SURVIVABILITY TECHNOLOGY FOR THE 21ST CENTURY WARSHIP

BY

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This is an edited version of the paper presented at the Institute of Marine Engineers conference INEC 98—Surviving the War, *held 15–17 April 1998.*

ABSTRACT

At a time of ever increasing procurement costs and uncertain threat scenarios, it is vital that the modern warship has a high probability of surviving all reasonable attacks or accidents. This level of survivability may be achieved by balancing the susceptibility of the vessel to weapon attack, the vulnerability of personnel and systems to instantaneous weapon effects and the recoverability of said systems and personnel against the effects of fire, flood and smoke.

This article describes initiatives within the Directorate of Marine Engineering of the Ship Support Agency to evaluate new and existing survivability technologies for future Royal Navy platforms. These technologies range from wholesale changes in ship architecture like Integrated Full Electric Propulsion and Integrated Platform Management Systems to the provision of 'hardwired' emergency breathing systems and dedicated escape trunks.

Finally, the authors present a personal vision of how technology can complement personnel to provide a more survivable future warship in a cost effective manner.

Introduction

What is survivability? Survivability is defined as:

> A combination of the susceptibility of a vessel to weapon hit and the vulnerability of the vessel to the effects of the weapon hit.

Vulnerability can in turn be considered to be a combination of the instantaneous effects of the weapon attack, blast, fragmentation etc. and the ability of the vessels systems to recover.

The Marine Engineer has the ability to influence all aspects of survivability by differing amounts. For example he will:

- Influence noise and infra-red signatures thus affecting susceptibility.
- Drive the layout of marine engineering equipment and systems, significantly affecting their vulnerability to instantaneous weapon effects.
- Specify the damage control and firefighting technology, affecting recoverability after a weapon hit.

Traditionally, revolutionary developments in warship technology have been aimed at improving weapons, reducing susceptibility and improving the normal performance of systems. Advances in damage control and firefighting technology have tended to be more evolutionary and usually occur as the result of lessons learned.

This article will concentrate on how technology can improve the recoverability of a warship, thus improving survivability. Although the article is written in the context of surviving a weapon hit, it must be recognized that most of the technologies will contribute to surviving the effects of damage due to an accident.

The threat

Until recently a main requirement for UK warships was to meet the threat from Cold War enemies. Enemy vessels were likely to be well armed with sophisticated reliable weapons and complemented by dedicated and reliable crews. With the end of the Cold War, future UK warships are likely to play a significant role in policing and peacekeeping activities. They may be required to police squabbles between well armed and equipped, though potentially undisciplined and unpredictable opponents. The situation will be made even more difficult by intense media and political scrutiny of any actions taken.

The conflict of the future is likely to be one where our ships are constrained in the use of force but, still required to face a real threat. Winning this war may not be a matter of overcoming the enemy with superior force, it may be simply surviving an unprovoked or unexpected attack.

Ignoring chemical and nuclear attack, the main physical threats to a warship are;

- Flood
- Fire
- Explosion.

These threats are not necessarily the result of an attack, they may be due to an accident. Furthermore the effects are not independent: Explosion of a weapon or magazine is likely to cause flooding and fire or alternatively, the spread of fire may cause an explosion.

Design for survivability and safety

The considerations when designing for survivability have much in common with safety. Indeed survivability is the logical extension of assuring the safety of the ship and its crew under the most extreme conditions. The safety policy for UK warships is laid down in JSP 430.[1] A key feature of the safety policy is use of the safety case methodology. This requires the identification of all hazards and provision of appropriate controls rather than just compliance with a set of prescribed standards, as is typical of regulatory documents.

As described previously, survivability is defined as a combination of the susceptibility of a vessel to weapon hit and the effects of the weapon hit.

Whilst the marine engineer has an important role in reducing the susceptibility of a vessel by reducing signatures, his main design role is to design cost effective systems that will either still perform adequately following damage or can easily be reconfigured; i.e. systems that are not vulnerable or systems that are recoverable. The definition of adequate will involve the systems ability to support the high level requirements to move and fight.

Minimizing vulnerability is all about countering the instantaneous effects of a hit. Minimizing the effects of a hit on systems may be achieved by either minimizing the damage to the equipment itself by hardening or protecting the equipment, or, accepting that damage may still occur, the effect of the damage may be mitigated against by duplication or redundancy.

