make the detection and assessment data usable strategically (to aid in planning the distribution of assets) and tactically (to aid in specific asset location and course).

- For chemicals, improve the capability to remotely identify a substance and track and predict the movement of the leading edge of a plume, whether water or air borne.
- For chemicals, improve the capability and process to evaluate unknown containers (drums).

Goal: Rapidly contain spills as close to the source as possible until the pollutant can be recovered, burned, or dispersed.

Objectives:

- Develop the means to divert and contain sinking and suspended oils in order to protect natural and economic resources and facilitate recovery.
- Develop the means to contain oil in various ice conditions to facilitate recovery or in situ burning.
- Monitor development of technologies that would allow the rapid solidification or jelling of oils with an ultimate objective of containing spills at the source.

Goal: Rapidly recover, burn, or disperse oil as appropriate.

Objectives:

- Develop the capability to cost-effectively recover sinking oil.
- Develop the capability to cost-effectively recover or burn in situ oil in ice.
- Develop repeatable, defensible processes to support timely response methodology decisions.
- Develop an economical capability to implement spill detection and assessment capabilities to optimize on-water recovery operations ("Airborne Remote Sensing").

Goal: Develop disposal processes for recovered oil and debris so as to minimize the impacts on society and the environment

Objectives:

- Develop improved technologies and guidelines for separation of oil, emulsion, and water.
- Develop improved emulsion breakers.
- Develop an off-the-shelf capability to treat recovered oil and debris is situ in remote locations.

Goal: Improve spill response process control and feedback factors, including C^3I and logistics, to help the field meet "Best Response" measures.

Objectives:

- Develop response training to the level that responders are "experienced" without oil being spilled into the environment. (This may include development of an environmentally benign pseudo-oil.)
- Improve spill information flow and sharing so that it is seamless and all responders have their appropriate piece of the "common operating picture".

- Remove logistics hurdles to rapid and effective spill assessment, containment, and countermeasures.

Goal: Stay current with respect to the response needs of the FOSC, developments in the response community, and the R&D efforts of others.

Objectives:

- Attend RRT and NRT meetings periodically to learn about current issues and develop contacts.
- Attend technical symposia and trade shows to learn about current developments.
- Seek opportunities to present RDC efforts in order to build support and create opportunities.

Goal: Help other organizations support the CG FOSC.

Objectives:

- Seek opportunities for coordination and partnership in R&D efforts (e.g., CRRC workshops).
- Provide advice on potential projects of others (i.e., peer review) to facilitate an understanding by others of the FOSC's needs.
- Consider small investments on the order of $20K in multi-agency projects when doing so "buys a seat at the table."

3.4 Project Ranking Process

As research needs will always exceed available funding and staff availability, a process was developed to guide the ranking of research priorities. The elements of the ranking process are:

- For each View (e.g., systems analysis, historical, political, etc.), Applicable Technology Improvement Areas (as indicated by a √ in the following table) were assigned by RDC subject matter experts. The **Count** was determined by the summation of checkmarks for each TIA. This approach gives equal weight to each view.
- An assessment of the **R&D Risk** the research area entails based on an estimate of the product maturity. The product maturity definitions are loosely based on Technology Readiness Levels (TRL) developed by the Department of Defense. Complete definitions of TRLs are presented in Appendix B. The three levels used for this plan are:

  <u>Near-Term/Current Technology</u>: Technology that is current and leading edge, or technology that is being used in other industries that may be applicable to oil spill response. This technology will be ready for full production or use in less than 2 years. Probability of success is medium-to-high. Roughly maps to Technology Readiness Levels 7-9.

  <u>Emerging Technology</u>: Technology that is in the early prototype stage that demonstrates potential usefulness for oil spill response. This technology will be ready for full production or use in 2-5 years. Probability of success is medium. Roughly maps to Technology Readiness Levels 4-6.

Future Technology: Technology which spans the range of maturity from basic research to active research and development moving towards a proof of concept. This technology will be ready for full production or use in more than 5 years. Probability of success is difficult to estimate. Roughly maps to Technology Readiness Levels 1-3.

For scoring, Near Term = 2; Emerging Technology = 1; Future Technology = 0.

- The **Phase** of the cleanup operation in which the technology improvement would come into play. Detect/Assess = 1; Control/Contain = 2; Counter = 3; Dispose = 4. In scoring the results, the phase is subtracted from 5 to emphasize technologies that apply earlier in the response cycle. Both experience and the systems analysis have shown that the earlier in the response cycle that a remedy is applied the more effective it is in altering the outcome.

