Damage Control Operational Concepts (DCOC)

Impact of Technology Insertion on Shipboard Damage Control Operations

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Document Owner

The primary contact for questions regarding this document is:

John R. Eckelberry
Phone: 757-518-2208
E-Mail: eckelberryj@mtstech.com

The alternate contact for questions regarding this document is:

Kenneth E. Halloway III
Phone: 757-518-2205
E-Mail: hallowayk@mtstech.com

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Submitted by

MTS Technologies, Inc.
5700 Cleveland Street
Suite 408
Virginia Beach, VA 23462-1752

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Purpose

This report satisfies the requirements of the Damage Control Operational Concepts (DCOC) contract with the Office of Naval Research, (ONR).

The Naval Research Laboratory (NRL) has been conducting research into the effect of reduced manning on the conduct of Damage Control (DC) operations in U.S. Navy ships under the Damage Control-Automation for Reduced Manning (DC-ARM) program. This research is ongoing. This report will enhance that research by reviewing Water Mist (WM) firefighting technologies.

Background

The DCOC Program was designed to investigate, analyze, and research DC Concepts, Technologies, Techniques, and Procedures to assist the Navy in transforming shipboard DC operations into the 21st Century in order to meet the needs of increasingly technologically based platforms.

DCOC is a congressionally funded program under the auspices of the ONR and NRL. Utilizing operations analysis and research methods linked to modeling and simulation, DCOC assesses technology insertions to improve current shipboard DC systems and processes. The requirement for damage detection, assessment, and control ties directly into ship survivability. The linchpin competency is identification and assessment of damage sustained either through battle or normal shipboard operation. The rapidity and accuracy with which such information gets to decision makers plays a significant role in the areas of command and control and response planning. Since the Navy must accomplish shipboard missions and tasks with fewer personnel, an automated DC assessment system is a valuable step in the design of newer ship classes.

The DC-ARM program has focused upon the use of WM systems in main and auxiliary engineering spaces to provide the "first line of defense" in fire suppression. This segment of the DCOC Program enhances this effort by providing a review and analysis of currently available WM systems for possible warship use.

Water Mist Technology

WM systems use fresh water to suppress and/or extinguish fires. Since the 1970's, the U.S. Navy has used HALON-1301 (Bromotriflouromethane, CF3Br) as the primary fire-extinguishing agent for the protection of shipboard main and auxiliary machinery spaces.[1] The Montreal Protocol banned chlorofluorocarbons in HALON-1301 internationally in 1994, and then the Clean Air Act banned them domestically[2]

Testing conducted during the 1990's validated that water, discharged as a mist of water droplets less than 1000 microns in size, proved effective in suppressing and extinguishing flammable liquid fires. The water droplets appeared very effective in the absorption of heat; accordingly, fire extinguishing is primarily through cooling, a process that causes evaporation of the water droplets and in turn displaces the oxygen in the space. The reduction of the temperature and the displacement of oxygen in the space remove two sides of the "Fire Triangle."

Small-scale test results encouraging. NRL conducted a series of tests using water, dispensed as a mist, to extinguish small-scale fires. Larger-scale tests, conducted aboard the Navy's Fire Test Facility, ex-USS *Shadwell* (LSD 15) in Mobile, Alabama and the Fire Research Facility in the upper Chesapeake Bay, validated that WM could suppress a main propulsion space fire and, in some cases, extinguish the fire.[3] The results also indicated that WM systems have a relatively low water demand (between .17 and 1.7 Lpm/m3). WM was effective if the mist was able to reach a concentration of at least 0.7 L/m3.

Full scale testing soon followed. This testing focused on the use of a WM system operated with fresh water at high pressure, fresh water at low pressure, and a water/air/nitrogen mixture. These tests indicated that WM could extinguish a fire in a minute or less, significantly reduced the ambient temperature of the space within seconds after activation, and were in fact a viable alternative to the use of manufactured chemicals in main machinery spaces. The use of WM in a main machinery space does not require the space to be isolated and the ventilation secured as is required for HALON-1301 to be effective. In addition, when using HALON-1301, personnel were required to remain clear of the space 30-45 minutes subsequent to its activation, thereby delaying damage assessment. WM allows personnel to be in the affected space and to perform real-time damage assessment and overhaul of the fire.