Examples of hardening and protection are:

- Shock mounting
- Ballistic protection
- Blast resistant doors
- Bulkheads or venting blast pressures with blow off plates.

A good example of providing redundancy is the concept of Integrated Full Electric Propulsion (IFEP),[2] where any of a number of distributed prime movers may provide power to the propulsors.

Minimizing the vulnerability of a warship to the effect damage is relatively straightforward. It is however potentially expensive and subject to the law of diminishing returns, particularly for smaller vessels. Robust tools,[3] exist to assess the vulnerability of the ship systems (including weapon systems) to the effects of weapon hits. These tools ultimately allow the designer to perform a cost trade off for potential vulnerability reduction measures and select the best or most cost effective, aligning well with the safety case philosophy of JSP 430.

Maximizing the recoverability of a warship is somewhat more difficult. The key issues are being able to recover from the longer term effects of the hit, these being:

- Flood.
- Fire and smoke.
- Damage to essential services, particularly electrical power and chilled water.

Modelling the recoverability of a warship will hinge on the ability to model the actions and abilities of the ships staff in the face of extreme conditions such as fire and smoke, as well as modelling the fire and smoke itself! In addition, to assess the effect of new technologies, the technologies themselves also need to be modelled. At present, the authors are unaware of the existence of any such models.

Recoverability for a warship design is therefore usually maximized by a applying a combination of:

- Prescriptive rules
- Past experience
- Subjective assessments
- Minor trials.

A significant proportion of the measures provided also contribute to safety, and as such are often mandated. As a result it is difficult to assess the contribution of any new equipment or technology on the overall survivability of the ship.

Functionality requirements

Before considering technologies themselves, it is worthwhile looking at the functionality of a man/machine system that will provide recoverability. This is known more simply as the Damage Control and Fire Fighting (DC & FF) system.

Following the hit the primary goal of the DC & FF system must be to deal with the effects of fire, smoke, flooding, and damage to essential equipment. Inherent to achieving this goal is the effective management of the personnel that are immediately available.

The functionality required from the DC & FF system is shown at table 1 along with a description of current solutions. The solutions described are not specific to any particular ship, but are typical of warships built in the late 70s or early 80s.

TABLE 1—*DC & FF System Functionality Requirements*

Fire & Smoke	**Current Solution**
Fire Precursor Detection	Manual (where detected) through ship staff rounds.
Fire & Smoke Detection	Remote with manual confirmation.
Fire & Smoke Source Identification	Manual interpretation of detector information with further manual confirmation.
Fire Alarm	Manual operation of alarm and voice information system.
Fire & Smoke Isolation.	Manual crash stop of fans and manual/remote operation of vent flaps and openings.
Fire Control & Removal	Automatic/remote operation of hard kill systems (halon etc.) and manual operation of soft kill systems (hoses).
Smoke Control & Removal	Manual operation of smoke removal fans.
Flooding	
Flood Detection	Remote with manual confirmation.
Flood Source Identification	Manual interpretation of detector information with further manual confirmation.
Flood Alarm	Manual operation of alarm and voice information system.
Flood Isolation	Manual and remote through closing of watertight doors, hatches and valves. Limited indication of opening/valve status. Manual shoring and plugging of leaks.
Flood Control & Removal	Manual and remote operation of fixed pumps. Manual movement and operation of portable pumps. Automatic drain-down of firefighting water. Manual damaged stability calculations.
Personnel Management	
Personnel Protection	Provision of personal breathing apparatus and firefighting equipment.
Personnel Management	Experience and training of damage control officer and team. Verbal information exchange and manual notation of information using incident boards.
Escape	Provision of alternative escape routes and breathing apparatus.
Essential Repairs	
Fault Identification & Location	Manual through interpretation of indicators with manual confirmation.
Fault Repair	Automatic or manual operation of change over switches. Remote or manual operation of valves. Manual rigging of cables or hoses.

It is apparent from table 1 that current DC & FF activities are manpower intensive. Men are involved in, or perform, nearly all of the functions, from simple tasks such as confirming alarms and crash stopping machinery to tasks such as stability calculations and complex decision making. Many of these function can however be automated, or assisted by technology.

The DC & FF system described has evolved over time with the inclusion of more and more separate alarms and indications for the different systems, increasing the potential for information overload. Furthermore communication of information between the deliberately separated damage control teams is verbal, leading to misinterpretation and the rapid compounding of errors. Manual recording of damage control information is also prone to errors resulting in a lack of traceabilty of actions in any subsequent enquiry.