The ranking of research priorities was then determined by:

Score = (Count)(R&D Risk Factor)(5 - Phase)

The scoring for each technology investment area is shown in the following tables. In Table 3, the technology investment areas are listed in the order in which they would occur (phase) in an event. In Table 4, the technology improvement areas are ordered by score.

Table 3. Technology Improvement Area Scoring.

Technology Improvement Area	Systems Analysis	Historical	Political	Emerging Threats	OSLTF/NRDA	Count	R&D Risk Factor	Phase	Score
Detect/Assess Surface Oil	√	√				2	2	1	16
Detect/Assess Sinking Oil	√	√	√	√	√	5	1	1	20
Detect/Assess Oil in Ice	√		√	√		3	1	1	12
Detect/Assess HAZMAT	√			√		2	1	1	8
Contain Sinking Oil	√	√	√	√	√	5	1	2	15
Contain Oil in Ice	√		√	√		3	1	2	9
Spill Control System	√	√			√	3	0	2	0
Recover Sinking Oil	√	√	√	√	√	5	1	3	10
Counter Surface Oil	√	√	√			3	2	3	12
Counter Oil in Ice	√		√	√		3	2	3	12
Waste Separation/Disposal	√	√				2	2	4	4
Response Process Control	√	√			√	3	1	2	9

Table 4. Technology Improvement Area Sorted by Score (High to Low).

Technology Improvement Area	Systems Analysis	Historical	Political	Emerging Threats	OSLTF/NRDA	Count	R&D Risk Factor	Phase	Score
Detect/Assess Sinking Oil	√	√	√	√	√	5	1	1	20
Detect/Assess Surface Oil	√	√				2	2	1	16
Contain Sinking Oil	√	√	√	√	√	5	1	2	15
Counter Surface Oil	√	√	√			3	2	3	12
Detect/Assess Oil in Ice	√		√	√		3	1	1	12
Counter Oil in Ice	√		√	√		3	2	3	12
Recover Sinking Oil	√	√	√	√	√	5	1	3	10
Contain Oil in Ice	√		√	√		3	1	2	9
Response Process Control	√	√			√	3	1	2	9
Detect/Assess HAZMAT	√			√		2	1	1	8
Waste Separation/Disposal	√	√				2	2	4	4
Spill Control System	√	√			√	3	0	2	0

3.5 Investment Priority Considerations

For each Technology Investment Area, consider the cost of meeting goals or objectives, the level of non-CG interest and investment, and the score from above.

- Maritime-specific: focus CG R&D funds on support of CG FOSCs, particularly on solving problems unique to the coastal zone, like tracking on-water spills.
- Discount research areas that others are heavily investing in, for example BP and Arco (now merged) committed to the State of Alaska to invest $200K per year for 10 years in oil in ice research. http://www.dec.state.ak.us/spar/ipp/docs/chartrpt01.pdf MMS is also an investor in this area and there is a significant effort in Norway.
- Emphasize areas that are under-funded, for example finding sunken oil.
- Emphasize research areas that touch capability gaps across multiple views.

Make small investments where they leverage other agency/organization efforts. The R&D Center Strategy and Business Plan states, "Continue to identify opportunities to leverage the resources of other agencies by actively engaging them in such a way that CG requirements are incorporated into their technology development initiatives."

- Cross-programmatic support: get better return on investment by working with other CG program areas with related needs (e.g., remote sensing of HAZMAT and WMD).

Table 5 provides estimates of investment costs for R&D projects aimed at closing capability gaps. The table also includes an indication of those areas in which other agencies or industry are investing. The most suitable CG investment areas, in consideration of the factors listed above, are highlighted.

The project scores and investment recommendations shown in Table 5 are the basis of the investment recommendations shown in Tables 6 through 8. The tables provide investment recommendations for FY08 through FY14 at annual funding rates of approximately 70 percent of current level of funding, the current level and 150% of the current level of funding.

The annual funding rates do not include funding for program support efforts (formerly the 9913 account), including outreach. Continued funding of program support efforts is a critical assumption in this spending plan as it allows the RDC to economically support efforts such as responding to oil in ice, a moderately high priority which requires CG visibility but which was not recommended for specific project funds because of the significant investments of other organizations.

Table 5. Recommended Technology Investments.