Coincident to the research conducted by the United States Navy, researchers and companies in Europe were considering WM as a primary extinguishing agent for both marine and land-based applications. In the 1990's, WM systems have been installed in cruise liners, bulk-carriers, and tankers. Tunnel systems also use WM.

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[1] Darwin, Robert L. and Williams, Frederick W., "The Development of Water Mist Fire Protection Systems for U.S. Navy Ships" Naval Engineers Journal, November, 2000, p.49

[2] *Ibid.*

[3] *Ibid.* p.51

Water Mist Research. During the 1990's over 40 scholarly papers were published addressing different aspects of the use of WM systems in marine applications. One of the results of this work was the realization that installation of WM systems could be beneficial to the conduct of DC operations in a reduced-manning environment. One of the conclusions of the initial DC-ARM testing in 1997–1998 was that the insertion of technology, particularly WM, would be instrumental in achieving established DC-ARM program goals.[4] Two other conclusions of the testing with respect to the insertion of technology was a recognition of a need for a Supervisory Control System for fire detection and suppression and the development of so-called, "smart valves" to control/regulate the operation of the installed WM system.

DC-ARM testing in subsequent years has focused on the refinement of techniques of fire suppression using WM. Initially the primary variables in these tests were the size of the WM droplets, the physical placement of the nozzles that dispensed the WM, and the spacing between individual nozzles. Although low-pressure applications were considered, the focus of WM system testing over the past several years has been high pressure (70 bar).

WM systems, using a small fraction of the volume discharged by traditional water sprinklers, can cool compartments from 500°C to 50°C within seconds of discharge. WM systems use fresh water. The tanks, once expended, can be refilled from the ship's potable water system. Alternatively, WM systems can use seawater in an emergency.

Current U.S. Navy Usage

The positive results obtained during the initial DC-ARM tests led the Naval Sea Systems Command (NAVSEA) to introduce a WM system into the new San Antonio (LPD 17) Class Amphibious Transport Dock. The system is being installed in the propulsion machinery spaces for fire protection.[5]

Operating at 70 bar (1000 psi), the system is designed to extinguish most unobstructed fires within one minute. The ship places control systems at each Enclosed Operating Station (EOS), by the main access trunk to each engineering compartment on the DC deck, and at the bottom of each escape trunk for the main machinery rooms and auxiliary machinery rooms. Additionally, any of the 21 multi-function workstations contained within the Engineering Control System can operate the WM extinguishing system. It has two WM pumping stations, each with its own potable water storage tank and an electric-driven positive displacement pump. The piping system is stainless steel. NRL conducted tests comparing WM systems to the two primary alternatives, HALON-1301 and FM-200.[6] The results of this analysis are in the table below:

[4] Williams, Frederick W. *et al.* Results of 1998 DC-ARM/ISFE Demonstration Tests NRL/FR/6180—00—9929, 25 APR 2000

[5] Leonard, J.T. *et al.* "Preliminary Ship Impact Study for Machinery Space Water Mist Total Flooding Systems" NRL Rpt Ser 6180/0550.2, Washington, DC 29 DEC 1994

[6] Williams, F.W. Back, G.G. *et al.*, "Water Mist System: LPD 17 Design Validation and Full Scale Machinery Space Water Mist Fire Suppression Tests" NRL ltr Rpt Ser 6180/0007 Washington DC 16 JAN 1997

Table 1. Ship Impact Alternative Fire Extinguishing Systems Machinery Spaces, LPD 17.

	HALON-1301	FM-200	WATER MIST
Weight	**45,000 lbs**	**95,600 lbs**	**96,400 lbs**
Footprint	480 sq ft.	1,500 sq ft.	450 sq ft.
Cost of Components FY 98 Dollars ($))	220,000	540,000	330,000
Relative Installed Cost	1.0	3.0	1.5

LPD 17 is currently under construction at Northrop-Grumman, Avondale Industries, New Orleans, Louisiana. NAVSEA anticipates using WM systems in the final ships of the ARLEIGH BURKE (DDG 51) Class Guided-Missile Destroyer, DDG 79 sub-class, with a retrofit of the earlier ships of the class likely as each enters into an extended maintenance or overhaul period. In addition, WM is being installed on LHD 8 and is being considered for the ship class that replaces the LHA1 Tarawa Class (LHA-R).