It is clear that simply adding more technology, rather than reducing the workload, can potentially increase it. Improvements can only be made where the technology complements the man by performing functions that man finds difficult or time consuming. The technology can not be considered in isolation to its use. Thus, to achieve full utilization of new technology some changes to the DC & FF organizational structure may be needed.

Survivability technologies

When deciding on the survivability technologies to be incorporated into a future warship design the potential lifespan of the class of ships must be considered. With a design phase of 10 to 15 years and a potential class life of 35 years (first of class in service to disposal of the last vessel), the total life of a vessel from initial concept to disposal could be 50 years. To limit the requirement for future upgrades, it is necessary to ensure that the technology is state of the art for the first of class. This is however at odds with the evolutionary design methods described previously.

In recognition of the requirement to support survivability studies for the Future Escort and the Future Carrier, early in 1997 a survey of damage control and firefighting technologies was conducted.[4] The aim of this survey was to provide a list of technologies, both new and existing, that will improve survivability of future vessels and to generate debate, resulting in focused research.

Of particular concern was the likelihood that the Future Escort Marine Engineering Department, which supplies most of the DC & FF manpower, would be smaller. This being due to increases in automation, particularly as a result of adopting IFEP and Electric Ship ideas.[2] The paper describing the results of the survey also gave vision of how the technologies would be integrated into the existing DC & FF organization.

A list of technologies and a brief description of their application is provided at tables 2, 3 and 4. Ideally, there would be four tables, each covering an aspect of the functionality requirements of table 1. This was however not possible; some technologies are multi-functional, meeting many requirements at the same time while others simply perform one function.

TABLE 2—*Platform Management System (PMS) Technologies*

Technology	Brief Description	Availability
PMS	An integrated platform control and surveillance system.	Now
PMS DC & FF Information Interface	An information system that replaces current ostensibly manual Damage Surveillance and Control (DSAC) systems.	Now
PMS Citadel Opening Status Indication	An information system that indicates the opening status for doors hatches ventilation flaps etc. Potentially includes remote actuation of some or all openings.	Now
PMS Personnel Position and Status Indication	An information system that indicates the position and status (e.g. injured) of all personnel.	Near Future
PMS Compartment Safe to Enter Indication	An information system that indicates compartment conditions in terms of temperature, visibility, atmosphere toxicity and flammability.	Near Future
PMS Shore/Ship Support Link	An information link to allow monitoring or control from shore or from another ship.	Now
PMS Electronic Damage Control Communications Link (EDCCL)	An electronic link to communicate high level weapon and system status information.	Now
PMS Stability Management	An information system that provides real time stability information based on either manual or sensor inputs.	Now
PMS Flood Management	A system that determines counter-flooding or pumping measures on the basis of flood sensors.	Near Future
PMS Rapid Reconfiguration of Firemain	A system that reconfigures the firemain following damage using pressure and flow information.	Near Future
PMS DC & FF IKBS	An Intelligent Knowledge Based System (IKBS) that provides solutions to unique DC & FF problems based the extrapolation of previous experience and knowledge of ship system configuration and layout.	Future
PMS Active de-smoking	Calculation and implementation of de-smoking solution on the basis of smoke density and compartment/trunking pressure sensing.	Future

The technologies range from simply having a PMS in the first place, to having a PMS incorporating advanced features such as automatic calculation of counter-flooding solutions or active de-smoking solutions. Incorporation of these advanced features will of course rely on a multitude of sensors.

Most of the PMS technologies shown at table 2 are available now or could be available in the near future. Only the DC & FF Intelligent Knowledge Based System and the active de-smoking are thought to require considerable development prior to implementation.