Technology Improvement Area	Estimated Cost of Meeting Goals/Objectives	Level of Non-CG Investment	Score
Detect/Assess Sinking Oil	Test technologies: Prototype system:	Minimal and sporadic in the U.S. where there is no well-funded sponsor with a stake in the issue. There is some level of investment in Europe where several major heavy oil incidents have occurred over the past decade.	20
Detect/Assess Surface Oil	Prototype remote system: Miniaturize remote system: Prototype Airborne Remote Sensing:	MMS and Environment Canada are investing in sensor prototype development. Industry was testing UAV. (Results unknown.)	16
Contain Sinking Oil	Test technologies: Prototype system: Suspended oils may cost double.	None Known	15
Counter Surface Oil	SMART Protocol: Dispersant Decision Making Process: Automate skimmer (requires remote sensor):	None, but MMS may be willing to co-fund. None, but MMS may be willing to co-fund.	12
Detect/Assess Oil in Ice	Prototype ground-based system: Prototype remote (air borne) system:	MMS and the North Slope oil developers are investing in this research. Sensors developed for sinking oils may be applicable with modifications.	12
Counter Oil in Ice	Mechanical recovery: prototype skimmer/technology improvements.	North Slope oil developers are investing in this research.	12
Recover Sinking Oil	Prototype technology improvements:	Some investments by specific OSROs. Most technology improvements occur in situ after a spill.	10
Contain Oil in Ice	Test technologies: Develop prototype:	North Slope oil developers are investing in this research.	9

Technology Improvement Area	Estimated Cost of Meeting Goals/Objectives	Level of Non-CG Investment	Score
	Chemical herders:		
Detect/Assess HAZMAT	Capability to track remotely in water: Capability to ID/track remotely in air: CAMEO development support: annually Prototype improved drum contents ID:	None known. Water density and turbidity make this especially challenging. Cost most probably will exceed remote detection in air. Significant investments are being made in this arena because of homeland security concerns. EPA has existing aircraft with limited systems. Cost sharing with EPA and NOAA. EPA has significant stake and may share cost.	8
Waste separation/disposal	Develop separation guide: Improve emulsion breakers: Prototype remote treatment of debris:	None known Emulsion breakers are under development.	4
Spill Control System	Millions…the idea is only at the concept stage and must overcome significant physical and chemical limitations.	Gelling agents such as the product "CI Agent" are being developed independently, but currently require a volume of agent roughly equivalent to that of the oil being gelled. Nanotechnology may offer future options and is currently being used in Europe to mark oil for identification.	0

Table 6. Investment Recommendations at 70% of Current Level Annually.

(Expenditures may vary in a given year due to project costs.)

FY	Technology Improvement Area	Investment	Comment
08	Detect/Assess Sinking Oil Detect/Assess HAZMAT	Prototype system: CAMEO development support:	Year 1 of 4; assumes test of one prototype and initial T&E costs.
09	Detect/Assess Sinking Oil Detect/Assess HAZMAT	Prototype system: CAMEO development support:	Continue prototype testing, year 2 of 4
10	Detect/Assess Sinking Oil Detect/Assess HAZMAT	Prototype system: CAMEO development support:	Continue prototype testing, year 3 of 4
11	Detect/Assess Sinking Oil Detect/Assess HAZMAT	Prototype system: CAMEO development support:	Complete prototype testing, final report, year 4 of 4
12	Contain Sinking Oil Counter Surface Oil	Test technologies: SMART Protocol CAMEO development support:	Assumes MMS shares cost
13	Contain Sinking Oil Detect/Assess Surface Oil	Prototype system: Preliminary Airborne Remote Sensing:	Year 1 of 3
14	Contain Sinking Oil Detect/Assess Surface Oil	Prototype system: $250K Prototype Airborne Remote Sensing:	Year 2 of 3
15	Contain Sinking Oil Waste separation/disposal Re-establish system status	Prototype system: Develop separation guide: Expert Workshops:	Year 3 of 3 Assumes response-focused and co-funded (MMS or CRRC?)

Table 7. Investment Recommendations at Current Level Annually.

(Expenditures may vary in a given year due to project costs.)