Additional Studies Conducted. NRL conducted additional studies and modeling of WM systems looking specifically at the reduction in temperature of the space after the initiation of the WM suppression system. Studies focused on both high pressure and low pressure applications aboard ex-USS Shadwell (LSD 15). In some tests, the ambient temperature of a space dropped 400°C, 30 seconds after initiation of the WM system. Additionally, NRL conducted tests using low-pressure systems in spaces other than propulsion machinery spaces.[7] During the low pressure testing, it was determined that the performance of the WM system is sensitive to the pressure of the water provided. Changes in operating pressure can affect droplet size, initial droplet momentum, and application density.

Other testing assessed the effectiveness of WM on electrical equipment and whether a self-contained WM system could be used to protect spaces such as offices, berthing spaces, and non-flammable equipment stowage lockers. All of this testing was designed to assess the applicability and effectiveness of WM systems under the DC-ARM program as a possible total ship protection program.[8] NRL continues to test differing configurations of WM systems aboard ex-USS *Shadwell* (LSD 15).

[7] Darwin, Robert L. and Williams, Frederick W., "The Development of Water Mist Fire Protection Systems for U.S. Navy Ships" Naval Engineers Journal, November, 2000, p.54

[8] *Ibid.*

Commercial Water Mist System Usage And Providers

Current Recognized Standards. The National Fire Protection Association [NFPA] recognizes the following broad operating pressure characteristics:

Less than 175 psi (10 bar)	Low-pressure
Greater than 175 psi, but less than 500 psi (35 bar)	Intermediate-pressure
Greater than 500 psi	High-Pressure

The systems onboard ex-USS *Shadwell* (LSD 15), currently being installed in USS San Antonio (LPD 17), and scheduled for placement in USS New Orleans (LPD 18) use MILSPEC piping standards.[9] However, several international companies, with subsidiaries in the United States, manufacture non-MILSPEC high-pressure WM systems that meet commercial U.S. Coast Guard and International Maritime Organization (IMO) specifications. These systems, which use different piping configurations, still meet the Navy's fire-fighting redundancy and sustainability requirements. The U.S. Coast Guard certifies US registered vessels' WM systems through Underwriter's Laboratory [UL]® experiment standards.

As previously stated, WM systems are currently in use in a wide spectrum of applications both marine and land-based. Most major cruise lines employ WM systems in their ship's propulsion engineering spaces and auxiliary spaces. Tunnels in Europe employ WM to suppress conflagration, decrease the ambient temperature in the tunnel itself, and aid in smoke removal, which assists emergency response personnel in dealing with the situation. There are more than twenty contractors either producing and supplying WM systems or evaluating differing applications for the use of WM, not all in a marine environment.

Piping System Key to U.S. Navy Application. NAVSEA requires P1-coded piping for liquid systems aboard U.S. Navy ships.[10] This piping is further coded by the pressure under which nominal operations are to be conducted: Schedule 40 (LP/IP) and Schedule 80 (HP). Research conducted by *MTS Technologies, Inc.* suggests that this requirement limits the usage of a number of Commercial-Off-The-Shelf (COTS) WM systems currently on the market. Examples:

Coastal Fire Protection Systems, an American distributor for Sweden's Ultra Fog® WM systems, manufactures high pressure systems (up to 200 bar) which meet IMO Safety of Life at Sea (SOLAS) standards. The piping systems range from 6 mm to 42 mm. Ultra Fog systems, installed on commercial vessels, earned certification from numerous insurance organizations, including Lloyd's Register of Shipping, London. However, given that this manufacturer does not utilize P1-coded piping, Coastal Fire is ineligible as a COTS provider to the U.S. Navy for this particular application.

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[9] MILSTD 278
[10] MILSTD 278

Marioff Corporation manufactures Hi-Fog® WM systems. A Finnish company with subsidiaries in the United States, Marioff places WM systems in commercial vessels, offshore oil platforms, and foreign navies (e.g., Norway, Germany). Its systems, approved by the American Bureau of Shipping, Lloyd's Register of Shipping, and other maritime insurance organizations, are on several new construction foreign warships and commercial vessels. Like other companies, Marioff also manufactures WM systems for land-based facilities.