TABLE 3—*Firefighting & Smoke Clearance Technologies*

Technology	Brief Description	Availability
Halon Replacements	Synthetic halo-carbon gasses which chemically extinguish fires.	Now
CO_2	Extinguishes fires by oxygen depletion. Bulkier than halon and potentially lethal.	Now
Inert Gas	Extinguishes fires by oxygen depletion. Bulkier than halon but non-lethal.	Now
Watermist	Potential halon replacement with additional smoke scrubbing qualities. Not proved to be effective against all fires.	Near Future
Non Aspirated Foams	Examples such as Aqueous Film Forming Foam (AFFF) are in wide use. Potential for use in a more concentrated form.	Now
Centre Fed Hosereels	Bulkier but less manpower intensive than traditional hoses. Has the potential to allow a rapid response with fewer fire team members.	Now
Fog Lances	Long lance with a fog distribution head. Can be inserted into smaller less complicated compartments to release a water fog	Now
Fixed Waterwalls	Simple plug in waterwall facilities at doors and hatches.	Now
Dry Grids	Low maintenance fixed dry grids. Requires hose connection from the High Pressure Salt Water (HPSW) System to activate.	Now
Fixed Boundary Cooling	Fixed sprays automatically operated by solenoid valves controlled by measured temperatures.	Future
Boundary Insulation	Increased use of boundary insulation to reduce the requirements for boundary cooling.	Now
Alternative Smoke Curtains	Inert gas smoke curtains as an alternative to cloth curtains fitted to some ships.	Future
Emergency Breathing Systems	Hardwired breathing system as installed on some submarines.	Now
Extended Duration Breathing Apparatus	Longer endurance Breathing Apparatus (BA).	Now
Hand Held Thermal Imaging	Hand held device to find fires or heat sources as a replacement to the more cumbersome Thermal Imaging Camera (TIC).	Now
Smoke Clearance	Provision of dedicated smoke clearance fans with associated trunking.	Now
Improved Ventilation System	Implementation of the Total Atmospheric Control System (TACS) where all air entering the citadel is through individual zone air filtration units.	Near Future
Clothing	Lighter and more modern firefighting clothing.	Now

Most of the technologies are available now and some have indeed been in service for a considerable time. In particular a number of potential Halon replacements are shown. All except watermist are shown to be available immediately. Watermist is considered to be available in the near future since it is still under investigation.[5]

Other firefighting and smoke clearance technologies shown at table 3, such as inert gas air curtains and fixed boundary cooling are definitely technologies for the future. Both of these technologies will require considerable development and in the case of the inert gas smoke curtains may not even be feasible at all.

TABLE 4—*Miscellaneous Technologies*

Technology	Brief Description	Availability
Emergency Dry Main	Alternative route to supply HPSW from bow to stern for firefighting purposes.	Now
Electrical Damage Control	Provision of hardwired emergency electrical risers.	Now
Lightweight Shores	Lightweight alternative to Acro-Props or wood for shoring, perhaps hydraulic, using a hand pump.	Near Future
Remotely Operated Quick Acting Watertight (QAWT) doors	Remotely operated quick acting watertight doors.	Near Future
Wire Free Communications	Wire free communications as an alternative to hardwired communications or sound powered telephones	Now
Emergency Escape Trunks	Dedicated pressurised escape trunks from specific areas, particularly deep manned spaces.	Now
Unmanned Zones	Unmanned ship zones potentially inerted (or with reduced oxygen levels) to reduce the risk of fire.	Near Future

Table 4 simply collects all of the miscellaneous technologies that do not fit into PMS or firefighting or smoke clearance. Indeed the emergency dry main and electrical damage control technology options are really vulnerability reduction measures since they provide additional redundancy to the HPSW system and electrical distribution system. However, they have been included since they potentially reduce the manpower needed to rig hoses or cables over damaged section of pipes or cables. Other technologies listed, such as remote operated QAWT doors and emergency escape trunks may ease the passage of men through the ship or secure a means of escape, allowing men to safely stay at their post for longer. Most of the technologies described at table 4 are thought to be available now or in the near future.

It is important to note that most of the technologies described at tables 2 to 4 can be implemented at different levels. Take for instance stability management. The level of implementation of stability management could range from computerizing the simple stability calculations that the Damage Control Officer (DCO) is able to perform (if of course he has time to do so!), i.e. providing a stability calculator, to providing a system that not only performs stability calculations but will even provide solutions to damaged stability problems. The latter is not much different to what chess computers have been able to do (for chess problems of course), for a long time!

Similarly technologies such as unmanned zones could be implemented to different levels, the lowest of which would be to reduce the oxygen content of the zone to a level where it would still support life but reduce the fire risk. The ultimate implementation of this technology would be to have zones of the ship inerted. However, the designer would have to be very sure that access to the unmanned zones is not required.

Other technologies such as hardwired emergency breathing systems could be implemented in a limited manner. It may be sensible to only provide these systems in vital operational spaces in to allow the ship to continue fighting even if filled with smoke. However a reliable escape route would need to be provided.