FY	Technology Improvement Area	Investment	Comment
08	Detect/Assess Sinking Oil Counter Surface Oil Detect/Assess HAZMAT	Prototype system: SMART Protocol CAMEO development support:	Year 1 of 3 Assumes MMS shares cost
09	Detect/Assess Sinking Oil Detect/Assess Surface Oil Detect/Assess HAZMAT	Prototype system: Preliminary Airborne Remote Sensing: CAMEO development support:	Continue prototype testing, year 2 of 3
10	Detect/Assess Sinking Oil Detect/Assess Surface Oil Detect/Assess HAZMAT	Prototype system: Prototype Airborne Remote Sensing: CAMEO development support:	Complete prototype testing, year 3 of 3, final report
11	Contain Sinking Oil Counter Surface Oil Detect/Assess HAZMAT	Test technologies: Dispersant decision process: CAMEO development support:	Assumes project completed except for final report
13	Contain Sinking Oil Counter Surface Oil	Prototype system: Dispersant decision process:	Year 1 of 2 Final report
14	Contain Sinking Oil Detect/Assess HAZMAT	Prototype system: Prelim improved drum eval:	Year 2 of 2
15	Detect/Assess HAZMAT Waste separation/disposal Waste separation/disposal Re-establish system status	Prototype improved drum eval: Develop separation guide: Prototype remote debris treatment: $ Experts workshop series:	Assumes response-focused and no cost sharing.

Note: FY-15 assumes expenditures curtailed while system status is re-established.

Table 8. Investment Recommendations at 150% of Current Level Annually.

(Expenditures may vary in a given year due to project costs.)

FY	Technology Improvement Area	Investment	Comment
08	Detect/Assess Sinking Oil Counter Surface Oil Detect/Assess Surface Oil Detect/Assess HAZMAT	Prototype system: SMART Protocol Preliminary Airborne Remote Sensing: CAMEO development support:	Year 1 of 2 Assumes MMS shares cost
09	Detect/Assess Sinking Oil Detect/Assess Surface Oil Detect/Assess HAZMAT	Prototype system: Prototype Airborne Remote Sensing: CAMEO development support:	Complete prototype testing, year 2 of 2, final report.
10	Contain Sinking Oil Counter Surface Oil Detect/Assess HAZMAT	Test technologies: Dispersant decision process: CAMEO development support:	
11	Contain Sinking Oil Detect/Assess HAZMAT Waste separation/disposal Detect/Assess HAZMAT	Prototype systems: . Improved drum eval: Develop separation guide: CAMEO development support:	Year 1 of 2
13	Contain Sinking Oil Waste separation/disposal	Prototype systems: Prototype remote debris treatment: Systems analysis workshops:	Year 2 of 2 The workshops would establish a new baseline, including prevention.
14			
15			

Note: FY-13 through FY-15 assumes expenditures curtailed while system status is re-established.

4.0 FUTURE PLANS

The previous section includes a breakdown of research recommendations by fiscal year based on current funding levels. Projects may be slowed or speeded up based on year-to-year funding levels and opportunities to leverage the resources of others. Recognizing that priorities may be changed by a major incident or event, wholesale re-racking of priorities to address the specific scenario of the last big spill should be done cautiously. The funding levels are in addition to the current Pollution Prevention and Response program support account which provides for routine outreach and coordination efforts.

For each of those funding levels, it is recommended that a series of expert workshops be conducted to reestablish a baseline for response capability and identify opportunities for future investments. The workshop concept should be broadened to include prevention opportunities as well as response, which will require a different set (or sets) of experts. It is recommended that the segments of the broader system to be examined be defined prior to engaging in expert workshops in order to aid in focusing the discussions. Finally, consideration should be given to leveraging established organizations such as the S&T Committee of the NRT or CRRC to bring in the right people to re-baseline R&D needs. The risk of that approach may be a loss of CG focus.

5.0 BIBLIOGRAPHY

U.S. Coast Guard Marine Safety and Environmental Protection Business Plan FY2001-2005

U.S. Coast Guard Research and Development Center Strategy and Business Plan 2006

U.S. Coast Guard Commandant Publication P3120.17, "Incident Management handbook"

Oil Pollution Research and Technology Plan published by the Interagency Coordinating Committee on Oil Pollution Research in 1997 (http://www.uscg.mil/hq/g-m/nmc/gendoc/coop/coop.htm)

Spills of Nonfloating Oils published by the NRC Marine Board in 1999

Spills of Emulsified Oils, National Academy of Sciences, 2002

Oil Spill Dispersants: Efficacy and Effects, National Academy of Sciences, 2005

Oil in the Sea III, National Academy of Sciences, 2003

National Oceanic and Atmospheric Administration, Office of Response and Restoration, HAZMAT Operating Plan FY 2007 – 2009