Chemetron Fire Systems™, a U.S. based subsidiary of the U.K. based Kidde Company, distributes an intermediate-pressure WM system. Operating at 24 bar, the WM systems operate with integrated software and control packages that optimize fire detection and suppression. As with high-pressure WM systems, commercial interests often install intermediate pressure systems on offshore drilling platforms in addition to shipboard compartments.

Wormald Ansul, a company based in the United Kingdom, is part of the Tyco International, Ltd. group of companies. Wormald manufactures ProtectoMist low-pressure WM system, which operates at 12 bars or less. Suitable for local or whole-space flooding, these systems incorporate detection and control systems marketed for berthing, passageway, and machinery spaces. They also advertise these systems for computer and other electronic areas. A more complete list of manufacturers and the systems they produce is at the end of this report.

NanoMist™ Systems, LLC uses sub-micron sized WM systems to protect computer and data centers, libraries, and restaurant kitchens. Experiments continue to indicate WM systems are appropriate for areas with electronics.

There are uses for WM systems in addition to the aforementioned marine applications. In July 2002, the Institution of Engineers of Ireland reported AQUASYS, an Austrian firm, developed a Tunnel Fire Suppression System for installation in the entire length of a tunnel.

DC Operations and DC-ARM

The objective of the DC-ARM Program, sponsored by NRL is to determine the benefits of technology insertion on combating shipboard damage in a reduced-manning environment.[11] The previous discussion has focused upon the installation and use of WM systems in propulsion machinery spaces with further application into designated general shipboard spaces.

These efforts have focused specifically on fire suppression and extinguishment. Certainly, combating fires aboard ship is the most manpower-intensive evolution in damage control. At the outset of the DC-ARM program, the Navy did not have consistent standards of performance for manning or effectiveness.[12] Subsequent testing by NRL established some standards of performance and effectiveness in fire suppression with respect to the employment of WM. However, no definable standards exist for manning in these DC events.

[11] Williams, Frederick W. *et al.* Results of 1998 DC-ARM/ISFE Demonstration Tests NRL/FR/6180—00—9929, 25 APR 2000

[12] *Ibid.*

The next-generation ship, DD(X), is anticipated to have only 95 personnel assigned. The emerging DD(X) strategy during battle is to continue to fight the ship even though the ship sustains battle damage, until the battle situation clears sufficiently to allow more personnel to respond to the damage itself.

During DC-ARM testing aboard ex-USS *Shadwell* (LSD 15) over the last several years, an electronic Supervisory Control System (SCS) has also been part of the tests. This system, based upon a computer graphic-user interface (GUI) enables a DC watchstander to monitor and/or respond to DC situations from a remote location. This adds another dimension to the DC problem. Overall, DC major concerns are a lack of situational awareness, situational assessment, and situational control. Factors affecting the ship's response to any DC problem include the requirements for establishing or restoring communications; surveying the extent of damage; restoring or redistributing fuel, water, or electrical power; coordinating the resources to combat the damage; and restoring normal ship operations. The SCS will assist in this effort by providing a certain level of situational awareness to not only the DC watchstander, but to the ship's command element as well.[13]

As has already been discussed, WM systems have proven as effective as HALON-1301 in suppressing propulsion machinery space fires. As NRL was assessing a prototype SCS in conjunction with DC-ARM testing, it was determined that significant improvement in DC reaction time and procedures can be realized by using an electronic SCS for situational awareness, as can be shown in the table below:[14]

Table 2: Summary of DC-ARM Key Performance Demonstrated.

DC-ARM Objectives	Time Standard	Baseline Demo FY 98 No SCS Used	FY 00 Demo SCS in Remote-Manual	FY 01 Demo SCS in Auto
Identify Primary Damage Area (PDA)	**≤ 9 min**	**18 min**	**3.3 sec**	**3.75 sec**
Extinguish Fires in PDA	≤ 33 min	62.5 min	40 min	37.1 min
Set Vertical Boundaries -Manually -w/Water Mist	**≤ 9 min**	**19.4 sec NA**	**NR 2.5 sec**	**NR 0.5 sec**
Set Horizontal Boundaries -Manually -w/Water Mist	≤ 13 min	13 min NA	6.3 min 1.8 min	4.8 min 0.45 sec
Isolate Firemain Rupture	**≤9 min**	**13.3 min**	**1.8 min**	**1.45 min**