The appendix to this article provides an imaginative description of how some of the technologies could contribute to survivability in an action scenario.

Technology selection

Tables 2, 3 and 4 show that there are many solutions that meet the DC & FF system functionality requirements of table 1. In particular there are often many solutions to one specific aspect of DC & FF. There is a need to be select the most cost effective technologies for implementation in a future warship.

Early work on technology selection concentrated on trying to develop a numerical modelling technique that would provide objective results on the survivability enhancement given by each technology. However, initial scoping work determined that this type of modelling was likely to be both difficult and expensive to develop, and would probably be unable to asses the effectiveness of all of the technologies.

The fallback was to perform a 'measures of effectiveness' analysis for the technologies. The following measures of effectiveness were considered:

(*a*) Military effectiveness.

Contribution to platform survivability by increasing the ability to maintain fighting effectiveness.

(*b*) Risk.

Overall risk, including development, installation and through life (i.e. reliability) risks.

(*c*) Cost.

Procurement and installation cost, through life cost and potential for manpower reduction.

(*d*) Statutory requirements.

Potential impact of future legislation.

Each technology was scored in terms of the above measures of effectiveness. This scoring was performed by various expert areas within the MoD Ship Support Agency and Procurement Executive.[6] The scoring was by necessity both subjective and relative due to the different types of technologies.

By combining the score for all of the measures of effectiveness, an overall score was derived. Table 5 shows all of the technologies with their overall score. The technologies are grouped into platform management system, fire-fighting and smoke clearance, and miscellaneous categories. They are also ordered in ascending score order for each category

TABLE 5—*Technology Ranking*

PMS technologies	Score
PMS	9
PMS DC & FF Information Interface	4
PMS Citadel Opening Status Indication	4
PMS Personnel Position and Status Indication	4
PMS Compartment Safe to Enter Indication	4
PMS Shore/Ship Support Link	4
PMS Flood Management	3
PMS Electronic Damage Control Communications Link (EDCCL)	2
PMS Stability Management	2
PMS Active de-smoking	2
PMS Rapid Reconfiguration of Firemain	1
PMS DC & FF IKBS	0
Firefighting and smoke clearance technologies	
Extended Duration BA	7
Improved Ventilation System	7
Centre Fed Hosereels	5
Fixed Waterwalls	5
Emergency Breathing Systems	5
Fog Lances	5
Clothing	5
CO_2	4
Watermist	4
Dry Grids	4
Fixed Boundary Cooling	4
Non Aspirated Foams	3
Boundary Insulation	3
Hand Held Thermal Imaging	3
Smoke Clearance	3
Halon Replacements	0
Inert Gas	0
Alternative Smoke Curtains	0
Miscellaneous technologies	
Wire Free Communications	7
Emergency Dry Main	4
Electrical Damage Control	4
Lightweight Shores	3
Emergency Escape Trunks	3
Unmanned Zones	3
Remotely Operated QAWT Doors	2

The results of the measures of effectiveness analysis were initially surprising. Apart form the top scorer being the PMS itself, the next most effective technologies were not PMS enhancements such as active de-smoking or personnel surveillance, but simple, potentially reliable portable equipment such as wire free communications and extended duration Breathing Apparatus.

On further investigation it was clear why these technologies had performed so well. In terms of the contribution to survivability, all technologies scored well. This is logical, otherwise they would not have been included in the first place! However the more advanced technologies tended to perform poorly in terms of risk and cost, reducing their overall scores.

In particular, technologies that combined a large number of sensors and actuators with complex analysis software did not perform very well. This was because the sensors, actuators and associated systems were perceived to be expensive to develop, purchase, install and could lead to an increased maintenance burden.

Conclusions

The functionality requirements for the warship damage control and firefighting system have been described. It is apparent that there are many areas where technology can complement man, reducing the burden placed on him. This in turn may allow the proportion of the complement devoted to DC & FF to be reduced.

A list of technologies that have the potential to satisfy the DC & FF system functionality requirements has been produced. Whilst most of the technologies are available now, some will require considerable development to be pulled through into service.

A 'measures of effectiveness' analysis has been performed to determine the most suitable technology solution for future platforms. The factors considered were, military effectiveness, risk, cost and statutory requirements. This analysis has shown that the platform management system is likely to be the most effective technology.