Coastal response research Center Workshop (series)

Selection Guide for Oil Spill Applied Technologies (January 2003), Scientific and Environmental Associates, Inc. for RRT III and RRT IV, 2003

Risk Assessment for the Coast Guard's Oil Spill Prevention, Preparedness and Response (OSPPR) Program (June 2001)

Review of the Coast Guard "STANDARD AFTER ACTION INFORMATION AND LESSONS LEARNED SYSTEM (CG-SAILS)"

Meeting notes, R&DC Discovery Division and G-MOR staff on 7 June 2005

Meeting notes, R&DC Discovery Division and G-MR staff on 10 May 2005

Meeting notes, R&DC Discovery Division and G-OPD staff on 7 June 2005

Meeting notes, R&DC Discovery Division and G-OPN staff on 23 May 2005

Meeting notes, R&DC Discovery Division and G-OPR staff on 7 June 2005

Meeting notes, Kurt Hansen (R&DC Oil/Hazmat Response PAM) and G-MOR staff on 12 October 2005

IMO Press Release on MEPC 44

IMO Press release on MEPC 45

Report from the Third IMO R&D Forum (**(http://www.imo.org/Environment/mainframe.asp?topic_id=345)**)

NOAA HAZMAT Evening Report of 6 September 2005

ATHOS 1 Response Management Roundtable Discussion of 11 January 2005

National Pollution Fund Center (NPFC) 2007 "Report on Oil Pollution Liability Limits"

Government Accounting Office report GAO-07-1085, "Major Oil Spills Occur Infrequently, but Risks to the Federal Oil Spill Fund Remain"

This page intentionally left blank.

APPENDIX A – GAPS IDENTIFIED BY WORKSHOPS

Table A-1. Gaps in Oil Response System Identified in Workshops.

(Workshops were conducted in Baltimore, Chicago, Houston, and Seattle.)

Gaps in oil response system ID'd at workshops	**Response phase**	**Tech Invest Area**	**Bal**	**Chi**	**Hou**	**Sea**
Information delays causes detection problems for field teams	Detection	C^3I	X	X	X	X
Notification standardization for non-tank vessels	Detection	C^3I				X
Real time feedback of spill map to responders and command center – data and communications gap	Detection	C^3I			X	X
Situational awareness of recovery vehicles (Blimp)	Detection	C^3I	X	X	X	X
Situational awareness of the overall spill management	Detection	C^3I			X	X
Source mapping from outfalls – GIS-based system models	Detection	C^3I		X		
Spill information management	Detection	C^3I			X	X
Command center information flow	C&C	C^3I			X	
Record keeping of spill situations	C&C	C^3I			X	
Standardization of contingency plans	C&C	C^3I		X		
Studies regarding non-traditional measures (herders, polymers)	Countering	Containment			X	
Absorbent booms	Containment	Containment		X	X	X
Boom deployment methods (helos, etc.)	Containment	Containment			X	
Boom weight	Containment	Containment	X	X	X	X
Booms in currents	Containment	Containment	X	X	X	X
Containment of sinking oil	Containment	Containment			X	
Entrainment	Containment	Containment	X	X	X	X
Fast water containment	Containment	Containment		X		X
Herding chemicals	Containment	Containment			X	
Non-mechanical means to gather oil	Containment	Containment	X	X	X	X
Protection/collection booming guidance (accurate predefined booming standards)	Containment	Containment	X			
Remote monitoring of containment (sensors, GIS, telemetry)	Containment	Containment			X	
Spreading of product	Containment	Containment	X	X	X	X
Universal boom and anchoring connections	Containment	Containment		X		
Product information available for decision making	Detection	Dispersants	X	X	X	X
Burn ignition systems	Countering	Dispersants		X		
Capabilities to ignite and sustain a burn	Countering	Dispersants			X	
Dispersant approval process consistency	Countering	Dispersants			X	
Dispersant monitoring	Countering	Dispersants				X
Dispersants, particularly for heavy oil, emulsified oil	Countering	Dispersants			X	
Hazing methods for wildlife	Countering	Dispersants			X	
Information to make determination (sell) for in situ burning or dispersion	Countering	Dispersants	X	X	X	X