[13] Williams, F.W. *et al.* FY 2001 DC-ARM Final Demonstration Report, NRL/MR/6180--02-8623, 31 MAY 2002
[14] Williams, F.W., DC-ARM Supervisory Control System Software Final Summary Report, Encl(1) to NRL ltr 3905 Ser 6180/0010 10 JAN 2001

As tested, the SCS performs the following functions:[15]

- Control of the Firemain
- Control of the installed WM system
- Visual and audio alarms and fire characterization information
- Video surveillance of compartments
- Access opening/closure data
- Entry of information into the system from verbal reports

CAE Corporation is developing the SCS under study. The data clearly show a marked improvement in DC capability over the non-automated procedures previously used. It is postulated that a major fuel/lube oil-fed fire in a propulsion machinery space could cause up to $1 million in damage to that space per minute. The ability to rapidly identify, respond to, and extinguish such a fire not only enhances battle readiness, but also reduces the cost of, or even the necessity for, repairs.

The speed of detection and response to conflagrations significantly improves the probability of limiting any potential damage caused by the event. Traditionally, cruise ships staff to only a third of the level of a U.S. Navy ship in the engineering spaces. These ships rely heavily upon technology and automation to handle both routine issues and emergencies.

A recent propulsion machinery space fire on a Cruise Ship emanating from one of its diesel engines was suppressed and extinguished by an automated fire suppression system, using WM in less than one minute, causing only $500 in damage to the space. The guests were unaware of the conflagration as it was dealt with so rapidly.

Applications for U.S. Navy Ships

The U.S. Navy has undertaken several initiatives in the wake of the USS Cole incident to modernize shipboard DC systems and processes. These initiatives focus on the use of automation and remote monitoring through introduction of new systems/software, automatic control elements for previously manual systems, and tactical management tools. These systems assist in assessing, containing, and recovering from casualties; however, they primarily address individual technical issues rather than the system-level issues.

New U.S. Navy ship design and construction is focused on placing the best combat systems and as much firepower as possible aboard the hull. In addition, these ships will operate with smaller-sized crews, focused on mission completion. The Navy's new Littoral Control Ship (LCS) is one example of this new focus. LCS will to bring the fight close to shore. New command and control systems will further automate functions and aid tactical decisions. The newest Combat Direction System (CDS) installed aboard both new and existing U.S. Navy ships allow for increased flexibility for shipboard personnel to operate the ship remotely from a number of locations on the ship.

[15] *Ibid.*

Given the capability of WM systems to suppress propulsion machinery space fires, with some research and credence given to WM use in other ship's spaces, it appears evident that the current applications that NRL has researched and tested through DC-ARM are both compatible and complimentary to the CDS installations. Further development of the SCS, with emphasis on integration with other installed systems, will enable rapid restoration of systems in the event of battle damage. Further, it will enable the ship's command and control node to maintain continuous situational awareness with respect to the ship's readiness to operate and execute its assigned missions.

Finally, improvement in the SCS and integration with CDS gives the ship's Commanding Officer the ability to assess the ship's capabilities, direct DC actions, and authorize changes to equipment or liquid loads from a remote location. This alone would increase the battle efficiency of individual ships considerably. Again, it is highly desirable to have, as the first response to a conflagration, an automated system with human intervention required only for overhaul of the affected space.

Issues yet to be addresssed. As promising as the results of the DC-ARM appear to be, the U.S. Navy still has a number of issues to be resolved. First is the development of a contemporary DC doctrine that reflects the advances in firefighting and incorporates the results of the extensive testing conducted by NRL since 1997.

Water mist advances need to be incorporated into current DC Doctrine. Once doctrine is refined and published, it can be distributed to the Type and Training commands.

A new training plan must be developed. Fire-fighting experts and community professionals need to develop training courses, manuals, and personnel qualifications standards (PQS). Coincident to this would be the upgrading of the Navy's firefighting training facilities to reflect both the use of WM systems and automated and remote control of these systems.