The next most effective technologies are likely to be simple portable equipment such as wire free communications, extended duration Breathing Apparatus, and improving the zoning and control of ventilation.

Technologies that are likely to rely heavily on sensors and actuators did not perform well in the measures of effectiveness analysis. This was because the sensors, actuators and associated systems were perceived to be expensive to develop, purchase, install, and fears that they could lead to an increased maintenance burden.

Disclaimer

The views expressed in this article are those of the authors and do not necessarily represent those of the Ministry of Defence or HM Government.

References

1. JSP 430—Ship Safety Management System Handbook, Volume 1, Issue 1, January 1996, Published by HMSO.
2. COMMANDER C.G. HODGE; COMMANDER D.J MATTICK. 'The Electric Warship III.' IMarE Evening Paper, Tuesday 16 December 1997.
3. LIEUTENANT COMMANDER K.A. HOWARD; D.W. ANDERSON. 'Comparative Vulnerability of Electric and Conventional Propulsion Systems.' First International Symposium and Exhibition, Civil and Military All Electric Ship, 13 & 14 March 1997.
4. LIEUTENANT COMMANDER M. MARTIN. 'Damage Control Technology, Innovation and Adaptation in the Future Escort.' Unpublished MoD paper, April 1997.

5. M. Edwards; S. Watkins. 'Further Evaluation of Watermist for the Royal Navy' Journal of Naval Engineering Volume 37(2) pp.239–252.

6. J. McCarthy. 'Damage Control and Firefighting Measures of Effectiveness.' Unpublished MoD paper, November 1997.

Appendix

Given the list of technologies described in the main body of this article, and considering the functionality requirements of the DC & FF system It is possible to construct a vision of how the survivability technologies may be applied.

Technology Vision

The frigate is in an action state, shut down and with the appropriate members of the damage control organization confined to their local positions.

An air launched incoming missile is detected with seconds to impact, self defence missile and gun systems are activated. Failure of these systems becomes apparent. With fraction of seconds remaining the most likely hit zone is calculated and communicated to the PMS via the EDCCL. In the potential hit zone, weapons and electrical systems that are sensitive to the transient effects of a missile hit are shut down and isolated. A crash stop of ventilation fans in the potential hit zone is also initiated.

The frigate is hit forward of amidships just above the waterline at the deckhead of a gas turbine alternator compartment. Fragments penetrate a ready use fuel tank initiating a fire and a section of the firemain is breached. Furthermore, the blast, channelled by a passageway, blows out both forward bulkhead airlock doors allowing smoke to spread forward to warfare/operations compartments.

Immediately following the damage, the firemain is automatically reconfigured using redundant pipework. Hard kill fire systems are activated in the gas turbine room but fail due to the large breach of the hull plating. The emergency breathing system fitted to the warfare/operations compartment activated allowing console operators to remain in position despite the smoke. A second incoming missile is detected and destroyed prior to impact. The attack is over.

Automatic boundary cooling of gas turbine uptakes is initiated and manual boundary cooling of the gas turbine compartment boundaries started. The flow rate of the boundary cooling water is monitored by the PMS, correlated with floodwater measurements and instantaneous stability margins displayed to the DCO and Commanding Officer. Warnings will be given if stability is likely to be compromised.

Further boundary cooling of the ship side is provided by fire hoses from a sister ship alongside. The damage control situation is monitored by the DCO of the sister ship, via the ship/ship PMS link. This officer is able to take over management of the situation, if the damaged ship's Damage Control Headquarters DCHQ is smoked out. The sister ship effectively forms an alternative DCHQ.

Personnel monitoring equipment indicates the whereabouts and status of all crew members to the DCO while wire free communications allow this information to be communicated to the firefighting teams improving the chances of a rescue being effected.

Temperature sensors indicate to the DCO that the fire in the gas turbine room is under control, meanwhile a damage repair party seals the damaged airlock door to the warfare/operations compartments. The PMS actively calculates the optimum smoke clearance solution for these compartments based on the smoke density distribution and implements it.

Prior to re-entry, compartment safe to enter indication equipment is used to determine the conditions in compartments, particularly if burnback is likely. Fixed waterwalls are activated for re-entry and the fire in the at the gas turbine room is finally extinguished. Fire sentries are posted.

Throughout the 4 hours incident the endurance of firefighting teams has been enhanced by the use of extended duration breathing apparatus, minimizing the number of personnel that need to be drawn from the operations/warfare department to tackle the incident.