Gaps in oil response system ID'd at workshops	**Response phase**	**Tech Invest Area**	**Bal**	**Chi**	**Hou**	**Sea**
Knowledge of effect of dispersed oil	Countering	Dispersants			X	
Monitoring of dispersant effectiveness for low concentrations of oils and in heavy weather	Countering	Dispersants			X	
Permission for dispersion/burning	Countering	Dispersants				X
Estimating oil layer thickness	Detection	Estimation	X	X	X	X
Estimation of discharge amount	Detection	Estimation			X	
Estimation of oil spill amount in pipelines	Detection	Estimation			X	
Estimation of thickness, portable	Detection	Estimation			X	X
Cost effective temporary storage	Disposal	Logistics	X	X	X	X
Storage of disposed materials in shallow/sensitive areas	Disposal	Logistics			X	
Detection assets are unavailable	Detection	Logistics	X	X	X	X
Detection resources (amount)	Detection	Logistics			X	X
Standardized equipment	Detection	Logistics			X	
Access and sustained response to remote sites	Countering	Logistics				X
Access to isolated areas for response	Countering	Logistics			X	
Deploy of equipment, access, too close to shore to disperse or burn	Countering	Logistics	X	X		
Deploy or disperse in shallow water	Countering	Logistics	X	X	X	
Facilities for dumping, burning or recycling	Countering	Logistics	X	X	X	
Insufficient equipment (amount)	Countering	Logistics	X	X	X	X
Standardization of gear between agencies	Countering	Logistics				X
Equipment requirements are over specified and too costly	Containment	Logistics	X		X	
Rapid response to oils in water	Containment	Logistics			X	X
Disseminate of studies information, research loop	C&C	Logistics			X	X
Sharing of equipment capabilities and studies	C&C	Logistics				X
Supply chain of products	C&C	Logistics			X	
Capabilities to detect spills from run offs	Detection	Mapping		X		
Detection of oil/tar balls in water column	Detection	Mapping	X			
Identification of leading edge of spill	Detection	Mapping		X	X	X
Locating source of mystery spills – abandoned vessels	Detection	Mapping				X
Mapping of extent of spill	Detection	Mapping	X	X	X	X
Mapping of subsurface oil	Detection	Mapping	X		X	
Mapping of subsurface oil	Detection	Mapping			X	
Monitoring for early detection on drill rigs	Detection	Mapping			X	
Portability of detection equipment	Detection	Mapping		X	X	X
Portable detection equipment availability	Detection	Mapping	X			
Tagging oil for mapping	Detection	Mapping				X
Tracking of oil by tagging	Detection	Mapping			X	
Tracking problems due to insufficient data	Detection	Modeling	X	X	X	X

Gaps in oil response system ID'd at workshops	**Response phase**	**Tech Invest Area**	**Bal**	**Chi**	**Hou**	**Sea**
Trajectory estimation in rivers	Detection	Modeling				X
Detection of new products and water solubles	Detection	Other		X		
Financial management systems for faster response and accounting	C&C	Other				X
Method to address brine from spills	Countering	Other			X	
Improve personnel monitoring	Detection	Other		X		
Decanting guidelines	Disposal	Recovery methods			X	
Decanting while skimming	Disposal	Recovery methods				X
De-emulsifiers	Disposal	Recovery methods			X	
Knowledge regarding the environmental fate of oil after disposal	Disposal	Recovery methods			X	
Offshore disposal or burning in high winds, storage and recycling required	Disposal	Recovery methods	X		X	X
Quantities of product to burn or dump, recycling required	Disposal	Recovery methods	X		X	X
Separation and emulsification chemicals	Disposal	Recovery methods				X
Separation equipment	Disposal	Recovery methods	X	X	X	X
Beach cleanup techniques and chemicals	Countering	Recovery methods	X	X	X	X
Chemical countermeasure studies on fresh water	Countering	Recovery methods		X		
Cold water pumping capabilities - VOPS	Countering	Recovery methods				X
Countering for entrained oil	Countering	Recovery methods	X	X	X	X
Decant sinking oil	Countering	Recovery methods			X	
Recovery of emulsified oil	Countering	Recovery methods	X	X	X	X
Recovery of oil in submerged vessels	Countering	Recovery methods				X
Recovery of submerged oil	Countering	Recovery methods			X	
Shore remediation: Surface agents, Delivery systems for chemical treatments for marsh and wetlands, Flushing techniques,	Countering	Recovery methods			X	X
Skimmer effectiveness in cold weather	Countering	Recovery methods				X
Skimmer encounter rate	Countering	Recovery methods			X	X
Skimmers	Countering	Recovery methods	X	X	X	X
Wildlife capture/ cleaning / hazing	Countering	Recovery methods				X
Wildlife cleaning techniques	Countering	Recovery methods		X	X	X
Responsible Party vessel response systems such as solidifier treatment of oil prior to exiting vessel	Containment	Recovery methods			X	X
Assessment and treatment for beach cleanup (buried oil)	C&C	Recovery methods				X
Plug or patch for leaks on responsible vessel	Countering	Spill control				X