The WM systems discussed use fresh water (not necessarily potable water). While there is a great deal of data concerning suppression and extinguishing times, there is little data concerning the amount of water necessary to achieve the required result. While larger ships have the ability to distill a great deal of seawater into fresh water, smaller ships (DD/DDG/CG) may only be able to distill 68,000 to 91,000 liters of fresh water per day. A Measure of Performance of a WM system would be the amount of fresh water used per conflagration. Discussions with chemical and fire experts testing the WM systems indicate that the amount of fresh water used does not appear to be excessive. It would be important to know whether the fresh water supply for the WM system would last for a serious conflagration and whether or not that supply could feasibly be replenished.

Alternate Water Mist System Uses. Another use for WM could be as the alternate source or the replacement for the currently installed Countermeasures Wash Down System. In addition, this system could be cross-connected to provide an alternate fresh and/or potable water source.

Maintenance and Logistics Concerns. The large number of DC systems and equipment, personnel protective gear, and different casualty situations require significant logistics support including technical manuals, part numbers, stock numbers, etc. In addition, this information must be readily available to the crew. Maintenance is crucial to insure the proper operation of DC systems and equipment in emergencies. Effective DC equipment maintenance is labor intensive and requires comprehensive documentation such as Maintenance Requirement Cards (MRC), proper tools and parts support, and personnel training. Simplification of this administrative and maintenance workload represents an additional potential manpower reduction.

The research for this report uncovered some concerns about the size of the fresh water tank required for the WM system and the ramifications for the ship's stability. Would that tank (or tanks) be a trade off for another tank? One possible answer to that question would be the designation of the WM tank(s) as an alternate source of potable water. However, significant specifications for the tank and other requirements must be taken into account. For example, the WM tank used in this way would have to be constructed identically to the other potable water tanks on the ship and able to be tested and flushed as required by the Naval Ship's Technical Manual. Additional piping would likely be required to achieve the required cross-connect capability.

Summary and Conclusions

The impact of technology on shipboard DC operations is profound. Technology solutions can positively influence ship survivability. Survivability is the capacity of a ship to absorb damage and maintain mission integrity. From a combat perspective, survivability consists of three elements:

- Susceptibility is the degree to which a ship is open to attack
- Vulnerability is the likelihood that the ship, or part of its mission capability, will be lost if the ship is hit
- Recoverability is the degree to which the ship and its crew can restore capabilities that existed before a hit caused damage. Recoverability encompasses the process of DC.

Damage Can Be The Result of Any Operation. Ships can sustain damage because of equipment failures, weather, and accidents as well as weapon hits. The nature and extent of damage must be detected and assessed, the spread of fire and smoke must be contained, fires must be extinguished and the smoke removed, flooding must be controlled and the water removed, areas with structural damage must be reinforced, mission capability must be restored, and Sailors must be protected. The lives of the crew and survival of the ship may well be at stake.

The processes involved in Recoverability, and in particular DC, are complex, interactive, labor intensive and time-sensitive. Rapid decisions and well-directed, effectively coordinated, and properly prioritized actions are essential. The principle areas discussed that affect DC in the U.S. Navy can be grouped in the following categories:

- Identification & assessment
- Communication
- Management
- Action
- DC personnel training
- Logistics
- Maintenance (of DC equipment)
- Development and assessment of next generation DC tactics/ equipment

This report has focused primarily on Management, Action, Training, Logistics, and Maintenance concerns. The other concerns deserve brief mention as well.

In the Identification & Assessment category, the speed at which the ship's force identifies and assesses the damage is very important. For the majority of the ships in the Fleet today, identification and assessment is performed by shipboard personnel in hazardous situations. DC sensors, and the information they provide, are currently limited. For example, smoke detectors are only used on a few ship classes and flood indicators are limited to simple point level sensors. Advances in sensor hardware and software (e.g., virtual presence DC sensors for fire, flooding software necessary to do complex calculations, etc.) continue development, or are in limited use, on U.S. Navy ships.

In the Communication category, major concerns involve the type, speed, accuracy, and redundancy of communication between command personnel and shipboard DC personnel during a damage situation. Communication between command and on-scene personnel is limited to the internal phone systems, wireless phone sets, and "messengers." Decisions of command personnel to mitigate the casualty rely on the speed and "correctness" of the information provided.

Development and Assessment of the next generation of DC equipment/tactics continue to be complex and costly endeavors. As previously discussed, there appears to be little movement outside of the R&D community to develop DC tactics that would better utilize what technology and R&D are bringing to the next generation of ships. The DC equipment/tactics must be tested under numerous casualty scenarios, taking into account the myriad test parameters necessary to simulate actual events. No current assessment tool is available to perform such evaluations in a cost effective manner.

A major challenge is the assessment of WM system use on U.S. Navy ships in pressures below the high-pressure level. Research indicates that there is a paucity of data concerning the application of WM at the intermediate and low-pressure systems. It has been theorized that WM systems, whole ship or individual self-contained systems, operated at a lower pressure, could be effective in office, crew living, and stowage spaces.[16] In addition, there are a number of flooding-type suppression systems, such as the Ordnance Magazine Sprinkler System, already installed and in use on U.S. Navy ships. Testing aboard ex-USS *Shadwell* (LSD 15) is ongoing to determine the effectiveness of WM as a replacement for these systems. One concern in replacing a sea water-serviced system with a fresh water system is the required amount of fresh water.

Lastly, testing continues concerning the use of WM on electric/ electronic equipment. Initial test results indicate that WM systems can extinguish fires in those spaces with little water and minimal damage to installed equipment. Further testing is required before full deployment of WM systems in electrified spaces.

Increases in technology with respect to automation and fire suppression will result in increased survivability and battle readiness of U.S. Navy ships. What is not as obvious is the specific application of technology to individual areas of concern. Testing and development of automated systems is ongoing with the goal of increasing the level of automation present in the DC process. Finally, while the technology grows, so must the infrastructure to support the insertion of that technology.

Recommendations

Given the findings listed in this report, *MTS Technologies, Inc.* recommends the following:

1. Continue testing WM systems, with particular emphasis on intermediate and low-pressure systems.
2. Re-examine the Navy requirement for P1 coded piping for WM systems. This may allow the utilization of COTS intermediate and low-pressure systems, thereby reducing the installation and maintenance costs.
3. Develop new doctrine and tactics for the use of remote sensors and automated firefighting techniques.
4. Develop a training program for the use of automated DC systems, to include classroom, updated live trainers, and PC-based courses.
5. Develop Personnel Qualification Standards for the maintenance and operation of the WM system and SCS.
6. Develop a new Main Space Fire Doctrine reflecting the impact of technology insertion described above.

[16] Darwin, Robert L. and Williams, Frederick W., "The Development of Water Mist Fire Protection Systems for U.S. Navy Ships" Naval Engineers Journal, November, 2000

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11. Military Sealift Command, Damage Control Information Newsletter Number 011: Water Mist Fire Suppression Systems, Part II, 30 September 1997, http://www.msc.navy.mil/n7/dc_info/ DCIN011.htm.

Listing of Water Mist Providers

The list of providers is contained in the table below:

Table 3: List of Water Mist System Providers.

CONTRACTOR	NATIONALITY	SYSTEM PRESSURE (BAR)	MATERIALS COST ($)	WEIGHT (LBS)
FOGTEC (TYCO)	**Germany**	**120**	**NR**	**NR**
Coastal Fire Protection	US/Sweden	100	70,000	3,000
NanoMist System LLC	**US**	**≤14.5**	**NR**	**NR**
Marioff (HIFOG)	Finland	140	212,550	28,660
CHEMETRON	**US**	**24.13**	**NR**	**NR**
SECURIPLEX	Canada	6.55	NR	NR
FIKE	**US**	**6.5**	**19,000**	**1,500**
Grinnell (TYCO)	Australia	8	NR	NR
KIDDE	**US**	**24.13**	**NR**	**NR**
NG-Avondale (est.)	US	70	528,000	30,300

Report Contributors

1. John R. Eckelberry, *MTS Technologies, Inc.*; Program Manager, Damage Control Operational Concepts
2. Kenneth E. Halloway III, *MTS Technologies, Inc.*; Lead Operations Analyst, DCOC
3. James V. Sullivan, *MTS Technologies, Inc.*; Operations Analyst, DCOC
4. Samuel Epstein, *MTS Technologies, Inc.*; Operations Analyst, DCOC

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