Gaps in oil response system ID'd at workshops	**Response phase**	**Tech Invest Area**	**Bal**	**Chi**	**Hou**	**Sea**
		systems				
Detection training	Detection	Training			X	X
Training	Detection	Training	X	X	X	X
Public education on cleanup and countermeasures	Countering	Training		X	X	X
Training and experience in lightering and salvage	Countering	Training				X
Training on use of dispersant and in situ burning	Countering	Training			X	X
Boom training (boom decision tree)	Containment	Training			X	
Formal training and skills	Containment	Training			X	X
Awareness training and update HAZWOPR training for oil spills	C&C	Training			X	X
Fake oil for training	C&C	Training				X
NIMS training and support	C&C	Training				X
Tactical guidance for spill cleanup – see Alaska STAR Tactics Manual	C&C	Training				X
Training and experience in all response phases including initial assessment	C&C	Training				X

Note: C&C is Command and Control, an aspect of the Control/Feedback Factors

Table A-2. Gaps in HAZMAT Response System Identified in Workshops.

Gaps in HAZMAT response system ID'd at workshops	**Response phase**	**Tech Invest Area**	**Bal**	**Chi**	Hou	**Sea**
Slow to get funding for response started	C&C	C^3I				X
Knowledge on reactivity of chemicals mixed together	C&C	C^3I				X
Equipment calibration process	C&C	C^3I				X
Information management for initial risks assessments	C&C	C^3I			X	
Assessment methods for container inspections	C&C	C^3I			X	
Information sharing between agencies regarding new technologies	C&C	C^3I		X		
Comms equipment	C&C	C^3I		X		
Personnel monitoring (air)	C&C	C^3I		X		
Investigation/identification job aids	C&C	C^3I		X		
Containment of entrained HAZMAT	Containment	Containment	X			
Containment of dispersed product	Containment	Containment	X			
Equipment for chemical response – lightering pumps	Disposal	Disposal		X		
Estimation of quantity	Detection	Estimation	X			
Places of refuge for major HAZMAT established	C&C	Logistics				X
Equipment specifically designed for the marine environment	C&C	Logistics		X		
Identification of type	Detection	Mapping	X			
Mapping of extent	Detection	Mapping	X			
Systems for UAVs and AUVs to measure extent, type and concentration	Detection	Mapping			X	
Small detection sensors to respond to multiple threats	Detection	Mapping			X	
Categorizing of HAZMATS in water flows and barrels	Detection	Mapping			X	
Harsh environment detection equipment	Detection	Mapping		X		
Equipment for multiple threats	Detection	Mapping		X		
Field identification equipment	Detection	Mapping		X		
Plume measuring equipment	Detection	Mapping		X		X
Equipment to identify solubles and mixtures	Detection	Mapping		X		
Bio identification	Detection	Mapping		X		
Detecting leak inside container or enclosed structure	Detection	Mapping		X		X
Air modeling	C&C	Modeling				X
Tracking models	C&C	Modeling		X		
Tracking of chemicals in barrels	C&C	Modeling		X		X
Water recovery and mitigation techniques	Countering	Recovery				X
Pumping and removal of solid materials	Countering	Recovery				X
Spray of aerial decontaminants	Countering	Recovery				X
Better training with local responders, industry, etc	C&C	Training				X
On scene information /identification training	C&C	Training				X

Gaps in HAZMAT response system ID'd at workshops	**Response phase**	**Tech Invest Area**	**Bal**	**Chi**	Hou	**Sea**
Awareness training for first responders	C&C	Training		X	X	X
Water recovery and mitigation techniques	Countering	Recovery				X

APPENDIX B: TECHNOLOGY READINESS LEVELS

Technology Readiness Levels in the Department of Defense (DOD) (Source: DOD (2006), *Defense Acquisition Guidebook*)	
Technology Readiness Level	Description
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Example might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high fidelity' laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.

9. Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.